From: Grizzle, Betty
To: Galloway, June -FS
Subject: Re: FW: Request for Input - North American Wolverine Species Status Review
Date: Thursday, December 15, 2016 2:58:35 PM
Attachments: image004.png
image002.png
image003.png
image001.png

Thanks June! I did receive this email message successfully, with the 4 attachments.
Betty

On Thu, Dec 15, 2016 at 1:30 PM, Galloway, June -FS <jgalloway02@fs.fed.us> wrote:

> Hello Betty,
>
> The Payette National Forest, in response to the request for information for the current wolverine proposed listing status review, is providing the following….
>
> - Forest Carnivore Surveys Winter 2015-2016 (CCS Agreement 16-CS-11041200-006, PNF and IDFG) – Interim Report (Attached), Summary of 2016 IDFG Wolverine Camera Stations and Individuals Detected (Attached). The 2016 Progress Report will be provided at the end of the year. I will send that to you as soon as I receive it, after I return from holiday leave as we discussed.
>
> - Wolverine Winter Recreation Research Project (Investigating the Interactions Between Wolverines and Winter Recreation) – 2014 and 2015 Progress Reports (Round River Conservation Studies and RMRS Cooperative Study) (Attached). I expect that Kim Heinemeyer will be sending all of their recent reports but thought that I would include these just in case. The full study progress report is expected late 2017 but we are expecting an interim briefing paper that I will provide when we receive it, if she has not already sent it to you.
>
> Please let me know if you have any questions regarding the information that we have provided.
>
> Thank you and happy holidays!
>
> June
>
> **June M. Galloway**
> **Forest Wildlife Biologist**
> **Forest Service**

Payette National Forest

p: 208-634-0791
f: 208-634-0744
jgalloway02@fs.fed.us

500 Mission Street, Bldg. 2
McCall, ID 83638-3805
www.fs.fed.us

Caring for the land and serving people

From: Schmidt, Barbara [mailto:barbara_schmidt@fws.gov]
Sent: Monday, December 05, 2016 2:41 PM
To: Lannom, Keith -FS <klannom@fs.fed.us>
Cc: Panek, George -FS <gpanek@fs.fed.us>; Galloway, June -FS <jgalloway02@fs.fed.us>; Lesch, Greg -FS <glesch@fs.fed.us>; Pierson, Kim -FS <kpierson@fs.fed.us>; Klinger, Lisa -FS <lklinger@fs.fed.us>; Botello, Anthony B -FS <abbotello@fs.fed.us>
Subject: Request for Input - North American Wolverine Species Status Review

Dear Mr. Lannom:

The U.S. Fish and Wildlife Service (Service) is in the process of determining the status of the distinct population segment (DPS) of the North American wolverine (*Gulo gulo luscus*; wolverine) in the contiguous United States. With the attached, we are providing early notification to you and other interested parties that we are initiating the status review process for wolverine and are seeking your input to ensure we have the best available information upon which to inform the status review. We will accept new information throughout this process; however, we respectfully request that you provide any pertinent information as soon as possible and **not later than December 30, 2016**, to ensure we have adequate time to consider it during our status review. Please be aware that all data and information submitted to us including names and addresses will become part of the decisional record for this package and may be made public.

Thank you for your interest in the conservation of wolverine. If you would like additional information or have questions about the species, please contact Betty Grissle of the Carlsbad Fish and Wildlife Office at (760) 431-9440 extension 215 or betty_grizzle@fws.gov. In Idaho, Bryon Holt of the Service's Northern Idaho Field Office, at (509) 893-8014 or bryon_holt@fws.gov, can also provide additional information regarding this species. Background information on the status of the wolverine under the Endangered Species Act (ESA) of 1973, as amended, is provided below as well as within the attached letter.

Wolverine ESA Status Background Information. On February 4, 2013, we published a

proposed rule to list the DPS of wolverine occurring in the contiguous United States as threatened, under the Act, with a proposed rule under section 4(d) of the Act that outlines the prohibitions necessary and advisable for the conservation of the wolverine (78 FR 7864). We also published on February 4, 2013, a proposed rule to establish a nonessential experimental population area for the North American wolverine in the Southern Rocky Mountains of Colorado, northern New Mexico, and southern Wyoming (78 FR 7890).

On August 13, 2014, based on our conclusion that the factors affecting the DPS as identified in the proposed rule were not as significant as believed at the time of the proposed rule's publication in 2013, we withdrew the proposed rule to list the DPS of the North American wolverine as a threatened species under the Act (79 FR 47522). In October 2014, complaints were filed in the District Court for the District of Montana by several organizations challenging our withdrawal of the proposal to list the North American wolverine DPS. As a result of the court order (issued April 4, 2016), the August 13, 2014, withdrawal was vacated and remanded to the Service for further consideration consistent with the order. On October 18, 2016, we published a *Federal Register* Notice reopening the comment period for 30 days on our February 4, 2013, proposed rule to list the distinct population segment of wolverine and announcing our initiation of a new status review of the wolverine, to determine whether this distinct population segment meets the definition of an endangered or threatened species under the Act, and request new information to inform our status review (81 FR 71670).

Barbara Schmidt

US Fish and Wildlife Service

1387 South Vinnell Way, Room 368

Boise, Idaho 83709

208-378-5259

http://www.fws.gov/idaho/

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--

Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

From: Roberts, Ann R -FS
To: Macfarlane, Diane -FS
Cc: betty_grizzle@fws.gov
Subject: Wolverine data for Sierra NF and related general info re listing consideration
Date: Wednesday, January 4, 2017 4:50:57 PM
Attachments: image001.png
image002.png
image003.png
image004.png
wolverine from snft.xlsx
Teton wolverine.jpg

Diane, here is a summary table of NRIS data from the Sierra NF (probably unchanged from the original data call a few years ago). I am cc-ing Betty since it appears time is of the essence. But I apologize, I am new at this, so I will let you decipher what is pertinent.

Historic Sierra NF data from NRIS: (attached; no new data). These are incidental observations. No sightings added for the Sierra NF since 2010, however, it is important to note that no systematic scientific camera/genetic sampling/track surveys have been conducted by protocol (Zielinski, et al.) to establish whether wolverines are present, let alone whether they are male/female. Suitable habitat exists as shown in the USFWS model (Copeland, et al.).

_____
Additional information:

Having worked recently (through 2016) collaboratively on systematic scientific meso-carnivore surveys on the Bridger-Teton NF with John Squires at Rocky Mtn Research Station, Grand Teton NP, and Zack Walker of the Wy GFD, I have the following information to add/note:

Current research: As you are probably already aware, the Rocky Mtn. Research Station (John Squires) / and Wy Game and Fish (Zack Walker) are analyzing genetic data gathered in an ongoing scientific survey conducted by Wy Game and Fish in cooperation with USFS, and they would likely be the best sources of current scientific data for the Rocky Mtn population from ongoing studies in the GYA.

Re Rocky Mtn. Distinct population Status: it does not seem logical to list the Wy pop as experimental (essential or non-) as was mentioned in the 2013 proposed rule if there are currently several known resident individuals, especially breeding females, which can contribute to recovery in Wyoming, Idaho, and Colorado. They warrant greater protection than experimental status because they would be essential to recovery in Wyoming and surrounding areas.

(There may be some public misperception that they pose a threat to livestock, however they generally do not, since they are primarily carrion eaters.) (We also have documented wolverines that overlap with grazing allotments on the Bridger-Teton and have no records or concerns raised regarding livestock conflicts from permittees).

Known threats: An unfortunate shooting by a rancher in North Dakota, and roadkill in Utah (of Wyoming individuals) are known threats/causes of death of at least two individuals in the past two years that were tracked moving great distances in the N. Rockies. Although males disperse further, both males and females are highly vulnerable to human-caused death such as roadkill and

shootings. Wolverines in Wyoming were documented crossing busy highways numerous times, including one we photographed on Teton Pass in 2016 (attached) that came across at least two highways in one week with numerous sightings from Star Valley. Highway crossings, climate change/habitat loss- particularly of high quality denning areas with persistent snow cover, and loss of habitat connectivity for dispersal and genetic viability continue to be primary issues of concern for individual wolverines and wolverine population recovery throughout the western US.

Thank you for the opportunity to provide data and input (hopefully it is useful). Please let me know if you need any additional information.

-Ann

Ann Roberts, MSF
Forest Biologist, Wildlife & Aquatics

Forest Service
Sierra National Forest

p: 559-297-0706 x4933
annrroberts@fs.fed.us

1600 Tollhouse Rd.
Clovis, CA 93611
www.fs.fed.us

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2016-06-01 10:32:35 AM M 3/3 46°F

TETON PASS

RECONYX

COMMON_NAM	SCIENTIFIC	SURVEY_OBS	OBS_METI	OBS_	OBSERVER_N	COMMENTS
California Wolverine	Gulo gulo luteus	1/1/1967	Visual	The a	HAMMOND, FLOYD (Unk	GIS# 3020. View Scale at Data Entry 1:13580; DXDS_CN: 9656 CMN_OBS_CN_LINK: FNAOBPT36.9303118.906005102004036863
California Wolverine	Gulo gulo luteus	1/1/1990	Visual	The a	BOLAND, UNKNOWN (Un	No Original. GIS# 1873. View Scale at Data Entry 1:10865; DXDS_CN: 9656 CMN_OBS_CN_LINK: FNAOBPT36 9162118.881505102004051738
California Wolverine	Gulo gulo luteus	7/1/2008	Visual	The a	PENSON, ART & JESSIE (L	Individual was also identified by track markings
California Wolverine	Gulo gulo luteus	1/1/1990	Visual	The a	BOLAND, UNKNOWN (Un	In Section 20. Exact location unknown. No original found. GIS# 1870. View Scale at Data Entry 1:13580; DXDS_CN: 9656 CMN_OBS_CN_LINK: FNAOBPT36.9578118.944605102004358567
California Wolverine	Gulo gulo luteus	1/1/1960	Track	Evide	VACCO, UNKNOWN (Unk	Exact date not given, Winter of about 1960. Tracks observed above Camp 7 near Hume Lake. Picture of tracks taken. Exact location unknown. Sierra NF GIS# 3698. View Scale at Data Entry 1:27436; DXDS_CN: 9656 CMN_OBS_CN_LINK: FNAOBPT36.7870118.90000
California Wolverine	Gulo gulo luteus	8/18/2010	Visual	The a	DECKER, JAMES (No Expe	Yellow stripe observed and a broom-like tail seen. The observer also saw the animal's face and identified the creature by the John Law's Field Guide picture and description. Creature was more than twice the size of a marmot and moved with great strength
California Wolverine	Gulo gulo luteus	6/26/1996	Visual	The a	ISSACS, R. (No Experience	1 furbearer was wadding in puddle, ignored observer, then looked back, crossed road, and went on his way. GIS# 1874. View Scale at Data Entry 1:25445; DXDS_CN: 9656 CMN_OBS_CN_LINK: FNAOBPT37.3099119 254004052005105411
California Wolverine	Gulo gulo luteus	8/20/1975	Visual	The a	BROMMERICH, THOM (U	1 wolverine seen at Lake of the Lone Indian. Tracks seen in the snow on Goodale Pass. GIS# 3022. View Scale at Data Entry 1:25267; DXDS_CN: 9656 CMN_OBS_CN_LINK: FNAOBPT37.4745118 937828042005865386
California Wolverine	Gulo gulo luteus	1/1/1978	Visual	The a	UNKNOWN, UNKNOWN (	No original. On old PRRD Report 1 database. GIS# 1875. View Scale at Data Entry 1:29743; DXDS_CN: 9656 CMN_OBS_CN_LINK: FNAOBPT37.2609119.118303052005740172
California Wolverine	Gulo gulo luteus	1/1/1974	Camera Se	The a	BERTRAM, UNKNOWN (U	Bertram caught glimpse of dark, furry animal uphill from trail, skirting line between sections 30 & 25. Took photos of tracks, traced one track, collected scats and hair. Scats & hair were not wolv DXDS_CN: 9656 CMN_OBS_CN_LINK: FNAOBPT36.9505118.9713
California Wolverine	Gulo gulo luteus	6/1/1975	Visual	The a	DUNHAM, UNKNOWN (U	Observed for 2 minutes on trail and in timber. GIS# 1871. View Scale at Data Entry 1:13580; DXDS_CN: 9656 CMN_OBS_CN_LINK: FNAOBPT36.9614118.938505102004067301
California Wolverine	Gulo gulo luteus	7/12/1977	Track	Evide	TOTH, ED (Unknown)	Saw tracks around a wolverine resting site in a hollow culled out log on SE side of the clearcut area adjacent to the proposed quarry site. Graveyard Meadow. GIS# 3024. View Scale at Data Entry 1:3 DXDS_CN: 9656 CMN_OBS_CN_LINK: FNAOBPT37.4631119.2989
California Wolverine	Gulo gulo luteus	1/1/1990	Visual	The a	BOLAND, UNKNOWN (Un	In Section 30. Exact location unknown. No original. GIS# 1872. View Scale at Data Entry 1:13580; DXDS_CN: 9656 CMN_OBS_CN_LINK: FNAOBPT36.9436118.962705102004131631
California Wolverine	Gulo gulo luteus	8/24/1978	Visual	The a	UNKNOWN, UNKNOWN (	Historical map in atlas. GIS# 1869. View Scale at Data Entry 1:29743; DXDS_CN: 9656 CMN_OBS_CN_LINK: FNAOBPT37.2759119.113703052005890613

From:	Roberts, Ann R -FS
To:	Grizzle, Betty
Cc:	Macfarlane, Diane -FS
Subject:	FW: wolverine data
Date:	Thursday, January 5, 2017 12:22:59 PM
Attachments:	image001.png image002.png image003.png image004.png CalifWolverineObsPoints_TES.shx CalifWolverineObsPoints_TES.dbf CalifWolverineObsPoints_TES.prj CalifWolverineObsPoints_TES.sbn CalifWolverineObsPoints_TES.sbx CalifWolverineObsPoints_TES.shp

---

Hi Betty, here are the shapefiles, will this work for you?

Ann Roberts, MSF
Forest Biologist, Wildlife & Aquatics

Forest Service
Sierra National Forest

p: 559-297-0706 x4933
annrroberts@fs.fed.us

1600 Tollhouse Rd.
Clovis, CA 93611
www.fs.fed.us

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From: Taylor, Heather M -FS
Sent: Tuesday, January 03, 2017 2:15 PM
To: Roberts, Ann R -FS <annrroberts@fs.fed.us>
Subject: RE: wolverine data

Hi Ann, Happy 2017 ☺
I'm around today and tomorrow and then in the afternoon on Thursday (off on Friday).

I took a look at the wildlife observation points data (for TES species) that is in the forest GIS library and pulled out the wolverine points (14 points, the most recent is from 2010 and two of the points are on other forests).

I've attached a shapefile of those points for you to look at. The last NRIS export was in July by Theresa.

I'd be happy to help, just don't know how much info I can provide other than pointing you to data layers. -h

Heather Taylor

GIS Specialist

Forest Service
Sierra National Forest

p: 559-877-2218 x3195
f: 559-877-3108
hmtaylor@fs.fed.us

57003 Rd. 225
North Fork, CA 93644
www.fs.fed.us

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From:	Grizzle, Betty
To:	Ed Turner
Subject:	Fwd: FW: wolverine data - GIS shapefiles
Date:	Thursday, January 5, 2017 12:33:05 PM
Attachments:	image001.png image002.png image004.png image003.png CalifWolverineObsPoints_TES.shx CalifWolverineObsPoints_TES.dbf CalifWolverineObsPoints_TES.prj CalifWolverineObsPoints_TES.sbn CalifWolverineObsPoints_TES.sbx CalifWolverineObsPoints_TES.shp

---

More data! This is the information from the Sierra National Forest, which is south of Yosemite (though 2 of these observations are apparently from other National Forests). I left a message with CDFW to see if he is aware of these observations/locations, but we could also cross-check these points with CNDDBs data set.

---------- Forwarded message ----------
From: **Roberts, Ann R -FS** <annrroberts@fs.fed.us>
Date: Thu, Jan 5, 2017 at 11:22 AM
Subject: FW: wolverine data
To: "Grizzle, Betty" <betty_grizzle@fws.gov>
Cc: "Macfarlane, Diane -FS" <dmacfarlane@fs.fed.us>

Hi Betty, here are the shapefiles, will this work for you?

Ann Roberts, MSF
Forest Biologist, Wildlife & Aquatics

Forest Service

Sierra National Forest

p: 559-297-0706 x4933
annrroberts@fs.fed.us

1600 Tollhouse Rd.
Clovis, CA 93611
www.fs.fed.us

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Sent: Tuesday, January 03, 2017 2:15 PM

To: Roberts, Ann R -FS <annrroberts@fs.fed.us>
Subject: RE: wolverine data

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I've attached a shapefile of those points for you to look at. The last NRIS export was in July by Theresa.

I'd be happy to help, just don't know how much info I can provide other than pointing you to data layers. -h

Heather Taylor
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hmtaylor@fs.fed.us

57003 Rd. 225
North Fork, CA 93644
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--

Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

From:	Krueger, Patricia A -FS
To:	Turner, Ed
Cc:	Betty Grizzle (Betty_Grizzle@fws.gov)
Subject:	FW: GULO_GULO
Date:	Friday, January 6, 2017 3:46:11 PM
Attachments:	image001.png image002.png image003.png image004.png GULO_GULO.gdb.zip

---

Here is the nationwide data from the Forest Service NRIS Wildlife database. As you get closer to completion of the analysis, please feel free to request an update to this data.

Do let me know if I can help further.

Thanks!

Patti

Patricia Krueger
Regional Threatened and Endangered Species Coordinator

Forest Service
Pacific Southwest Region, Regional Office

p: 707-562-8954
c: 707-373-3702
pkrueger@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

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From: Grapentine, Joel -FS
Sent: Friday, January 06, 2017 1:59 PM
To: Krueger, Patricia A -FS <pkrueger@fs.fed.us>
Cc: Lindemann, Tim -FS <timlindemann@fs.fed.us>
Subject: GULO_GULO

Patti,

Obs and Sites for GG.

Joel Grapentine, M.S.
GIS Database Analyst

Forest Service Contractor
R05 Headquarters

p: 707-562-8845 x8845
jgrapentine@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

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From: Grizzle, Betty
To: Krueger, Patricia A -FS
Cc: Turner, Ed
Subject: Re: FW: GULO_GULO
Date: Friday, January 6, 2017 3:56:58 PM
Attachments: image001.png
image002.png
image003.png
image004.png

Thank you, Patti! Yes, we have received reports, data, etc. from various National Forests within the presumed range of the wolverine. Although some information was not provided in GIS format, we have been successful (in most cases, to date) in our subsequent requests. The nationwide data will be of great value in cross-checking other sources.
Betty

On Fri, Jan 6, 2017 at 2:45 PM, Krueger, Patricia A -FS <pkrueger@fs.fed.us> wrote:

> Here is the nationwide data from the Forest Service NRIS Wildlife database. As you get closer to completion of the analysis, please feel free to request an update to this data.
>
> Do let me know if I can help further.
>
> Thanks!
>
> Patti
>
> **Patricia Krueger**
> **Regional Threatened and Endangered Species Coordinator**
> **Forest Service**
>
> **Pacific Southwest Region, Regional Office**
>
> **p: 707-562-8954**
> **c: 707-373-3702**
> **pkrueger@fs.fed.us**
>
> 1323 Club Drive
> Vallejo, CA 94592
> www.fs.fed.us
>
> **Caring for the land and serving people**

From: Grapentine, Joel -FS
Sent: Friday, January 06, 2017 1:59 PM
To: Krueger, Patricia A -FS <pkrueger@fs.fed.us>
Cc: Lindemann, Tim -FS <timlindemann@fs.fed.us>
Subject: GULO_GULO

Patti,

Obs and Sites for GG.

Joel Grapentine, M.S.
GIS Database Analyst

Forest Service Contractor

R05 Headquarters

p: 707-562-8845 x8845
jgrapentine@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

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--

Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

From: Yates, Richard E -FS
To: Grizzle, Betty
Subject: GNP progress report 2008
Date: Monday, January 9, 2017 11:20:25 AM
Attachments: image001.png
Copeland_yates_Jan2008.pdf

Betty; attached is our final GNP report. Should have some helpful information.

Rick

Rick Yates
Wildlife Biologist
Flathead National Forest
Swan Lake Ranger District

p: 406-837-7543
fax: 406-837-7503
richardeyates02@fs.fed.us
200 Ranger Station Road
Bigfork, MT 59911

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Wolverine Population Assessment in Glacier national Park

Comprehensive Summary Update

January, 2008

Jeffrey P. Copeland
Richard E. Yates

USDA Forest Service, Rocky Mountain Research Station,
Missoula, MT

Wolverine Population Assessment in Glacier National Park, Comprehensive Summary Update

Jeffrey P. Copeland, Rocky Mountain Research Station, Missoula, MT
Richard E Yates, Rocky Mountain Research Station, Missoula, MT

January 2008

USDA Forest Service, Rocky Mountain Research Station, 800 E. Beckwith, Missoula, Montana 59807
The Ecology and Management of Wildlife and Habitats, RWU 4201

Contributors:

John Squires, Rocky Mountain Research Station, Missoula, MT

Leonard Ruggiero, Rocky Mountain Research Station, Missoula, MT

Michael Schwartz, Rocky Mountain Research Station, Missoula, MT

Kevin McKelvey, Rocky Mountain Research Station, Missoula, MT

Kristy Pilgrim, Rocky Mountain Research Station, Missoula, MT

Dan Pletscher, College of Forestry and Conservation, University of Montana

John Waller, Glacier National Park

Executive Summary

The Glacier National Park Wolverine Research Project has completed its fifth and final year of study. Research pursued two primary objectives: 1) live-trap, radio-instrument and monitor wolverine to describe their distribution and reproductive status, and 2) locate natal and maternal dens, and rendezvous sites, and characterize associated landscape features. Secondary objectives included the investigation of wolverine demographics, the relationship between reproduction and winter recreation, and a description of wolverine home ranges, movement, and habitat use. Twenty-eight wolverines (13 males, 15 females) were captured and 27 instrumented, providing over 30,000 relocations. We documented 23 reproductive sites for 6 adult females. Dens occurred beneath deep snow most commonly on upper slopes of sparse timber structurally tied to downed woody debris, rock caves, and boulder talus. Seven kits were captured and instrumented at den sites. Monitoring of kits and mothers through their first summer provided 30 maternal care (rendezvous) sites occurring primarily in boulder talus and cliff areas. Kits became independent of their mother by mid to late September, at 6-7 months-of-age. Kit survival to adulthood was low as evidenced by 5 of 7 kits dying during their first year. In cases where the cause of death could be determined, mortality was attributed to predation (1), shooting (1), and fall from a cliff (1). Two adults died during the study period; one female killed in an avalanche, and one male from predation. Three subadults were killed during the study: a male was legally trapped and killed outside GNP as a disperser, a second subadult male was killed by construction activity on the Going-to-the-Sun Road in GNP, and a subadult female appeared to have been gored to death, presumably by a mountain goat. GPS collars provided data on rates of movement, habitat use, activity, and social interactions. Wolverines followed traditional routes moving over 150 km/week at a rate of approximately 4 km/hr with long-distance movements (commonly exceeding 10 km) interspersed with localization periods at foraging and/or resting sites of up to 60 hrs. Travel routes commonly intercepted uninhabited dwellings and developed areas within the park, and included snowbound roads and trails. Two young wolverines dispersed from GNP during the study period. One subadult male traveled approximately 100 miles to the Northwest Peaks Natural Area in northwestern Montana in 2004. A subadult female moved 55 miles south into the Swan Range in early 2007. Wolverine home ranges averaged 521 km^2 for males and 139 km^2 for females. Scat (n=142) and prey remain (n=55) samples are being analyzed to provide food habits data. DNA profiling indicates limited population structuring with a few established resident males contributing to most of the reproduction. Based on habitat distribution and spatial use, GNP appears to support a stable-to-increasing population of between 40 and 45 individuals.

The findings presented herein are preliminary results, provided to meet commitments to granting agencies and organizations and update project contributors and supporters. Report prepared in January, 2008.

Acknowledgements

Field Research Technicians: Kate Wilmot, Marci Johnson, Rebecca Hadwen, Allen Hoffs, Laura Robinson, Ryan Williams, Brady Dunn, and Todd Ulizio.

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We extend our deepest appreciation to Glacier National Park for inviting us to study this incredible animal, to the Glacier National Park Fund whose enthusiasm and support kept the project afloat, and to the dozens of contributors and volunteers who gave so much to insure our success.

USDA Forest Service Region 1

GLACIER NATIONAL PARK FUND

The University of Montana

Earth Friends WILDLIFE FOUNDATION

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YELLOWSTONE TO YUKON CONSERVATION INITIATIVE

Northern Rockies Conservation Cooperative

Preface

The Glacier National Park Wolverine Ecology Study began in the fall of 2002 with the primary objective of investigating wolverine reproductive ecology. Prior to this research, reproductive dens of only 2 female wolverines had ever been located in the contiguous U.S. Increasing interest in winter recreation had necessitated consideration of disturbance issues that agencies were not adequately prepared to address given, at the time, that our familiarity with even the most general wolverine ecology was limited to information provided by only two US-based field studies. While the Glacier National Park wolverine project was initiated to further our understanding of the wolverine's ecological role within the park, it grew into an opportunity to extend knowledge well beyond administrative boundaries as a result of dedicated field personnel, continued agency interest, and support from private NGOs and individuals. Over the course of 5 years we instrumented 27 individual wolverines which occupied nearly half of Glacier National Park. This provided an unprecedented opportunity to study the lives, the relationships, and the habitat associations of one of the rarest and most elusive carnivores on the planet. Without question, the gift of wolverine insight provided by the first animal captured in the study, male M1, has been beyond measure. M1 was given the name "Piegan" in honor of the Blackfeet Nation. Piegan benevolently traveled over a thousand miles through Glacier National Park festooned with a GPS collar recording his movements at 5 minute intervals, ultimately providing over 18,000 GPS locations. Through these data we observed his remarkable winter ascents over Grinnell Point and the Continental Divide, his attentiveness to his females and kits at winter den sites, and his crafty avoidance of our traps. Through 5 years, Piegan sired nearly a dozen kits as his genetic roots extended across Glacier National Park and beyond, providing the core for our understanding the wolverine of Glacier National Park.

The Glacier Wolverine Project ended with this fall's field season. Over the following months we will be analyzing data to produce a comprehensive final report and peer-reviewed research papers.

Jeff Copeland
Rick Yates

We dedicate this to the memory of Grace Kirshner

The rugged mountains and subalpine meadows of Glacier National Park typify wolverine habitat in the western United States.

Capture of wolverines in Glacier National Park (GNP) began in January 2003 and occurred only during winter months to avoid conflicts with bears. Twenty-one wolverines were captured over 5 trapping seasons using 12 log box traps (Figure 1). Most traps (9) were located east of the Continental Divide (Figure 2). In addition, seven juveniles were caught by hand at reproductive dens. Twenty-seven individuals were marked using VHF implant transmitters and 13 of those also carried a GPS or ARGOS satellite collar for at least 2 weeks.

Throughout the study, we relied on conventional VHF telemetry to routinely locate individual animals. Most telemetry data were gathered by ground-tracking methods whenever possible. Fixed-wing telemetry fights were kept to a minimum due to GNP management concerns regarding aircraft disturbance to park visitors. Aerial telemetry mostly occurred in months of reproductive denning (Feb. - May) and were essential for locating females at den sites. Additional monthly flights were necessary to monitor survival, general distribution, and dispersal of study animals (Figure 3).

Figure 1. Wolverine trap in Glacier National Park

Survivorship

An in-depth analysis of survivorship is best accomplished with long-term datasets that account for natural variability in survival over time. For instance, 4 years of monitoring central Idaho wolverines found a level of mortality in adult females that was much higher than could be expected to maintain a population over the long term. In GNP, we experienced an unusually high incidence of mortality in young individuals, where 5 of 7 wolverines marked as juveniles did not survive to adulthood. We expect this represents an unusually high incidence of mortality in juveniles.

Preliminary survivorship analysis indicates that the probability of a juvenile wolverine in GNP surviving past its 1st year is about 58%, while a subadult has a 53% likelihood of surviving to adulthood. Once a GNP wolverine reaches adulthood, its probability of surviving through any given year is about 96%. That value drops to 85% when we consider the probability of survival throughout our 4 year study period. These values, along with a fecundity rate of about 29% (proportion of female kits/female/year) indicates that the GNP wolverine population is likely increasing by about 5% per year.

By the numbers

28 - Number of individual wolverines captured

169 - Number of times wolverine were captured

34,375 - Number of GPS locations collected 2005-2007

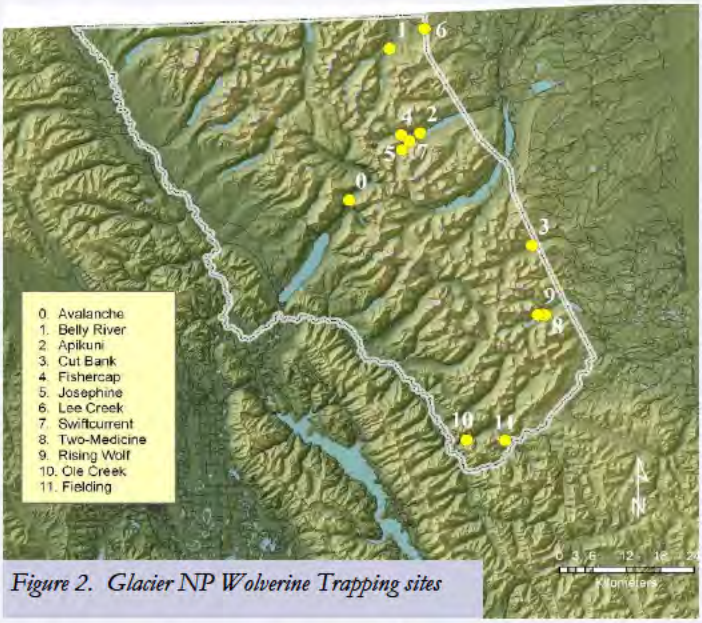


Figure 2. Glacier NP Wolverine Trapping sites

Mortality

During the study, 10 wolverine mortalities were documented (4 juveniles, 4 subadults, and 2 adults). Subadult male M8 was legally trapped in December 2004 on the Kootenai National Forest. Two male kits (M9 & M10), born in 2004, died during their first year. One was legally shot by a trapper outside the park boundary, and the second died of unknown cause at approximately 9-10 months of age. A 2005 male kit (M18) was killed by an unknown predator at 8 months of age. The second 2005 male kit (M19) died (as a subadult) of unknown cause in 2006. A 3-year-old adult female (F5) died in an avalanche in April 2005. In September 2006, female kit F21 died in a fall. Subadult female F24 was killed by a puncture wound in April 2007, which appeared to have been inflicted by a mountain goat. Adult male (M16) was killed by an unknown predator in July or August 2007, and was found dead near the remains of a Bighorn Sheep carcass. A fourth subadult (a male), not captured during the study, was killed

on the Going-to-the-Sun Road by road reconstruction activity in October 2007.

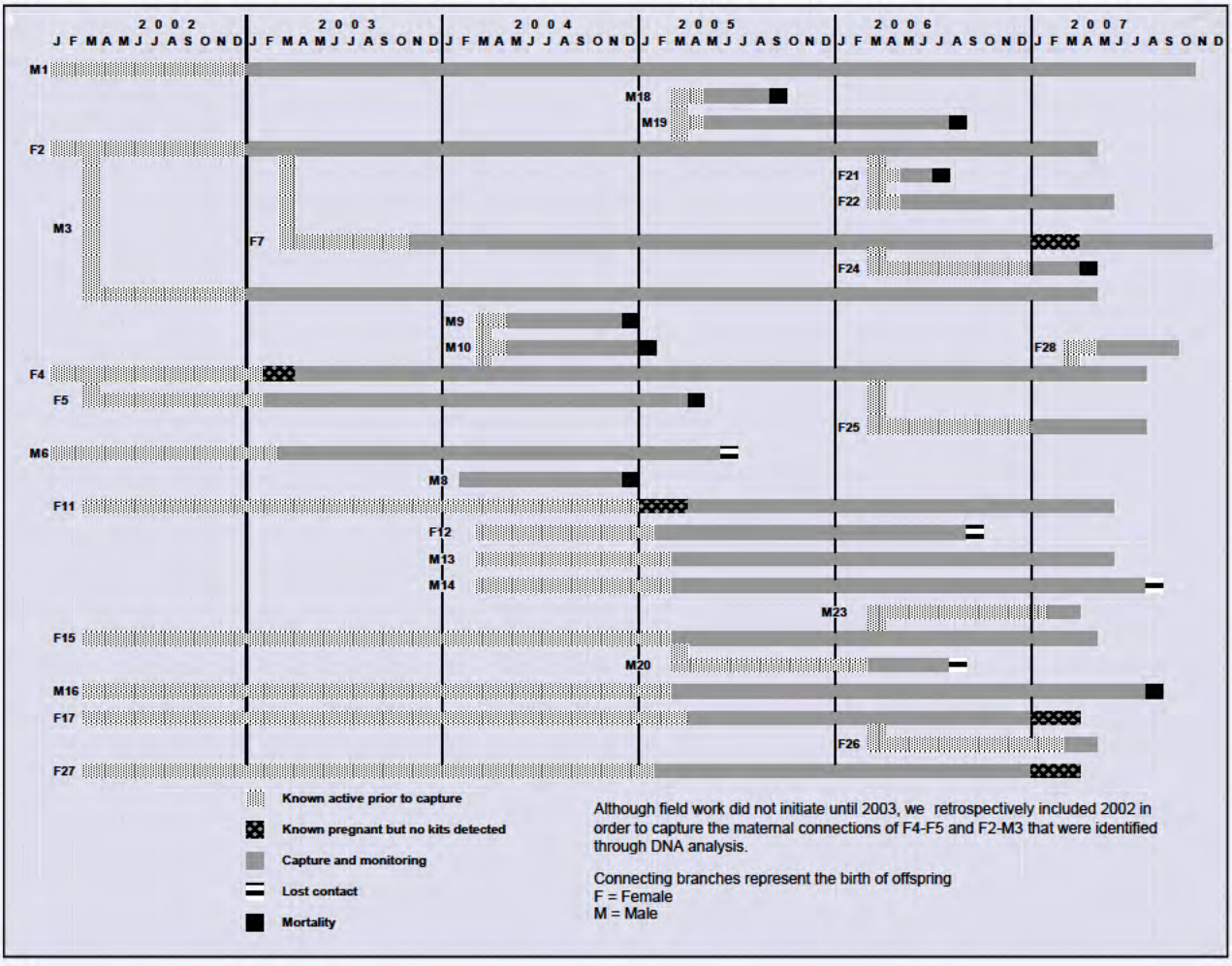
Dispersal

Two dispersals of wolverine study animals have been documented to date. Yearling male (M8) left Glacier park about a week after its initial capture in February 2004. He moved from the Many Glacier Valley to the southern Whitefish Range in early March where we closely monitoring his movements until he disappeared in early April. In late July, U.S. Fish and Wildlife Service researchers conducting a grizzly bear flight in the northern portion of the Kootenai National Forest detected M8's telemetry signal near American Creek. They continued to monitor M8 near the Northwest Peaks Natural Area until

This six-year time-table of wolverine relatedness, survival, and reproduction provides a rarely obtained dataset representing several individuals and generations across half the lifetime of a wolverine. Longer term studies, at multiple study sites, are necessary for understanding the natural variation that is inherent in wild populations.

DR. DAN SAVAGE HOLDING A KIT CAPTURED IN MAY, 2007

Figure 3. Time periods of study animal monitoring and maternal relatedness



he was legally taken by a trapper in December 2004. He had traveled over 200 kilometers from GNP, as measured by straight-line distance. Subadult female F26 was captured in the Two Medicine Valley in February 2007. She left GNP by March and was found on a survey flight in August, 55 miles south of her last location. Her movement south from GNP to the Flathead National Forest took her through portions of the Great Bear Wilderness and across Hungry Horse Reservoir. However, this location may not represent her final dispersal point. During the study four other subadult wolverines, likely dispersers, (1 female, 3 males: F12, M14, M20, and M23) disappeared from GNP.

Wolverine Reproductive Ecology

Reproductive rates

Female wolverine reach sexual maturity as yearlings but generally don't produce their first litter until they are 3 years old. Litter sizes are normally 2-3 kits with sex ratios generally approaching 50:50. Studies conducted on trapper-killed wolverine carcasses report pregnancy rates ranging from 70-90% in adult (>2 years old) females. Most field ecology studies report the number of kits/female at weaning age (9-10 weeks-of-age) as less than 1 suggesting that less than half of reproductively mature females are taking kits from conception to weaning.

From 2002 - 2007 we documented 19 pregnancies by GNP wolverines for a pregnancy rate of 68%. Females produced 21 kits, or 0.75 kits/female/year. Kits remained with their mothers until mid-late September of their first year (6-7 months of age). After separation, kits generally remained within their father's home range, but were also documented moving into an adjacent female's home range.

Denning

Females select den sites at locations where deep snow (2-3 meters) persists until time of weaning in early May. Dens are occupied by late February and occur under snow, at ground level, in natural cavities that form beneath downed trees or boulders. A female may use multiple den sites prior to weaning, which may be due to disturbance or unfavorable conditions resulting from cold or moisture. The den in which kits are born is termed the "natal den." Dens used subsequently, but prior to weaning, are called "maternal dens." Once the kits wean, they travel with their mother for up to 4 months. During this time, females may leave kits at "rendezvous sites" while she forages and/or mates.

Natal and maternal dens are very similar in structure, most often associated with down and dead whitebark pine or subalpine fir. Dens in GNP commonly occurred at or just below treeline.

Entrance to natal den. Note tracks leading to hole under cliff.

We documented 14 natal and maternal dens for 3 GNP females, along with over 30 rendezvous sites. All of these sites were visited, mapped, and measured. We documented an additional 10 den sites associated with 3 other females, which were not confirmed or visited by field personnel due to their inaccessibility.

Genetics

DNA analysis will help clarify our understanding of relatedness within the GNP study population, but more importantly it will allow us to gauge how the GNP population contributes to the overall genetic fitness of the broader northern Rocky Mountain population. Genetic fitness is generally measured in terms of the degree of genetic variation, or allele frequency, within a population. This degree of allelic frequency provides a metric of genetic fitness termed "effective population size" (N_e), which is a measure of the portion of the population that is actually contributing

to the transfer of genes from generation to generation. Populations that are small tend to lose genetic variability through inbreeding, leaving populations less adaptable to random environmental changes. Wolverine populations are vulnerable to inbreeding depression due to their naturally low population densities.

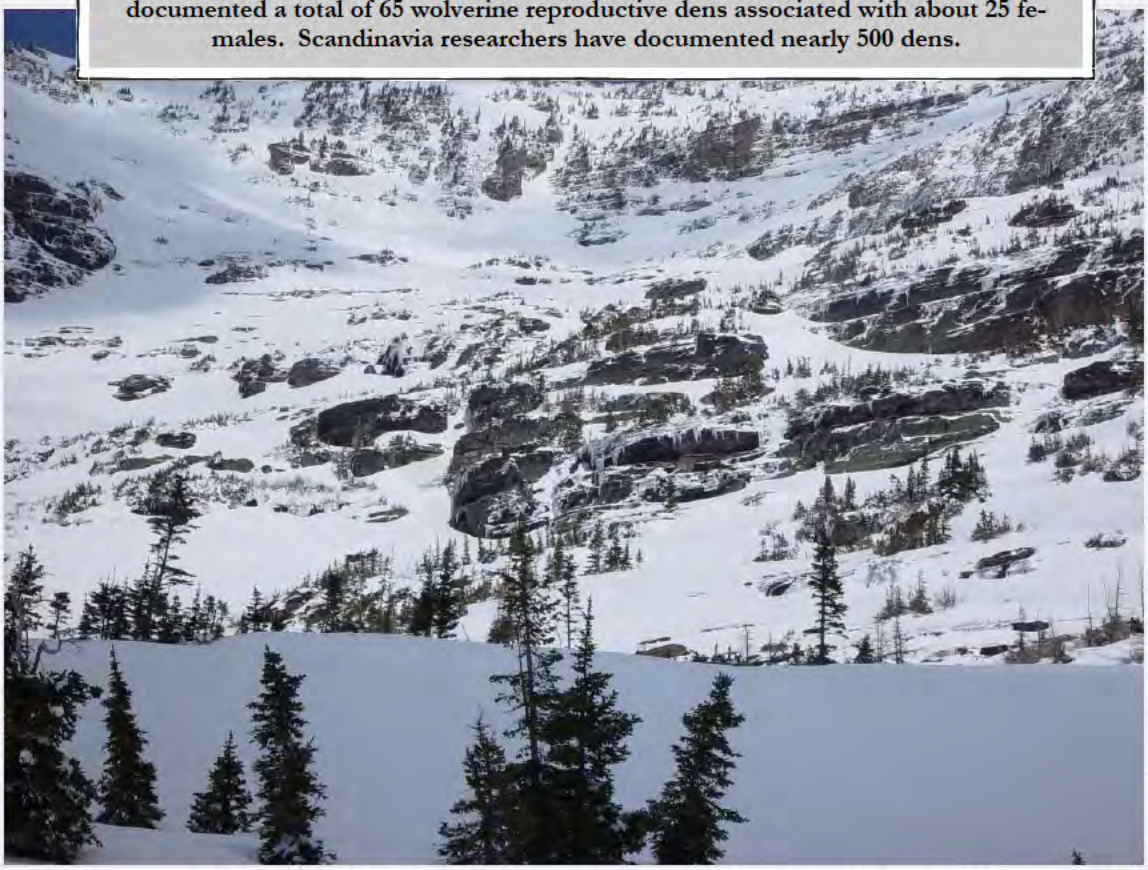
Conservation biologists have worked under a rule of genetic variation termed the "50/500 rule", which states that an N_e of $\geq$ 50 is necessary to ensure short-term survival and minimize the risks of inbreeding, and an $N_e \geq 500$ to ensure long-term survival through the ability to adapt to environmental change. Recent genetic analyses at the Rocky Mountain Research Station Wildlife Genetics Lab suggest $N_e = 18$ for GNP wolverine and only 39 for the entire northern Rocky Mountain population. These numbers are reminders of the naturally low population densities at which wolverine persist, underscore the essentialness of viable connective corridors, and emphasize the importance of GNP as a wolverine refuge and source population to the surrounding region.

Genetic-based analysis of wolverine relatedness, along with continuous monitoring of study animals, allowed us to extend our time table of parent-offspring and sibling relationships back to the year 2002 (Figure 3).

Site of parturition in natal den. Note chewing on sides of log and bed of wood chips.

This contributed to our understanding of reproductive parameters and survivability as well. Future analyses will assess the congruence between genetic relatedness, spatial distribution, and social interaction.

The discoveries of reproductive dens in Glacier National Park doubled our sample of known wolverine dens in the contiguous US. Researchers across North America have documented a total of 65 wolverine reproductive dens associated with about 25 females. Scandinavia researchers have documented nearly 500 dens.



Typical wolverine denning habitat in Glacier National Park. Downed trees, cliffs, and boulders provide natural cavities under a deep blanket of snow, which provides protection from predators and insulating warmth for the kits.

Recent technological advances in GPS technology currently provide lighter weight and more power-efficient transmitters enabling researchers to consider GPS study of small carnivores such as wolverine. This study played an important role in the development of that technology. We worked directly with manufacturers in the creation of smaller, more ergonomic collar systems, and improved designs to avoid potential collar-related injuries. However, a GPS collar, suitable for wolverine, that reliably acquires high frequency location data for an entire year is still unavailable due to battery limitations. Our study's high wolverine recapture rate and a GPS collar design that allowed on-site battery replacement and data download, enabled us to acquire short duration, high fix-frequency data. These data, in turn, will allow us to investigate wolverine movement at various temporal and spatial scales during winter months, which will provide a better understanding of both the capacity of wolverine movement and the ecological constraints of those movements across the landscape.

Table 1 Minimum convex polygon (100%) home range sizes for adult wolverines in Glacier National Park, 2007 [a]

Animal ID	Current Age/Sex	N (locations)	Home Range (km^2)
M1	Adult male	171	438
F2	Adult female	204	167
M3	Adult male	152	749
F4	Adult female	205	207
F5	Adult female	123	121
M6	Adult male	33	312
F7	Adult female	38	140
F11	Adult female	22	80
M13	Adult male	11	587
F15	Adult female	33	72
F17	Adult female	11	150

[a]Home range analyses include only VHF telemetry relocations across all years.

Home Range

Home ranges of wolverines in GNP are considerably smaller than home ranges documented in other studies; an indication that GNP provides a rich and diverse habitat for wolverine (Figure 4. Table 1). Adult home range size for males and females averages 521 and 139 km^2 respectively. Still, population estimates for Glacier National Park are expected to indicate only 40-50 individuals.

Currently, it appears that 3 wolverines are established residents of the Many Glacier Valley. M1 is the resident male associated with resident females F2 and F4. Male M3 and female F15, residents of the Belly River area, make occasional forays into Many Glacier, most likely stimulated by

the availability of food at our traps. Females F11 and F7 remain mostly west of the Continental Divide with F7 making occasional forays to Logan Pass, while F11 remains primarily in the Livingston Range centered around Vulture Peak in the upper Logging Creek area. Several individuals associated with the Two Medicine area have not had their spatial juxtaposition well defined due to a lack of telemetry locations. Adult male M16 may have been the resident male for the south-eastern portion of the park, yet he appeared to center his activity in the St. Mary Valley. He died in early 2007. Female F17 is a Two Medicine resident adult that may have been associated with M16, but has most recently been mated with M13, an adult male that ranges between Logan Pass and Mount Rockwell.

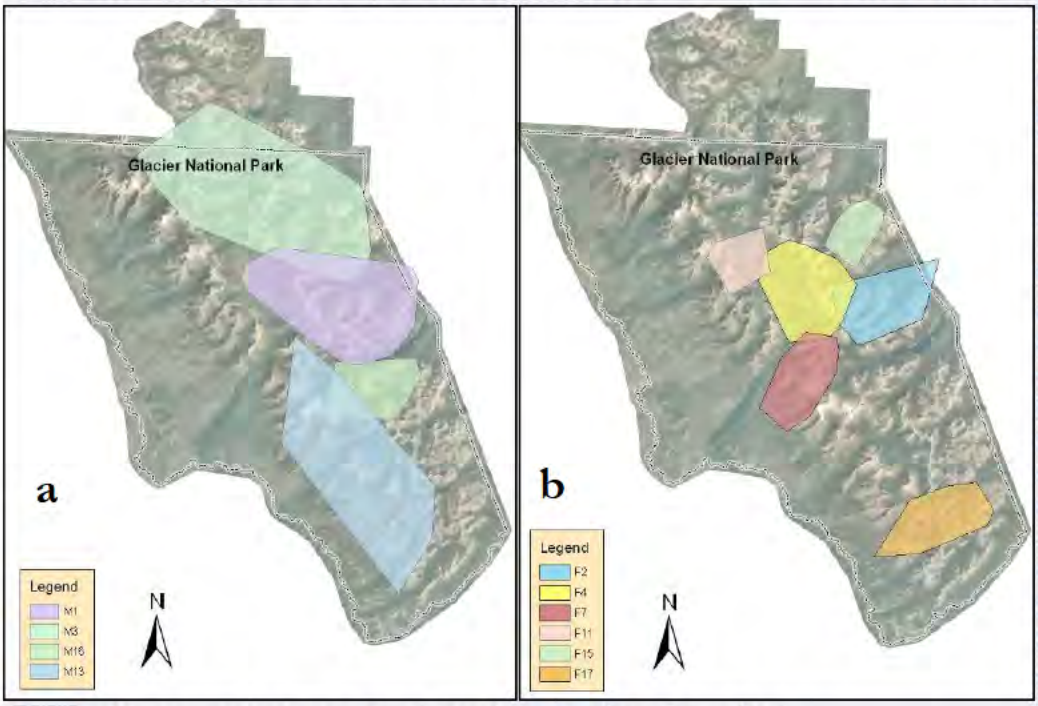


Figure 4. Home ranges of male (a) and female (b) wolverines in Glacier National Park

Social interactions

Understanding the intraspecific relationships in wolverine populations may provide important insight into spatial and social population structure. Anecdotal accounts of interactions among wolverines continue to increase as research techniques improve our ability to more closely monitor individuals over time. Evidence of sociality, documented in central Idaho wolverines, was strongly reinforced in GNP. We documented over 60 instances in

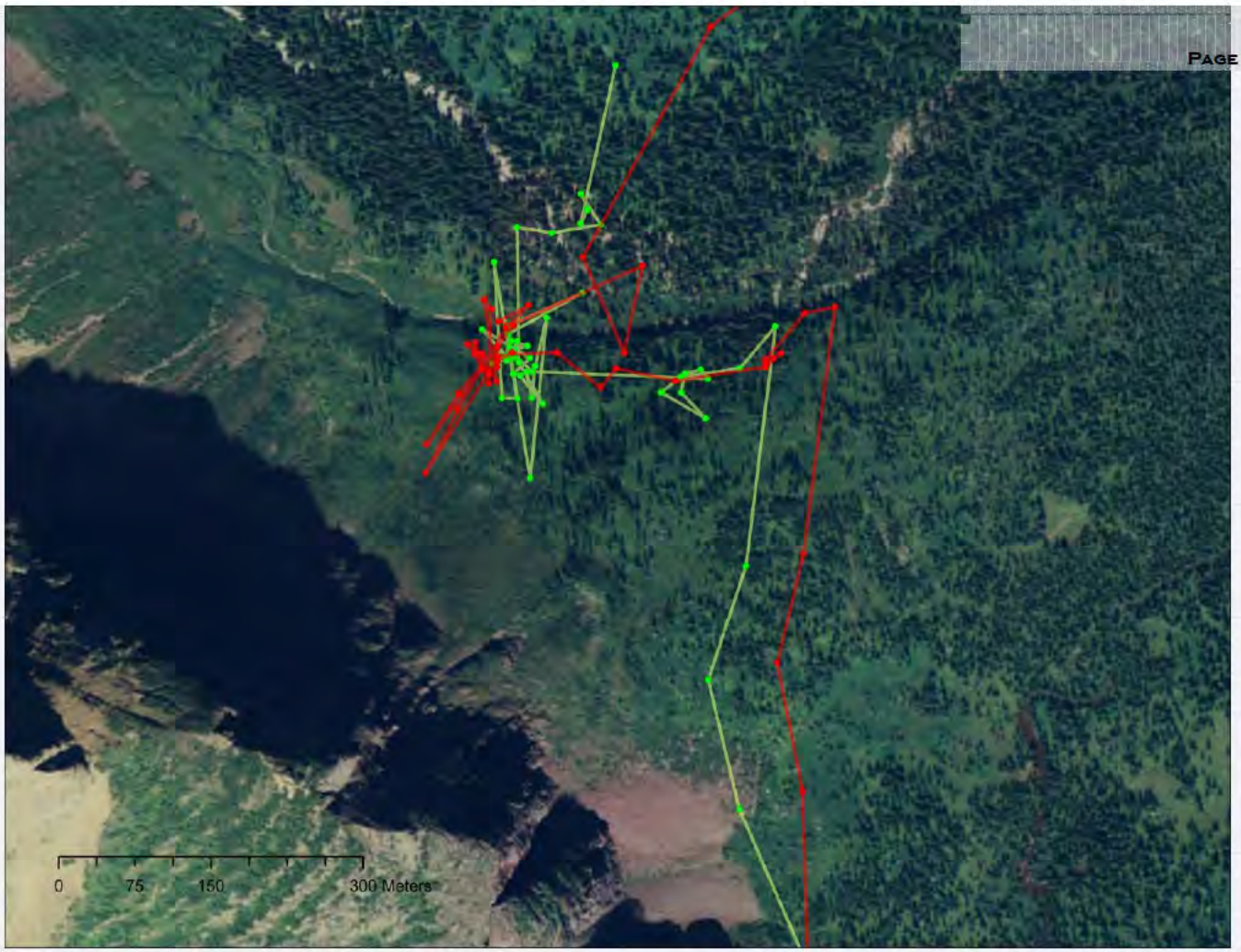


Figure 5. GPS data showing pairing of Belly River male M3 (red line) and his juvenile offspring, M23 (green line). Both individuals met at the outlet of Helen Lake, then traveled north where they stopped for several hours. They left together although M23's GPS collar quit shortly. This sort of social interaction between a resident male and subordinate male is extremely unusual for any carnivore species outside of the most social of the carnivores. It suggests a much more highly developed sociality than previously thought and indicates the possibility of male parental care in wolverine.

which GNP wolverines were found together or near one-another, not including pairings between adult males and females during the mating season. Seventeen of these instances occurred between Many Glacier male M1 and his offspring.

It is not uncommon for GNP visitors to see two wolverines together. Most often these are probably siblings that remain together through the summer months while under the supervision of their mother. Female F7 frequents the Logan Pass area where she and her offspring are commonly seen near Hidden Lake during the summer. Female F4 and her kits are occasionally seen along the Highline Trail hunting ground squirrels and marmots. Occasionally, father-offspring pairings occur once the juveniles separate from each other and their mother (after September). If juveniles remain in their natal areas, at some point they will make contact with their father. This pairing may benefit the offspring as the adult male shares knowledge of travel paths and forage sites (Figure 5).

Fine-scale GPS monitoring in GNP also provided an opportunity to intensively track multiple individuals, and thereby monitor movements and distribution in time and space. Our GPS data, which is currently under analysis, provided evidence of 2 instances in which a resident male visited, and most likely entered the den of a reproductive female (Figure 6). Such interactions in solitary carnivores are remarkable and significant to understanding how wolverine social structure might respond to management activities. For instance, juvenile survivorship that is strongly tied to an extended parental care period which includes participation by the offspring's father, may be altered by a harvest strategy that targets adult males. For a low population density species, such as the wolverine, this knowledge could be critical to population persistence in areas where the species is already rare.

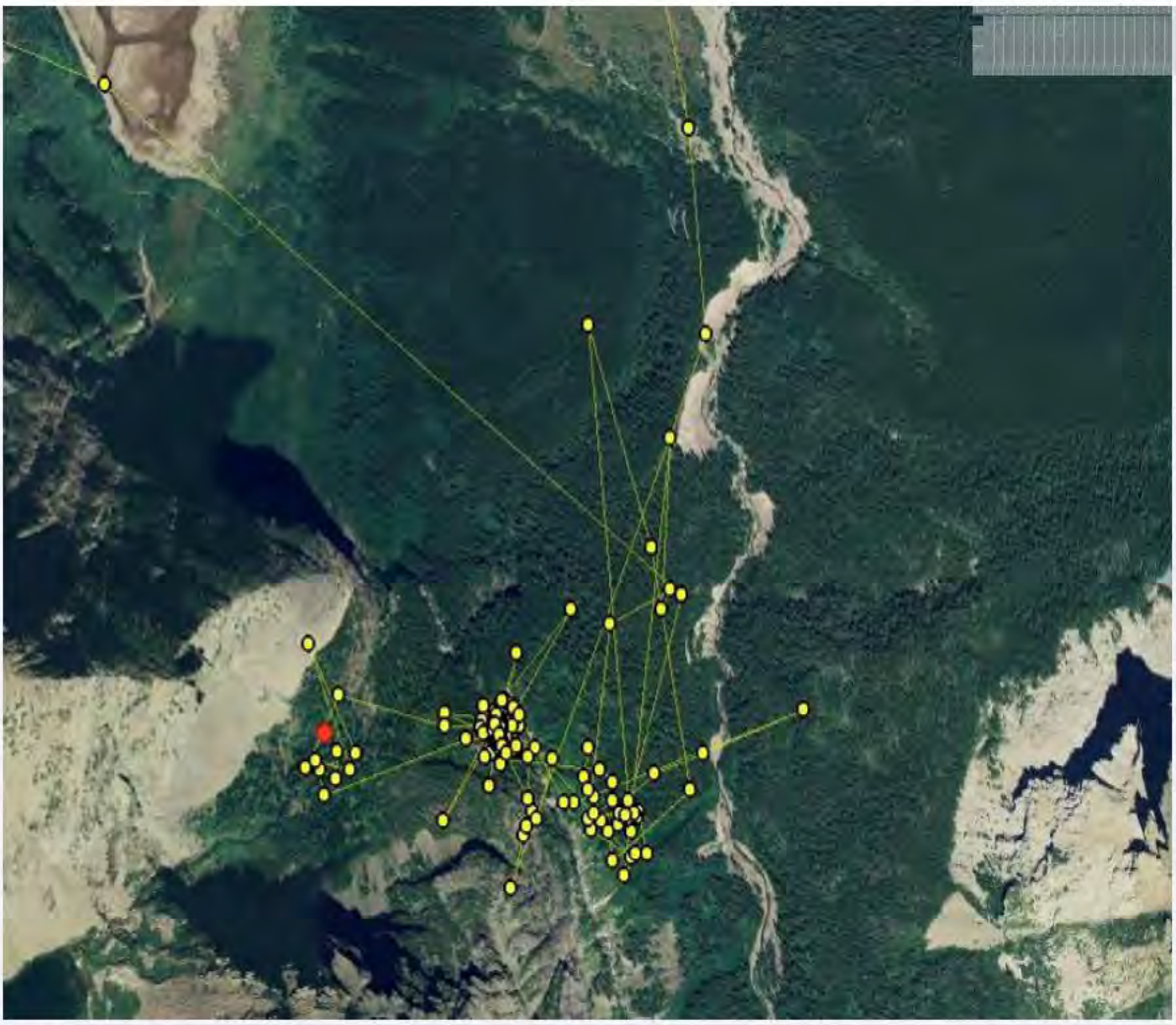


Figure 6. The resident male (green dots) cluster near the female's den (red dot) for several hours. At one point he approached the den and his GPS collar went off the air for 6 hours indicating he had likely went into the den.

Wolverine Movement, Habitat Associations, and Activity

The wolverine's world-wide range is strongly tied to a specific habitat signature; referred to as tundra or taiga at northern latitudes, boreal at mid-latitudes, and subalpine in the south. Wolverine habitat is defined by a tundra-subalpine signature that effectively restricts its range. At northern latitudes, wolverine habitat occurs virtually everywhere, but to the south, the subalpine lifezone necessary for wolverine presence becomes restricted to an elevational band, resulting in a naturally fragmented distribution (Figure 7).

Populations that are further restricted to island habitats are vulnerable to extinction unless they are able to spatially communicate with neighboring populations. Western Montana and GNP typify this insular population structure more so than anywhere else across the wolverine's range. By studying how wolverine move across the landscape and their response to changes in habitat and encounters with human-related features, we can better predict how changes to the landscape might impact the persistence of populations.

To understand how wolverine respond to the landscape, it is necessary to study their movement at varying scales. The GNP study provided a unique opportunity to view fine-scale movement using GPS technology. In addition, our high recapture rate allowed for collection of multiple data sets on the same individuals. These data will provide an unprecedented look at patterns and rates of movement, and how movement relates to habitat features, foraging behavior, and sociality among study animals.

Patterns and rates of movement

The speed at which an animal moves across the landscape is indicative of its interest in a particular habitat. Analyzing fine-scale patterns of movement helps us better understand how individuals space themselves across the landscape and how that relates to food resources. GNP wolverine display a movement pattern that indicates a patchy distribution of food resources; individuals move long distances to food patches and remain there for a period of time. Our GPS

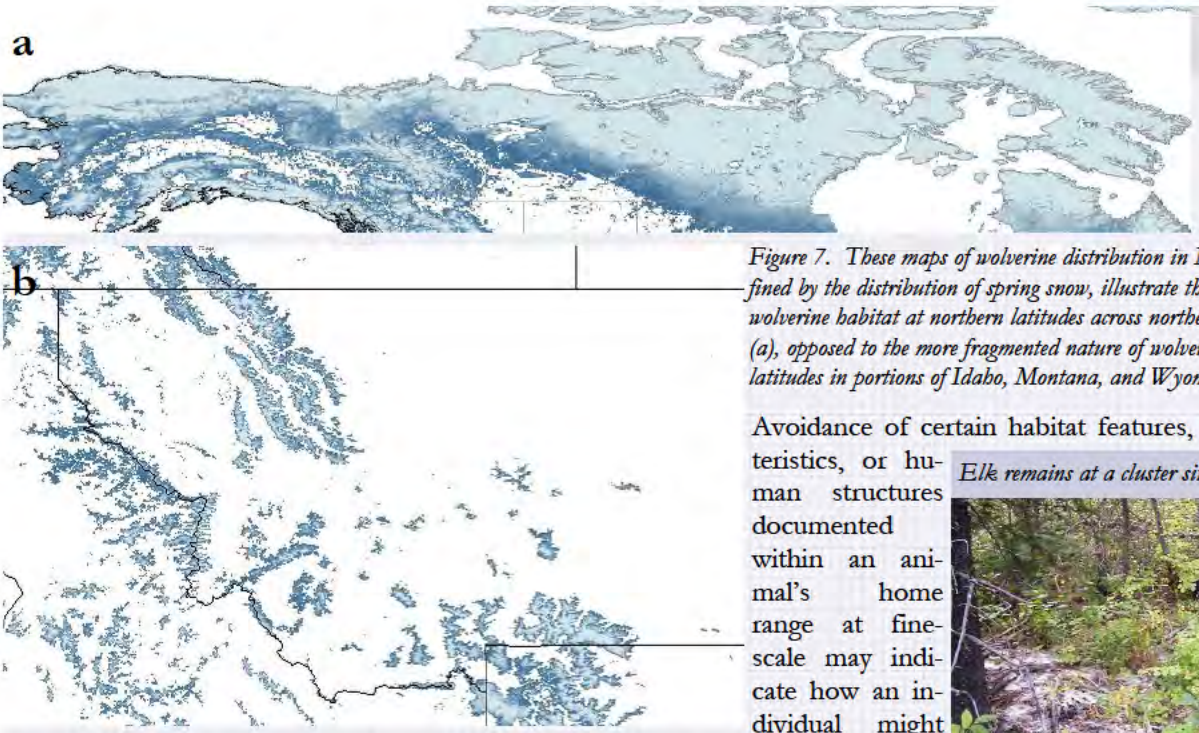


Figure 7. These maps of wolverine distribution in North America , as defined by the distribution of spring snow, illustrate the continuous nature of wolverine habitat at northern latitudes across northern Canada and Alaska (a), opposed to the more fragmented nature of wolverine habitat at southern latitudes in portions of Idaho, Montana, and Wyoming (b).

data indicate that movement to and from these patches occurs at a rate of about 4 km/hour indicating that little time is spent hunting or pursuing other interests between patches. GPS points tend to show as clusters at these patches (Figure 8). Project personnel investigated these cluster sites to determine the nature of their use by wolverines. During a 7-day period, a wolverine may stop at a dozen such sites, which represent a variety of activities, such as foraging, interactions with other individuals, or simply periods of rest. An adult male wolverine travels in excess of 150 km during this period and generally follows a movement pattern that will be repeated throughout the year (Figure 9).

The relationship between movement and habitat

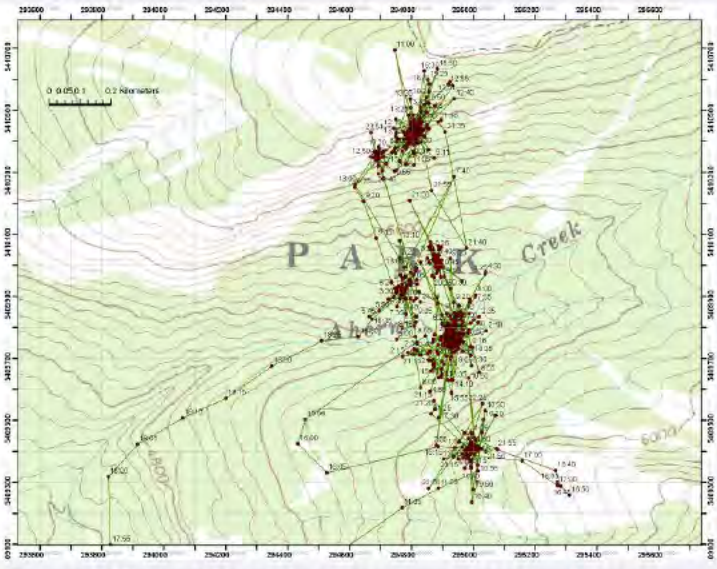


Figure 8. GPS point clusters identify sites of concentrated use. Project personnel investigate these sites to determine the nature of use.

Avoidance of certain habitat features, topographic characteristics, or human structures documented within an animal's home range at fine-scale may indicate how an individual might be expected to move at larger scale, such as during a dispersal attempt This study's fine-scale GPS data, collected at a rate of 5 minutes/fix attempt, will be used to develop habitat resistance models which will inform us how wolverine relate, and respond to various habitat features. Preliminary analysis of how each 5-minute "step" in the animal's movement is influenced by changes in elevation, and comparing this with the availability of changing elevation across the park, indicates that the wolverine operates as largely a "flat-land" species as it maximizes its efficiency traversing some of the most rugged topography in North America. Glacier park wolverines avoid uphill slopes greater than 5%, and downhill descents greater than about 3% slope as they contour the landscape (Figure 10). This apparent avoidance of steep slopes is confounded by the occasional ascent over such formidable obstacles such as Mt. Cleveland (Figure 11) and Iceberg Notch. Further analysis will refine these results, but we can speculate that traversing might allow the individual to efficiently travel country that provides the highest likelihood of providing food, and in the process conserve energy for necessary ascents over cliffs and peaks.

Elk remains at a cluster site.

Movement and foraging behavior

We investigated 102 cluster sites derived from GPS data. Animal remains were documented at 41 of these sites. Most sites were visited 7-8 months after the cluster was used by a wolverine; there is a likelihood that animal remains or evidence of foraging had deteriorated or been moved during that interval. We are investigating other ways of determining the nature of a wolverine's presence at a cluster site. One such indicator of use might be the pattern of activity cycling exhib-

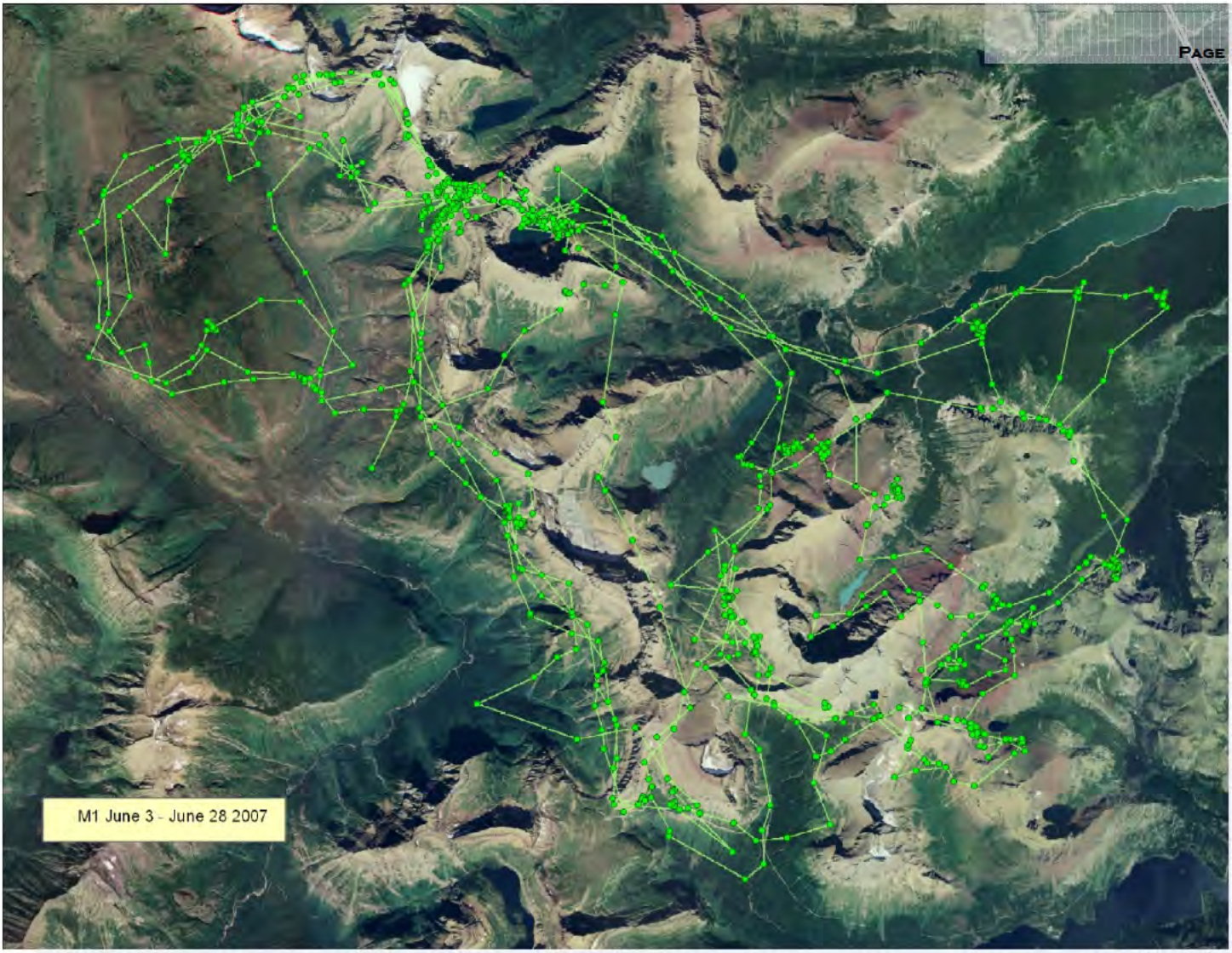


Figure 9. Typical GPS path of adult male wolverine. The movement path between each dot represents a 5 minute movement averaging about 300 meters. A typical adult male will travel approximately 150 km a week. Clusters of points show places where the individual stopped to forage, rest, or interact with other individuals.

ited by wolverines at known foraging sites. GPS collars were equipped with activity sensors that recorded collar vibrations at 5 minute intervals. Wolverines at confirmed foraging sites exhibited a fairly well defined pattern of activity-inactivity that tended to cycle around an approximate 2-hour period (Figure 12). This cycle is noticeably absent from many cluster sites, which may indicate that the animal is simply resting, rather than foraging. The relationship between activity patterns and foraging behavior will be useful in developing energetic models that will, in turn, help us understand the relationship between food availability and spatial needs of the wolverine.

Food habits

Food habits will be described through the analysis of scats, photographic evidence from park visitors, and collection of prey remains at rendezvous, forage, cache, and reproductive den sites. Analysis of 142 scat samples is currently underway. Forage sites (N=56) were documented using VHF telemetry and GPS analysis and visual locations by GNP staff.

Management Implications

Scandinavian wolverine research found a significant relationship between female reproductive output and the availability of food. We suspect that a relatively abundant food resource in Glacier National Park is at largely responsible for the high population densities observed in this study. Healthy populations of mountain goat, mountain sheep, elk, and deer provide winter surpluses in the form of winter carrion, while abundant hoary marmot and ground squirrel populations provide ample hunting opportunity for wolverines in the spring and summer. Any activity that limits the availability and abundance of prey species will adversely impact wolverine. As such, we would encourage continuation of Glacier National Park's policy regarding the removal of carcasses as a deterrent to grizzly bear-human conflicts. Leaving carcasses in place, as is current policy, provides for-

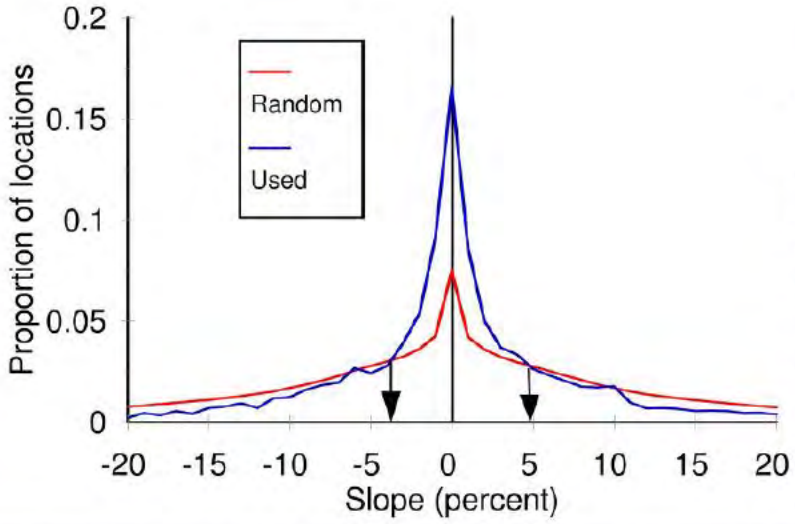


Figure 10. This graphic represents of distribution of choices made by wolverine as to whether the individual moves uphill or downhill as it moves across the landscape. The red line represents choices that could be made, while the blue line represents choices that were made by this particular study animal. Where the lines cross represents the point where avoidance and preference meet. Between –5 and +5% the wolverine is using mild slopes much more than would be expected by random chance. Beyond these points, the individual is using those slopes less than expected, indicating avoidance of steep slopes.

aging opportunity for wolverine and other scavangers.

Concerns over the sensitivity of denning female wolverine to human-related activities such as snowmobiling and backcountry skiing has lead management agencies to restrict winter access into areas used by wolverines as potential denning habitat. Until we develop a better understanding of this relationship, consideration should be given to protecting potential denning habitat during the critical denning months of February through April. As global warming continues to reduce the extent of deep, spring snow necessary to wolverine denning, protection of habitat through the denning period will become increasingly important to wolverine persistence.

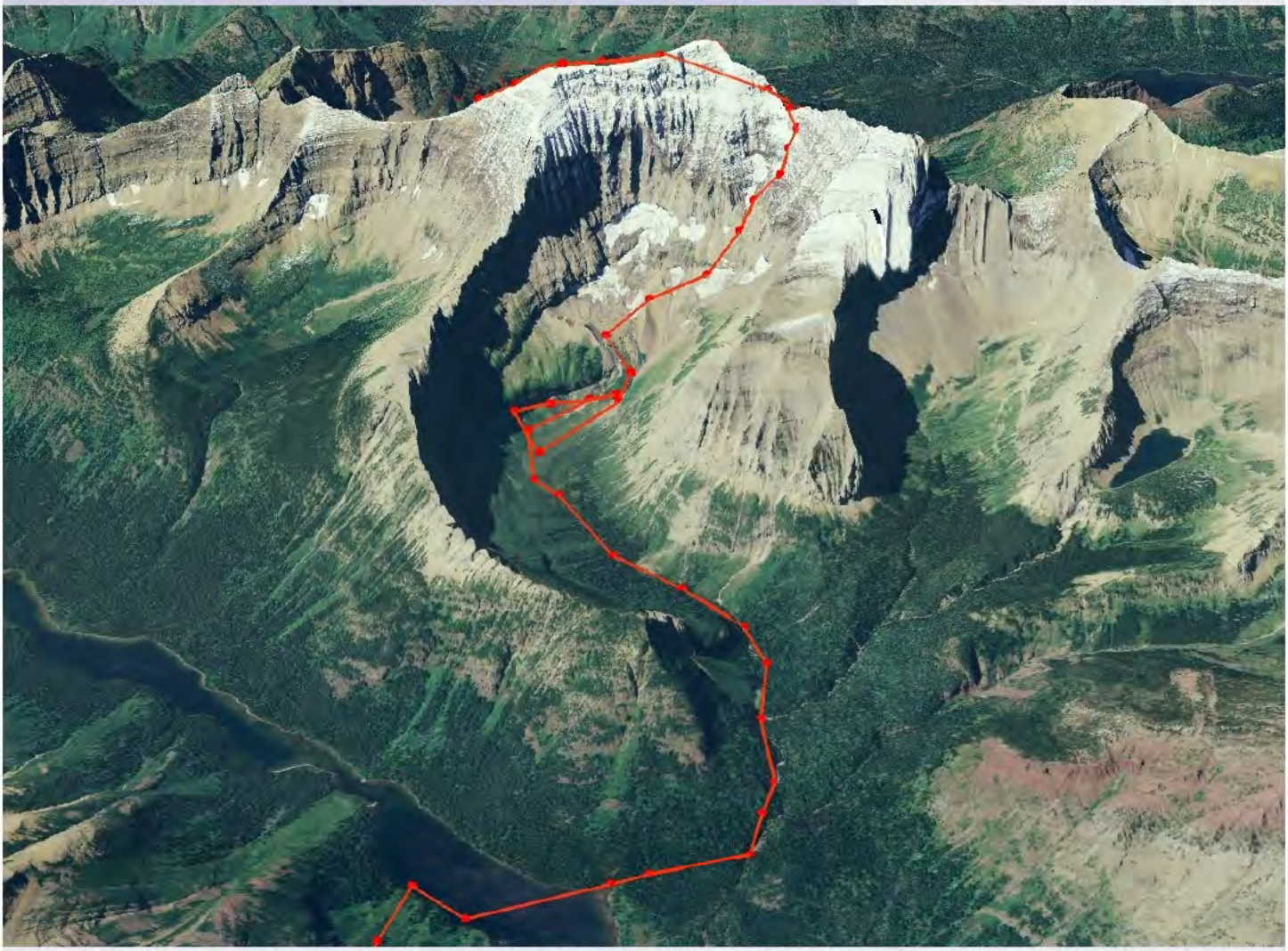


Figure 11. The Belly River resident male, M3, traverses his way to the base of Mt. Cleveland. He ascended to the summer, nearly 5,000 vertical feet, in less than 90 minutes.

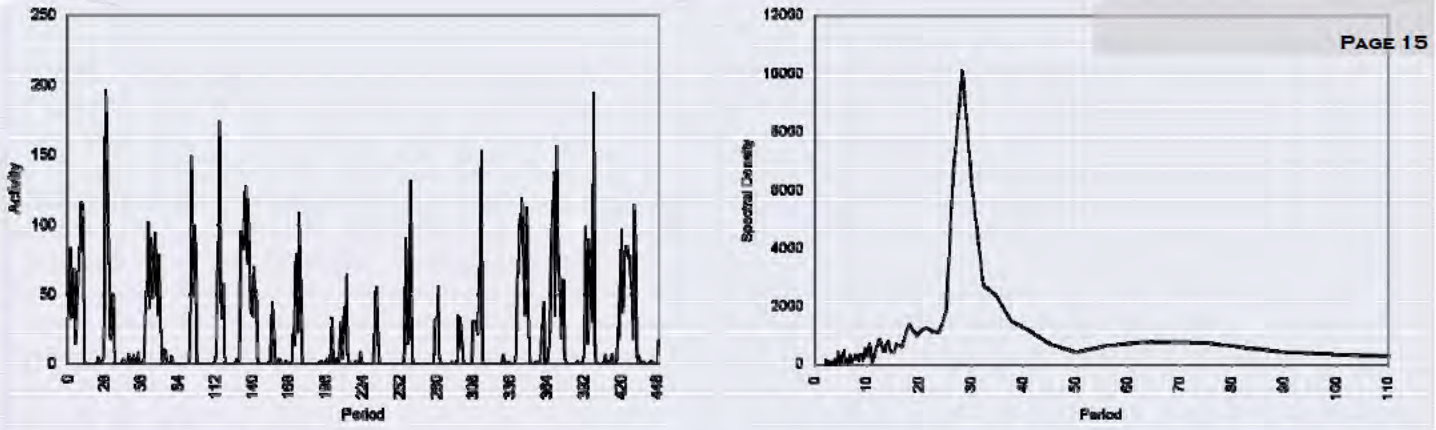


Figure 12. The graph on the left shows activity cycling across a 37 hour (448 periods times 5 minute/period) stay at a cluster site. The graph on the right (spectral density plot) is used to determine the periodicity, indicating that the primary activity cycle is 28 periods, or about 140 minutes.

While Glacier National Park manages its winter landscape as wilderness, thereby restricting motorized access during winter months, spring snow plowing on the Going-to-the-Sun road occurs very near to areas of documented wolverine denning. The timing of a den abandonment in Alder Creek coincided with the onset of snow plowing in 2004. Females are known to occasionally move kits to secondary dens prior to weaning so while this particular incident cannot be directly tied to the plow activity, it is certainly notable in its coincidence. The Sun road is included in the home ranges of at least 3 adult female wolverines so it is recommended that potential disturbance related to plowing be considered in future planning.

Glacier National Park provides what may be the best opportunity in the world to observe a wolverine in a natural setting. GNP should take considerable pride in the knowledge that this fact alone makes this site unique in the national park system.

Products

A comprehensive report will detail all aspects of this research and data analysis. Data that provide adequate sample size and quality will be submitted to peer-reviewed journals and included as appendices to the comprehensive report. Listed below are current published works, papers in review or preparation, or papers planned for preparation which include data collected in this study.

1. *Sources and patterns of wolverine mortality in western Montana. Squires et al. 2007. Journal of Wildlife Management 71(7).*
2. *Volatile compounds from headspace of wolverine urine—in review*
3. *Does spring snow define a bioclimatic niche for the wolverine?—in prep*
4. *Global warming and a snow dependent species: a case for the wolverine—in prep*
5. *Deriving minimum-cost pathways for wolverine movement through habitat resistance modeling—in prep*
6. *Fine-scale genetic structuring in exploited and non-exploited wolverine populations.*
7. *Defining patterns and scale of wolverine movement in winter.*
8. *Activity cycling of wolverine in Glacier National Park.*
9. *Socio-spatial structuring in non-exploited wolverine populations.*
10. *The reproductive dens of the wolverine in Glacier National Park.*
11. *Energetics and foraging strategies of the wolverine in Glacier National Park.*
12. *Food habits of the wolverine in Glacier National Park.*

From: Turner, Ed
To: Betty Grizzle
Subject: USFS Decades
Date: Tuesday, January 17, 2017 6:08:07 PM
Attachments: USFS NRIS by Decade.pdf

Betty here is a map of the USFS NRIS data by decades.

Maybe Wednesday I can show you the USFS site data, as I don't think we can use that with this type of decade mapping, or may not be able to really use it and will just have to use USFS NRIS in this map along with all the States data.

No luck on NM and I tried basic web searches too with nothing. I can try USGS sciencebase if needed.

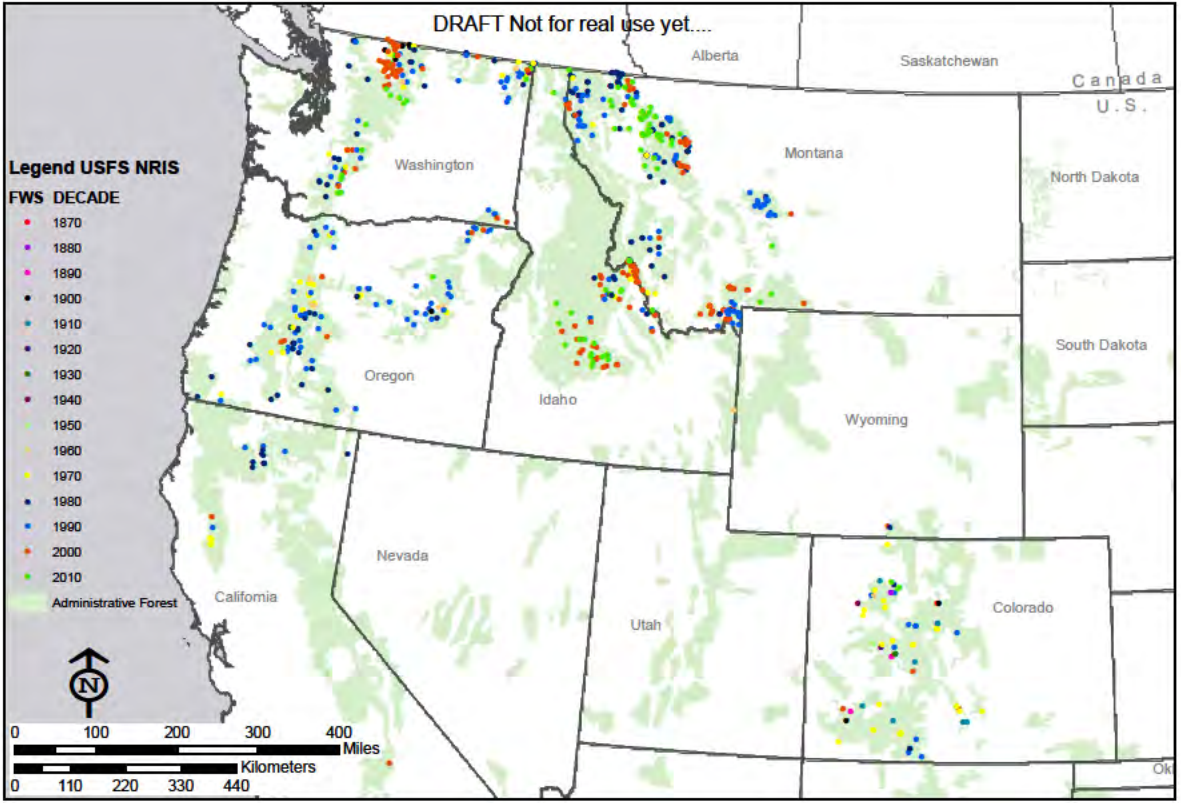
On the tables, I can run finds on DEN, but I get every word that has den in it. Ex. Hayden Creek. I will add fields to the northern most states and try to grab anything with den. That may limit the data down, so I can further just scan through for actual den locations.

Pulled in the WY data, most in Tetons and some in Bighorns and down southeast I guess east of Laramie and Cheyenne too.

--
Edwin Turner, Geographer
GIS Mapping and Analysis Branch

DOI-R8-CFWO
USFWS Carlsbad Fish and Wildlife Office
2177 Salk Ave. Suite 250
Carlsbad, CA 92008
760.431.9440 x266

Ed_Turner@fws.gov
760.431.9440 x266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Wyoming
Nevada
California
Utah
Colorado
Legend USFS NRIS
FWS DECADE
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Administrative Forest
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Miles
Kilometers
0 110 220 330 440

From:	Turner, Ed
To:	Betty Grizzle
Subject:	Amethyst Lake UT
Date:	Thursday, January 19, 2017 3:52:02 PM
Attachments:	Amethyst Lake (Uinta Mountains) Wolverine Sighting.pdf

---

--

Edwin Turner, Geographer
GIS Mapping and Analysis Branch

DOI-R8-CFWO
USFWS Carlsbad Fish and Wildlife Office
2177 Salk Ave. Suite 250
Carlsbad, CA 92008
760.431.9440 x266

Ed_Turner@fws.gov
760.431.9440 x266

From:	Nathan D Berg
To:	Garcia de la Cadena, Dan -FS
Cc:	Danielle K Chi; Cowley, Paul -FS; Jacobson, Lee -FS; Labrum, Kevin C -FS; Gray, Anthony A -FS; Hartman, Karen -FS; kevinbunnell@utah.gov; masakowright@utah.gov; brianmaxfield@utah.gov; kimberlyasmus@utah.gov; binman@wcs.org; kinman@wcs.org
Subject:	Amethyst Lake (Uinta Mountains) Wolverine Sighting
Date:	Friday, September 10, 2010 10:41:00 AM

Hi Dan,

Below is this summer's wolverine sighting report from Amethyst Lake. I also spoke to Mr. Buxton on the phone. Sounds like a pretty solid report. If you have further questions feel free to email or call Mr. Buxton. FYI: UDWR documented (with photos) excellent wolverine tracks in the Amethyst Lake area 4-5 years ago.

Thanks.

Nate

Nathan D. Berg
Wildlife Biologist
Heber-Kamas Ranger District
Uinta-Wasatch-Cache National Forest
nathanberg@fs.fed.us
435.654.7227 Heber Office
435.783.8705 Kamas Office
435.671.0364 Cell

----- Forwarded by Nathan D Berg/R4/USDAFS on 09/10/2010 10:21 AM -----

Michael Buxton <michaelsbuxton@gmail.com>

09/10/2010 09:46 AM

To Nathan D Berg <nathanberg@fs fed.us>
cc
Subject Re: Your Wolverine Sighting

Hi Nate

My siting of the wolverine took place around 8pm on Friday, August 20, 2010. The location was near the southwest corner of Amethyst Lake. Fishing had become poorer due to wind, so I hiked up a rocky 100ft incline directly up from the lake at this corner. I did not have any camera with me. At the top of this incline is a rocky ledge which is probably a few hundred feet wide before inclining again westward up the mountain. I began walking toward the north along this ridge and maybe 200 feet along this ridge I saw the wolverine, walking about 60 feet in front of me, crossing my path so I could see its right side perfectly. I was alone in the siting; my 25 year old son was on the south side of the lake.

The first thing I noticed was its size--it was as large as a small-to-medium sized dog. It was quite round around the belly, furry and what seemed a little fat. When I

saw it, it was obvious to me it was not a badger or marmot, and certainly not a bear cub. The other thing I quickly noticed was its strange way of walking--kind of a slow trot and loping side to side. It seemed almost comical. I stopped immediately and stood still. It stopped at the east edge of the ledge and stopped, standing still, and looking at me. It appeared it was heading into some brush, but was interested in me. This was the amazing thing to me--it was just as curious about me as I was about it, so we stood there and stared at each other for more than 10 minutes. It kept looking over at me and then away. I inched forward at times and it noticed this but it stayed put. Eventually I got too close for its comfort (about 50 feet) and it quickly moved into the brush and I did not see it again.

It's head was black. Most of it's body fur was dark brown, but there was golden color on it's neck and behind it's ears. At the top of it's tail was golden/tan color and about 1/4 of the way down it became dark brown through to the end. It's feet were very dark brown/black. I did not smell a scent.

I have never seen a wolverine before so this was a wonderful experience for me, I was certainly not expecting it. If anyone has further questions, please email me or contact me at 801-318-1900. I live in Orem, UT and work as a professor at BYU.

Michael Buxton

On Tue, Sep 7, 2010 at 9:18 AM, Nathan D Berg <nathanberg@fs.fed.us> wrote:

> Hi Michael,
>
> It was good speaking with you on the phone last week. Thanks a bunch for reporting your wolverine sighting. This is an important rare carnivore sighting. If you would send me a detailed report of this sighting I would very much appreciate it.
>
> Thanks for your help. Please feel free to contact me if you have any questions.
>
> Nate
>
> Nathan D. Berg
> Wildlife Biologist
> Heber-Kamas Ranger District
> Uinta-Wasatch-Cache National Forest
> nathanberg@fs.fed.us
> 435.654.7227 Heber Office
> 435.783.8705 Kamas Office
> 435.671.0364 Cell

From:	Turner, Ed
To:	Betty Grizzle
Subject:	Fwd: Wolverine Data request
Date:	Thursday, January 19, 2017 4:33:53 PM
Attachments:	image004.png image003.png image001.png image002.png Amethyst Lake (Uinta Mountains) Wolverine Sighting.pdf Locations of Potential Wolverine Sightings or Tracks.pdf Reported Wolverine Sightings 2008-2016.xlsx

---

Record of email with letter about Amethyst Lake. Plus excel table that I will use to get Utah data and map. I think they may be same records as other maps, but will look at it all and see.

---------- Forwarded message ----------
From: **Lee, Matthew B -FS** <mblee@fs.fed.us>
Date: Tue, Jan 10, 2017 at 12:46 PM
Subject: RE: Wolverine Data request
To: "Turner, Ed" <ed_turner@fws.gov>
Cc: "Manders, Pamela - FS" <pmanders@fs.fed.us>, "Hacker, Christina - FS" <chacker@fs.fed.us>

Hey Ed,

Attached is the data from our wildlife bios. One is an email describing a siting at Amethyst Lake, another is a rough map of locations, and the spreadsheet contains the coordinates.

Here is a link to the Utah Division of Wildlife Resources GIS Data website. Again nothing wolverine, but maybe for future reference.

http://dwrcdc.nr.utah.gov/ucdc/DownloadGIS/disclaim.htm

Here is a link to a Utah DWR article about the wolverine we caught on the camera, and another one that was hit and killed near Bear Lake.

https://wildlife.utah.gov/wildlife-news/1872-wolverine-found-in-rich-county.html

Salt Lake Tribune Article:

http://archive.sltrib.com/story.php?ref=/sltrib/news/58142331-78/wolverine-utah-species-wildlife.html.csp

Wolverine hit by car near Bear Lake:

http://www.cachevalleydaily.com/news/local/article_196bfeb0-3fe5-11e6-aa54-ab9ce673074f.html

Let me know if there is anything else we can help with,

Matthew Lee
GIS Coordinator
Forest Service

Ashley and Uinta-Wasatch-Cache National Forests
p: 801-999-2132
mblee@fs.fed.us
857 W. South Jordan Parkway
South Jordan, UT 84095
www.fs.fed.us

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From: Turner, Ed [mailto:ed_turner@fws.gov]
Sent: Tuesday, January 10, 2017 11:51 AM
To: Lee, Matthew B -FS <mblee@fs.fed.us>
Subject: Wolverine Data request

Hi Matt, Thanks for the help.

Ed

--

Edwin Turner, Geographer

GIS Mapping and Analysis Branch

DOI-R8-CFWO

USFWS Carlsbad Fish and Wildlife Office

2177 Salk Ave. Suite 250

Carlsbad, CA 92008

760.431.9440 x266

Ed_Turner@fws.gov

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--
Edwin Turner, Geographer
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From:	Nathan D Berg
To:	Garcia de la Cadena, Dan -FS
Cc:	Danielle K Chi; Cowley, Paul -FS; Jacobson, Lee -FS; Labrum, Kevin C -FS; Gray, Anthony A -FS; Hartman, Karen -FS; kevinbunnell@utah.gov; masakowright@utah.gov; brianmaxfield@utah.gov; kimberlyasmus@utah.gov; binman@wcs.org; kinman@wcs.org
Subject:	Amethyst Lake (Uinta Mountains) Wolverine Sighting
Date:	Friday, September 10, 2010 10:41:00 AM

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Thanks.

Nate

Nathan D. Berg
Wildlife Biologist
Heber-Kamas Ranger District
Uinta-Wasatch-Cache National Forest
nathanberg@fs.fed.us
435.654.7227 Heber Office
435.783.8705 Kamas Office
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----- Forwarded by Nathan D Berg/R4/USDAFS on 09/10/2010 10:21 AM -----

Michael Buxton <michaelsbuxton@gmail.com>

09/10/2010 09:46 AM

ToNathan D Berg <nathanberg@fs fed.us>
cc
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Michael Buxton

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> Thanks for your help. Please feel free to contact me if you have any questions.
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>
> Nathan D. Berg
> Wildlife Biologist
> Heber-Kamas Ranger District
> Uinta-Wasatch-Cache National Forest
> nathanberg@fs.fed.us
> 435.654.7227 Heber Office
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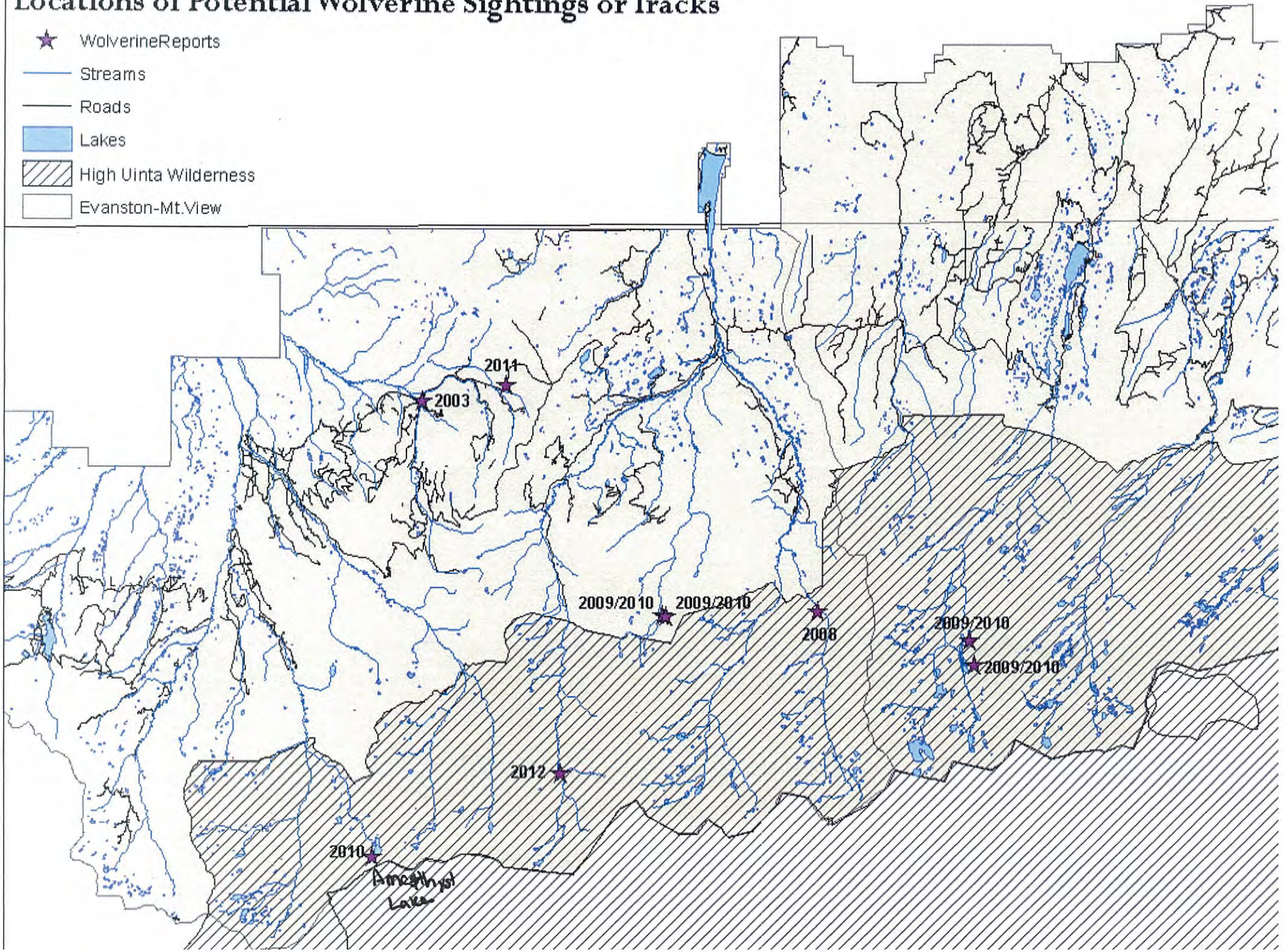
Locations of Potential Wolverine Sightings or Tracks



Location	Year	Type	Easting	Northing
Little East Fork of the East Fork Blacks Fork	2008	sighting	539934	452153
East Fork Smiths Fork	2009/2010	tracks	546841	4519175
Lower Red Castle Lake	2009/2010	tracks	546633	4520218
Middle Fork Blacks Fork	2009/2010	tracks	533061	4520218
Tokewanna Peak	2009/2010	tracks	533220	4521320
McKenzie Creek	2011	tracks	526094	4531501
West Fork Blacks Fork	2012	sighting	528502	4514421
SW Amethyst Lake	8/20/10	sighting	?	?
Hwy 150 (~0.59 miles south of FS Rd 110)	May-16	sighting	510344.9	4511428
East Fork Blacks Fork Guard Station	2/18/14	picture	538631	4525504

Confirmed?
no
no
no
no
no
no
no
no
no
yes

From:	Shoemaker, Justin
To:	Conor McGowan; Guinotte, John; Stephen Torbit; Marjorie Nelson; Seth Willey
Subject:	Fwd: Draft maps, etc.
Date:	Friday, January 20, 2017 10:23:47 AM
Attachments:	Draft_Count_Table.pdf USFS NRIS by Decade.pdf

We may discuss these on today's call.

Justin Shoemaker
Senior Listing Biologist
U.S. Fish and Wildlife Service, Region 6
1511 47th Avenue, Moline, IL 61265
Phone: 309-757-5800 ext. 214
Email: justin_shoemaker@fws.gov

---------- Forwarded message ----------
From: **Grizzle, Betty** <betty_grizzle@fws.gov>
Date: Wed, Jan 18, 2017 at 3:36 PM
Subject: Draft maps, etc.
To: "Shoemaker, Justin" <justin_shoemaker@fws.gov>, "Bush, Jodi" <jodi_bush@fws.gov>

Justin and Jodi - A few **preliminary** draft documents:

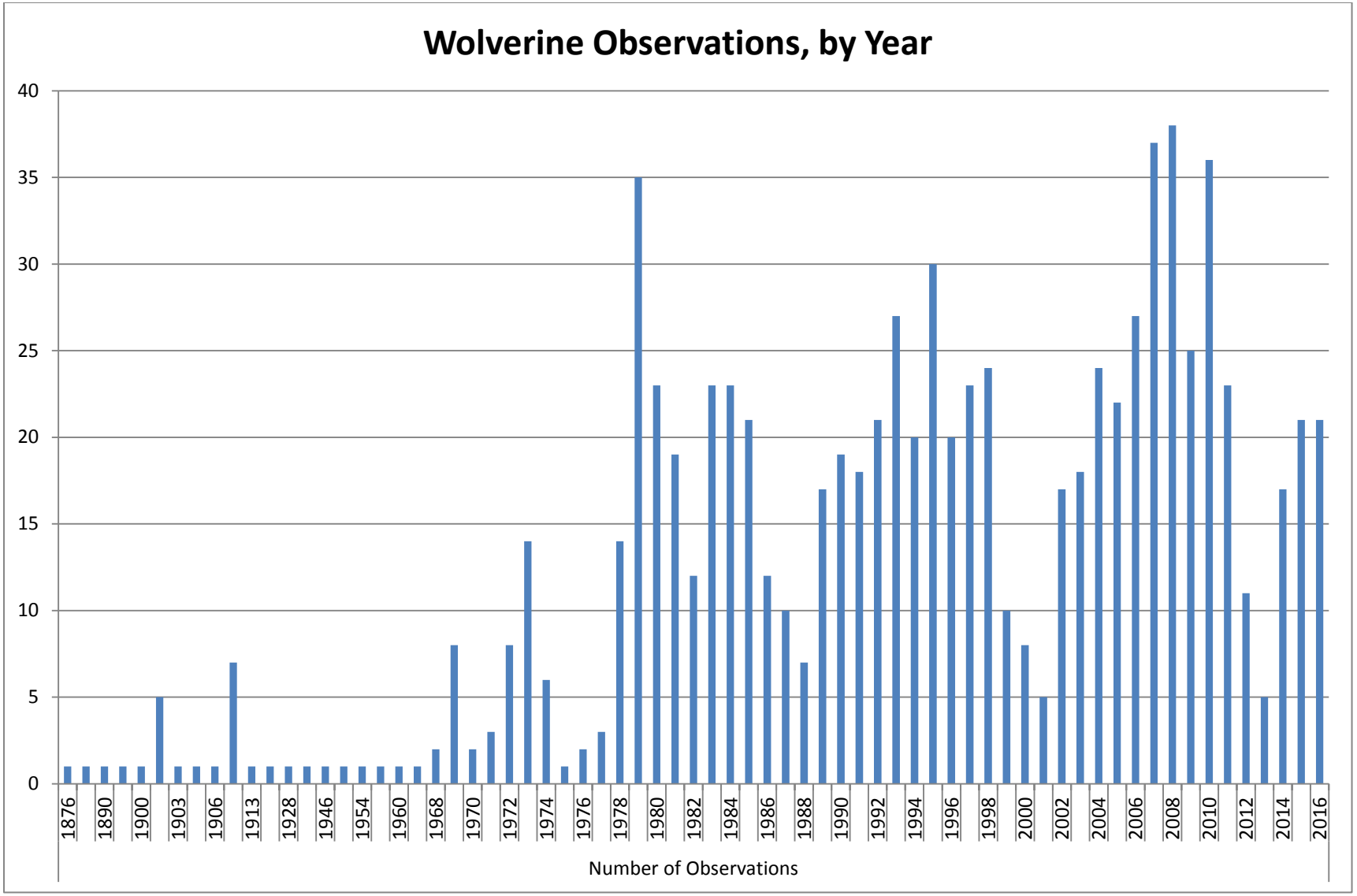
1) Map of US Forest Service wolverine observations by decade (from their NRIS Wildlife database)
2) Figure (histogram) illustrating these observations over time (by year)
(we have several other State data sets with observations - will explain later why USFS only presented here)
Ed is still working with USFS on gathering some missing data (Wyoming and Utah, though we have State records); hopefully we can add these today or tomorrow.

Still working on the mapping all of the den sites, but we have 17 records for Montana and 7 for Idaho.

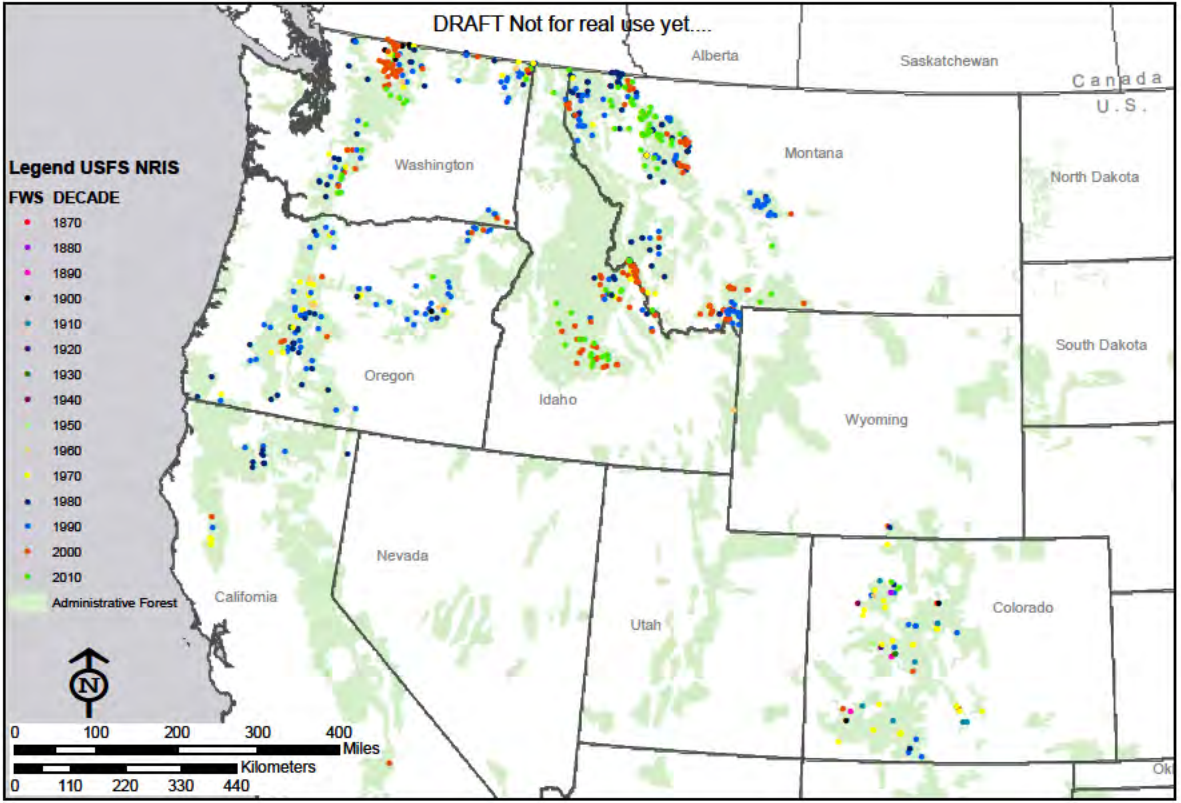
Please do not distribute these documents.

--

Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax



DRAFT DELIBERATIVE DOCUMENT - FOR DISCUSSION PURPOSES ONLY; Source: USFS NRIS wildlife database.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Kilometers
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From:	Krueger, Patricia A -FS
To:	Turner, Ed
Cc:	Betty Grizzle (Betty_Grizzle@fws.gov); Barrera, Bobbi L -FS
Subject:	RE: FW: GULO_GULO
Date:	Monday, January 23, 2017 9:39:26 AM
Attachments:	image001.png image002.png image003.png image004.png

---

Sorry as I was out of the office unexpectedly. This would include the data across the Forest Service that was placed into NRIS Wildlife and Quality Controlled "passed". Couple things that could be:

1. Data not in NRIS Wildlife. Could be in local records.
2. Data in NRIS Wildlife, but not Quality Controlled.

Do note that this database is set for the National Forest System side of the Forest Service (non-research). Specific to New Mexico/Arizona, they have a due date of March 31 for the data that came within the last year, so it is possible that if it is recent, it may not be in the Wildlife database yet.

If you are having any difficulty, the Deputy Director of that region may be able to make contact as well. Her name is Bobbi Barrera and I have cc-ed her into this conversation.

Thanks!

Patti

Patricia Krueger
Regional Threatened and Endangered Species Coordinator

Forest Service
Pacific Southwest Region, Regional Office

p: 707-562-8954
c: 707-373-3702
pkrueger@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

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From: Turner, Ed [mailto:ed_turner@fws.gov]
Sent: Friday, January 13, 2017 2:26 PM
To: Krueger, Patricia A -FS <pkrueger@fs.fed.us>
Cc: Betty Grizzle (Betty_Grizzle@fws.gov) <Betty_Grizzle@fws.gov>
Subject: Re: FW: GULO_GULO

Hi Patti, Hope all's well.

Quick question, the NRIS would that wolverine pull have captured any data in New Mexico? The Range seems to have run down into the Taos and Wheeler Peak area, but we have not found any data.

We have had word that some have been sited down there, but no actual spatial information.

I will try to contact Carson/ Santa Fe Nation Forests and I had a buddy from USFS Taos that I'll call, but just thought I should check with you about the data pull first.

Thanks and hope you have a good holiday weekend,

Ed

On Fri, Jan 6, 2017 at 2:45 PM, Krueger, Patricia A -FS <pkrueger@fs.fed.us> wrote:

> Here is the nationwide data from the Forest Service NRIS Wildlife database. As you get closer to completion of the analysis, please feel free to request an update to this data.
>
> Do let me know if I can help further.
>
> Thanks!
>
> Patti
>
> **Patricia Krueger**
> **Regional Threatened and Endangered Species Coordinator**
> **Forest Service**
> **Pacific Southwest Region, Regional Office**
> **p: 707-562-8954**
> **c: 707-373-3702**
> **pkrueger@fs.fed.us**
> 1323 Club Drive
> Vallejo, CA 94592
> www.fs.fed.us
>
> **Caring for the land and serving people**
>
> ---
>
> **From:** Grapentine, Joel -FS
> **Sent:** Friday, January 06, 2017 1:59 PM
> **To:** Krueger, Patricia A -FS <pkrueger@fs.fed.us>
> **Cc:** Lindemann, Tim -FS <timlindemann@fs.fed.us>
> **Subject:** GULO_GULO
>
> Patti,

Obs and Sites for GG.

Joel Grapentine, M.S.
GIS Database Analyst

Forest Service Contractor
R05 Headquarters

p: 707-562-8845 x8845
jgrapentine@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

Caring for the land and serving people

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--

Edwin Turner, Geographer
GIS Mapping and Analysis Branch

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USFWS Carlsbad Fish and Wildlife Office
2177 Salk Ave. Suite 250
Carlsbad, CA 92008
760.431.9440 x266

Ed_Turner@fws.gov
760.431.9440 x266

From:	Krueger, Patricia A -FS
To:	Turner, Ed; McDonald, Peter M -FS
Cc:	Betty Grizzle (Betty_Grizzle@fws.gov); Barrera, Bobbi L -FS
Subject:	RE: FW: GULO_GULO
Date:	Monday, January 23, 2017 11:15:16 AM
Attachments:	image001.png image002.png image003.png image004.png

---

Hi Peter,

I do recall years back when Nancy was still in position and we had the TES meeting in Colorado the discussion on the wolverine that wandered through Colorado. But I may be confusing it with Lynx since that was our primary discussion. Do you have any information or data on this to provide to FWS? Or do you know whom the contact would be so that they could acquire the data?

Thanks!

Patti

Patricia Krueger
Regional Threatened and Endangered Species Coordinator

Forest Service
Pacific Southwest Region, Regional Office

p: 707-562-8954
c: 707-373-3702
pkrueger@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

Caring for the land and serving people

From: Turner, Ed [mailto:ed_turner@fws.gov]
Sent: Monday, January 23, 2017 9:56 AM
To: Krueger, Patricia A -FS <pkrueger@fs.fed.us>
Cc: Betty Grizzle (Betty_Grizzle@fws.gov) <Betty_Grizzle@fws.gov>; Barrera, Bobbi L -FS <blbarrera@fs.fed.us>
Subject: Re: FW: GULO_GULO

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> If you are having any difficulty, the Deputy Director of that region may be able to make contact as well. Her name is Bobbi Barrera and I have cc-ed her into this conversation.
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> Patti
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> **Patricia Krueger**
> **Regional Threatened and Endangered Species Coordinator**
> **Forest Service**
> **Pacific Southwest Region, Regional Office**
> **p: 707-562-8954**
> **c: 707-373-3702**
> **pkrueger@fs.fed.us**
> 1323 Club Drive
> Vallejo, CA 94592
> www.fs.fed.us
> **Caring for the land and serving people**
>
> **From:** Turner, Ed [mailto:ed_turner@fws.gov]
> **Sent:** Friday, January 13, 2017 2:26 PM
> **To:** Krueger, Patricia A -FS <pkrueger@fs.fed.us>

Cc: Betty Grizzle (Betty_Grizzle@fws.gov) <Betty_Grizzle@fws.gov>
Subject: Re: FW: GULO_GULO

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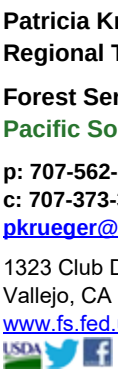

Caring for the land and serving people

From: Grapentine, Joel -FS
Sent: Friday, January 06, 2017 1:59 PM
To: Krueger, Patricia A -FS <pkrueger@fs.fed.us>
Cc: Lindemann, Tim -FS <timlindemann@fs.fed.us>
Subject: GULO_GULO

Patti,

Obs and Sites for GG.

Joel Grapentine, M.S.
GIS Database Analyst

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R05 Headquarters

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Edwin Turner, Geographer
GIS Mapping and Analysis Branch

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From: McDonald, Peter M -FS
To: Krueger, Patricia A -FS; Turner, Ed
Cc: Betty Grizzle (Betty_Grizzle@fws.gov); Barrera, Bobbi L -FS; Eric.Odell@state.co.us
Subject: RE: FW: GULO_GULO
Date: Monday, January 23, 2017 11:32:08 AM
Attachments: image001.png
image002.png
image003.png
image004.png

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eric.odell@state.co.us

Peter

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p: 303-275-5029 (primary)
c: 303-475-3515 (travel & telework)
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Program website: www.fs.usda.gov/detail/r2/landmanagement/?cid=stelprdb5188017
Intranet (FS only): http://fsweb.r2.fs.fed.us/rr/R2_TES_Site_2007
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To:	McDonald, Peter M -FS
Cc:	Krueger, Patricia A -FS; Betty Grizzle (Betty_Grizzle@fws.gov); Barrera, Bobbi L -FS; Eric.Odell@state.co.us
Subject:	Re: FW: GULO_GULO
Date:	Monday, January 23, 2017 11:47:12 AM
Attachments:	image003.png image002.png image001.png image004.png

---

Hello Peter, Thank you for Eric's contact. I will see what Eric knows and if he can help with a location down into NM.

Thanks, Ed

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From:	Turner, Ed
To:	Odell - DNR, Eric
Cc:	Jim Stuart
Bcc:	betty_grizzle@fws.gov
Subject:	Re: FW: GULO_GULO
Date:	Monday, January 23, 2017 2:20:07 PM
Attachments:	image003.png image001.png image004.png image002.png

---

Hello Eric, Thank you for all that information, very helpful.

I will check with Jim and see if he has anything to help.

Have a great day, Ed

On Mon, Jan 23, 2017 at 12:51 PM, Odell - DNR, Eric <eric.odell@state.co.us> wrote:

> Hi Ed-
>
> I don't have any knowledge of a wolverine moving from Colorado into NM. The furthest south that M56 moved that we have knowledge of is about 25 miles southwest of Fairplay, Colorado. Also, he wasn't necessarily tracked to North Dakota. His signal was lost in CO, and he wasn't heard from again until he was shot by the rancher in ND. We have no knowledge of the path that was taken between CO and ND.
>
> New Mexico does not consider wolverine as part of their native fauna. You could be in touch with Jim Stuart (copied on this email), who is my counterpart in NM on any information that they may have on wolverine presence in their state.
>
> Hope that this is helpful in your endeavor. Feel free to contact with any other questions.
> Eric
>
> On Mon, Jan 23, 2017 at 12:07 PM, Turner, Ed <ed_turner@fws.gov> wrote:
>
> > Hello Eric, I was wondering if you could help with our effort. We are currently trying to compile records of Wolverine and we have heard that a wolverine moved down from Colorado into NM.
> >
> > I'm thinking the Wanderer M56 that Peter mention is the one that moved down from Yellowstone, went through CO, ended up in NM, then tracked north into North Dakota.
> >
> > If this is the case, would you have any information that would help with his southern most point.
> >
> > Thank you for any assistance you can give.
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> > Ed
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---------- Forwarded message ----------
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Date: Mon, Jan 23, 2017 at 10:31 AM
Subject: RE: FW: GULO_GULO
To: "Krueger, Patricia A -FS" <pkrueger@fs.fed.us>, "Turner, Ed" <ed_turner@fws.gov>
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data that came within the last year, so it is possible that if it is recent, it may not be in the Wildlife database yet.

If you are having any difficulty, the Deputy Director of that region may be able to make contact as well. Her name is Bobbi Barrera and I have cc-ed her into this conversation.

Thanks!

Patti

Patricia Krueger
Regional Threatened and Endangered Species Coordinator
Forest Service

Pacific Southwest Region, Regional Office

p: 707-562-8954
c: 707-373-3702
pkrueger@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

Caring for the land and serving people

From: Turner, Ed [mailto:ed_turner@fws.gov]
Sent: Friday, January 13, 2017 2:26 PM
To: Krueger, Patricia A -FS <pkrueger@fs.fed.us>
Cc: Betty Grizzle (Betty_Grizzle@fws.gov) <Betty_Grizzle@fws.gov>
Subject: Re: FW: GULO_GULO

Hi Patti, Hope all's well.

Quick question, the NRIS would that wolverine pull have captured any data in New Mexico? The Range seems to have run down into the Taos and Wheeler Peak area, but we have not found any data.

We have had word that some have been sited down there, but no actual spatial information.

I will try to contact Carson/ Santa Fe Nation Forests and I had a buddy from USFS Taos that I'll call, but just thought I should check with you about the data pull first.

Thanks and hope you have a good holiday weekend,

Ed

On Fri, Jan 6, 2017 at 2:45 PM, Krueger, Patricia A -FS <pkrueger@fs.fed.us> wrote:

> Here is the nationwide data from the Forest Service NRIS Wildlife database. As you get closer to completion of the analysis, please feel free to request an update to this data.
>
> Do let me know if I can help further.
>
> Thanks!
>
> Patti

Patricia Krueger
Regional Threatened and Endangered Species Coordinator
Forest Service

Pacific Southwest Region, Regional Office
p: 707-562-8954

c: 707-373-3702
pkrueger@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

Caring for the land and serving people

From: Grapentine, Joel -FS
Sent: Friday, January 06, 2017 1:59 PM
To: Krueger, Patricia A -FS <pkrueger@fs.fed.us>
Cc: Lindemann, Tim -FS <timlindemann@fs.fed.us>
Subject: GULO_GULO

Patti,

Obs and Sites for GG.

Joel Grapentine, M.S.
GIS Database Analyst

Forest Service Contractor

R05 Headquarters

p: 707-562-8845 x8845
jgrapentine@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

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--
Edwin Turner, Geographer
GIS Mapping and Analysis Branch

DOI-R8-CFWO
USFWS Carlsbad Fish and Wildlife Office
2177 Salk Ave. Suite 250
Carlsbad, CA 92008
760.431.9440 x266

Ed_Turner@fws.gov
760.431.9440 x266

--
Eric Odell
Species Conservation Program Manager
Terrestrial Section
P 970.472.4340 | F 970.472.4458 | C 970.217.3915
317 West Prospect Road, Fort Collins, CO 80526
eric.odell@state.co.us | cpw.state.co.us

--
Edwin Turner, Geographer
GIS Mapping and Analysis Branch

DOI-R8-CFWO

USFWS Carlsbad Fish and Wildlife Office
2177 Salk Ave. Suite 250
Carlsbad, CA 92008
760.431.9440 x266

Ed_Turner@fws.gov
760.431.9440 x266

From:	Turner, Ed
To:	Stuart, James N., DGF
Cc:	Odell - DNR, Eric
Bcc:	betty_grizzle@fws.gov
Subject:	Re: FW: GULO_GULO
Date:	Monday, January 23, 2017 2:26:18 PM
Attachments:	image003.png image001.png image002.png image004.png

---

Hello Jim, Thank you for the quick reply to Eric's request.

That seems to clear up things as Betty talked about the sighting out at Wheeler Peak, but had no information that would allow me to map it.

Alyssa Radcliff told me about one that moved into the Taos area, but then returned north. She couldn't remember the date, but thought it was historical. She must have been recalling the 1800's record.

This info will help us to decide what to do next as far as range extent.

Thank you again for all your help,

Ed

On Mon, Jan 23, 2017 at 1:10 PM, Stuart, James N., DGF <james.stuart@state.nm.us> wrote:

> Hello Ed – As Eric says, we have no confirmed evidence of wolverine occurring in NM. Betty Grizzle of your office has shared some anecdotal reports FWS has received but we consider these unverified. The Aubry et al. (2007) paper mentions a possible old (1800s) pelt specimen from Taos NM, and that's the most substantive record we might have.
>
> Thanks,
>
> Jim
>
> James N. Stuart
>
> Non-game Mammals
>
> NM Dept. of Game & Fish
>
> POB 25112, Santa Fe, NM 87504
>
> (505) 476-8107

james.stuart@state.nm.us

Conserving New Mexico's Wildlife for Future Generations

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From: Odell - DNR, Eric [mailto:eric.odell@state.co.us]
Sent: Monday, January 23, 2017 1:51 PM
To: Turner, Ed
Cc: Stuart, James N., DGF
Subject: Re: FW: GULO_GULO

Hi Ed-

I don't have any knowledge of a wolverine moving from Colorado into NM. The furthest south that M56 moved that we have knowledge of is about 25 miles southwest of Fairplay, Colorado. Also, he wasn't necessarily tracked to North Dakota. His signal was lost in CO, and he wasn't heard from again until he was shot by the rancher in ND. We have no knowledge of the path that was taken between CO and ND.

New Mexico does not consider wolverine as part of their native fauna. You could be in touch with Jim Stuart (copied on this email), who is my counterpart in NM on any information that they may have on wolverine presence in their state.

Hope that this is helpful in your endeavor. Feel free to contact with any other questions.

Eric

On Mon, Jan 23, 2017 at 12:07 PM, Turner, Ed <ed_turner@fws.gov> wrote:

Hello Eric, I was wondering if you could help with our effort. We are currently trying to compile records of Wolverine and we have heard that a wolverine moved down from Colorado into NM.

I'm thinking the Wanderer M56 that Peter mention is the one that moved down from Yellowstone, went through CO, ended up in NM, then tracked north into North Dakota.

If this is the case, would you have any information that would help with his southern most point.

Thank you for any assistance you can give.

Ed

--

Edwin Turner, Geographer

GIS Mapping and Analysis Branch

DOI-R8-CFWO

USFWS Carlsbad Fish and Wildlife Office

2177 Salk Ave. Suite 250

Carlsbad, CA 92008

760.431.9440 x266

Ed_Turner@fws.gov

760.431.9440 x266

---------- Forwarded message ----------
From: **McDonald, Peter M -FS** <petermcdonald@fs.fed.us>
Date: Mon, Jan 23, 2017 at 10:31 AM
Subject: RE: FW: GULO_GULO

To: "Krueger, Patricia A -FS" <pkrueger@fs.fed.us>, "Turner, Ed" <ed_turner@fws.gov>
Cc: "Betty Grizzle (Betty_Grizzle@fws.gov)" <Betty_Grizzle@fws.gov>, "Barrera, Bobbi L -FS" <blbarrera@fs.fed.us>, "Eric.Odell@state.co.us" <Eric.Odell@state.co.us>

Hi Patti, we have some anecdotal reports on the wanderer M56, but Colorado Parks and Wildlife would likely have more detailed information. A good starting point would probably be their carnivore lead Eric Odell:
P 970.472.4340 | F 970.472.4458 | C 970.217.3915

eric.odell@state.co.us

Peter

Peter McDonald
Regional Program Leader
Threatened, Endangered and Sensitive Species

Forest Service
Rocky Mountain Region

p: 303-275-5029 (primary)
c: 303-475-3515 (travel & telework)
petermcdonald@fs.fed.us

740 Simms Street
Golden, CO 80401
www.fs.fed.us

Caring for the land and serving people

Program website: www.fs.usda.gov/detail/r2/landmanagement/?cid=stelprdb5188017
Intranet (FS only): http://fsweb.r2.fs.fed.us/rr/R2_TES_Site_2007
Interagency ESA site: www.fs.usda.gov/detail/r2/landmanagement/?cid=stelprdb5341949

From: Krueger, Patricia A -FS
Sent: Monday, January 23, 2017 11:15 AM
To: Turner, Ed <ed_turner@fws.gov>; McDonald, Peter M -FS <petermcdonald@fs.fed.us>
Cc: Betty Grizzle (Betty_Grizzle@fws.gov) <Betty_Grizzle@fws.gov>; Barrera, Bobbi L -FS <blbarrera@fs.fed.us>
Subject: RE: FW: GULO_GULO

Hi Peter,

I do recall years back when Nancy was still in position and we had the TES meeting in Colorado the discussion on the wolverine that wandered through Colorado. But I may be confusing it with Lynx since that was our primary discussion. Do you have any information or data on this to provide to FWS? Or do you know whom the contact would be so that they could acquire the data?

Thanks!

Patti

Patricia Krueger
Regional Threatened and Endangered Species Coordinator
Forest Service

Pacific Southwest Region, Regional Office

p: 707-562-8954
c: 707-373-3702
pkrueger@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

Caring for the land and serving people

From: Turner, Ed [mailto:ed_turner@fws.gov]
Sent: Monday, January 23, 2017 9:56 AM
To: Krueger, Patricia A -FS <pkrueger@fs.fed.us>
Cc: Betty Grizzle (Betty_Grizzle@fws.gov) <Betty_Grizzle@fws.gov>; Barrera, Bobbi L -FS <blbarrera@fs.fed.us>
Subject: Re: FW: GULO_GULO

Hello Patricia, Thank you for giving me the heads-up on the data.

I ended up contacting Alyssa Radcliff at the Questa Ranger District out by Taos, NM and she indicated that historically a wolverine had moved down into NM, but then continued back north.

Apparently there is no data for them down in NM.

Thanks again and hope you have a good day,

Ed

On Mon, Jan 23, 2017 at 8:39 AM, Krueger, Patricia A -FS <pkrueger@fs.fed.us> wrote:

> Sorry as I was out of the office unexpectedly. This would include the data across the Forest Service that was placed into NRIS Wildlife and Quality Controlled "passed". Couple things that could be:
>
> 1. Data not in NRIS Wildlife. Could be in local records.
> 2. Data in NRIS Wildlife, but not Quality Controlled.
>
> Do note that this database is set for the National Forest System side of the Forest Service (non-research). Specific to New Mexico/Arizona, they have a due date of March 31 for the data that came within the last year, so it is possible that if it is recent, it may not be in the Wildlife database yet.
>
> If you are having any difficulty, the Deputy Director of that region may be able to make contact as well. Her name is Bobbi Barrera and I have cc-ed her into this conversation.
>
> Thanks!
>
> Patti
>
> **Patricia Krueger**
> **Regional Threatened and Endangered Species Coordinator**
> **Forest Service**
>
> **Pacific Southwest Region, Regional Office**
>
> **p:** 707-562-8954
> **c:** 707-373-3702

pkrueger@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

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From: Turner, Ed [mailto:ed_turner@fws.gov]
Sent: Friday, January 13, 2017 2:26 PM
To: Krueger, Patricia A -FS <pkrueger@fs.fed.us>
Cc: Betty Grizzle (Betty_Grizzle@fws.gov) <Betty_Grizzle@fws.gov>
Subject: Re: FW: GULO_GULO

Hi Patti, Hope all's well.

Quick question, the NRIS would that wolverine pull have captured any data in New Mexico? The Range seems to have run down into the Taos and Wheeler Peak area, but we have not found any data.

We have had word that some have been sited down there, but no actual spatial information.

I will try to contact Carson/ Santa Fe Nation Forests and I had a buddy from USFS Taos that I'll call, but just thought I should check with you about the data pull first.

Thanks and hope you have a good holiday weekend,

Ed

On Fri, Jan 6, 2017 at 2:45 PM, Krueger, Patricia A -FS <pkrueger@fs.fed.us> wrote:

> Here is the nationwide data from the Forest Service NRIS Wildlife database. As you get closer to completion of the analysis, please feel free to request an update to this

data.

Do let me know if I can help further.

Thanks!

Patti

Patricia Krueger
Regional Threatened and Endangered Species Coordinator
Forest Service

Pacific Southwest Region, Regional Office

p: 707-562-8954
c: 707-373-3702
pkrueger@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

Caring for the land and serving people

From: Grapentine, Joel -FS
Sent: Friday, January 06, 2017 1:59 PM
To: Krueger, Patricia A -FS <pkrueger@fs.fed.us>
Cc: Lindemann, Tim -FS <timlindemann@fs.fed.us>
Subject: GULO_GULO

Patti,

Obs and Sites for GG.

Joel Grapentine, M.S.
GIS Database Analyst

Forest Service Contractor

R05 Headquarters

p: 707-562-8845 x8845
jgrapentine@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
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--

Edwin Turner, Geographer

GIS Mapping and Analysis Branch

DOI-R8-CFWO

USFWS Carlsbad Fish and Wildlife Office

2177 Salk Ave. Suite 250

Carlsbad, CA 92008

760.431.9440 x266

Ed_Turner@fws.gov

760.431.9440 x266

--

Eric Odell
Species Conservation Program Manager

Terrestrial Section

P 970.472.4340 | F 970.472.4458 | C 970.217.3915

317 West Prospect Road, Fort Collins, CO 80526

eric.odell@state.co.us | cpw.state.co.us

--

Edwin Turner, Geographer
GIS Mapping and Analysis Branch

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USFWS Carlsbad Fish and Wildlife Office
2177 Salk Ave. Suite 250
Carlsbad, CA 92008
760.431.9440 x266

Ed_Turner@fws.gov
760.431.9440 x266

From:	Krueger, Patricia A -FS
To:	Turner, Ed
Cc:	Betty Grizzle (Betty_Grizzle@fws.gov); Jacobson, Lee -FS
Subject:	Wolverine Data for Bridger Teton NF plus
Date:	Monday, January 23, 2017 4:54:09 PM
Attachments:	image001.png image002.png image003.png image004.png

---

Hi Ed,
I had a voice mail from you that you were looking for data from Bridger Teton NF. My point of contact is Lee Jacobson and he can be reached at ljacobson@fs.fed.us or 801-625-5664. I believe the other locations you were interested in were also in his region. If he does not know about the data, I am sure he can direct you to those who might.

Hi Lee – Ed Turner works for FWS and he is working with Betty Grizzle who is writing up the package for listing for Wolverine. Please help them find the missing data that has been referenced to them. Thanks!

Thanks!

Patti

Patricia Krueger
Regional Threatened and Endangered Species Coordinator

Forest Service
Pacific Southwest Region, Regional Office

p: 707-562-8954
c: 707-373-3702
pkrueger@fs.fed.us

1323 Club Drive
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From: Schwartz, Michael K -FS
To: Grizzle, Betty
Subject: RE: Taxonomy question
Date: Monday, January 23, 2017 5:00:01 PM

Hi Betty,
I did contact Robert Ekblom, the wolverine researcher from Sweden, and he stated: "I'm sorry to say that I have no input whatsoever when it comes to classification of the American vs Euroasian wolverines. I have not worked with any samples from outside of Scandinavia."
Sorry. I don't have any additional information.
Mike

From: Grizzle, Betty [mailto:betty_grizzle@fws.gov]
Sent: Monday, January 23, 2017 4:04 PM
To: Schwartz, Michael K -FS <michaelkschwartz@fs.fed.us>
Subject: Re: Taxonomy question

HI again Mike - Did you get a response from Sweden on this issue? FYI - Wilson and Reeder (2005) only describe *Gulo gulo* (no subspecies).

On Wed, Jan 18, 2017 at 10:00 AM, Grizzle, Betty <betty_grizzle@fws.gov> wrote:

> Thanks Mike. Yes, if you could check with the Swedes, that would be helpful.
> Banci's (1994) discussion suggests that it's only one species, so there does still seem to be some debate about this.
> Betty
>
> On Wed, Jan 18, 2017 at 9:54 AM, Schwartz, Michael K -FS <michaelkschwartz@fs.fed.us> wrote:
>
> > Hi Betty,
> > I think the IUCN sees two subspecies. Gulo gulo gulo (Eurasian) and Gulo gulo luscus (North American). See http://www.iucnredlist.org/details/9561/0
> > Historically there was G.g. vancouverensis and G.g. katschemakensis on the Kenai peninsula and Vancouver Island. I haven't checked Wilson and Reeder (2005) but they are generally splitters.
> > If you want I can contact folks working on the wolverine genome in Upsala to see where they stand on the issue?
> > Hope you are well.
> > Best Regards,
> > Mike
> >
> > **From:** Grizzle, Betty [mailto:betty_grizzle@fws.gov]
> > **Sent:** Wednesday, January 18, 2017 8:59 AM
> > **To:** Schwartz, Michael K -FS <michaelkschwartz@fs.fed.us>
> > **Subject:** Taxonomy question
> >
> > Hi Mike - A question for you. From all of my readings, review of comments, etc., the

wolverine in North America is consider *Gulo gulo*, with no subspecies designation. Some authors (older publications) have separated New World from Old World, but, reading Banci (1994) for example, there seems to be more evidence for one species, with some ecotypic variation.
Is there a currently accepted classification?

Thanks for your time,
Betty

--

Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

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U.S. Fish and Wildlife Service
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--

Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist

U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

From: Grizzle, Betty
To: Shoemaker, Justin
Subject: Fwd: Taxonomy question
Date: Tuesday, January 24, 2017 10:10:13 AM

FYI - see message from Mike below.
Tomasik and Cook (2005, p. 387) state: "Currently, **the 2 most common** taxonomic views either split the wolverine into 2 subspecies....or recognize G. gulo as a single Holarctic taxon."

However, several published studies re genetics have been published since 2005, though they are fairly limited in scope (e.g., mtDNA analyses based on short sequence fragment of control region, Zigouris et al. 2013; that paper was also not included in Withdrawal Lit Cited/Considered).
As I noted below, Wilson and Reeder only consider one species.

---------- Forwarded message ----------
From: **Schwartz, Michael K -FS** <michaelkschwartz@fs.fed.us>
Date: Mon, Jan 23, 2017 at 3:59 PM
Subject: RE: Taxonomy question
To: "Grizzle, Betty" <betty_grizzle@fws.gov>

Hi Betty,

I did contact Robert Ekblom, the wolverine researcher from Sweden, and he stated: "I'm sorry to say that I have no input whatsoever when it comes to classification of the American vs Euroasian wolverines. I have not worked with any samples from outside of Scandinavia."

Sorry. I don't have any additional information.

Mike

From: Grizzle, Betty [mailto:betty_grizzle@fws.gov]
Sent: Monday, January 23, 2017 4:04 PM
To: Schwartz, Michael K -FS <michaelkschwartz@fs.fed.us>
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Betty

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>
> I think the IUCN sees two subspecies. Gulo gulo gulo (Eurasian) and Gulo gulo luscus (North American). See http://www.iucnredlist.org/details/9561/0
>
> Historically there was G.g. vancouverensis and G.g. katschemakensis on the Kenai peninsula and Vancouver Island. I haven't checked Wilson and Reeder (2005) but they are generally splitters. If you want I can contact folks working on the wolverine genome in Upsala to see where they stand on the issue?
>
> Hope you are well.
>
> Best Regards,
>
> Mike
>
> **From:** Grizzle, Betty [mailto:betty_grizzle@fws.gov]
> **Sent:** Wednesday, January 18, 2017 8:59 AM
> **To:** Schwartz, Michael K -FS <michaelkschwartz@fs.fed.us>
> **Subject:** Taxonomy question
>
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>
> Is there a currently accepted classification?
>
> Thanks for your time,
>
> Betty

--

Betty J. Grizzle, D.Env.

Fish and Wildlife Biologist

U.S. Fish and Wildlife Service

Carlsbad Fish and Wildlife Office

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Carlsbad, CA 92008

760-431-9440, ext. 215

760-431-5901 fax

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Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008

760-431-9440, ext. 215
760-431-5901 fax

From:	Turner, Ed
To:	Stuart, James N., DGF
Cc:	Odell - DNR, Eric
Bcc:	betty_grizzle@fws.gov
Subject:	Re: FW: GULO_GULO
Date:	Wednesday, January 25, 2017 11:15:33 AM
Attachments:	image003.png image002.png image001.png image004.png

---

Hello Jim, Thank you again for clarification on the NM possibility and historical account.

I know Betty spoke with you, and I will forward this info for her too.

Thanks again and have a great day,

Ed

On Tue, Jan 24, 2017 at 8:01 AM, Stuart, James N., DGF <james.stuart@state.nm.us> wrote:

> Follow-up to my reply yesterday: The pelt from the Taos area, taken in about 1860, might have originated in NM or possibly in CO – since Fort Burgwyn was a fur trade post, it's unclear where it might have been taken. As I recall, the specimen could not be located in the USNM collection a few years ago although it is cataloged there.
>
> My perspective is that wolverine may have ranged into northern NM historically, perhaps only in small numbers, but that we likely did not have a resident population. The more recent observation reports are difficult to assess and might or might not represent wolverine. As I recall, we summarized what we knew about NM wolverine in the letters submitted to FWS in 2013, which Betty has. As for range extent, I would consider NM on the "fuzzy edge" of historic wolverine distribution, where individuals might have occasionally occurred.
>
> Thanks,
>
> Jim
>
> James N. Stuart
>
> Non-game Mammals
>
> NM Dept. of Game & Fish
>
> POB 25112, Santa Fe, NM 87504
>
> (505) 476-8107

james.stuart@state.nm.us

Conserving New Mexico's Wildlife for Future Generations

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From: Turner, Ed [mailto:ed_turner@fws.gov]
Sent: Monday, January 23, 2017 2:26 PM
To: Stuart, James N., DGF
Cc: Odell - DNR, Eric
Subject: Re: FW: GULO_GULO

Hello Jim, Thank you for the quick reply to Eric's request.

That seems to clear up things as Betty talked about the sighting out at Wheeler Peak, but had no information that would allow me to map it.

Alyssa Radcliff told me about one that moved into the Taos area, but then returned north. She couldn't remember the date, but thought it was historical. She must have been recalling the 1800's record.

This info will help us to decide what to do next as far as range extent.

Thank you again for all your help,

Ed

On Mon, Jan 23, 2017 at 1:10 PM, Stuart, James N., DGF <james.stuart@state.nm.us> wrote:

Hello Ed – As Eric says, we have no confirmed evidence of wolverine occurring in NM. Betty Grizzle of your office has shared some anecdotal reports FWS has received but we consider these unverified. The Aubry et al. (2007) paper mentions a possible old (1800s) pelt specimen from Taos NM, and that's the most substantive record we might have.

Thanks,

Jim

James N. Stuart

Non-game Mammals

NM Dept. of Game & Fish

POB 25112, Santa Fe, NM 87504

(505) 476-8107

james.stuart@state.nm.us

Conserving New Mexico's Wildlife for Future Generations

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From: Odell - DNR, Eric [mailto:eric.odell@state.co.us]
Sent: Monday, January 23, 2017 1:51 PM
To: Turner, Ed
Cc: Stuart, James N., DGF
Subject: Re: FW: GULO_GULO

Hi Ed-

I don't have any knowledge of a wolverine moving from Colorado into NM. The furthest south that M56 moved that we have knowledge of is about 25 miles southwest of Fairplay, Colorado. Also, he wasn't necessarily tracked to North Dakota. His signal was lost in CO, and he wasn't heard from again until he was shot by the rancher in ND. We have no knowledge of the path that was taken between CO and ND.

New Mexico does not consider wolverine as part of their native fauna. You could be in touch with Jim Stuart (copied on this email), who is my counterpart in NM on any information that they may have on wolverine presence in their state.

Hope that this is helpful in your endeavor. Feel free to contact with any other questions.

Eric

On Mon, Jan 23, 2017 at 12:07 PM, Turner, Ed <ed_turner@fws.gov> wrote:

Hello Eric, I was wondering if you could help with our effort. We are currently trying to compile records of Wolverine and we have heard that a wolverine moved down from Colorado into NM.

I'm thinking the Wanderer M56 that Peter mention is the one that moved down from Yellowstone, went through CO, ended up in NM, then tracked north into North Dakota.

If this is the case, would you have any information that would help with his southern most point.

Thank you for any assistance you can give.

Ed

--

Edwin Turner, Geographer

GIS Mapping and Analysis Branch

DOI-R8-CFWO

USFWS Carlsbad Fish and Wildlife Office

2177 Salk Ave. Suite 250

Carlsbad, CA 92008

760.431.9440 x266

Ed_Turner@fws.gov

760.431.9440 x266

---------- Forwarded message ----------
From: **McDonald, Peter M -FS** <petermcdonald@fs.fed.us>
Date: Mon, Jan 23, 2017 at 10:31 AM
Subject: RE: FW: GULO_GULO
To: "Krueger, Patricia A -FS" <pkrueger@fs.fed.us>, "Turner, Ed" <ed_turner@fws.gov>
Cc: "Betty Grizzle (Betty_Grizzle@fws.gov)" <Betty_Grizzle@fws.gov>, "Barrera, Bobbi L -FS" <blbarrera@fs.fed.us>, "Eric.Odell@state.co.us" <Eric.Odell@state.co.us>

Hi Patti, we have some anecdotal reports on the wanderer M56, but Colorado Parks and Wildlife would likely have more detailed information. A good starting point would probably be their carnivore lead Eric Odell:
P 970.472.4340 | F 970.472.4458 | C 970.217.3915

eric.odell@state.co.us

Peter

Peter McDonald
Regional Program Leader
Threatened, Endangered and Sensitive Species

Forest Service
Rocky Mountain Region

p: 303-275-5029 (primary)
c: 303-475-3515 (travel & telework)
petermcdonald@fs.fed.us

740 Simms Street
Golden, CO 80401

www.fs.fed.us

Caring for the land and serving people

Program website: www.fs.usda.gov/detail/r2/landmanagement/?cid=stelprdb5188017
Intranet (FS only): http://fsweb.r2.fs.fed.us/rr/R2_TES_Site_2007
Interagency ESA site: www.fs.usda.gov/detail/r2/landmanagement/?cid=stelprdb5341949

From: Krueger, Patricia A -FS
Sent: Monday, January 23, 2017 11:15 AM
To: Turner, Ed <ed_turner@fws.gov>; McDonald, Peter M -FS <petermcdonald@fs.fed.us>
Cc: Betty Grizzle (Betty_Grizzle@fws.gov) <Betty_Grizzle@fws.gov>; Barrera, Bobbi L -FS <blbarrera@fs.fed.us>
Subject: RE: FW: GULO_GULO

Hi Peter,

I do recall years back when Nancy was still in position and we had the TES meeting in Colorado the discussion on the wolverine that wandered through Colorado. But I may be confusing it with Lynx since that was our primary discussion. Do you have any information or data on this to provide to FWS? Or do you know whom the contact would be so that they could acquire the data?

Thanks!

Patti

Patricia Krueger
Regional Threatened and Endangered Species Coordinator
Forest Service

Pacific Southwest Region, Regional Office

p: 707-562-8954
c: 707-373-3702
pkrueger@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

Caring for the land and serving people

From: Turner, Ed [mailto:ed_turner@fws.gov]
Sent: Monday, January 23, 2017 9:56 AM
To: Krueger, Patricia A -FS <pkrueger@fs.fed.us>
Cc: Betty Grizzle (Betty_Grizzle@fws.gov) <Betty_Grizzle@fws.gov>; Barrera, Bobbi L -FS <blbarrera@fs.fed.us>
Subject: Re: FW: GULO_GULO

Hello Patricia, Thank you for giving me the heads-up on the data.

I ended up contacting Alyssa Radcliff at the Questa Ranger District out by Taos, NM and she indicated that historically a wolverine had moved down into NM, but then continued back north.

Apparently there is no data for them down in NM.

Thanks again and hope you have a good day,

Ed

On Mon, Jan 23, 2017 at 8:39 AM, Krueger, Patricia A -FS <pkrueger@fs.fed.us> wrote:

> Sorry as I was out of the office unexpectedly. This would include the data across the Forest Service that was placed into NRIS Wildlife and Quality Controlled "passed". Couple things that could be:
>
> 1. Data not in NRIS Wildlife. Could be in local records.
> 2. Data in NRIS Wildlife, but not Quality Controlled.
>
> Do note that this database is set for the National Forest System side of the Forest Service (non-research). Specific to New Mexico/Arizona, they have a due date of March 31 for the data that

came within the last year, so it is possible that if it is recent, it may not be in the Wildlife database yet.

If you are having any difficulty, the Deputy Director of that region may be able to make contact as well. Her name is Bobbi Barrera and I have cc-ed her into this conversation.

Thanks!

Patti

Patricia Krueger
Regional Threatened and Endangered Species Coordinator
Forest Service

Pacific Southwest Region, Regional Office

p: 707-562-8954
c: 707-373-3702
pkrueger@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

Caring for the land and serving people

From: Turner, Ed [mailto:ed_turner@fws.gov]
Sent: Friday, January 13, 2017 2:26 PM
To: Krueger, Patricia A -FS <pkrueger@fs.fed.us>
Cc: Betty Grizzle (Betty_Grizzle@fws.gov) <Betty_Grizzle@fws.gov>
Subject: Re: FW: GULO_GULO

Hi Patti, Hope all's well.

Quick question, the NRIS would that wolverine pull have captured any data in New Mexico? The Range seems to have run down into the Taos and Wheeler Peak area, but we have not found any data.

We have had word that some have been sited down there, but no actual spatial information.

I will try to contact Carson/ Santa Fe Nation Forests and I had a buddy from USFS Taos that I'll call, but just thought I should check with you about the data pull first.

Thanks and hope you have a good holiday weekend,

Ed

On Fri, Jan 6, 2017 at 2:45 PM, Krueger, Patricia A -FS <pkrueger@fs.fed.us> wrote:

> Here is the nationwide data from the Forest Service NRIS Wildlife database. As you get closer to completion of the analysis, please feel free to request an update to this data.
>
> Do let me know if I can help further.
>
> Thanks!
>
> Patti

Patricia Krueger
Regional Threatened and Endangered Species Coordinator
Forest Service

Pacific Southwest Region, Regional Office
p: 707-562-8954

c: 707-373-3702
pkrueger@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

Caring for the land and serving people

From: Grapentine, Joel -FS
Sent: Friday, January 06, 2017 1:59 PM
To: Krueger, Patricia A -FS <pkrueger@fs.fed.us>
Cc: Lindemann, Tim -FS <timlindemann@fs.fed.us>
Subject: GULO_GULO

Patti,

Obs and Sites for GG.

Joel Grapentine, M.S.
GIS Database Analyst

Forest Service Contractor

R05 Headquarters

p: 707-562-8845 x8845
jgrapentine@fs.fed.us

1323 Club Drive
Vallejo, CA 94592
www.fs.fed.us

Caring for the land and serving people

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--

Edwin Turner, Geographer

GIS Mapping and Analysis Branch

DOI-R8-CFWO

USFWS Carlsbad Fish and Wildlife Office

2177 Salk Ave. Suite 250

Carlsbad, CA 92008

760.431.9440 x266

Ed_Turner@fws.gov

760.431.9440 x266

--

Eric Odell

Species Conservation Program Manager

Terrestrial Section

P 970.472.4340 | F 970.472.4458 | C 970.217.3915

317 West Prospect Road, Fort Collins, CO 80526

eric.odell@state.co.us | cpw.state.co.us

--

Edwin Turner, Geographer

GIS Mapping and Analysis Branch

DOI-R8-CFWO

USFWS Carlsbad Fish and Wildlife Office

2177 Salk Ave. Suite 250

Carlsbad, CA 92008

760.431.9440 x266

Ed_Turner@fws.gov

760.431.9440 x266

--

Edwin Turner, Geographer
GIS Mapping and Analysis Branch

DOI-R8-CFWO
USFWS Carlsbad Fish and Wildlife Office
2177 Salk Ave. Suite 250
Carlsbad, CA 92008

760.431.9440 x266

Ed_Turner@fws.gov
760.431.9440 x266

From: Yates, Richard E -FS
To: Grizzle, Betty
Subject: RE: Manuscript publication date?
Date: Tuesday, February 28, 2017 4:11:24 PM
Attachments: Yates et al_Abstract_Wolverine Repro Dens.docx

Hey Betty; I went ahead and attached an abstract for a wolverine reproductive den site habitat paper that I will be giving at the Montana Chapter of the Wildlife Society next week in Helena. I hope the information is useful. The talk is on Friday March 10th at the Radisson Colonial Hotel in Helena, MT.

Rick

From: Grizzle, Betty [mailto:betty_grizzle@fws.gov]
Sent: Tuesday, February 21, 2017 10:27 AM
To: Yates, Richard E -FS <richardeyates02@fs.fed.us>
Subject: Manuscript publication date?

Hi Rick - Do you have a date for the publication of your article "Food habits of wolverines in Glacier National Park, Montana?"

--

Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

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Wolverine Reproductive Den Habitat in Glacier National Park, Montana

Richard E. Yates, Jeffrey P. Copeland, and John R. Squires – USDA Forest Service, Rocky Mountain Research Station, Missoula, Montana 59801

Wolverine reproductive dens occur in habitat not easily accessible to humans during the denning period (Feb – May) and can be challenging to find. As such, few den sites have been precisely described. From 2003 – 2007 we located and documented 14 natal and maternal dens of 3 reproductive female wolverine in Glacier National Park. Two females were known to have produced young in multiple years, using different den sites each year. Reproductive dens occurred at an average elevation of 1890m (range: 1805-1999m), on 9° slopes (range: 5-22º), within a variable range of aspects ($\bar{x}$=201°), and with an average snow depth of 2.6m (range: 2.4-3.4m). Den structures included downed trees, large boulders, and rock caves associated with alpine cirques, ridges, and cliff bands at, or below, existing tree line. Distance to occupied human development averaged 6.4km, and distance between denning areas of the same female in different years averaged 5.8km. Various climate change models predict less persistent snowpack in many areas of the conterminous United States, with a resultant potential for increased isolation of island populations of wolverines.

From:	Yates, Richard E -FS
To:	Grizzle, Betty
Cc:	Jeff Copeland
Subject:	FW: Manuscript publication date?
Date:	Wednesday, March 1, 2017 9:01:33 AM
Attachments:	Yates et al_Abstract_Wolverine Repro Dens.docx

Greetings Betty; I had a correction to this abstract that I needed to make, so please use this latest copy. The change had to do with the mean aspect. I needed to calculate that mean using circular statistics, which I have now done. So the mean changes from 201 degrees to 263 degrees. Sorry for any confusion this may have caused.

Rick

From: Yates, Richard E -FS
Sent: Tuesday, February 28, 2017 4:09 PM
To: 'Grizzle, Betty' <betty_grizzle@fws.gov>
Subject: RE: Manuscript publication date?

Hey Betty; I went ahead and attached an abstract for a wolverine reproductive den site habitat paper that I will be giving at the Montana Chapter of the Wildlife Society next week in Helena. I hope the information is useful. The talk is on Friday March 10th at the Radisson Colonial Hotel in Helena, MT.

Rick

From: Grizzle, Betty [mailto:betty_grizzle@fws.gov]
Sent: Tuesday, February 21, 2017 10:27 AM
To: Yates, Richard E -FS <richardeyates02@fs.fed.us>
Subject: Manuscript publication date?

Hi Rick - Do you have a date for the publication of your article "Food habits of wolverines in Glacier National Park, Montana?"

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Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

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From: Grizzle, Betty
To: Yates, Richard E -FS
Cc: Jeff Copeland
Subject: Re: FW: Manuscript publication date?
Date: Wednesday, March 1, 2017 9:44:04 AM

Thanks Rick for the update! I hope the presentation goes well in Helena.
Betty

On Wed, Mar 1, 2017 at 7:59 AM, Yates, Richard E -FS <richardeyates02@fs.fed.us> wrote:

> Greetings Betty; I had a correction to this abstract that I needed to make, so please use this latest copy. The change had to do with the mean aspect. I needed to calculate that mean using circular statistics, which I have now done. So the mean changes from 201 degrees to 263 degrees. Sorry for any confusion this may have caused.
>
> Rick
>
> ---
>
> **From:** Yates, Richard E -FS
> **Sent:** Tuesday, February 28, 2017 4:09 PM
> **To:** 'Grizzle, Betty' <betty_grizzle@fws.gov>
> **Subject:** RE: Manuscript publication date?
>
> Hey Betty; I went ahead and attached an abstract for a wolverine reproductive den site habitat paper that I will be giving at the Montana Chapter of the Wildlife Society next week in Helena. I hope the information is useful. The talk is on Friday March 10th at the Radisson Colonial Hotel in Helena, MT.
>
> Rick
>
> **From:** Grizzle, Betty [mailto:betty_grizzle@fws.gov]
> **Sent:** Tuesday, February 21, 2017 10:27 AM
> **To:** Yates, Richard E -FS <richardeyates02@fs.fed.us>
> **Subject:** Manuscript publication date?
>
> Hi Rick - Do you have a date for the publication of your article "Food habits of wolverines in Glacier National Park, Montana?"

--

Betty J. Grizzle, D.Env.

Fish and Wildlife Biologist

U.S. Fish and Wildlife Service

Carlsbad Fish and Wildlife Office

2177 Salk Ave, Suite 250

Carlsbad, CA 92008

760-431-9440, ext. 215

760-431-5901 fax

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Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

From:	Conor McGowan
To:	Grizzle, Betty
Cc:	Conor McGowan; Justin Shoemaker/R6/FWS/DOI
Subject:	Re: Life table
Date:	Wednesday, March 29, 2017 11:37:06 AM
Attachments:	BIOC_2017_402_Original_V0 (1).pdf

That is the general approach, yes. It will take on the order of months to pull the modeling framework together before we approach the experts with our description.

Here is a link to the tortoise SSA and I've attached a manuscript that we prepared and submitted last week on the modeling work that we did.

https://www.regulations.gov/contentStreamer?documentId=FWS-R2-ES-2015-0150-0003&contentType=pdf

On Wed, Mar 29, 2017 at 10:59 AM, Grizzle, Betty <betty_grizzle@fws.gov> wrote:

> Thanks, Conor, that makes sense. Let me know what metrics might be important to evaluate/confirm. I believe we decided to use the approach you mentioned on the call last week - prepare a summary of the overall approach/model "construction" and send that to outside experts for review. Correct?
>
> Also, can you please send me the SSA Report for tortoise? Or you can send me the docket number at regulations.gov so I can locate it online. Thanks.
> Betty
>
> On Wed, Mar 29, 2017 at 8:44 AM, Conor McGowan <cpmcg00@gmail.com> wrote:
>
> > Hi Betty,
> >
> > This model structure is a bit different that I usually work with. Uses an individual based modeling approach, largely because it was originally designed for zoo populations and captive release assessments, and those models require lots or data and good precision to be useful. So, I tend to avoid that approach and what I'l like to do here is convert these metric to a population model and incorporate parametric uncertainty to go along with environmental variation and demographic stochastic. So the short answer is that, getting a more local expert to review and "approve" or modify the life table used in this model for Scandinavian is fine, but I want you to be aware that we will not be using these numbers as is in the eventual model.
> >
> > If you have questions, please let me know.
> >
> > Conor
> >
> > --
> > //----------
> > Conor P. McGowan, Ph.D.
> > Assistant Leader and Associate Research Professor
> > USGS, Alabama Cooperative Fish and Wildlife Research Unit
> > School of Forestry and Wildlife Sciences,
> > Auburn University
> > Auburn, AL 36849-5418

EM:cmcgowan@usgs.gov
Ph:334 844 9231
www.auburn.edu/~cpm0014
//----------

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Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

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//----------
Conor P. McGowan, Ph.D.
Assistant Leader and Associate Research Professor
USGS, Alabama Cooperative Fish and Wildlife Research Unit
School of Forestry and Wildlife Sciences,
Auburn University
Auburn, AL 36849-5418

EM:cmcgowan@usgs.gov
Ph:334 844 9231
www.auburn.edu/~cpm0014
//----------

Manuscript Details

Manuscript number	BIOC_2017_402
Title	Incorporating population viability models into species status assessment and listing decisions under the U.S. Endangered Species Act
Article type	Full Length Article

Abstract

Assessment of a species' status is a key part of management decision making for endangered and threatened species under the U.S. Endangered Species Act. Predicting the future state of the species is an essential part of species status assessment, and projection models can play an important role in developing predictions. We built a stochastic simulation model that incorporated parametric and environmental uncertainty to predict the likely future status of the Sonoran desert tortoise in the south western United States and north central Mexico. Sonora desert tortoise was a candidate species for listing under the Endangered Species Act, and decision makers wanted to use model predictions in their decision making process. The model accounted for future habitat loss and possible effects of climate change induced drought to predict future population growth rate, abundance and quasi-extinction probability. Our model predicts that the population will likely decline over the next few decades, but there is very low probability of quasi extinction less than 75 years into the future. Climate change induced increases in drought frequency and intensity may increase extinction risk for the species. Our model helped decision makers predict and characterize uncertainty about the future status of the species. We were also able to incorporate complex ecological processes (e.g., climate change effects on tortoises) in transparent and explicit ways that were tailored to support decision making.

Keywords	Climate effects on viability; Endangered species listing decisions; parametric uncertainty; sensitivity analysis; Sonora desert tortoise
Taxonomy	Applied Ecology, Population Dynamics, Wildlife Population

Corresponding Author	Conor McGowan
Corresponding Author's Institution	U.S. Geological Survey
Order of Authors	Conor McGowan, Nathan Allan, Jeff Servoss, Shaula Hedwall, Brian Woolridge

Suggested reviewers	Sarah Converse, Robert Steidl, Michael Reed

Submission Files Included in this PDF

File Name [File Type]

BioConCoverLetter3-10-17.docx [Cover Letter]

17.02.23 IP-084680 SDT-MS-Draft3-3-10-17.docx [Manuscript File]

To view all the submission files, including those not included in the PDF, click on the manuscript title on your EVISE Homepage, then click 'Download zip file'.

Dr. R.B. Primack
Editor, Biological Conservation

March 10, 2017

Dear Dr. Primack,

We are submitting our research manuscript entitled “Incorporating population viability models into species status assessment and listing decisions under the U.S. Endangered Species Act” to Biological Conservation for consideration for publication. The content of the manuscript has not been published nor is currently under consideration for publication at any other journal. We followed ethical standards in completing this work and have no conflict of interests in publishing this material.

In the paper we report on a modeling framework used to support a decision process for Sonora Desert Tortoise in the United States and Mexico for listing the species as threatened or endangered under the U.S. Endangered Species Act. We relied on experts, used available data, and published literature to construct a model of population dynamics that projected to population and evaluated the effects of potential habitat loss and climate changed induced droughts on abundance and quasi-extinction probability in the future. The model and the predictions were used as a key part of the decision not to list this species at this time. The population viability approach and decision specific modeling could be a very useful frame work to improving the transparency and repeatability of listing decisions and other endangered species management decisions.

Thank you for considering our paper for publication. No portion of this work has been published or is currently submitted to any other journal. All listed authors are agreed upon the content of the paper, all funding sources for the research are listed in the acknowledgements, as are collaborators on the research that are not listed as authors. We will not gain financially in any way from the publication of this research and we have followed all relevant ethical standards. We suggest Robert Stiedl at the University of Arizona (steidl@ag.arizona.edu), Dr. Sarah Converse of the USGS (sconverse@usgs.gov) or Dr. Michael Reed at Tufts University (Reed@tufts.edu) as potential reviewers of this manuscript. We look forward to hearing from you regarding our work.

Sincerely,

Conor P. McGowan
U.S. Geological Survey
Alabama Cooperative Fish and Wildlife Research Unit
Auburn University

Incorporating population viability models into species status assessment and listing decisions under the U.S. Endangered Species Act.

Conor P. McGowan, U.S. Geological Survey, Alabama Cooperative Fish and Wildlife Research Unit, Auburn University, Auburn, AL, 36849; cmcgowan@usgs.gov

Nathan Allan, U.S. Fish and Wildlife Service, Southwest Region, Ecological Services, Austin, TX 78613; nathan_allan@fws.gov

Jeff Servoss, U.S. Fish and Wildlife Service, Arizona Ecological Services Office, Tucson, AZ 85745; jeff_servoss@fws.gov

Shaula Hedwall, U.S. Fish and Wildlife Service, Arizona Ecological Services Office, Flagstaff, AZ 86001; shaula_hedwall@fws.gov

Brian Woolridge, U.S. Fish and Wildlife Service, Arizona Ecological Services Office, Flagstaff, AZ 86001; brian_wooldridge@fws.gov

This draft manuscript is distributed solely for purposes of scientific peer review. Its content is deliberative and predecisional, so it must not be disclosed or released by reviewers. Because the manuscript has not yet been approved for publication by the U.S. Geological Survey (USGS), it does not represent any official USGS finding or policy.

ABSTRACT:

Assessment of a species' status is a key part of management decision making for endangered and threatened species under the U.S. Endangered Species Act. Predicting the future state of

the species is an essential part of species status assessment, and projection models can play an important role in developing predictions. We built a stochastic simulation model that incorporated parametric and environmental uncertainty to predict the likely future status of the Sonoran desert tortoise in the south western United States and north central Mexico. Sonora desert tortoise was a candidate species for listing under the Endangered Species Act, and decision makers wanted to use model predictions in their decision making process. The model accounted for future habitat loss and possible effects of climate change induced drought to predict future population growth rate, abundance and quasi-extinction probability. Our model predicts that the population will likely decline over the next few decades, but there is very low probability of quasi extinction less than 75 years into the future. Climate change induced increases in drought frequency and intensity may increase extinction risk for the species. Our model helped decision makers predict and characterize uncertainty about the future status of the species. We were also able to incorporate complex ecological processes (e.g., climate change effects on tortoises) in transparent and explicit ways that were tailored to support decision making.

Keywords: Climate effects on viability, Endangered species listing decisions, parametric uncertainty, sensitivity analysis, Sonora desert tortoise

Assessment of a species' biological status is a key part of management decision making by the U.S. Fish and Wildlife Service for endangered and threatened species under the U.S. Endangered Species Act (Doremus 1997; Regan *et al*. 2012; Smith *et al*. in review). Historically, status assessments can include current abundance estimation, recent population trends and an accounting of past and on-going factors affecting the species (Waples *et al*. 2013). However, predictive modeling can play a crucial role in management decisions for protected species by incorporating qualitative information into explicit quantitative risk assessments (Smith *et al*. in review, McGowan and Ryan 2009, McGowan and Ryan 2010). Model-based predictions can project future population size and growth and transparently present the uncertainty in those predictions, as well as assess the effectiveness of management actions on future population status (Morris and Doak 2002). Explicit predictions about future outcomes, and the uncertainty associated with those predictions, allow decision makers to understand and base their decisions on the likely future status of, and risks to, a species.

Population viability models have a long history of use in assessment of species at risk of endangerment or extinction and in assessing the relative importance of demographic parameters for species viability (e.g., Boyce 1992, Morris and Doak 2002). Generally these viability analyses focus on theoretical assessments (e.g., elemental sensitivity analysis of a Leslie matrix model; Morris and Doak 2002) lacking a specific decision context (e.g., listing determination under the Endangered Species Act). However, more recently researchers and managers are applying population viability-type models to support specific decision contexts for species conservation (e.g., McGowan and Ryan 2009, New *et al*. 2012, Converse *et al*. 2013, Robinson *et al*. 2016, Doak *et al*. 2015, Wolf *et al*. 2015). Models tailored to specific decision

60 contexts may not allow for broad advances in population ecology theory, but they can support
61 management decisions by evaluating uncertainties and stochastic elements that often impede
62 decision making.

63 Decisions on whether or not to list species as endangered (i.e., at imminent risk of
64 extinction) or threatened (i.e., at risk of becoming endangered) under the Endangered Species
65 Act could benefit from explicit models that characterize uncertainty in predictions. Deciding to
66 list or not list a species comes with the risk of providing a species protection that is not needed,
67 or not providing protection to a species that might require protection to avoid extinction. The
68 risk assessments that support these important decisions could be greatly enhanced by explicit
69 extinction probability predictions, and the predicted range of future population status (e.g.,
70 estimate median future abundance and the 2.5 and 97.5 percentiles on future abundance).
71 Explicit presentation of these uncertainties allow decision makers to understand the most likely
72 future state of a population and species, and also provide an estimate of the probability that
73 the future state of the population is lower or higher than the most likely prediction. If done
74 effectively, a decision maker can visualize and understand what the distribution of future
75 population status is and use that information to determine whether protection is warranted.
76 Specially tailored models can incorporate the best available demographic data, specific threats
77 or management benefits experienced by populations, and demographic and environmental
78 stochasticity along with parametric uncertainty. Models specifically tailored to a decision
79 context also allow for developing scenarios that evaluate ongoing and future influences on the
80 populations and species with greater specificity than a sensitivity analysis in a traditional
81 population viability analysis (e.g., Morris and Doak 2002).

We built a demographic population viability model to represent Sonoran desert tortoise (*Gopherus morafkai*, hereafter SDT) populations in Arizona, U.S., and Sonora, Mexico. The model was based on the best available demographic data and published analyses, and it included parametric uncertainty and environmental variation as sources of uncertainty in the projections (McGowan *et al*. 2011). The model predicts the probability of quasi-extinction (i.e., the probability of abundance declining to less than a pre-determined abundance threshold) at each time step under current habitat and environmental conditions and possible future scenarios of changing habitat and environmental conditions. We also incorporated a framework to evaluate a wide array of future possible conditions and estimate the relationship between those varied future conditions and quasi-extinction probability through regression analysis of the model output. For the purposes of this model and as part of the species status assessment, we are treating the species as two large populations, one in Arizona, U.S., and one in Sonora, Mexico (U.S. Fish and Wildlife Service 2015). The service decided to subdivide the species into the two populations because of differing management practices, grazing practices, invasive grass communities and other issues in Arizon vs. Mexico. We anticipated that, though the species are genetically and ecologically indistinct, future scenarios would be different for these two portions of the range. The model was a key part of the species status assessment that was conducted in order to inform the decision whether or not to list the SDT as a threatened or endangered species under the Endangered Species Act.

Methods

Model Development

We built a female-only, stage-structured matrix model to reflect the SDT life cycle (Figure 1). The conceptual model of the tortoise's life cycle was elicited from taxa experts based on published literature (Van Devender 2002, Rostal *et al.* 2014) and in some areas based on Mojave desert tortoise (*Gopherus agassizii*) population models (Darst *et al*. 2013). The life cycle diagram presents three main life stages (Adults (A), small juveniles (J_1) and large juveniles (J_2)). Small juveniles, once hatched, can survive each year and remain in the small juvenile age class for approximately 5 years (McCoy *et al*. 2014). Little is known about the habits or survival rates of small juveniles because they are difficult to detect in the wild and, therefore, have received little study. However, this life stage, given its size (<40 mm), is expected to be the most susceptible to predation and other causes of mortality (McCoy *et al*. 2014), and survival rates of newly hatched tortoises in their first year are presumed to be very low. McCoy *et al*. (2014), suggest that, for North American tortoises in general, first year survival is as low as 10%, and it increases about 1-2% annually thereafter until the animals are in the subadult or large juvenile stage. Larger juveniles have approximately 0.77 annual survival and remain in that age class for 10 or 12 years (until approximately the age of 15) and then transition into the breeding adult age class. Adults have very high survival rates, 0.93 – 0.98 annually (Zylstra *et al.* 2013) and, given these high survival rates, can live for many years as adults. Approximately 52% of females will breed in any given year, and the females lay small clutches of approximately 5 eggs with approximately equal sex ratios (~2.5 female eggs per female; Campbell *et al.* 2014), but many nests most likely fail before hatching, as is the case with other species of North American tortoises (McCoy *et al.* 2014).

In our simulation model we set mean annual adult survival ($\overline{S}^{A}$) to 0.95 (SD = 0.009), based on the results of Zylstra *et al*. (2013). We created a probability of annual breeding parameter (P_b) with mean of 0.52 (SD = 0.06) and a fecundity (F) or clutch size parameter with mean of 2.5 eggs per female (SD = 0.5; Campbell *et al*. 2014). Zylstra *et al*. (2013) estimated annual survival of large juveniles ($\overline{S}^{J2}$) to average 0.77 (SD = 0.032), but they had limited data for these parameter estimates. Small juvenile survival rates were largely unknown because of the difficulties in studying the early life stages. Experts agreed that generation time for SDT is approximately 25 years. When combined with the well-studied adult survival and fecundity rates we used the PopBio package (Stubben and Milligan 2007) in program R (R core development team 2013) to test different values for the lesser known parameters (small juvenile survival, $\overline{S}^{J1}$; small to large juvenile transition, $\overline{T}^{12}$; large juvenile to adult transition, $\overline{T}^{2A}$) to see what values led to the estimated 25-year generation time. The "generation.time" function calculates the expected average time between generations, defined as the average age at which a female produces her median off spring (Morris and Doak 2002, Stubben and Milligan 2007). With this approach we adjusted mean parameter values in the model to set mean annual small juvenile survival ($\overline{S}^{J1}$) at 0.006 (SD = 0.00012) and small to large juvenile transition ($\overline{T}^{12}$) at 0.083 (SD = 0.00032). In our model, the $\overline{S}^{J1}$ parameter is very low, but it combines annual nest survival (hatching probability, see above) with the very low survival rates of the first few years of life (McCoy *et al*. 2014). Though uncertain and low, these early life stage parameters values are consistent with the life history strategy of other long lived chelonid taxa (e.g., logger head sea turtles, Crouse *et al*. 1987). We set large juvenile survival and large juvenile to adult transition ($\overline{T}^{2A}$) to sum to the Zylstra *et al*. (2013) annual survival estimate of

146 0.77. Mean large juvenile annual survival ($\overline{S}^{J2}$) was set to 0.67, and the transition rate to
147 adulthood ($\overline{T}^{2A}$) was set to 0.1, since the individuals stay in this stage for approximately 10
148 years, we assume that on average 10% transition annually. With these parameters we
149 constructed a projection matrix as follows:

150
$$\begin{bmatrix} N_{t+1}^{J1} \\ N_{t+1}^{J2} \\ N_{t+1}^{A} \end{bmatrix} = \begin{bmatrix} S_t^{J1} & 0 & (F_t * P_b) \\ T_t^{12} & S_t^{J2} & 0 \\ 0 & T_t^{2A} & S_t^{A} \end{bmatrix} \times \begin{bmatrix} N_t^{J1} \\ N_t^{J2} \\ N_t^{A} \end{bmatrix}$$

151 We incorporated the projection into a stochastic simulation model that replicated the
152 population 1000 times and projected the population 200 years into the future (i.e.,
153 approximately 8 generations). In the model survival rates (S_t^{J1}, S_t^{J2}, S_t^{A}), inter-size class transition
154 rates (T_t^{12}, T_t^{2A}), and proportion of females that breed (P_b) were drawn from beta distributions
155 derived from the mean and standard deviations described above, while fecundity rates (F_t)
156 were drawn from a log-normal distribution. In addition to modeling temporal stochasticity
157 using the standard deviation estimates and statistical distribution draws described above, we
158 used the methods described by McGowan *et al*. (2011) to incorporate parametric uncertainty
159 into the adult survival parameter because we used the "sensitivity" function in the popbio
160 package (Stubben and Milligan 2007) and determined that population growth is most sensitive
161 to adult survival. Published estimates of parameter variance did not partition variance into
162 sampling and process variance (e.g. Gould and Nichols 1996) and therefore parametric
163 uncertainty levels for any of the parameters are unknown. The approach presented by
164 McGowan *et al*. (2011) involves using the replication loop of the model to pick an average adult
165 survival rate for the population that serves as the mean value for each year in that replicate of

the population (Figure 1). Under this approach each replicate of the population projection has a different mean value of adult survival and those values are drawn from a beta distribution based on the parameter mean and variance due to parametric uncertainty (McGowan et al 2011). The other standard deviations and variance parameters reported above were used in the model as temporal variability to mimic environmental stochasticity (McGowan et al. 2011).

The model predicted mean population growth rate, abundance (female adults), and the proportion of replicates that went quasi-extinct on an annual basis. We used two different thresholds for quasi-extinction, 2% and 4% of the estimated maximum possible population size (~7,000 and 12,000 adult females in Arizona, respectively; and ~4,000 and 8,000 adult females in Sonora, respectively), to allow decision makers to see the implications of choosing a quasi-extinction threshold. These two thresholds represented massive declines from current estimated abundances but these quasi-extinction levels would also represent densities of 0.6 and 1.2 total adult tortoises per km^2under the low or high thresholds. Experts believed that these densities were probably below densities at which tortoises would be able to successfully find mates for sustaining reproduction. If tortoise actually decline to these low abundances, it is more probable that they would likely persist in a small number of populations restricted to the highest quality habitats, but would likely be subjet to allee effects and the negative effects of demographic stochasticity..

Conceptual Model of SDT Ecology and Stressors

We organized a workshop of tortoise experts and we elicited a conceptual model of SDT ecology seeking to identify ecological stressors to individuals and the populations. The

187 workshop participants used available scientific literature and experience to formulate opinions
188 regarding ecology and potential environmental stressors to explore and evaluate. At the
189 workshop we used the basic concepts of conceptual modeling as a guide for developing the
190 diagrams to represent SDT ecology and threats (Davies *et al*. 2006).

191 At the workshop, experts explored the possible effects of nonnative grasses (primarily
192 red brome [*Bromus rubens*] and buffelgrass [*Pennisetum ciliare*]) on SDT habitat and nutrition
193 and how those issues could affect demographics of SDT. Experts generally agreed that
194 nonnative grass species can reduce forage quality that might affect tortoise nutrition (Nagy *et*
195 *al*. 1998, Hazard *et al*. 2010, Gray 2012, Nussear *et al*., unpub. data, 2015), and, therefore,
196 breeding probability, clutch sizes, and growth rates of tortoises. We also recognized that some
197 nonnative grasses (e.g., *Schismus* spp.) have some limited nutritional value to tortoises (Nagy *et*
198 *al*. 1998, Lovich and Ernst 2009, Hazard *et al*. 2010).

199 Experts suggested that, at the spatial scale of our defined populations (i.e., Arizona. U.S.
200 and Sonora, Mexico), wildfire in the desert may not be a significant source of fatality (but note
201 exceptions such as Esque *et al*. 2003). Generally, fires occur at much smaller spatial scales than
202 our population segments, i.e., individual fires effect very small proportions of the population
203 and can be considered stochastic variation in survival rates. Historically, fire suppression
204 policies have been widely implemented and largely effective in minimizing fire impacts across
205 much of the SDT range in Arizona. However, multiple fires in areas invaded by fire-adapted
206 nonnative grasses may perpetuate conversion of desert scrub into desert grassland (D'Antonio
207 and Vitousek 1992), which may lower habitat quality for SDT. We noted that wildfire may have

208 a lesser effect on SDT compared to Mojave desert tortoises because of the differences in
209 habitat preferences and the plant communities in the two species' ranges, though this subject
210 remains controversial.

211 Experts also indicated that crop agriculture and grazing (AIDTT 2000, Oftedal 2007)
212 probably had minimal direct effects on individual SDT (especially compared to Mojave desert
213 tortoise) because SDT most often inhabit steep, rocky, upland areas, where crop agriculture
214 does not occur and grazing pressure is reduced. However, grazing and agriculture can facilitate
215 encroachment of nonnative grasses that can affect SDT habitat quality. Workshop participants
216 identified urbanization as a key component of habitat loss for SDT populations and also
217 believed that urbanization can lead to direct effects on individual tortoise survival through
218 various mechanisms, such as roadway strikes (AGFD 2012), collection of wild tortoises
219 (Grandmaison and Frary 2012), release of captive tortoises (Jones 2008, Edwards *et al.* 2010),
220 feral dog predation (Jones 2008), and off-road vehicle use (Boarman 2002, Ouren *et al.* 2007,
221 USGAO 2009). Although, the magnitude, frequency, and spatial extent of these direct effects
222 on survival have not been effectively measured, Zylstra *et al*. (2013) found that SDT survival
223 rates decreased with increasing proximity to urban areas.

224 Experts identified climate change-induced drought as a potential major factor in SDT
225 population viability. Some researchers have concluded recently that the Sonoran Desert scrub
226 habitat might expand under some climate change scenarios, thus benefitting SDT (Van Riper *et*
227 *al*. 2014) provided the species is able to move into expanding habitat at a rate commensurate
228 with changes to its existing habitat. However, other researchers expect climate change to

negatively impact tortoises (Zylstra *et al*. 2013) primarily though increasing severity and magnitude of drought (Seagar *et al*. 2007, IPCC 2014, Cook *et al*. 2015). To a lesser extent warming temperatures could affect sex ratios at the population level as atmospheric temperatures can affect nest temperatures that determine the sex of developing eggs (Janzen 1994). Climate change could also affect forage quality of plants by altered timing or intensity of seasonal monsoon rains that, in turn, could affect the annual probability of breeding, clutch size, and life-stage transitions (via juvenile growth rates). Climate change, via drought frequency and magnitude, might also affect survival rates of juvenile and adult tortoise, as Zylstra *et al*. (2013) reported a 0.1 to 0.15 decline in annual survival probability for marked tortoise during periods of drought, though overall estimated population growth rates were stable during that 22 year study, despite droughts.

The process of developing a conceptual model also identified a number of other concerns to explore with respect to SDT population viability, many of which are highly uncertain or lack data to formalize a functional relationship beyond conceptual linkages. Through that process, however, we identified two key factors with high potential to affect tortoise populations in the future: habitat availability and drought. Many of the stressors (nonnative grasses, wildfire, and various effects from urbanization) identified in the literature and in the conceptual modeling workshop affect SDT populations via changes in habitat quantity and quality, and climate change-induced drought could be accounted for in changes to annual survival of tortoises. We incorporated these two primary factors into our simulation model and explored the effects of each on population viability.

Environmental Parameters

To model the effects of limiting habitat quantity and quality on the population, we created a ceiling-type density-dependence function in the model (e.g., Morris and Doak 2002), whereby if the population exceeded an established an abundance ceiling of maximum population size (akin to a carrying capacity), the proportion of females that breed (P_b) declined to zero. Ceiling-type density dependent functions are simple and not ecologically realistic (Morris and Doak 2002) in calculating that all of the females in the population fail to breed in a single year once the carrying capacity is reached. However, reducing the P_b parameter to zero has the same effect as reducing P_b parameter to 80% or 50% of normal but reducing to zero affects the population faster, and the population is more quickly restored to the carrying capacity when the population exceeds the ceiling threshold. Ceiling-type density dependent functions lack biological detail but are commonly used in population viability modeling when the functional form of density dependence in the population is unknown (e.g., Morris and Doak 2002, McGowan and Ryan 2009) as is the case with the SDT. In addition, they are useful for capturing effects of density dependence without speculating on the exact mechanism or mathematical formulation of density on demographic rates (Lande 1993, Middleton *et al*. 1995, Morris and Doak 2002). The maximum population size (i.e., the carrying capcity) in a given simulation was determined by the amount (km^2) of habitat in a given quality multiplied by an average expected density of adult female tortoises for each of those conditions. A separate geospatial analysis estimated availability of predicted potential SDT habitat and ranked the habitat conditions across the species range as high, medium, and low condition (U.S. Fish and Wildlife Service 2015) based on land cover vegetation type, slope, and elevation because these

features are useful predictors of potential SDT habitat (Zylstra and Steidl 2008). We further categorized potential habitat quality into primary, secondary, and tertiary suitability based on land management, proximity to urban areas, presence of invasive vegetation, and potential fire risk (USFWS 2015, Smith et al. in review.). Using data from long-term monitoring plots (Zylstra and Steidl 2009) we estimated densities of 17.1 per km^2 in areas of primary habitat, 9.4 per km^2 in secondary habitat, and 2.0 per km^2 in tertiary habitat (U.S. Fish and Wildlife Service 2015). The model calculated maximum population size as follows:

$$Pop_{max} = (D_P \times A_P) + (D_S \times A_S) + (D_T \times A_T)$$

where *D* was the density in primary (subscript *p*), secondary (subscript *s*) and tertiary (subscript *t*) and A is the area of habitat (in square kilometers).

We conducted two primary sets of simulations with this habitat-derived ceiling type density dependent function. First, we could set specific habitat quality amounts derived from GIS analyses and simulate population changes under specific habitat scenarios. Within a simulation, we allowed the ceiling threshold to be reduced annually, to represent habitat loss or degradation over time. Secondly, we could also establish a maximum habitat area drawn from a uniform random distribution ranging from 120% of current to 20% of current total. We then randomly assigned habitat into the three quality classes by multiplying the total by three randomly generated proportions that summed to 1.0. With this approach we could explore the effect of a wide variety of differing amounts of habitat on the probability of extinction through regression based sensitivity analyses (described in detail below).

We included a drought effect on survival of all age classes in our model. We drew a random value of the proportion of the population exposed to drought in any specific year from a beta distribution derived from historic drought data (the annual proportion of Arizona counties within the SDT range exposed to moderate to severe drought from 1900-2000). We used data from the Western Regional Climate Center, Reno, NV,

WestWideDroughtTracker, (http://www.wrcc.dri.edu/wwdt/time/; accessed 5/7/2015) and downloaded the 12-month average Palmer Drought Severity Index (PDSI), ending in December of each year from 1901 through 2000 for each of seven counties in or near the range of the SDT in Arizona. For each year we determined whether each county had been in at least moderate drought, i.e., the PDSI was less than -1.99 for the 12 months ending in December. We then divided the spatial area of the drought counties by the total area of the seven counties in the SDT range to approximate the annual average proportion of the SDT range that experiences moderate or higher drought. Annual survival for adults and juveniles exposed to drought was reduced to approximate the results reported in Zysltra *et al.* (2013). For the projection simulation model, survival became the weighted average of the animals exposed and not exposed to drought, for example for adult survival:

$$S_t^{A,d} = \left(P_{drought} \times S_t^A \times DE_t\right) + \left(\left(1 - P_{drought}\right) \times S_t^A\right)$$

where $P_{drought}$ is the proportion of the population exposed to drought and $S_t^{A,d}$ is the survival rate of adults for the full population, given the proportion that was exposed to drought. DE_t is the drought effect in a specific year which was modeled as a uniform random number between 0.8 and 0.99 (i.e., a 1% to 20% reduction in survival due to the drought), to represent differing

drought severity from year to year. Some droughts have low severity and do not effect survival very much and others, especially multi-year droughts, can have much greater survival consequences (Zylstra *et al*. 2013). With this framework we can model a wide array of droughts of different magnitudes and spatial extents to account for possible impacts of climate change as related to drought, and we can examine the effect of drought spatial magnitude on extinction probability.

Model Outputs

We used the model described above to run a set of 18 predetermined habitat, population and climate-based scenarios (9 each for Arizona, U.S., and Sonora, Mexico, USFWS 2015). The simulated scenarios combined different future habitat states and loss rates with different climate change intensities to represent a range of possible future ecological conditions for the SDT populations. The model used 1000 replications to project annual population outcomes 200 years into the future under each scenario and tracked adult age class population size, population growth rate (rate of annual change) and to project whether the population fell below the predetermined quasi-extinction threshold in each year.

Extinction sensitivity to drought and habitat loss

We also used an analysis similar to McGowan *et al.* (2014) to build a triple loop simulation model (Figure 2) that allowed us to simulate thousands of replicates with a wide variety of habitat, drought, and population size scenarios to examine the functional form of the relationship between those factors to quasi-extinction probability. In the outer most loop of the model, we selected 1,000 maximum total habitat areas and the mean proportions in each

habitat quality category. The minimum possible values for total habitat was 20% of the current amount and the maximum was set at 120% of the current amount, derived from the separate GIS analysis of available habitat in Arizona and Sonora (U.S. Fish and Wildlife Service 2015). We also selected 1,000 values for increasing the mean of the proportion of the population exposed to droughts from a uniform distribution between 0.1 and 2.0 (representing between a 10% and 200% increase in the mean, i.e. mean population exposed to drought between 0.11 and 0.3 proportion of population). We multiplied this uniform random value by the empirically derived mean proportion exposed to drought value and that product served as the mean $P_{drought}$ each year in that replicate of the simulation. Furthermore, we randomly selected 1,000 random starting population sizes between 75,000 and 500,000 females. In the second loop (Figure 2) the model replicated the population 1,000 times for each of the 1,000 sets of values passed forward from the outermost loop. In that second loop, our model selected the mean values for the demographic parameters based on the statistical distributions described previously for each of the 1,000 replicates, and those values were passed into the interior loop, also known as the annual loop (Figure 2). The this analysis projected the population 200 years into the future and tracked adult age class population size, population growth rate (rate of annual change), and whether the population fell below the quasi-extinction threshold in each year. For each of the 1,000 replicates in the secondary loop we saved the proportion of replicates that went quasi-extinct at 25 years, 50 years, 100 years, and 200 years into the future, alongside the maximum abundance values, the initial population size, and the mean proportion affected by drought for that set of replicates.

At the end of that simulation we had 1,000 measures of extinction probability at 25, 50, 100 and 200 years coupled with maximum abundance, initial abundance, and proportion exposed to drought. We used those results as data to assess binomial regression models of extinction probability with maximum abundance, initial abundance, and proportion exposed to drought as covariates in the regression models. Using AIC model selection criteria (Burnham and Anderson 2004), we evaluated and compared multiple models of quasi-extinction. Models had one, two, or three covariates of mean drought, starting population size and/or maximum population size. The regression parameters in those models show the relative probable effect of each covariate on the probability of quasi-extinction and whether the covariate has a positive or negative association with probability of quasi-extinction.

With the regression parameters, we can also predict the probability of quasi-extinction for specified sets of covariate values. We used the regression parameters to generate a table of expected quasi-extinction probability under varying conditions

Results

Continuation of urrent conditions

We used the simulation model to evaluate a set of baseline conditions and four future scenarios each for Arizona, U.S. (Table 1) and Sonora, MX (Figure 1), which assume the continuation of current habitat and drought conditions given our uncertainty regarding population density and starting population size. The Baseline scenario represents the best possible case with no climate change related effects on drought and all habitats in the best possible condition. The other four continuation of current condition scenarios in Arizona and

Sonora project current conditions into the future (Table 1). In all scenarios the population declined over time with mean population growth rates slightly negative ($\lambda \approx 0.996$). Probability of quasi-extinction varied among scenario but largely because we used two different quasi-extinction thresholds (2% and 4% of maximum population size) to allow decision makers to the see the consequences of picking a quasi-extinction threshold. Under all continuation of current conditions scenarios for both Arizona and Sonora, probability of quasi-extinction was ~ 0.00 at 50 years and at 100 years was < 0.01 for scenarios with a 2% abundance quasi-extinction threshold and approximately 0.05 for scenarios with 4% abundance quasi-extinction threshold. In other words, there was less than 0.01 probability of falling below 2% of the initial population and approximately 0.05 probability of falling below 4% of the initial population size 100 years into the future.

We note that results from all scenarios (continuation of current conditions and foreseeable future conditions; see below) median abundance exhibited steep declines in the first few years, but those declines are a mathematical artifact of setting the initial population size equal to the population ceiling in the simulations. When the population starts at the carrying capacity the median abundance will initially decline because a large proportion of the 1,000 replicates will decline and those that don't decline cannot exceed the maximum population ceiling, therefore, the median which is a representation of the "middle trajectory" will decrease. These results do not mean that we expect to see immediate rapid decline in the population before growth rates stabilize after 10 or so years.

Foreseeable Future conditions

The future scenario simulations added increased potential for drought (i.e., climate change effects) and annual habitat loss and degradation rates to mimic the effects of urbanization, wildfire and exotic vegetation encroachment on habitat carrying capacity (U.S. Fish and Wildlife Service 2015). We ran four future scenarios each for Arizona (Table 1) and for Sonora (Table 2). The simulations showed a decline in the median abundance and faster declines than the continuation of current conditions scenarios. Mean population growth in Arizona was approximately 0.99, meaning, on average populations declined by approximately 0.8% annually and was 0.99 in Sonora. Quasi-extinction probabilities were higher than the "current conditions" scenarios, but were still very dependent on whether a 2% or 4% of the initial population was used as the quasi-extinction threshold. For the Arizona population, under the worst climate change and habitat loss scenario we simulated (Table 1, scenario 8), the probability of quasi-extinction was still 0.00 at 50 years and was 0.07 at 100 years. The worst case scenario for Sonora (Table 2) had a probability of quasi-extinction of 0.00 at 50 years and 0.09 at 100 years.

Full simulation and regression modeling results

A regression model with maximum population size (*MaxPop*), initial female abundance (*NAI*) and mean drought exposure (*MDR*) as the independent variables and quasi-extinction probability as the dependent variable was the best model to explain variation in quasi-extinction probability at 200 years and at 100 years. At 50 years, the regression model explained less of the variation in quasi-extinction probability but that is most likely because a smaller proportion of the population trajectories fell below the quasi-extinction threshold; at

25 years none of the simulated populations surpassed the quasi-extinction threshold so no regression model converged on beta parameter estimates. We tested regression models with drought as the only covariate, and, while these models performed well, the AIC model selection analysis indicated that adding initial abundance and maximum population size improved model fit. Differing levels of *MaxPop* relate to differing amounts of available habitat. The regression equation for 200 years was:

$$P_{Qe200} = -3.019 + (14.13\ x\ MDR) - \left(1.588e^{-6} x\ NAI\right) - (1.145e^{-6} x\ MaxPop).$$

The regression parameters indicate that drought has a relatively very large and positive effect on quasi-extinction probability and initial population size and maximum population size have a smaller but significantly negative effects on quasi-extinction ($p<<0.01$ for both covariates). The regression equation for 100 years was:

$$P_{Qe100} = -5.602 + (18.42\ x\ MDR) - \left(5.363e^{-6} x\ NAI\right) - (1.797e^{-6} x\ MaxPop).$$

The regression equation for 50 years was:

$$P_{Qe50} = -10.68 + (2.894\ x\ MDR) - \left(3.429e^{-5} x\ NAI\right) - (2.155e^{-6} x\ MaxPop).$$

Generally, as the time horizon on the simulation shortened the strong positive effect of drought on quasi-extinction probability remained and the weaker, but significant, effect of NAI and *MaxPop* also remained.

With the regression parameter estimates (intercept and slope terms) we constructed tables demonstrating the changing expected probability of quasi extinction under varying drought and initial abundance conditions, along with habitat-limited maximum population size

(e.g., Tables 3 and 4). The tables enable us to visualize more effectively the relationship between these variables. We can also use the regression equation to calculate the expected quasi-extinction probability for any combination of values for the independent variables. Under this analysis, at 50 years, for example, there is very low probability of quasi-extinction (falling below fewer than 8,000 females in Arizona) regardless of starting population size or drought magnitude. As another example, at 100 years quasi-extinction probability gets as high as 0.35 when, on average, 30% of the population is exposed to drought annually and there are only 100,000 females in the population initially. Whereas with, on average, 15% of the population exposed to drought and an initial abundance of 150,000 females, predicted quasi-extinction probability at 100 years was 0.025. These tables essentially allow us to evaluate additional future scenarios simultaneously within the range of possible future variation.

Discussion

Our model predicts steady, gradual decline in SDT population size over time and near zero quasi-extinction probabilities in the next 50-75 years (2 to 3 tortoise generations). Low extinction risk in this timeframe is not unexpected due, in part, to long life spans (i.e., high annual survival rates) of adult tortoises. With mean annual adult survival rates at 0.95, there is approximately a 0.36 probability that an adult alive today will still be alive 20 years in the future and a 0.21 probability that they will be alive in 30 years. This high capacity for longevity in the SDT population likely insulates the species from high short term extinction risk.

Predicted habitat loss and habitat degradation rates had a small overall effect on projected future abundance and on estimated quasi-extinction probability in our simulations.

That could be because of the way we structured density dependence in the model as a ceiling-type density dependence function. With a more sophisticated model of density effects on demographics, the model output may have been more sensitive to habitat loss. However, we do not currently have sufficient data with which to develop a more ecologically sophisticated model, and it is unclear if a more sophisticated analysis would have had more value to the decision making process. On the other hand, given the severe ceiling threshold function (i.e., if the ceiling is exceeded $P_b = 0.0$) we would have expected a more sensitive response to habitat loss if it was a major limiting factor. In our case, habitat loss probably had a small effect on quasi-extinction probability because of the spatial scale at which we modeled the populations. Each modeled population had thousands of square kilometers of habitat available remaining at the end of the model scenarios, even after decades of simulated habitat loss. This is consistent with the expected future habitat conditions across the landscape for the SDT as much of the U.S. range is under public ownership and management and is, therefore, unlikely to become urbanized (U.S. Fish and Wildlife Service 2015). If we had modeled more, spatially limited sub-populations, loss of habitat may have been sufficient to put some sub-populations at higher risk of extirpation.

Climate change-induced drought showed strong potential to greatly increase quasi-extinction risk over the long term (beyond 100 years) (Table 3). This result is not surprising since typically for long-lived species population growth is most sensitive to the adult survival parameter in the Leslie matrix analysis, and climate-driven drought negatively impacted survival through simulated drought magnitude and intensity. Though we did not model climate and weather systems directly in our model, the approach we used captured the essential aspect of

481 climate change effects on the species, as indicated by taxa experts at our workshop and in the
482 literature (Zylstra *et al*. 2013). It is important for decision makers, biologists, and modelers to
483 recognize that not all details of a system need to be incorporated into a model of that system in
484 order for the model to be useful for informing decisions (Starfield 1997, Nicolson *et al*. 2002,
485 McGowan and Ryan 2010). However, given the simplicity of our climate change functions in
486 this model, it may be valuable in future analyses to explore additional formulations of climate
487 change and other climate change scenarios. However, the regression analysis of simulated data
488 provided a powerful tool to estimate the probable effect of climate-driven drought on quasi-
489 extinction probability up to 200% more intense and frequent than historical rates over the past
490 century.

491 The regression analyses also allowed us to explore a wide variety of scenarios in
492 simulations without the time-consuming effort to design and test each of those scenarios. This
493 analysis is akin to a sensitivity analysis (Wisdom and Mills 1997, Boyce 1992, Morris and Doak
494 2002). And the regression analysis provided an efficient way to summarize the results of those
495 numerous scenarios to communicate with the decision makers. . McGowan *et al*. (2014) used
496 this approach to identify the conditions under which risk was acceptably low in order to identify
497 recovery criteria for a threatened population of piping plovers. Similarly, these relationships
498 can be used for evaluating questions such as, how severe would climate change effects have to
499 be to increase the risk of quasi-extinction to an unacceptable level over a given future time
500 period. The specific scenario simulations are helpful because they present our best estimates
501 of plausible future environmental conditions. Furthermore, the regression analyses and tables
502 of predicted outcomes (Table 3 and 4) allow for an analysis of a much wider array of possible

503 future system states (population status, climate change intensity, etc.) and could be an
504 important contributor to inform agency decisions. We could further improve the presentation
505 of uncertainty in the regression analysis results by generating tables that use the upper and
506 lower bound of the 95% confidence intervals of the regression parameter estimates, thereby
507 showing the full range of expected effects of the important variables on quasi-extinction
508 probability.

509 The output of our model was used as one key piece of the analysis for the species
510 status assessment of the SDT. The assessment informed agency decision makers on their
511 determination whether the biological status of the SDT met the definition of an endangered or
512 threatened species under the Endangered Species Act. An endangered species is defined as
513 one that is in danger of extinction throughout all or a significant portion of its range. A
514 threatened species is one that is likely to become endangered in the foreseeable future
515 throughout all or a significant portion of its range. While our model complexity was useful for
516 evaluating future scenarios and predicting tortoise population states in the future, this level of
517 model complexity is not required to support and inform decision making. We had useful data
518 available and reliable experts to help with model development, but in many endangered
519 species decision contexts such data are not available. However, the steps of conceptual
520 modeling and scenario evaluation are still possible and useful in all species assessments (Smith
521 et al. in review).

522 We recognize that the model and its output cannot answer the question of whether the
523 SDT should be afforded protection under the Endangered Species Act. There are additional

524 policy issues for decision makers to address with the results of this or any ecological risk model.
525 For example, what time frame should be considered? And also what level of extinction risk or
526 future population decline is tolerable over that time period? No amount of quantitative risk
527 analysis can answer these questions; however, using a model, such as we have here, can give
528 the decision maker explicitly derived predictions about future population states, extinction
529 probability estimates, and the uncertainty surrounding those predictions upon which to base
530 the policy decision. The decision makers in this instance determined that the levels of risks
531 facing the SDT did not warrant protection as an endangered species. Decision makers further
532 decided to use a 75-year maximum prediction horizon as the foreseeable future for this analysis
533 and subsequently determined that the predicted abundance was high enough and quasi-
534 extinction risk was low enough over that time frame, that listing as a threatened species was
535 also not warranted at this time (U.S. Federal Register 2015). Our modeling played a key role in
536 providing the information that decision makers used to make their decision.

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authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service. Any use of product names and information in this paper does not imply endorsement by the U.S. government.

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Table 1: Predicted population growth rate, change in median female abundance and the probability of quasi-extinction (model outputs) for the baseline, four continuation of current conditions scenarios ("Scenarios 1-4") and four future conditions scenarios ("Scenarios 5-8") in Arizona, U.S. at 50 and100 years into the future. The Scenarios had varying drought, maximum population size (Max Pop), Habitat loss rates, initial population size (Initial Pop) and quasi-extinction thresholds (Qe threshold).

Scenario inputs						Scenario outputs				
	Drought	Max Pop	Habitat loss rate	Initial Pop	Qe Threshold	Population growth rate	Median population change, 50 years	Qe 50 yrs	Median population change, 100 years	Qe 100 yrs
Baseline	Historic Drought	320,000	0	320,000	7,000	0.997	6,433	0.000	-3,294	0.000
Scenario 1	Historic Drought 10%	290,000	0	290,000	7,000	0.996	-12,507	0.000	-33,684	0.001
Scenario 2	Historic Drought 10%	140,000	0	140,000	12,000	0.996	-1,880	0.000	-5,887	0.031
Scenario 3	Historic Drought 10%	240,000	0	240,000	7,000	0.995	-5,726	0.000	-10,987	0.002
Scenario 4	Historic Drought 10%	120,000	0	120,000	12,000	0.995	-789	0.000	-6,076	0.031
Scenario 5	Historic Drought 15%	290,000	9%	290,000	7,000	0.996	-7955	0.000	-26783	0.000
Scenario 6	Historic Drought 15%	140,000	9%	140,000	12,000	0.996	-2575	0.000	-13767	0.030
Scenario 7	Historic Drought 25%	240,000	9%	240,000	7,000	0.995	-14323	0.000	-42031	0.001
Scenario 8	Historic Drought 25%	120,000	9%	120,000	12,000	0.995	-11247	0.000	-28780	0.047

Table 2: Predicted population growth rate, change in median female abundance and the probability of quasi–extinction (model outputs) for the baseline, four continuation of current conditions scenarios ("Scenarios 1-4") and four future conditions scenarios ("Scenarios 5-8") in Sonora, Mexico, at 50 and 100 years into the future. The Scenarios had varying drought, maximum population size (Max Pop), Habitat loss rates, initial population size (Initial Pop) and quasi-extinction thresholds (Qe threshold)

Scenario inputs						Scenario outputs				
	Drought	Max Pop	Habitat loss rate	Initial Pop	Qe Threshold	Population growth rate	Median population change, 50 years	Qe 50 yrs	Median population change, 100 years	Qe 100 yrs
Base line	Historic Drought	320,000	0	320,000	4,000	0.997	5,601	0.000	-523	0.004
Scenario 1	Historic Drought 10%	290,000	0	290,000	4,000	0.997	338	0.000	-3,571	0.005
Scenario 2	Historic Drought 10%	140,000	0	140,000	8,000	0.997	891	0.000	-2,060	0.028
Scenario 3	Historic Drought 10%	240,000	0	240,000	4,000	0.997	-3,198	0.000	-8,147	0.001
Scenario 4	Historic Drought 10%	120,000	0	120,000	8,000	0.996	-3,621	0.000	-8,823	0.044
Scenario 5	Historic Drought 15%	290,000	9%	290,000	4,000	0.996	-5573	0.000	-17538	0.002
Scenario 6	Historic Drought 15%	140,000	9%	140,000	8,000	0.996	-2749	0.000	-8941	0.059
Scenario 7	Historic Drought 25%	240,000	9%	240,000	4,000	0.995	-7692	0.000	-16796	0.004
Scenario 8	Historic Drought 25%	120,000	9%	120,000	8,000	0.995	-5653	0.002	-11769	0.086

Table 3: Quasi-extinction probability (i.e., the probability of falling below 8000 females) at 100 years, given 350,000 females as the maximum population size and varying values for initial female abundance and mean drought exposure.

100 years Max pop = 350,000 females

	Starting population size						
Magnitude of drought	100000	150000	200000	250000	300000	350000	400000
0.10	0.013	0.010	0.008	0.006	0.005	0.004	0.003
0.15	0.033	0.025	0.019	0.015	0.011	0.009	0.007
0.20	0.078	0.061	0.047	0.037	0.028	0.022	0.017
0.25	0.176	0.141	0.111	0.087	0.068	0.053	0.041
0.30	0.349	0.291	0.239	0.194	0.155	0.123	0.097

710

711 Table 4: Quasi-extinction probability (i.e., the probability of falling below 8000 females) at 50
712 years, given 350,000 females as the maximum population size and varying values for initial
713 female abundance and mean drought exposure.

50 years Max pop = 350,000 females

	Starting population size						
Magnitude of drought	100000	150000	200000	250000	300000	350000	400000
0.10	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.15	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.20	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.25	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.30	0.001	0.000	0.000	0.000	0.000	0.000	0.000

714

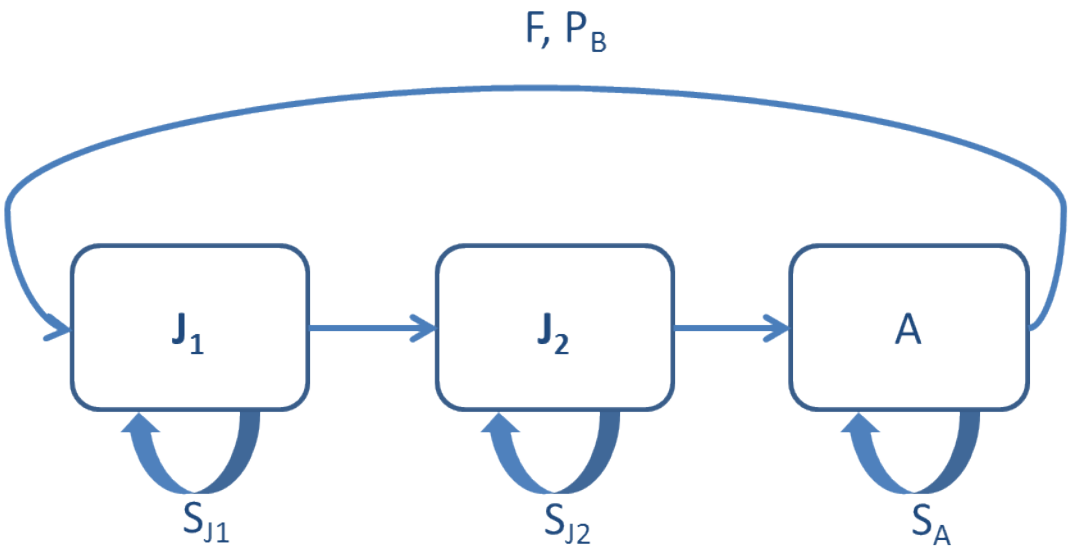
715

716 Figure 1: Life cycle diagram of SDT. Adults (A) produce hatchlings (J_1) (via fedundity (F) and

717 breeding probability (P_B) parameters) and which can survive (S_{J1}) and after approximately 5

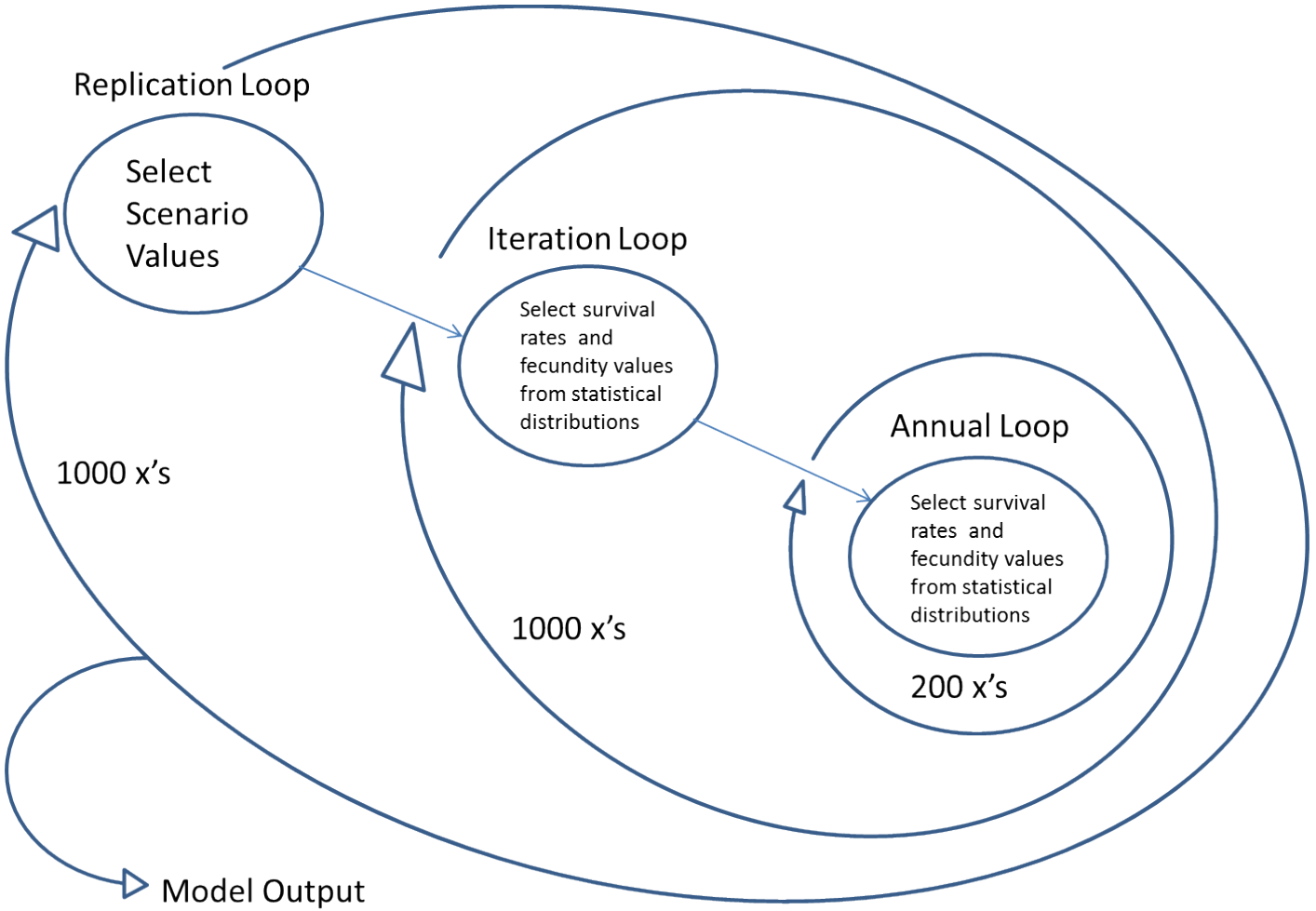
718 years become older juveniles (J_2) which can survive (S_{J2}) and after an additional 10-12 become

719 adults.



720

Figure 2: Demonstration of the triple loop structure used in the SDT simulation model to generate 1000 probabilities of extinction with 1000 initial population sizes, habitat inputs and proportion of the population exposed to drought.


Replication Loop
Select Scenario Values
Iteration Loop
Select survival rates and fecundity values from statistical distributions
Annual Loop
Select survival rates and fecundity values from statistical distributions
1000 x's
1000 x's
200 x's
Model Output

From: McGowan, Conor
To: Shoemaker, Justin; Conor McGowan
Subject: Re: Wolverine PVA
Date: Thursday, April 20, 2017 12:49:31 PM
Attachments: Wolverine population modeling.pptx

Hi Justin,

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Let me know what you think.

Take care,

Conor

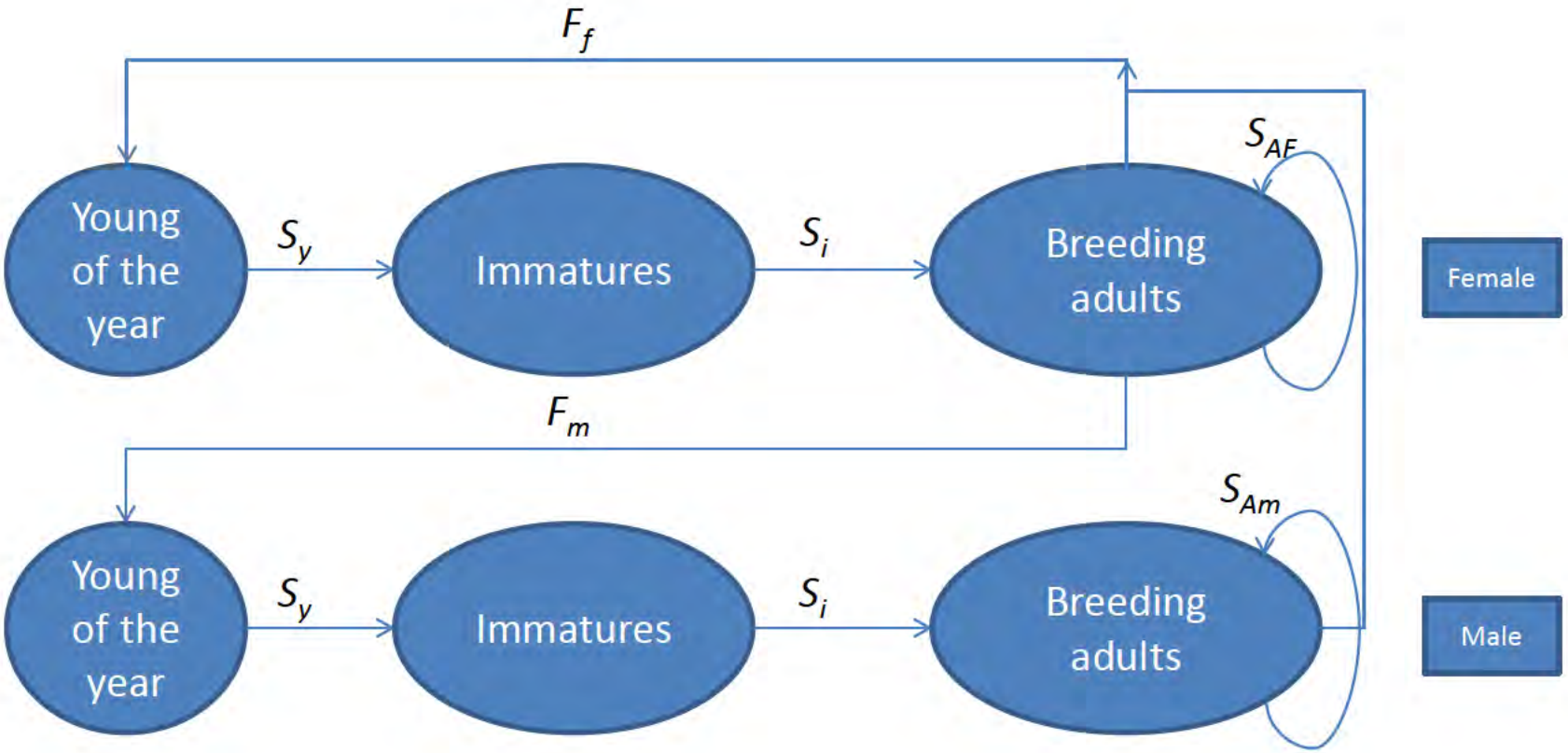
On Thu, Apr 20, 2017 at 9:27 AM, Shoemaker, Justin <justin_shoemaker@fws.gov> wrote:

> Conor,
>
> Checking in to see if you've had any more time to think about the wolverine PVA or start that process. Maybe we can chat if you have time?
>
> Justin Shoemaker
> Classification Biologist
> U.S. Fish and Wildlife Service, Region 6
> Phone: 309-757-5800 x214
> Email: justin_shoemaker@fws.gov

--
Conor P. McGowan, Ph.D.
Assistant Leader and Associate Research Professor
USGS, Alabama Cooperative Fish and Wildlife Research Unit
School of Forestry and Wildlife Sciences,
Auburn University
Auburn, AL 36849-5418

EM:cmcgowan@usgs.gov
Ph:334 844 9231
www.auburn.edu/~cpm0014

Wolverine population modeling



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From: Shoemaker, Justin
To: Grizzle, Betty; Guinotte, John
Subject: Fwd: Wolverine PVA
Date: Thursday, April 20, 2017 12:51:35 PM
Attachments: Wolverine population modeling.pptx

FYI

Justin Shoemaker
Classification Biologist
U.S. Fish and Wildlife Service, Region 6
Phone: 309-757-5800 x214
Email: justin_shoemaker@fws.gov

---------- Forwarded message ----------
From: **McGowan, Conor** <cmcgowan@usgs.gov>
Date: Thu, Apr 20, 2017 at 1:49 PM
Subject: Re: Wolverine PVA
To: "Shoemaker, Justin" <justin_shoemaker@fws.gov>, Conor McGowan <cpmcg00@gmail.com>

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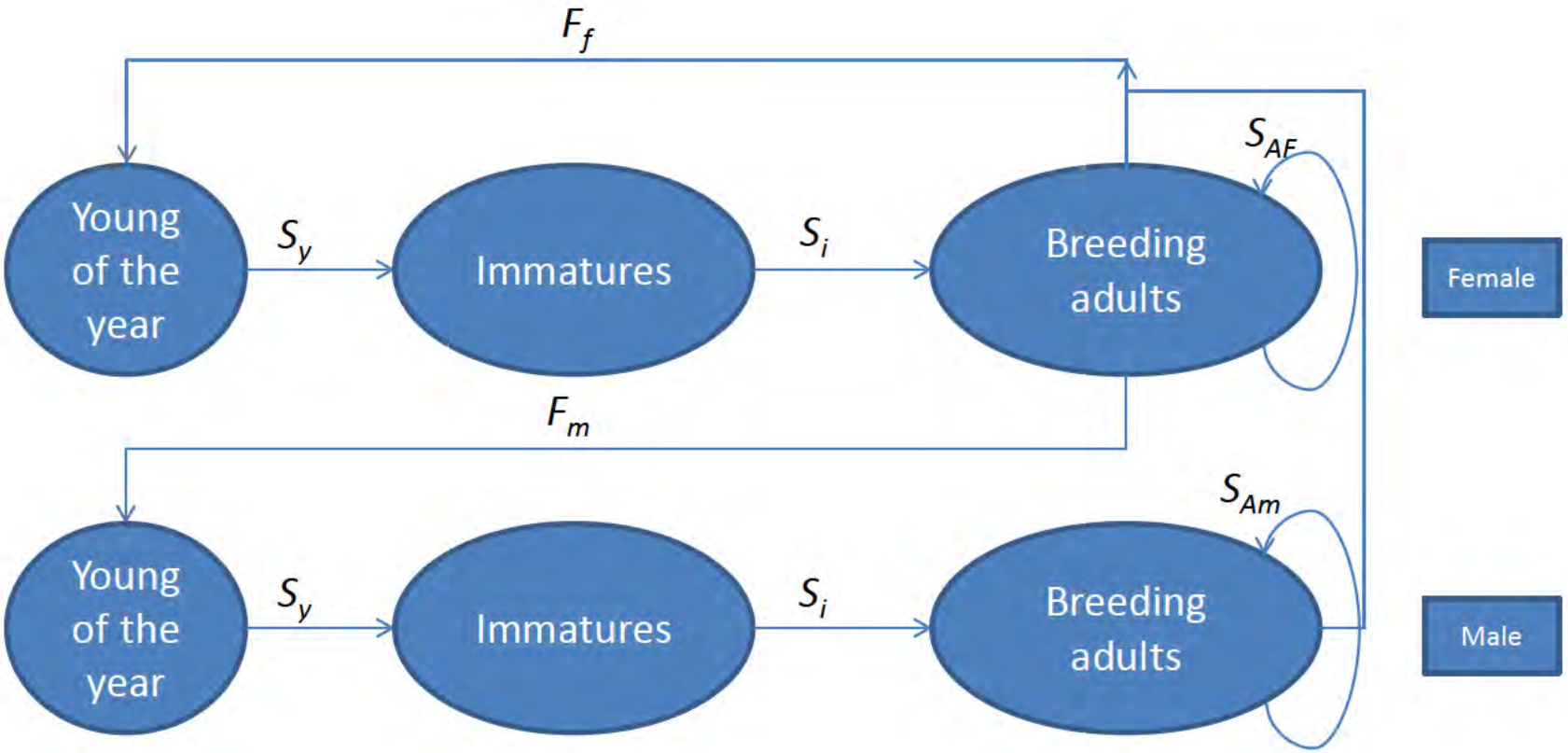
Wolverine population modeling



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From: Guinotte, John
To: Kevin Doherty; Stephen Torbit
Subject: Fwd: Wolverine PVA
Date: Thursday, April 20, 2017 1:08:09 PM
Attachments: Wolverine population modeling.pptx

John Guinotte
Fish and Wildlife Biologist
Ecological Services
U.S. Fish and Wildlife Service
Mountain Prairie Region 6
134 Union Blvd., Lakewood, CO 80228
303-236-4264
john_guinotte@fws.gov

---------- Forwarded message ----------
From: **Shoemaker, Justin** <justin_shoemaker@fws.gov>
Date: Thu, Apr 20, 2017 at 12:51 PM
Subject: Fwd: Wolverine PVA
To: "Grizzle, Betty" <betty_grizzle@fws.gov>, "Guinotte, John" <john_guinotte@fws.gov>

FYI

Justin Shoemaker
Classification Biologist
U.S. Fish and Wildlife Service, Region 6
Phone: 309-757-5800 x214
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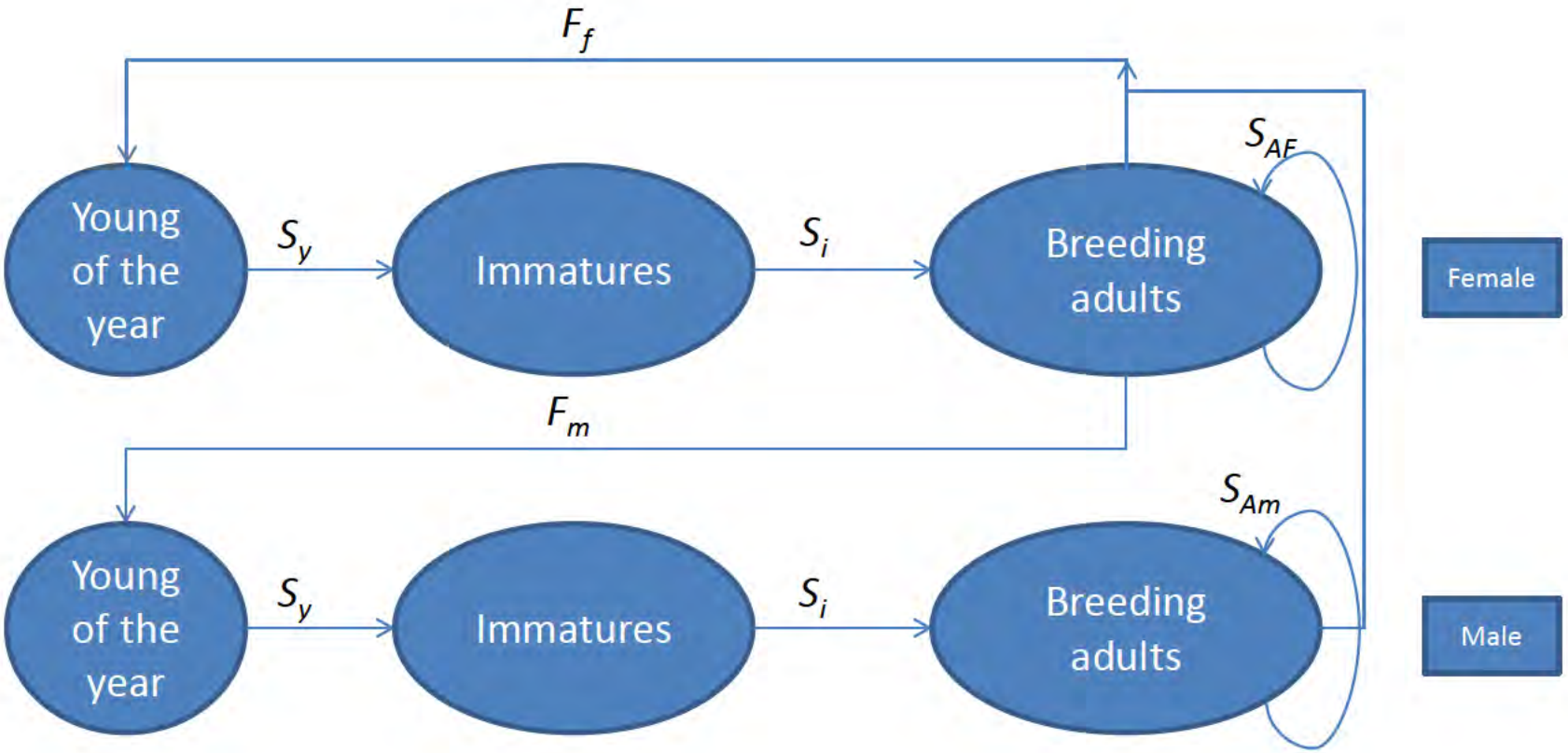
Wolverine population modeling



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From: Shoemaker, Justin
To: McGowan, Conor
Subject: Re: Wolverine PVA
Date: Monday, April 24, 2017 8:11:42 AM

Conor,

Is there a time this week that we could have a call to discuss? I'd like to have Betty and John on the call as well.

I am on travel most of tomorrow and in a meeting all day on Wed and all morning on Thursday.

Justin Shoemaker
Classification Biologist
U.S. Fish and Wildlife Service, Region 6
Phone: 309-757-5800 x214
Email: justin_shoemaker@fws.gov

On Thu, Apr 20, 2017 at 1:49 PM, McGowan, Conor <cmcgowan@usgs.gov> wrote:

> Hi Justin,
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>
> Let me know what you think.
>
> Take care,
>
> Conor
>
> On Thu, Apr 20, 2017 at 9:27 AM, Shoemaker, Justin <justin_shoemaker@fws.gov> wrote:
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> > Conor,
> >
> > Checking in to see if you've had any more time to think about the wolverine PVA or start that process. Maybe we can chat if you have time?
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> Conor P. McGowan, Ph.D.

Assistant Leader and Associate Research Professor
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School of Forestry and Wildlife Sciences,
Auburn University
Auburn, AL 36849-5418

EM:cmcgowan@usgs.gov
Ph:334 844 9231
www.auburn.edu/~cpm0014

From: Conor McGowan
To: Guinotte, John
Subject: Re: PVA touch base?
Date: Tuesday, April 25, 2017 10:59:30 AM
Attachments: Wolverine population modeling.pptx

Hi John,

Here is the Wolverine ppt that I described on the phone yesterday. Hopefully we can all get on the phone soon to discuss.

Take care,

Conor

On Mon, Apr 24, 2017 at 12:01 PM, Guinotte, John <john_guinotte@fws.gov> wrote:

> Works for me.
> Thanks John
>
> John Guinotte
> Fish and Wildlife Biologist
> Ecological Services
> U.S. Fish and Wildlife Service
> Mountain Prairie Region 6
> 134 Union Blvd., Lakewood, CO 80228
> 303-236-4264
> john_guinotte@fws.gov
>
> On Mon, Apr 24, 2017 at 10:26 AM, Novak, Kate <kate_novak@fws.gov> wrote:
>
> > Sure.. so talking today at 1:30pm MST? That works fine for me. Is that ok with everyone else?
> >
> > Here is a conference line we can use-
> >
> > 1.866.813.7644
> >
> > Participant Code 8189857
> >
> > Kate
> >
> > On Fri, Apr 21, 2017 at 12:13 PM, McGowan, Conor <cmcgowan@usgs.gov> wrote:
> >
> > > Could we do 30 minutes earlier on Monday? If not 2pm is ok, But I need to be off the phone by 3:3 MT.
> > >
> > > On Thu, Apr 20, 2017 at 5:07 PM, Novak, Kate <kate_novak@fws.gov> wrote:
> > >
> > > > John / Conner
> > > >
> > > > Thanks a call all together on Monday afternoon would be great. I have also cc'd my supervisor, Laura Romin. She will join the call too if she has availability. Would 2pm MST Monday work for all?

Also I will send you a list of some PVA assumptions that Laura drafted today.. very preliminary 1st cut. Any input on this would be super helpful! I will forward that in a separate email in a few minutes.

Thanks for your time!

Kate

On Thu, Apr 20, 2017 at 1:13 PM, Guinotte, John <john_guinotte@fws.gov> wrote:

> Hi Kate, Just heard back from Connor re PVA request. Do you want me to arrange a 3 way call for us on this? Do these times work for you? Connor is the person who will be able to answer your specific PVA questions.
> Best, John
>
> ---------- Forwarded message ----------
> From: **McGowan, Conor** <cmcgowan@usgs.gov>
> Date: Thu, Apr 20, 2017 at 12:28 PM
> Subject: Re: PVA touch base?
> To: "Guinotte, John" <john_guinotte@fws.gov>
>
> Hi John, Obviously I was unable to get on the phone yesterday. I was doing phone interviews for hiring a post-doc to help me on this project. I would have time tomorrow between 1:30 and 2 central time or Monday in the afternoon. Let me know if that would work.
>
> Thanks,
>
> Conor
>
> On Wed, Apr 19, 2017 at 12:36 PM, Guinotte, John <john_guinotte@fws.gov> wrote:
>
> > Hi Conor,
> >
> > Are you around today for a quick call this afternoon? I'd like to touch base with you on the wolverine PVA and another request we had out of Utah.
> >
> > Thanks John
> >
> > John Guinotte
> > Fish and Wildlife Biologist
> > Ecological Services
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www.auburn.edu/~cpm0014

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Kate Novak
Fish and Wildlife Biologist
US Fish and Wildlife Service, Utah Field Office
2369 West Orton Circle, Suite 50
West Valley City, Utah 84119

kate_novak@fws.gov
(801)975-3330 x132
(801)975-3331 (fax)
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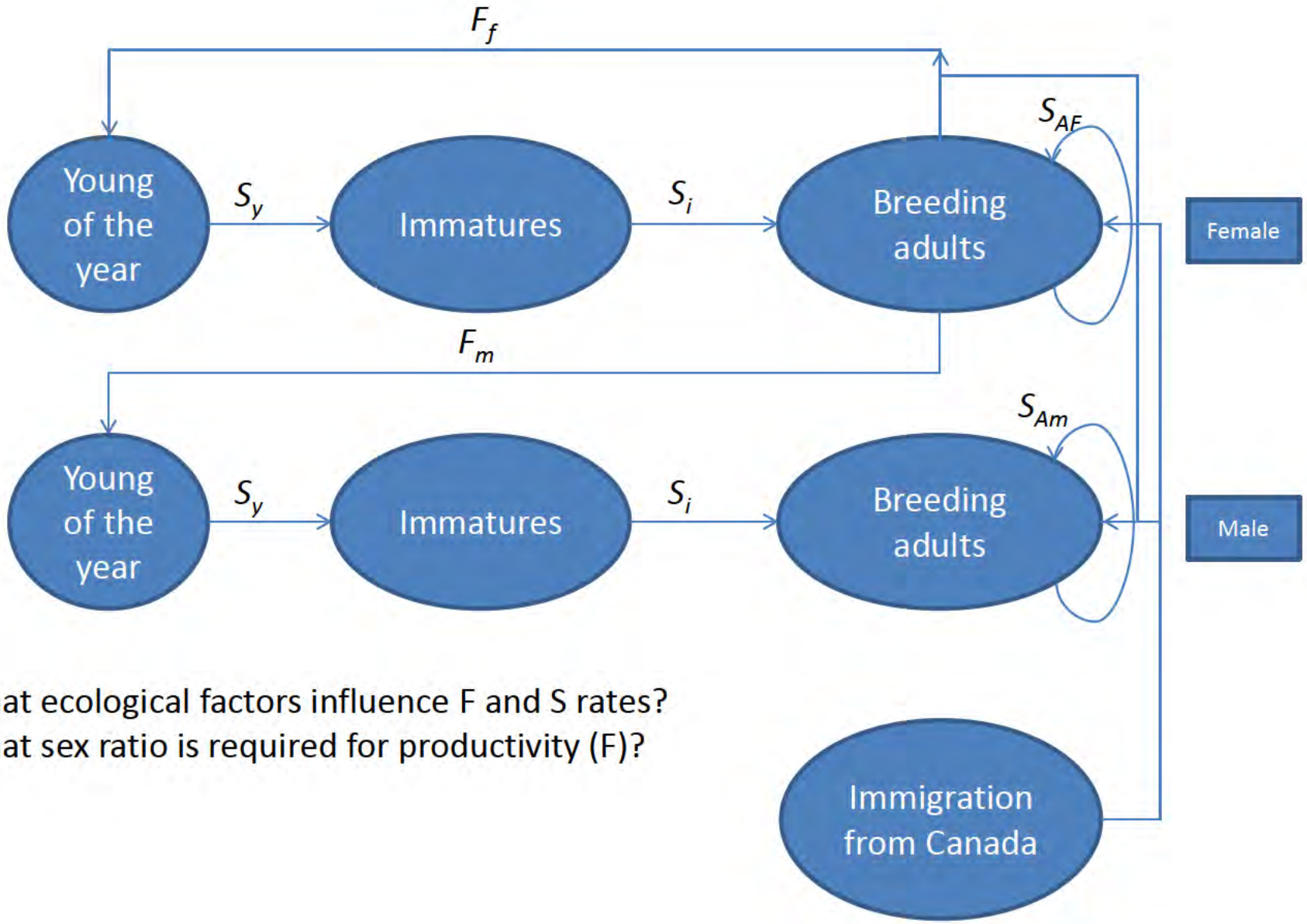
Wolverine population modeling



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From: McGowan, Conor
To: Conor McGowan
Cc: Justin Shoemaker/R6/FWS/DOI
Subject: Re: Wolverine PVA
Date: Thursday, April 27, 2017 1:10:51 PM

Justin, I should have indicated it was Friday I was free from 9-2. Also on Monday in the afternoon.

On Tue, Apr 25, 2017 at 11:55 AM, Conor McGowan <cpmcg00@gmail.com> wrote:

> Justin,
>
> I would be available to meet from 9-2 central (8-1 mountain). Monday I am booked, But Tuesday I am available too. Let me know.
>
> Conor
>
> On Thu, Apr 20, 2017 at 1:49 PM, McGowan, Conor <cmcgowan@usgs.gov> wrote:
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From:	Shoemaker, Justin
To:	Jodi Bush
Subject:	Fwd: Wolverine PVA
Date:	Friday, April 28, 2017 12:04:16 PM
Attachments:	Wolverine population modeling.pptx

Justin Shoemaker
Classification Biologist
U.S. Fish and Wildlife Service, Region 6
Phone: 309-757-5800 x214
Email: justin_shoemaker@fws.gov

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From: **Shoemaker, Justin** <justin_shoemaker@fws.gov>
Date: Thu, Apr 20, 2017 at 1:51 PM
Subject: Fwd: Wolverine PVA
To: "Grizzle, Betty" <betty_grizzle@fws.gov>, "Guinotte, John" <john_guinotte@fws.gov>

FYI

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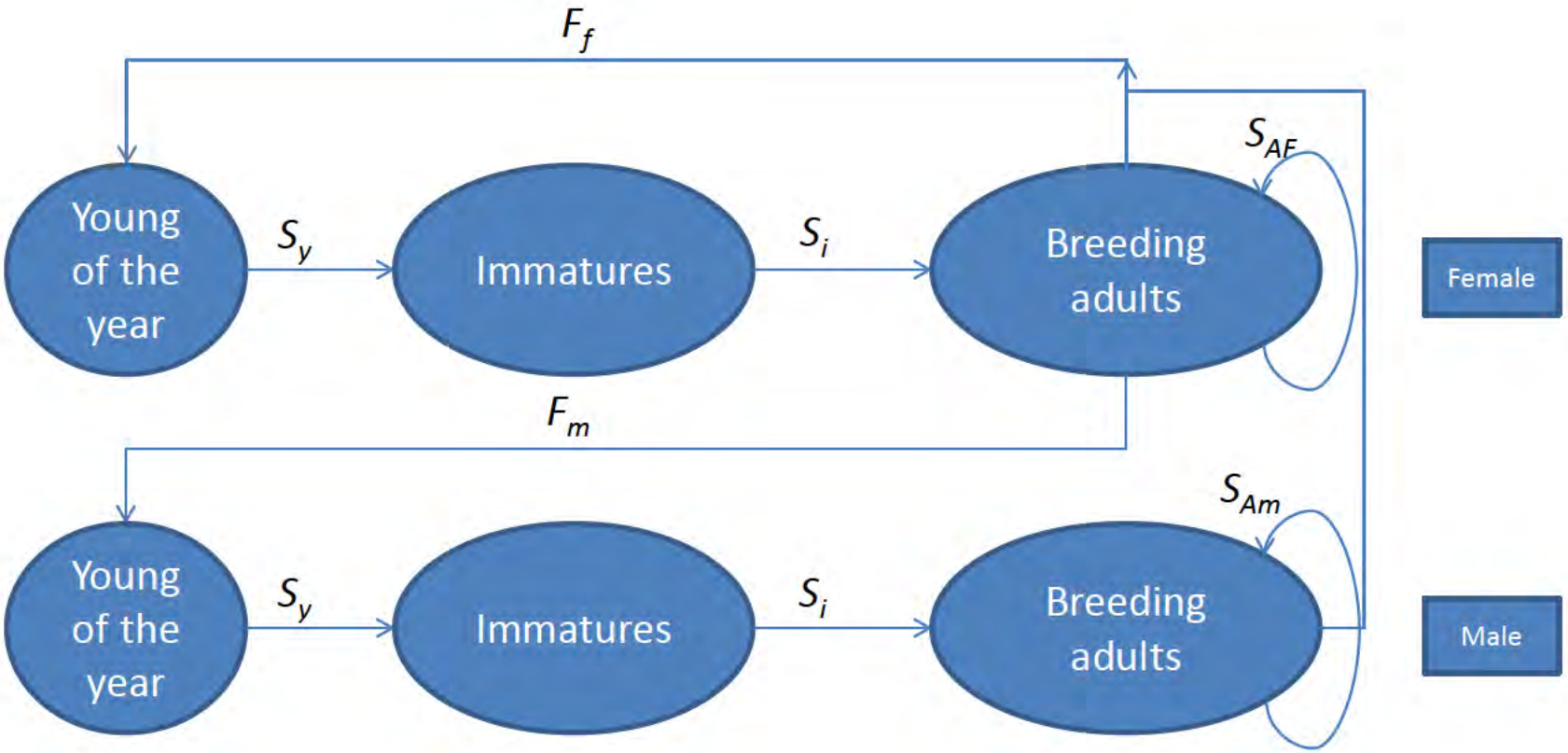

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From:	Conor McGowan
To:	Grizzle, Betty; Justin Shoemaker/R6/FWS/DOI; Conor McGowan; Guinotte, John
Subject:	Wolverine Prototype model
Date:	Monday, May 8, 2017 3:37:30 PM
Attachments:	Wloverine1.xlsx

Hi folks,

I've put together a pretty simple deterministic model for Wolverines. I converted the basic demographic rates from the scandanavian life table and input them on the spread sheet. I also incorporated functions to allow a population ceiling that can be annually reduced to reflect habitat loss, a function to lower adult male survival to capture the effects of possible road construction and disturbance on male survival, and function to reduce productivity to relect the possible effects of snow of denning success.

If you want to schedule a call to look at this I'd be happy to go through it. I think it is a good start, capturing most of our thoughts on the issues faced by wolverines, but it would require stochasticity and a better capturing of uncertainty.

Thanks,

Conor

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//----------
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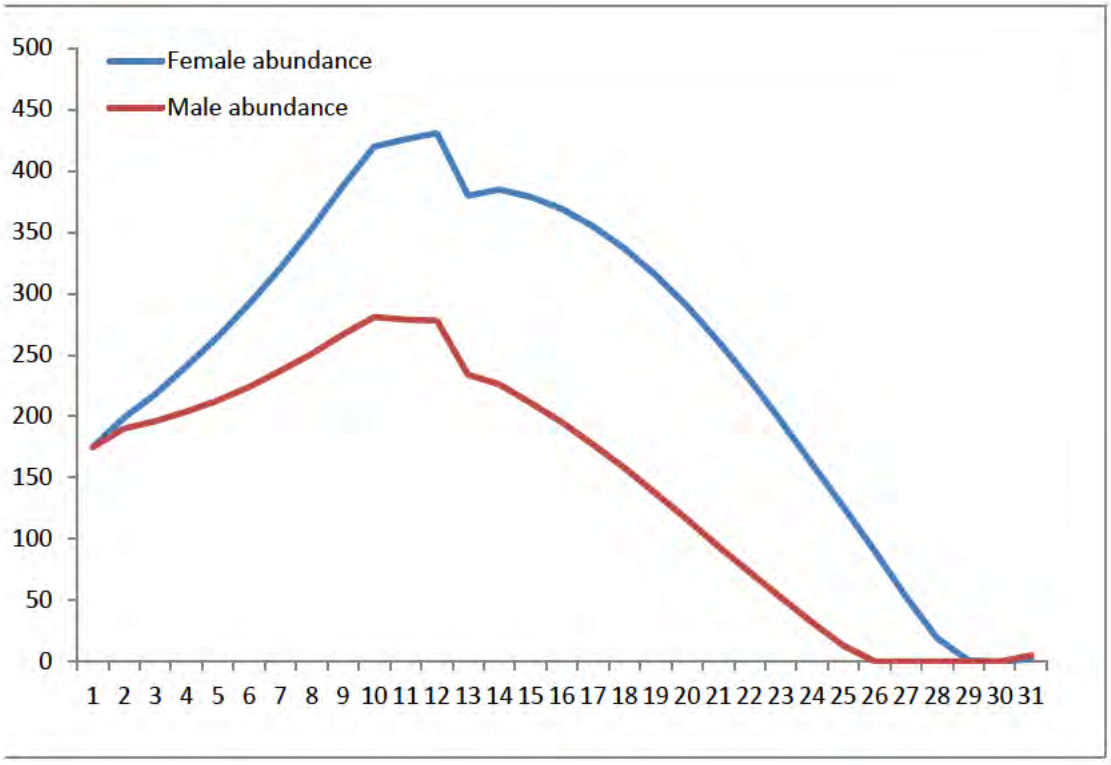
//----------

Wolverine

Ni	350	initial abundance	
Sri	0.5		
Sam	0.84	0.005	Male survival decline due to dispersal
Saf	0.89		
Si	0.861		
Sy	0.79		
Ff	0.913	0.1	Fertility decline due to snow loss
Fm	0.74	0.1	Fertility decline due to snow loss
csr	0.4		
Max pop	700	0.01	decline in K due to habitat loss
Fim	2		
Mim	5		

	female	male
0	175	175
1	199	190
2	218	196
3	241	204
4	265	213
5	292	224
6	321	237
7	353	251
8	388	267
9	420	281
10	426	279
11	431	278
12	380	234
13	385	226
14	379	211
15	369	195
16	355	177
17	337	158
18	315	137
19	290	116
20	261	94
21	230	73
22	196	52
23	161	32
24	126	13
25	90	0
26	53	0
27	19	0
28	1	0
29	0	0
30	2	5

P-preg	sex ratio	MaxPop	Sam	tot pop	Lambda		
0.39	0.5	700	0.84	350			
0.39	0.488432	693	0.8358	389	1.111429	0.561328	-0.43867
0.39	0.47343	686	0.831621	414	1.064267	0.603499	-0.3965
0.39	0.458427	679	0.827463	445	1.074879	0.655376	-0.34462
0.39	0.445607	672	0.823326	478	1.074157	0.71131	-0.28869
0.39	0.434109	665	0.819209	516	1.079498	0.77594	-0.22406
0.39	0.424731	658	0.815113	558	1.081395	0.848024	-0.15198
0.39	0.415563	651	0.811037	604	1.082437	0.927803	-0.0722
0.39	0.407634	644	0.806982	655	1.084437	1.017081	0.017081
0.39	0.400856	638	0.802947	701	1.070229	1.098746	0.098746
0.181489	0.395745	632	0.798933	705	1.005706	1.115506	0.115506
0.174203	0.392102	626	0.794938	709	1.005674	1.132588	0.132588
0.152215	0.381107	620	0.790963	614	0.866008	0.990323	-0.00968
0.129771	0.369885	614	0.787008	611	0.995114	0.995114	-0.00489
0.105254	0.357627	608	0.783073	590	0.96563	0.970395	-0.02961
0.081489	0.345745	602	0.779158	564	0.955932	0.936877	-0.06312
0.055414	0.332707	596	0.775262	532	0.943262	0.892617	-0.10738
0.028384	0.319192	590	0.771386	495	0.930451	0.838983	-0.16102
0	0.303097	584	0.767529	452	0.913131	0.773973	-0.22603
0	0.285714	578	0.763691	406	0.89823	0.702422	-0.29758
0	0.264789	572	0.759873	355	0.874384	0.620629	-0.37937
0	0.240924	566	0.756073	303	0.853521	0.535336	-0.46466
0	0.209677	560	0.752293	248	0.818482	0.442857	-0.55714
0	0.165803	554	0.748532	193	0.778226	0.348375	-0.65162
0	0.093525	548	0.744789	139	0.720207	0.25365	-0.74635
0	0	543	0.741065	90	0.647482	0.165746	-0.83425
0	0	538	0.73736	53	0.588889	0.098513	-0.90149
0	0	533	0.733673	19	0.358491	0.035647	-0.96435
0	0	528	0.730005	1	0.052632	0.001894	-0.99811
#DIV/0!	#DIV/0!	523	0.726354	0	0	0	-1
0.39	0.714286	518	0.722723	7	#DIV/0!	0.013514	-0.98649


Female abundance
Male abundance
500
450
400
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

From: Conor McGowan
To: Grizzle, Betty
Subject: Re: Wolverine Prototype model
Date: Wednesday, May 17, 2017 8:56:56 AM

I'll call you. I am working from home this morning.

On Wed, May 17, 2017 at 9:52 AM, Grizzle, Betty <betty_grizzle@fws.gov> wrote:

> Just us. Do you want to call me or should I call you?
>
> On Wed, May 17, 2017 at 7:49 AM, Conor McGowan <cpmcg00@gmail.com> wrote:
>
> > Is there a call in line or any google hangout? Will Justin and or john be joining us?
> >
> > On Mon, May 15, 2017 at 9:32 PM, Conor McGowan <cpmcg00@gmail.com> wrote:
> >
> > > That should be fine.
> > >
> > > Conor McGowan, Ph.D.
> > >
> > > U.S. Geological Survey
> > > Alabama Cooperative Fish and Wildlife Research Unit
> > >
> > > On May 15, 2017, at 4:07 PM, Grizzle, Betty <betty_grizzle@fws.gov> wrote:
> > >
> > > > How about Wednesday morning, 10:00 am your time?
> > > >
> > > > On Mon, May 15, 2017 at 10:49 AM, Conor McGowan <cpmcg00@gmail.com> wrote:
> > > >
> > > > > All times are central time:
> > > > >
> > > > > Tomorrow I am available from 10-1
> > > > > Wednesday I am available from 10-4
> > > > > Thursday I am available from 9-11 and again from 12-2
> > > > > Friday I am available from 10-1.
> > > > >
> > > > > Thanks,
> > > > >
> > > > > Conor
> > > > >
> > > > > On Mon, May 15, 2017 at 11:23 AM, Grizzle, Betty <betty_grizzle@fws.gov> wrote:
> > > > >
> > > > > > Thanks Conor. Justin was out most of last week, and the Regional Office had some water damage to deal with.
> > > > > > I also have a busy day today, but am in most of the week (except Wed afternoon). What's a good day and time for you for a short phone call?
> > > > > >
> > > > > > On Mon, May 15, 2017 at 9:18 AM, Conor McGowan <cpmcg00@gmail.com> wrote:
> > > > > >
> > > > > > > Hi Betty, I was expecting John or Justin to chime in as well, but if you want to get on the phone some time that would be fine. I am super busy today, but have availability the rest of the week.

Thanks,

Conor

On Tue, May 9, 2017 at 9:46 AM, Grizzle, Betty <betty_grizzle@fws.gov> wrote:

> Thanks Conor! I would like to go over this with you and others. I am teleworking today and tomorrow, but can participate in conference call.
>
> On Mon, May 8, 2017 at 2:36 PM, Conor McGowan <cpmcg00@gmail.com> wrote:
>
> > Hi folks,
> >
> > I've put together a pretty simple deterministic model for Wolverines. I converted the basic demographic rates from the scandanavian life table and input them on the spread sheet. I also incorporated functions to allow a population ceiling that can be annually reduced to reflect habitat loss, a function to lower adult male survival to capture the effects of possible road construction and disturbance on male survival, and function to reduce productivity to relect the possible effects of snow of denning success.
> >
> > If you want to schedule a call to look at this I'd be happy to go through it. I think it is a good start, capturing most of our thoughts on the issues faced by wolverines, but it would require stochasticity and a better capturing of uncertainty.
> >
> > Thanks,
> >
> > Conor
> >
> > --
> > //----------
> > ----------
> > Conor P. McGowan, Ph.D.
> > Assistant Leader and Associate Research Professor
> > USGS, Alabama Cooperative Fish and Wildlife Research Unit
> > School of Forestry and Wildlife Sciences,
> > Auburn University
> > Auburn, AL 36849-5418
> >
> > EM:cmcgowan@usgs.gov
> > Ph:334 844 9231
> > www.auburn.edu/~cpm0014
> > //----------
> > ----------

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Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

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Conor P. McGowan, Ph.D.
Assistant Leader and Associate Research Professor
USGS, Alabama Cooperative Fish and Wildlife Research Unit
School of Forestry and Wildlife Sciences,
Auburn University
Auburn, AL 36849-5418

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//----------

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Conor P. McGowan, Ph.D.
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Auburn University
Auburn, AL 36849-5418

EM:cmcgowan@usgs.gov
Ph:334 844 9231
www.auburn.edu/~cpm0014
//----------

From: Guinotte, John
To: Nelson, Marjorie
Subject: Fwd: Wolverine Prototype model
Date: Tuesday, May 30, 2017 10:02:20 AM
Attachments: Wloverine1.xlsx

John Guinotte
Fish and Wildlife Biologist
Ecological Services
U.S. Fish and Wildlife Service
Mountain Prairie Region 6
134 Union Blvd., Lakewood, CO 80228
303-236-4264
john_guinotte@fws.gov

---------- Forwarded message ----------
From: **Conor McGowan** <cpmcg00@gmail.com>
Date: Mon, May 8, 2017 at 3:36 PM
Subject: Wolverine Prototype model
To: "Grizzle, Betty" <betty_grizzle@fws.gov>, Justin Shoemaker/R6/FWS/DOI <justin_shoemaker@fws.gov>, Conor McGowan <cmcgowan@usgs.gov>, "Guinotte, John" <john_guinotte@fws.gov>

Hi folks,

I've put together a pretty simple deterministic model for Wolverines. I converted the basic demographic rates from the scandanavian life table and input them on the spread sheet. I also incorporated functions to allow a population ceiling that can be annually reduced to reflect habitat loss, a function to lower adult male survival to capture the effects of possible road construction and disturbance on male survival, and function to reduce productivity to relect the possible effects of snow of denning success.

If you want to schedule a call to look at this I'd be happy to go through it. I think it is a good start, capturing most of our thoughts on the issues faced by wolverines, but it would require stochasticity and a better capturing of uncertainty.

Thanks,

Conor

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//----------
Conor P. McGowan, Ph.D.
Assistant Leader and Associate Research Professor
USGS, Alabama Cooperative Fish and Wildlife Research Unit
School of Forestry and Wildlife Sciences,
Auburn University
Auburn, AL 36849-5418

EM:cmcgowan@usgs.gov
Ph:334 844 9231
www.auburn.edu/~cpm0014
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Wolverine

Ni	350	initial abundance	
Sri	0.5		
Sam	0.84	0.005	Male survival decline due to dispersal
Saf	0.89		
Si	0.861		
Sy	0.79		
Ff	0.913	0.1	Fertility decline due to snow loss
Fm	0.74	0.1	Fertility decline due to snow loss
csr	0.4		
Max pop	700	0.01	decline in K due to habitat loss
Fim	2		
Mim	5		

	female	male
0	175	175
1	199	190
2	218	196
3	241	204
4	265	213
5	292	224
6	321	237
7	353	251
8	388	267
9	420	281
10	426	279
11	431	278
12	380	234
13	385	226
14	379	211
15	369	195
16	355	177
17	337	158
18	315	137
19	290	116
20	261	94
21	230	73
22	196	52
23	161	32
24	126	13
25	90	0
26	53	0
27	19	0
28	1	0
29	0	0
30	2	5

P-preg	sex ratio	MaxPop	Sam	tot pop	Lambda		
0.39	0.5	700	0.84	350			
0.39	0.488432	693	0.8358	389	1.111429	0.561328	-0.43867
0.39	0.47343	686	0.831621	414	1.064267	0.603499	-0.3965
0.39	0.458427	679	0.827463	445	1.074879	0.655376	-0.34462
0.39	0.445607	672	0.823326	478	1.074157	0.71131	-0.28869
0.39	0.434109	665	0.819209	516	1.079498	0.77594	-0.22406
0.39	0.424731	658	0.815113	558	1.081395	0.848024	-0.15198
0.39	0.415563	651	0.811037	604	1.082437	0.927803	-0.0722
0.39	0.407634	644	0.806982	655	1.084437	1.017081	0.017081
0.39	0.400856	638	0.802947	701	1.070229	1.098746	0.098746
0.181489	0.395745	632	0.798933	705	1.005706	1.115506	0.115506
0.174203	0.392102	626	0.794938	709	1.005674	1.132588	0.132588
0.152215	0.381107	620	0.790963	614	0.866008	0.990323	-0.00968
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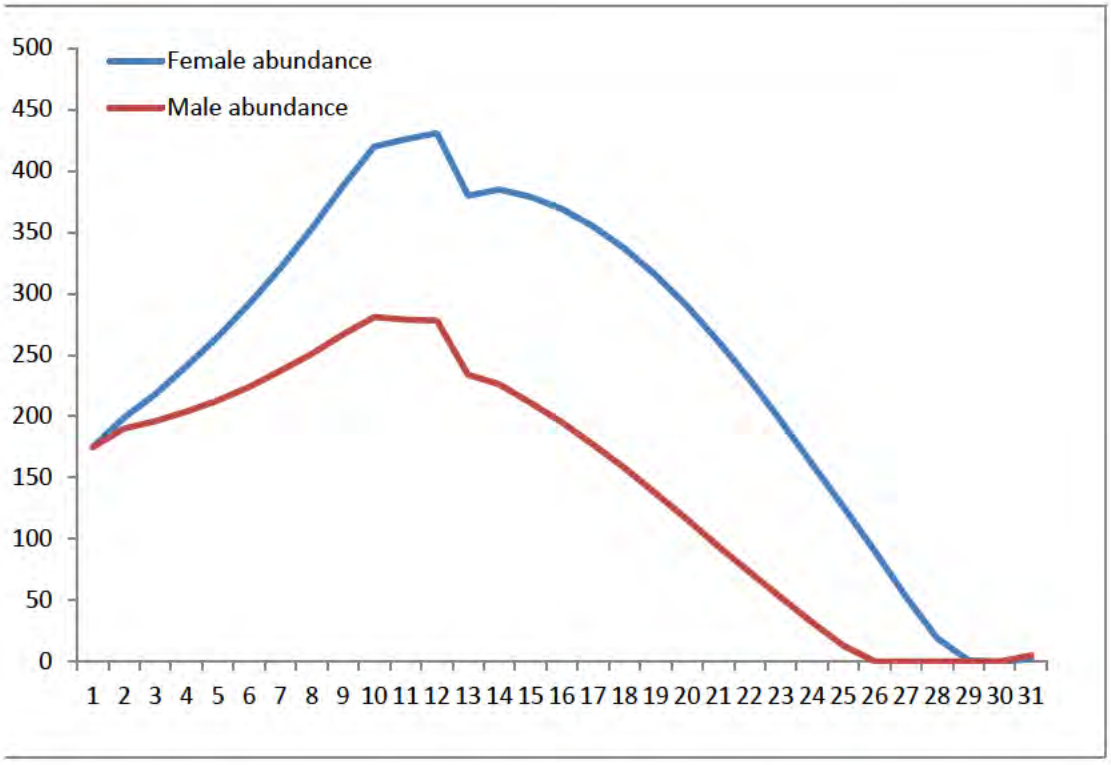
0.081489	0.345745	602	0.779158	564	0.955932	0.936877	-0.06312
0.055414	0.332707	596	0.775262	532	0.943262	0.892617	-0.10738
0.028384	0.319192	590	0.771386	495	0.930451	0.838983	-0.16102
0	0.303097	584	0.767529	452	0.913131	0.773973	-0.22603
0	0.285714	578	0.763691	406	0.89823	0.702422	-0.29758
0	0.264789	572	0.759873	355	0.874384	0.620629	-0.37937
0	0.240924	566	0.756073	303	0.853521	0.535336	-0.46466
0	0.209677	560	0.752293	248	0.818482	0.442857	-0.55714
0	0.165803	554	0.748532	193	0.778226	0.348375	-0.65162
0	0.093525	548	0.744789	139	0.720207	0.25365	-0.74635
0	0	543	0.741065	90	0.647482	0.165746	-0.83425
0	0	538	0.73736	53	0.588889	0.098513	-0.90149
0	0	533	0.733673	19	0.358491	0.035647	-0.96435
0	0	528	0.730005	1	0.052632	0.001894	-0.99811
#DIV/0!	#DIV/0!	523	0.726354	0	0	0	-1
0.39	0.714286	518	0.722723	7	#DIV/0!	0.013514	-0.98649


Female abundance
Male abundance
500
450
400
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

From:	Conor McGowan
To:	Marjorie Nelson/ARL/R9/FWS/DOI; Justin Shoemaker/R6/FWS/DOI; Grizzle, Betty; Guinotte, John
Subject:	Wolverine
Date:	Saturday, August 5, 2017 9:33:44 PM
Attachments:	example wolverine scenarios.xlsx WolverinePrototype2.R

Hi Marj, Justin, Betty and John,

It has been a long time since I've heard from any of you about the Wolverine PVA modeling that we discussed in June. I have gone a head and incorporated some of the revisions to the prototype model in excel that we discussed and I also took the step of moving the model into a computer programming language that allows me to better incorporate variability and uncertainties. I'd still of course call it a prototype. I've built in three mechanisms for anthropocentric "threats": 1) is a climate change induced snow effect where some proportion of the females are unable to find a suitable denning sites because of lack of snow. The proportion starts out very small (<1% of females) and can be increased annually. 2) Disturbance effects on male survival, The model randomly picks years for disturbance and then in those years reduces male survival by about 5-10%. This disturbance effect is a single year and the following year male survival returns to normal. The frequency of disturbance years can be manipulated to explore different disturbance frequencies. 3) Habitat loss, the model annually reduces the maximum possible population size by what ever percentage we want to test. So what that leads us to is, if you all like/accept those three main threats we need to come up with scenarios to evaluate using the simulation model...that is, what is a low, moderate and high level of each threat variable. These will be paired with a low and high immigration rate from Canada. I've attached the model code in case you are interested, and I've also attached a spread sheet with example scenarios to help prompt your thinking. I've included a few comments in the spread sheet to help explain what the values might mean. I am happy to get on the phone and go through the model design and to talk about any needed modifications, but I am traveling internationally for the next two weeks. We will have to find a time after August 21 to arrange a meeting. I will have some access to email during my travel so feel free to email me.

Thanks,

Conor

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//----------
Conor P. McGowan, Ph.D.
Assistant Leader and Associate Research Professor
USGS, Alabama Cooperative Fish and Wildlife Research Unit
School of Forestry and Wildlife Sciences,
Auburn University
Auburn, AL 36849-5418

EM:cmcgowan@usgs.gov
Ph:334 844 9231
www.auburn.edu/~cpm0014
//----------

	Snow effect	Disturbance Frequencies	Habitat loss
Low	0.005	0.1	0.025
Moderate	0.01	0.2	0.05
High	0.02	0.3	0.1
	rate of increase for the proportion of females that cannot find adequate den sites	Frequencies of disturbance years	Rate of decline in carrying capacity

Attachment 20170805 213344_EM_Wolverine.R (3844 Bytes) cannot be converted to PDF format.

From: Conor McGowan
To: Shoemaker, Justin
Cc: Marjorie Nelson/ARL/R9/FWS/DOI
Subject: Re: Wolverine
Date: Tuesday, August 22, 2017 2:12:15 PM

Hi Justin,

Let me know if you want to try and get on the phone this week or next. I am available tomorrow afternoon, and most of the day on Friday. Next week I am available on Monday afternoon Tuesday morning and most of the day on Wednesday.

Thanks,

Conor

On Mon, Aug 7, 2017 at 5:08 PM, Conor McGowan <cpmcg00@gmail.com> wrote:

> Ok Justin,
>
> I received a voice mail from Marj and we played a little phone but weren't able to actually speak. I wanted to get something done for you all because I believe the time line for a completed PVA is October (?). I am happy to get on the phone when I get back. I am back in the US on Monday the 21st and could talk after 2:30 mt, I am avail Tuesday, Wednesday and Friday that week too.
>
> Thanks,
>
> Conor
>
> Conor McGowan, Ph.D.
>
> U.S. Geological Survey
> Alabama Cooperative Fish and Wildlife Research Unit
>
> On Aug 7, 2017, at 3:48 PM, Shoemaker, Justin <justin_shoemaker@fws.gov> wrote:
>
>> Conor,
>>
>> I understand Marj has been trying to get in touch with you regarding the PVA effort for a few weeks now. Since that hasn't happened yet, I think it would be best to not go any further with this until you have a chance to discuss with Marj and I. I can set up a call with the three of us when you return.
>>
>> Have a nice trip, travel safe.
>>
>> Justin Shoemaker
>> Classification and Recovery Biologist
>> U.S. Fish and Wildlife Service, Region 6
>> Phone: 309-757-5800 x214

Email: justin_shoemaker@fws.gov

On Sat, Aug 5, 2017 at 10:32 PM, Conor McGowan <cpmcg00@gmail.com> wrote:

> Hi Marj, Justin, Betty and John,
>
> It has been a long time since I've heard from any of you about the Wolverine PVA modeling that we discussed in June. I have gone a head and incorporated some of the revisions to the prototype model in excel that we discussed and I also took the step of moving the model into a computer programming language that allows me to better incorporate variability and uncertainties. I'd still of course call it a prototype. I've built in three mechanisms for anthropocentric "threats": 1) is a climate change induced snow effect where some proportion of the females are unable to find a suitable denning sites because of lack of snow. The proportion starts out very small (<1% of females) and can be increased annually. 2) Disturbance effects on male survival, The model randomly picks years for disturbance and then in those years reduces male survival by about 5-10%. This disturbance effect is a single year and the following year male survival returns to normal. The frequency of disturbance years can be manipulated to explore different disturbance frequencies. 3) Habitat loss, the model annually reduces the maximum possible population size by what ever percentage we want to test. So what that leads us to is, if you all like/accept those three main threats we need to come up with scenarios to evaluate using the simulation model...that is, what is a low, moderate and high level of each threat variable. These will be paired with a low and high immigration rate from Canada. I've attached the model code in case you are interested, and I've also attached a spread sheet with example scenarios to help prompt your thinking. I've included a few comments in the spread sheet to help explain what the values might mean. I am happy to get on the phone and go through the model design and to talk about any needed modifications, but I am traveling internationally for the next two weeks. We will have to find a time after August 21 to arrange a meeting. I will have some access to email during my travel so feel free to email me.
>
> Thanks,
>
> Conor
>
> --
> //----------
> --
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> Assistant Leader and Associate Research Professor
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>
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> > //----------
> > --

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//----------
Conor P. McGowan, Ph.D.
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Auburn University
Auburn, AL 36849-5418

EM:cmcgowan@usgs.gov
Ph:334 844 9231
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//----------

From:	Kuennen, Reed -FS
To:	Grizzle, Betty
Cc:	Allen, Lydia R -FS; Staab, Cara - FS
Subject:	Wolverine info - Flathead NF
Date:	Thursday, September 7, 2017 5:27:58 PM
Attachments:	image002.png image003.png Wolverine_excerpt_FEIS_final_draft_9-7-17.docx Wolverine_excerpt_BA_6-12-17.docx

---

Hi Betty. Attached is the final draft of the wolverine section of our revised forest plan EIS and the wolverine section of the BA we submitted to the USFWS, as requested for the species status review you are compiling. I have also included the section providing a summary of plan components for connectivity, since some of these plan components are referenced in the wolverine section. Our references are linked from the text to the endnote references section, so I have also included an excerpt of wildlife references.

Our preferred alternative is B modified. Please feed to call me if you have questions or anything you would like to discuss. If there is information I need to correct or update, including our science citations, please let me know.

I can provide you with figures cited if you need them (they are still highlighted in yellow in the attached text since we are now in the process of producing final maps and figure numbers).

Thanks!

M. Reed Kuennen
Wildlife Biologist
Forest Service
Flathead National Forest
p: 406-758-5256
c: 406-862-6716
f: 406-758-5367
rkuennen@fs.fed.us
650 Wolfpack Way
Kalispell, MT 59937
www.fs.fed.us
Caring for the land and serving people

From: Grizzle, Betty [mailto:betty_grizzle@fws.gov]
Sent: Thursday, September 07, 2017 4:31 PM
To: Kuennen, Reed -FS <rkuennen@fs.fed.us>
Subject: Wolverine info - Flathead NF

Hi Reed - Sorry I missed your phone call. Yes, if you have an updated section that you can send, that would be very helpful.

I will be in the office tomorrow (7:15 am PDT) so I may call you if I have other questions.

Thanks for your help in collecting this information
Betty

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Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

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Wolverine

When the Forest's assessment was published (April 2014), the USFWS had published a proposed rule to list the North American wolverine distinct population segment (DPS) in the contiguous United States (USFWS, 2013a). However, on August 13, 2014, the USFWS withdrew its previous proposal (USFWS, 2014b). On April 14, 2016, the Court remanded the matter to the U.S. Fish and Wildlife Service for further consideration consistent with order CV 14-246-M-DLC (Consolidated with Case Nos.14-247-M-DLC and 14-250-M-DLC). The wolverine is now listed as a proposed threatened or endangered species for the Flathead National Forest, pending completion of a status review by the USFWS.

Affected environment

Population, life history, and distribution

Wolverines are year-round residents across most of Alaska, British Columbia, and the northern portion of the other Canadian provinces. The southern portion of the species' range extends into high-elevation alpine portions of Washington, Idaho, Montana, Wyoming, California, and Colorado They occur at low densities, are difficult to detect, range widely, and inhabit remote and rugged landscapes away from human populations, so conducting research on wolverines is challenging (IDFG, 2014). Wolverine populations in Montana were heavily trapped in the early 1900s and were near extinction by 1920. However, numbers increased in the western part of the state from 1950 to 1980 (Hornocker & Hash, 1981). State fish and wildlife agencies in four states, including Montana, have recently initiated a cooperative, coordinated wolverine monitoring project.

The Forest lies within the Northern Rocky Mountains area assessed by the USFWS. Wolverine population growth and expansion has been documented in the North Cascades and Northern Rocky Mountains (USFWS, 2013a). According to the USFWS (2013a), "wolverine records from 1995 to 2005 indicate that wolverine populations currently exist in the northern Rocky Mountains and that the bulk of the current population occurs here. Within the area known to currently have wolverine populations, relatively few wolverines can coexist due to their naturally low population densities, even if all areas were occupied at or near carrying capacity. Given the natural limitations on wolverine population density, it is likely that historic wolverine population numbers were also low" (p. 7868).

On the Forest, studies or research on wolverine occurred in the 1980s (Hornocker & Hash, 1981). Hornocker and Hash conducted telemetry research on 24 individual wolverines over a 5-year period within a study area making up about 1,300 km^2 of the Flathead National Forest. Their study area was primarily made up of the South Fork of the Flathead drainage and secondarily portions of the Sun, Swan, and Middle Fork of the Flathead River drainages. About one-half the study area was used for timber harvest and recreational purposes, and the other half was wilderness. Hornocker and Hash found that wolverines were at relatively high densities in the South Fork of the Flathead River drainage and they concluded the population was stable (Hornocker & Hash, 1981).

Current information for the Forest is based on (1) reported trapping records, (2) non-invasive monitoring including remote cameras and DNA analysis of hair or scat, and (3) observations/sightings of either the species or tracks recorded in Forest or state databases. No recent research that would estimate population levels has been conducted for wolverine on the Forest. The Forest and other cooperators detected a minimum of 13 individual wolverines within Forest geographic areas (based upon genetic analysis of samples collected during non-invasive carnivore monitoring in areas accessible by snowmobile from 2012-2015) (Curry et al., 2016; Pilgrim & Schwartz, 2015; Ruby, 2016; SWCC, 2014, 2015).

Wolverines are a wide-ranging species with populations that fluctuate in response to prey availability, juvenile dispersal, and mortality of adult females. Wolverines are distributed across the Forest in suitable habitats (USDA, n.d.). Research on wolverines in Glacier National Park (adjacent to the Forest) has occurred in the last decade (Copeland & Yates, 2006; J. R. Squires, Copeland, Ulizio, Schwartz, & Ruggiero, 2007). Copeland and Yates found that wolverines were constantly on the move, with adult female home ranges that averaged 55 mi^2. Adult males ranged over an even larger area, including lands outside the park, with home ranges that averaged 193 mi^2 (Copeland & Yates, 2006). Prior to this study, not much was known about den sites of reproductive female wolverines in Montana because den sites of reproductive females are often in remote terrain that is very difficult to study. During the first 3 years of the study, data was collected for 19 wolverines, and information about reproductive dens was obtained for two adult females that raised four offspring (kits). Females used two to three different dens prior to weaning of kits at 6-7 months of age. Abandonment of natal and maternal dens may be a preemptive strategy that confers an advantage to females if prolonged use of the same den makes a den more evident to predators (USFWS, 2013a). Survival of young was low, even in the national park setting where trapping does not occur and where there is no motorized disturbance in winter or spring.

The USFWS stated that the Northern Rocky Mountains portion of the North American wolverine distinct population segment is thought to be the largest subpopulation and the most genetically resilient of the current subpopulations (USFWS, 2013a). Persistent spring snow cover is also correlated with gene flow because this is where the wolverine's within-home range movements and dispersal occurs year-round (M. K. Schwartz et al., 2009). Wolverines are known to make long-distance movements that are not impeded by topography (Copeland & Yates, 2006; J. R. Squires et al., 2007).

Habitat

Copeland and others defined snow persisting to mid-May and accumulating to depths greater than 5 feet as "persistent spring snow," stating that this factor appears to be a requirement for denning by reproductive females. Copeland and others modeled persistent spring snow for 7 years from 2000-2006 (which was variable from year to year). Their model displays the number of years out of 7 that a GIS pixel was classified as snow (e.g., 7 years out of 7 vs. 1 year out of 7). For the Glacier National Park study site (adjacent to the Forest), 93 percent of wolverine telemetry locations were in the spring snow coverage area. Data on denning female wolverines in the United States is limited. Copeland considered all known wolverine dens in Norway and Sweden to display preference, finding that areas with persistent spring snow 5, 6, and 7 years out of 7 were preferred (McKelvey et al., 2011). About 90 percent of the 62 known den sites in North America occurred in areas that had persistent spring snow for 5, 6, or 7 years out of 7 (Weaver, 2014).

Magoun and Copeland (1998) described two types of reproductive dens, natal dens where young are born and maternal dens where the mother may move the kits if conditions are no longer suitable at the natal den. Sites used for maternal dens are often close to the natal den and have similar structure, although the distance between the natal den and maternal den can be up to about 2 miles away. For purposes of effects analysis, figures and text refer to this as maternal denning habitat. Copeland and others found that reproductive dens were excavated in the snow and were on upper slopes in sparse timber beneath downed, woody debris or rocks. Dens are typically used through late April or early May. Kits gathered at rendezvous sites that were primarily in boulder, talus, and cliff areas (Copeland et al., 2010). Wolverine reproductive den sites may not occur in the same exact spot year after year. Home range boundaries are dynamic, as are population demographics.

Copeland stated that wolverine year-round habitat use also takes place almost entirely within the area defined by deep persistent spring snow (Copeland et al., 2010). Year-round habitat is found at high elevations where rocky alpine habitats, glacial cirque basins, and avalanche chutes have food sources such

as marmots, voles, and carrion (Copeland et al., 2007; Hornocker & Hash, 1981; Robert M. Inman et al., 2007; Magoun & Copeland, 1998). Wolverines appear to rely on the cold and snow to cache carrion (Robert M. Inman, Magoun, Persson, & Mattisson, 2012). Wolverines also travel through the area where snow persists through mid-May when dispersing, and they minimize travel through low elevation habitat (McKelvey et al., 2011). A new study by Webb and others (2016) found that wolverines in the boreal forest region of northern Alberta were not as closely associated with persistent spring snow as wolverines in the Rocky Mountains and suggested that these two very different habitats should be separated for analysis purposes and study of climate change effects.

Wolverine habitat is also characterized primarily by low levels of human development (Copeland, 1996; Hornocker & Hash, 1981; Krebs, Lofroth, & Parfitt, 2007; USFWS, 2013a). This negative association with frequent human presence is sometimes interpreted as active avoidance of human disturbance, but it may simply reflect the wolverine's preference for cold, snowy, and high-elevation habitat that humans don't often develop. There is uncertainty with respect to effects of human recreation use on wolverines.

The USFWS assessed effects of a variety of human activities that can affect wolverines or their habitat. The USFWS stated that

> Few effects to wolverines from land management actions such as grazing, timber harvest, and prescribed fire have been documented. Wolverines in British Columbia used recently logged areas in the summer and moose winter ranges for foraging (Krebs et al., 2007, pp. 2189-2190). Males did not appear to be influenced strongly by the presence of roadless areas (Krebs et al., 2007, pp. 2189-2190). In Idaho, wolverines used recently burned areas despite the loss of canopy cover (Copeland, 1996). Management activities such as timber harvest and prescribed fire do occur in wolverine habitat; however, for the most part, wolverine habitat tends to be located at high elevations and in rugged topography that is unsuitable for intensive timber management. Wolverines are not thought to be dependent on specific vegetation or habitat features that might be manipulated by land management activities, nor is there evidence to suggest that land management activities are a threat to the conservation of the species. (USFWS, 2013a)

The USFWS also stated that it is unlikely that wolverines avoid the type of low-use forest roads that generally are found in wolverine habitat. Based on the best available science, the USFWS concluded that wolverines do not avoid human development of the types that occur within suitable wolverine habitat and that there is no evidence that wolverine dispersal is affected by infrastructure development (USFWS, 2013a).

Krebs and others (2007) modeled male versus female wolverine habitat selection in British Columbia, hypothesizing that food, predation risk, and human disturbance affected habitat selection. Krebs and others based their model on 39 adult wolverines (23 females and 16 males) that were located a total of 2,125 times within two study areas. These authors modeled selection in two time periods: winter and non-winter. The winter season was defined as the period when there was persistent snow cover at treeline. Human use variables included in the models they tested included those associated with winter recreation activity, roads, and forest harvesting. Winter recreation data included estimates of snowmobile primary use sites, locations of runs for two helicopter skiing companies in the Columbia Mountains study area, and backcountry ski use centered on the Trans-Canada Highway corridor within and adjacent to Mount Revelstoke and Glacier National Parks. These authors stated that extensive forest harvesting had occurred within a large portion of the study area.

Krebs and others (2007) concluded that male wolverine habitat associations were most supported by the food hypothesis in both summer and winter. Moose winter ranges, valley bottom forests, and avalanche terrain were positively associated with winter male wolverine use. Habitat use by male wolverines in

winter was also negatively associated with helicopter skiing areas in the Columbia Mountains. The authors stated that

> habitat associations of females were more complex; combinations of variables supporting food, predation risk, or human disturbance hypotheses were included in most supported models from both summer and winter in both study areas. Females were associated with alpine and avalanche environments where hoary marmot and Columbia ground squirrel prey are found in summer. Roaded and recently logged areas were negatively associated with female wolverines in summer. In the Columbia Mountains, where winter recreation was widespread, females were negatively associated with helicopter and backcountry skiing. Moose winter ranges within rugged landscapes were positively associated with females during winter. Our analysis suggests wolverines were negatively responding to human disturbance within occupied habitat. The population consequences of these functional habitat relationships will require additional focused research. Our spatially explicit models can be used to support conservation planning for resource extraction and tourism industries operating in landscapes occupied by wolverines. (abstract)

Human Disturbance

Some scientists have expressed concern about effects of human activities on female wolverines with young kits during the mid-February to mid-May time period because food resources are scarce for foraging females. As the kits mature, the mother will leave them for longer periods of time to find food; but until they are at least 10 weeks old, the kits cannot travel with their mother. If a female needs to move kits to a new location, or to another maternal den, she must carry them in her mouth. If the female needs to move the kits very far, the probability of kits dying increases. Reproductive females and kits are most at risk of predation (Magoun & Copeland, 1998), and, according to Persson in 2005, females are most vulnerable to energetic pressures due to the high cost of lactation during this period (Krebs et al., 2007). The threshold for the amount of human activity that can occur before it affects male and female wolverine habitat selection is unknown, but the predominant activity in some portions of wolverine habitat during this time period is backcountry recreation.

Winter backcountry opportunities in the northern Rocky Mountains include snowshoeing, snowboarding, skiing, snowcat- or trackster-assisted skiing/snowboarding, snow bikes, and snowmobiling. Heinemeyer and Squires (2015) are investigating winter recreation use (primarily skiing, snowboarding, and snowmobiling) in wolverine habitat in central Idaho and the Yellowstone region of Idaho, Montana, and Wyoming.

Heinemeyer and Squires stated that wolverines appear to tolerate many types of winter recreation in their home ranges. Wolverines have been documented to persist and reproduce in habitats with high levels of human use and disturbance, including developed alpine ski areas and areas with motorized snowmobile use (Heinemeyer, 2012; Heinemeyer & Squires, 2013). Heinemeyer and Squires (2014) stated, "Wolverines appear to tolerate winter recreation in their home ranges, including denning females. Based on our preliminary findings, potential wolverine habitats that have even high levels of winter recreation may support resident wolverines despite the potential human disturbance" (p. 4). This suggests that wolverines can survive and reproduce in areas that experience human use and disturbance; however, there is uncertainty as to whether there is a threshold for the amount of disturbance that wolverines (particularly reproductive females) will tolerate within their home range.

Heinemeyer and Squires (2014) indicated there may be increasing avoidance of winter recreation areas as the amount of an individual wolverine's home range affected by winter recreation increases. They also noted that the reproductive status of the females may affect their potential response to winter recreation, with reproductive females having higher movement rates when in a high recreation zone. In their 2015

annual report, Heinemeyer and Squires (2015) stated that the field data collection for the wolverine-winter recreation project was completed and they were focused on analyzing responses of wolverines to winter recreation (p. 12). The response of individual wolverines to human disturbance is still being analyzed.

In the Columbia Mountains of southern British Columbia, where winter recreation is widespread, both female and male wolverines are negatively associated with helicopters and backcountry skiing. As Krebs and others (2007) stated, "We expected predation risk to be an important factor during winter denning season when reproductive females must provision and protect developing neonates from predation (e.g., Burkholder 1962, Magoun and Copeland 1998, Persson et al. 2003). Our results support this hypothesis. Females were negatively associated with broad landscapes of winter range where wolves concentrated (Allison 1998, Kunkel and Pletscher 2001) and positively associated with rugged terrain where security habitat is presumably more abundant" (p. 2188). In three of the four female seasonal models and one male model, human use variables contributed to the most supported models.

On the Forest, there are approximately 1.7 million acres of modeled wolverine habitat (see Figure B-21), based upon the composite Inman/Copeland model (USFWS, 2013a, 2014b; Woods, Morey, & Mitchell, 2014). The majority of modeled habitat occurs in the Bob Marshall Wilderness complex in the South Fork and Middle Fork geographic areas, with lesser amounts in the Swan and Mission Mountain portions of the Swan Valley geographic area as well as the Whitefish Range portion of the North Fork and Salish Mountains geographic areas. On the Forest, about 59 percent of modeled year-round wolverine habitat (USFWS, 2013a, 2014b) is in designated wilderness, where motorized uses (including snowmobling, helicopter-assisted skiing or snowboarding, and trackster-assisted skiing or snowboarding) are not allowed. Nonmotorized uses on the Forest are not restricted, but because much of the wilderness area on the Forest is large and remote, it is also difficult to access for nonmotorized winter recreation.

Wilderness areas provide habitat where the risk of human disturbance to wolverines is very low during the time period when females have dependent young. In addition, about 25 percent of modeled wolverine habitat is in inventoried roadless areas, where road-building is not allowed and timber harvest is restricted. Outside wilderness and roadless areas, restrictions on motor vehicle and motorized over-snow vehicle use provide additional habitat for wolverines with a low risk of human disturbance during time periods when wolverines may be sensitive—particularly in the North Fork geographic area where use is restricted to specific routes in much of the area (table 40).

Climate Change

There is uncertainty on effects to wolverines from climate change that is associated with scale. Potential effects of future climate changes on persistent spring snow is uncertain or more variable based upon geographic location and atmospheric circulation patterns (such as the Pacific Decadal Oscillation). Stewart (2009) examined data for the western U.S. from 1949-2004 (page 88, figure 3). Stewart's summary of findings stated that decreasing snowpack, snow to precipitation ratios, earlier spring snowmelt runoff, and longer summer flows have been noted at low to mid-elevations. In contrast, for higher elevations (which stay well below freezing) in the western North American mountains, any warming effects have been compensated by precipitation increases, resulting in increased snowpack. At a region-wide scale, the preliminary Northern Rockies Adaptation Partnership risk assessment for the wolverine (NRAP, 2015) states that there is no evidence that wolverines in the Northern Rocky Mountains can persist in areas distant from extensive areas of spring snow, and thus their adaptive capacity appears to be low. The authors estimated that the magnitude of effects would be low in 2030 and moderate in 2050, with a high likelihood of effects across all time periods. Across the northern Rockies as a whole, losses of current levels of persistent spring snowpack are estimated to be around 30 percent by mid-century (NRAP, 2015). McKelvey and others (2011) stated: "although wolverine distribution is

closely tied to persistent spring snow cover (Copeland et al. 2010), we do not know how fine-scale changes in snow patterns within wolverine home range may affect population persistence." The USFWS concurred with this finding, stating, "an improved understanding of how microclimatic variation alters the habitat associations of wolverines at fine spatial scales is needed" (USFWS, 2014b, p. 47527).

According to the models used in an assessment by McKelvey and others (2011), northern Montana (including the Forest), the southern Bitterroot Mountains, and the Greater Yellowstone Ecosystem retain significant spring snow in the next 50 years, whereas central Idaho is projected to lose significant spring snow (McKelvey et al., 2011). There are variations in climate models, but models generally indicate earlier snowmelt in the northern Rockies in the future, a pattern that has been ongoing since at least the 1950s. Although wolverines are known to spend the majority of their time at high elevations, the degree to which earlier snowmelt may affect wolverines and the connectivity of meta-populations is also uncertain. Wolverines are a highly wide-ranging species, and recent research in Glacier National Park has demonstrated that habitat connectivity between Glacier National Park, the Forest, and Canada currently supports wolverine movement (Copeland & Yates, 2006).

In areas open to motorized over-snow vehicle use, the amount of use has increased over the last few decades because technical advancements in motorized over-snow vehicles are occurring and the human population in the Flathead Valley has grown. Backcountry skiing has also increased in popularity. Glacier National Park provides over 1 million acres (much of it at high elevations) that is closed to motorized over-snow vehicle use. In combination with wilderness areas on the Forest to the south, there are over 2 million acres of habitat available to wolverines where there is no motorized over-snow vehicle use allowed and where ungulates are present to provide sources of carrion. In addition, wolverine movement is not impeded by topography. Research in Glacier National Park has shown that they can rapidly ascend very steep terrain with deep snow, so it is likely that they can avoid people if they choose to.

Much of Whitefish Mountain Resort is in an area of persistent spring snow. Adjacent areas are modeled as maternal denning habitat, but it is unknown whether a wolverine would den there due to the high level of human disturbance. In the past decade, skiers riding the lift observed a wolverine as it fed on carrion. Blacktail Mountain Ski Area has a small amount of modeled maternal denning habitat, but because it is small and widely separated from other areas of wolverine habitat, it is unlikely to receive wolverine denning use.

Effects of the Framework Programmatic Action

Year-round wolverine habitat

For assessing effects to wolverine habitat, we used the composite model adopted as best available science by the USFWS for wolverine habitat across the United States (USFWS, 2013a, 2014b) (Figure B-21), which incorporated the work of two groups of scientists (Copeland et al., 2010; R. M. Inman et al., 2011). As described in the "affected environment" section, research results suggest wolverines are generally tolerant of recreation activities (Heinemeyer & Squires, 2014, p. 4). Thresholds for the amount of development or human recreation use that individual wolverines will tolerate in their home ranges are unknown but are being investigated. Plan components would support key ecosystem characteristics for wolverines because about 59 percent of modeled year-round wolverine habitat (USFWS, 2013a, 2014b) is in designated wilderness, where motorized and mechanized uses such as snowmobiling, helicopter-assisted skiing or snowboarding, and snow bikes are not allowed. Nonmotorized and non-mechanized uses on the Forest are not restricted. Because much of the wilderness area on the Forest is remote, it is difficult to access for nonmotorized and non-mechanized winter recreation.

Plan components support connectivity by: 1) designating management areas that form large contiguous blocks of habitat with low levels of human development to provide for potential range shifts of this species, 2) providing for ecological conditions that meet subsistence and movement needs in connectivity areas, 3) limiting mortality risk through management of motorized access, 4) working with adjacent landowners and other interested parties to improve connectivity and linkage opportunities across multiple jurisdictions (e.g., cooperative agreements, highway approaches/ crossings, and land consolidations, exchanges, acquisitions, easements). Some of the key plan components include:

- Guideline FW-GDL-IFS-13 specifies that "Within areas specifically identified as being important for wildlife connectivity across highways (see table 7) the Forest should cooperate with highway managers and other landowners to design approaches and crossings that contribute to wildlife and public safety.

- Desired condition FW-DC-LSU-01 specifies that land ownership adjustments, through purchase, donation, exchange, or other authority, improve national forest management by consolidating ownership, reducing wildlife-human conflicts, providing for wildlife habitat connectivity, improving public access to public lands, and retaining or acquiring key lands for wildlife and fish and within Wild and Scenic River corridors.

- Desired condition FW-DC-P&C-01 specifies that the Forest work towards an all-lands approach to management, cooperating with other land managers, for example, to mitigate threats or stressors, provide for wildlife and fish habitat connectivity, and provide social, economic and ecological conditions that contribute to mutual objectives.

- GA-HH-DC-03 specifies that the Coram connectivity area (see Figure B-10) provides habitat connectivity for a north-south movement corridor for wide-ranging species (e.g., grizzly bear, Canada lynx, wolverine) moving between the southern and northern watersheds on the Forest.

- GA-MF-DC-04 specifies that the Nyack, Essex, and Pinnacle connectivity areas (see Figure B-10) provide habitat connectivity for wide-ranging species (e.g., grizzly bear, Canada lynx, wolverine) moving north-south between Glacier National Park and the Bob Marshall Wilderness Complex and east-west in the Middle Fork watershed.

- GA-NF-DC-06 specifies that the Haskill Basin connectivity area (see Figure B-10) provides habitat connectivity for wide-ranging wildlife species (e.g., grizzly bear, Canada lynx, wolverine) moving north-south between the Swan Range and the Whitefish Range.

- GA-NF-DC-07 specifies that the North Fork and North Whitefish Range connectivity areas (see Figure B-10) provides habitat connectivity for wide-ranging wildlife species (e.g., grizzly bear, Canada lynx, wolverine) moving between Glacier National Park and the Whitefish Range.

- GA-SM-DC-04 specifies that in areas between the [grizzly bear] primary conservation area and the Salish demographic connectivity area, NFS lands are consolidated and conservation easements with willing landowners are supported in a manner that provides habitat connectivity and facilitates movement of wildlife. NFS lands in the Swift Creek-Stillwater connectivity area (see Figure B-10) provide habitat connectivity for wide-ranging wildlife species (e.g., grizzly bear, Canada lynx, elk) moving between the Whitefish and Salish Mountain Ranges.

Maternal denning habitat

For effects to maternal denning habitat, we used areas providing persistent spring snow in at least 5 years out of 7, based upon the model developed by Copeland and others (2010). These areas are also most

likely to retain snow as the climate changes. Modeled maternal denning habitat encompasses about 655,000 acres or 27 percent of all Forest lands. Table 40 displays the percentage of the Forest where motorized over-snow vehicle use would be suitable (see Figure B-19). With alternative B-modified, an additional 15% of modeled maternal denning habitat would be in recommended wilderness (MA1b) and this management area would not be suitable for motorized or mechanized use. Wilderness areas provide habitat where the risk of human disturbance to wolverines is very low during the time period when females have dependent young.

Table 1. Modeled maternal denning habitat by alternative with persistent spring snow (5, 6, or 7 years out of 7).

Over-snow use in modeled denning habitat with persistent snow 5, 6, or 7 years out of 7	Existing	Alternative B-modified
Acres where motorized over-snow vehicle use is suitable	74,048	71,547
Acres where motorized over-snow vehicle use is not suitable	580,644	583,145
% of total where motorized over-snow vehicle use is suitable	11%	11%

The proposed action includes the following guideline (FW-GDL-REC-04):

To limit the risk of cumulative impacts to female wolverines with dependent young, there should be no net increase in miles of designated motorized over-snow vehicle routes or areas where motorized over-snow vehicle use would be suitable, in modeled wolverine maternal denning habitat on NFS lands at a forestwide scale. Specific locations of routes or areas suitable for motorized over-snow vehicle use are shown in Figure B-44 in this BA.

Plan components for motorized over-snow vehicle use would support key ecosystem characteristics for wolverines because activities that have a risk of disturbing reproductive females with offspring would be suitable on no more than 11 percent of modeled wolverine maternal denning habitat (see Figure B-19 and table 40). The proposed action would change an area in lower Big Creek, including about 992 acres of modeled maternal denning habitat, to suitable for motorized over-snow use. The proposed action would change the boundaries of areas in Skyland Creek that are suitable for motorized over-snow use, resulting in a net increase of about 1,584 acres of modeled maternal denning habitat. About 4,886 acres of modeled maternal denning habitat across the forest would become unsuitable for motorized over-snow use, resulting in a small net decrease in the acreage where potential disturbance effects could occur. It is presently unknown how these changes would affect female wolverines with offspring because thresholds for levels of human disturbance in areas of denning habitat are unknown at this time, but this plan component would limit the risk of effects. Amendment 24 (USDA, 2006) to the existing forest plan designated specific routes and areas, as well as seasons, for motorized over-snow use as directed by §212.81 of the Travel Management Rule.

The proposed action also includes a guideline that would benefit the wolverine by limiting the risk of other types of human activities that may cause disturbance in modeled maternal denning habitat. FW-GDL-WL-04 states, “To limit or mitigate the risk of impacts to species that may be sensitive to helicopter disturbance, new projects or activity authorizations should include strategies or design features that protect key habitats during key time periods listed in table 41. This guideline does not apply to low-altitude helicopter flights or landings for emergency purposes, approved site maintenance, or other approved administrative activities.”

Table 2. Key habitats and key time periods for wolverine

Species	Key Habitat	Time period
Wolverine	Modeled wolverine maternal denning habitat identified in cooperation with U.S. Fish and Wildlife Service and the USFS Rocky Mountain Research Station	February 15 to May 15

Cumulative effects on the wolverine

Cumulative effects under the Endangered Species Act include state, tribal, local, or private actions that are reasonably certain to occur in the action area. Past actions have been included in the environmental baseline. Future site-specific Forest Service activities are subject to future section 7 consultation requirements and are not included in the cumulative effects analysis in this biological assessment.

The wolverine trapping harvest during the 30 years prior to 2007 was considered stable, with a statewide average of 10.5 wolverines taken annually during this time period (Giddings, 2009, pp. 35-39). Then, based on research findings by Squires and others (J. R. Squires et al., 2007), wolverine trapping quotas were adjusted downward for the two large ecosystems in the state; the Northern Continental Divide Wildlife Management Unit (WMU 1) and the Greater Yellowstone (WMU 3). Further analysis tied to the genetic make-up of the Montana wolverine population, the issue of maintaining population connectivity, and recognizing the core population areas of three major ecosystems (now including the central Idaho wilderness area) led to additional regulation changes in 2008. These adjustments included delineating four wildlife management units and reducing quotas to a statewide total of five animals, with a central Montana wildlife management unit quota of 0, to promote population connectivity among the three major ecosystems in the state where harvest is allowed (Giddings, 2009, pp. 35-39). In December 2012, a state district court judge in Helena granted a temporary restraining order that blocked the opening of Montana's 2012–13 wolverine trapping season, and it remained closed with a quota of "0" in 2013–14 and 2014–15. The future of wolverine trapping is unknown. The Forest is within wolverine management unit 1 (WMU 1) (northwest Montana), which had a quota of three wolverines (with a maximum of one female) in 2010 and has had a quota of 0 since then (MTFWP, 2015). Since trapping was suspended in 2011, there has been one wolverine trapped accidentally (T. Thier, MFWP, personal communication, 2016). Glacier National Park, encompassing about one million acres adjacent to the Forest, is closed to trapping. Any cumulative effects to the wolverine resulting from trapping and winter recreation access on all lands are highly uncertain at this time, but investigations are ongoing. Management on the Forest has supported wolverine populations in the past and is expected to continue to do so in the future.

Lands managed by the Confederated Salish and Kootenai Tribes include the Mission Mountains Tribal Wilderness Area and the South Fork Jocko Primitive Area. Cumulative adverse effects to the wolverine are not expected as a result of management actions on tribal lands.

Private lands

Private lands do not generally occur in modeled wolverine habitat on the Flathead National Forest. The human population in northwest Montana has grown at a relatively high rate during the past few decades, and growth is expected to continue. Increasing residential development along highways that cross wolverine habitat and demand for recreational opportunities can result in disturbance or habitat fragmentation,

With respect to connectivity and highways on the Forest, there is one high-elevation paved highway along the border between the Forest and Glacier National Park. Since 2011, there have been two wolverines killed by vehicles in MFWP Region 1 (T. Thier, MFWP, personal communication, 2016). Squires and others concluded that wolverine movements are unpredictable and are not well suited for planning

structural highway mitigation projects. They suggested that connectivity for wolverines may be facilitated by limiting permanent developments through conservation easements and land purchases (J. R. Squires et al., 2007). The Forest and Montana DNRC recently completed the Legacy land acquisition in the Swan Valley geographic area of the Forest. This acquisition and other conservation easements on private lands may benefit wolverines in the future by limiting the density of permanent human developments and facilitating movement between mountain ranges.

Wolverine determination of effects and rationale

The proposed action may affect and is not likely to jeopardize the wolverine.

Rationale for Determination

The wolverine is proposed for listing. Five factors are utilized to determine if a species should be listed under the Endangered Species Act (Federal Register at 7874):

A. the present or threatened destruction, modification, or curtailment of its habitat or range;
B. overutilization for commercial, recreational, scientific, or educational purposes;
C. disease or predation;
D. the inadequacy of existing regulatory mechanisms; and
E. other natural or man-made factors affecting its continued existence.

Factor A is the primary factor relevant to the proposed programmatic action. Under factor A, the USFWS recognized the following categories of impacts to wolverine habitat: (1) climate change, (2) habitat impacts due to human use and disturbance, (3) dispersed recreation activities, (4) infrastructure development, (5) transportation corridors, and (6) land management. Effects of climate change and human use and disturbance are described in the affected environment section. As detailed in previous sections, the suite of plan components in the revised forest plan limit potential impacts due to human use and disturbance, dispersed recreation activities, infrastructure development, and land management, considering anticipated future climates.

The proposed action plan components beneficial to grizzly bear and Canada lynx would also benefit the wolverine. Specific plan components for the wolverine would reduce the risk of impacts due to dispersed recreation activities on the Forest in light of a changing climate and uncertainty of effects.

Wolverine

Introduction

When the Forest's assessment was published (April 2014), the USFWS had recently published a proposed rule to list the North American wolverine as a threatened distinct population segment in the contiguous United States (USFWS, 2013a). However, on August 13, 2014, the USFWS withdrew its previous proposal (USFWS, 2014b). On April 14, 2016, the Court remanded the matter to the USFWS for further consideration consistent with order CV 14-246-M-DLC (consolidated with case nos.14-247-M-DLC and 14-250-M-DLC). The wolverine is now listed as a proposed threatened or endangered species for the Flathead National Forest, pending a status review by the USFWS (USFWS, 2016b).

Methodology and analysis process

Coarse-filter plan components addressed in section 3.7.4 provide for habitat diversity that benefits wolverines. The wolverine indicators, plan components, and alternatives were developed after considering key indicators addressed in other sections of the final EIS, key stressors, public comments, and issues identified during scoping. The biological basis for key ecosystem characteristics and impacts of human activities is described in more detail in the affected environment section below on wolverine. Key indicators for analysis specific to the wolverine are listed in the section below on the consequences of the alternatives.

For assessing effects to wolverine habitat as a whole, the Forest used the composite model adopted as best available science by the USFWS for wolverine habitat across the United States (USFWS, 2013a, 2013e, 2014b) (see figure B-21 in the biological assessment for the revised forest plan), which incorporates the work of two groups of scientists (Copeland et al., 2010; R. M. Inman et al., 2011). For assessing localized effects to maternal and natal denning habitat of wolverines, the Forest used a GIS layer of the model by Copeland and others (2010). Copeland and others defined snow persisting to mid-May and accumulating to depths greater than 5 feet as "persistent spring snow," stating that this factor appears to be a requirement for denning by reproductive females. Copeland and others modeled persistent spring snow for seven years from 2000-2006 (it varied from year to year). Their model displays the number of years out of seven that a GIS pixel was classified as snow (e.g., seven years out of seven, one year out of seven). For the Glacier National Park study site (adjacent to the Forest), 93 percent of wolverine telemetry locations were located in the spring snow coverage area. About 90 percent of the 62 known den sites in North America occurred in areas that had persistent spring snow for at least five years out of seven (Weaver, 2014). McKelvey and others studied all known wolverine dens in Norway and Sweden, finding that areas with persistent spring snow at least five years out of seven were preferred (McKelvey et al., 2011). Therefore, in order to analyze the effects to maternal and natal denning habitat of wolverines, the Forest considered areas providing persistent spring snow at least five years out of seven (on average). For simplicity, figures 1-18 to 1-21, the final EIS, and the analysis refer to this as "maternal denning habitat." In addition, areas with persistent spring snow at least five years out of seven are most likely to retain snow as the climate changes, whereas lower elevation areas that retain persistent spring snow only one year out of seven are more likely to lose snow in the future as the climate changes. These models are designed and updated by researchers.

Spatial and temporal analysis

The analysis area for indirect effects of the revised forest plan is the area encompassed by the geographic areas of the Forest. Because wolverines are wide-ranging, the cumulative effects analysis is discussed in the context of the northern Rocky Mountains, including areas of persistent spring snow habitat modeled by the USFWS that are adjacent to the Forest (see USFWS, 2013e).

Information sources and incomplete or unavailable information

The Forest completed a thorough review of scientific information and then used the best available scientific information to inform the planning process, develop plan components, and assess consequences of alternatives. The USFWS wolverine status review is not yet available and some research on the effects of winter recreation on the wolverine is ongoing, so complete results are not yet available.

Downscaled climate models are used to predict the effects of a changing climate (see figure 1-05). For this final EIS, the Forest used a compilation of climate change effects published for the Northern Region Adaptation Partnership (Halofsky et al., in press) that summarizes climate change projections by subregions. For more details, see section 3.1.1 and McKelvey and Buotte (in press); the latter provides a summary of climate effects to wildlife in the northern Rocky Mountains. Downscaled winter climate and precipitation models have a higher level of uncertainty than summer climate models (Joyce et al., in press). Future climate uncertainty and anticipated variability is associated with scale. Potential effects of future changes on persistent spring snow are uncertain or variable due to geographic location, atmospheric circulation patterns (such as the Pacific Decadal Oscillation), and elevation (see sections 3.1.1 and 3.7.4, subsection "High-elevation habitat associates" for more details). Similarly, future risks to the wolverine are uncertain, as discussed in the cumulative effects section.

Affected environment

Population, life history, and distribution

Wolverines are year-round residents across most of Alaska, British Columbia, and the northern portion of the other Canadian provinces. The southern portion of the species' range extends into high-elevation alpine portions of Washington, Idaho, Montana, Wyoming, California, and Colorado. Wolverines occur at low densities, range widely, inhabit remote and rugged landscapes away from human populations, and are difficult to detect, so conducting research on wolverines is challenging (IDFG, 2014). Wolverine populations in Montana were heavily trapped in the early 1900s and were near extinction by 1920. However, numbers increased in the western part of the state from 1950 to 1980 (Hornocker & Hash, 1981). State fish and wildlife agencies in four states, including Montana, have recently initiated a cooperative, coordinated wolverine monitoring project.

The Forest lies within the northern Rocky Mountains area assessed by the USFWS. Wolverine population growth and expansion has been documented in the North Cascades and northern Rocky Mountains (USFWS, 2013a). According to the USFWS (2013a), "Wolverine records from 1995 to 2005 indicate that wolverine populations currently exist in the northern Rocky Mountains and that the bulk of the current population occurs here. Within the area known to currently have wolverine populations, relatively few wolverines can coexist due to their naturally low population densities, even if all areas were occupied at or near carrying capacity. Given the natural limitations on wolverine population density, it is likely that historic wolverine population numbers were also low" (p. 7868).

The USFWS stated that the northern Rocky Mountains portion of the North American wolverine distinct population segment is thought to be the largest subpopulation and the most genetically resilient of the current subpopulations within the United States (USFWS, 2013a). Persistent spring snow cover is correlated with gene flow because this is where the wolverine's within-home-range movements and dispersal occurs year-round (Michael K. Schwartz et al., 2009). Wolverines are known to make long-distance movements that are not impeded by topography (Copeland & Yates, 2006; J. R. Squires, Copeland, Ulizio, Schwartz, & Ruggiero, 2007).

On the Forest, Hornocker and Hash conducted telemetry research on 24 individual wolverines over a five-year period within a study area making up about 1,300 square kilometers of the Flathead National Forest

(Hornocker & Hash, 1981). Their study area was primarily located in the South Fork of the Flathead River watershed and, secondarily, portions of the Sun, Swan, and Middle Fork of the Flathead River watersheds. About one half of the study area had timber harvest and a wide variety of types of recreation, and the other half was wilderness. Hornocker and Hash found wolverines at relatively high densities in the South Fork of the Flathead River watershed, and they concluded the population was stable (Hornocker & Hash, 1981).

Wolverines are distributed across the Forest in suitable habitats (USDA, n.d.). Current information for wolverines on the Forest is based on (1) reported trapping records; (2) non-invasive monitoring, including remote cameras and DNA analysis of hair or scat; and (3) observations/sightings of either the species or tracks recorded in Forest or State databases (USDA, n.d.). No recent research that would estimate population levels has been conducted for wolverine on the Forest. The Forest and other cooperators detected a minimum of 13 individual wolverines within Forest geographic areas (based upon genetic analysis of samples collected during non-invasive carnivore monitoring in areas accessible by snowmobile from 2012-2015) (Curry et al., 2016; Pilgrim & Schwartz, 2015; Ruby et al., 2016; Swanson, 2017; SWCC, 2014, 2015).

Wolverines are a wide-ranging species with populations that fluctuate in response to prey availability, juvenile dispersal, and mortality of adult females. Magoun and Copeland (1998) described two types of reproductive dens: natal dens where young are born and maternal dens where the mother may move the kits if conditions are no longer suitable at the natal den. Sites used for maternal dens are often close to the natal den and have a similar structure. Copeland and others found that dens were excavated in the snow and were on upper slopes in sparse timber beneath downed woody debris or rocks. Dens are typically used through late April or early May. Kits gather at rendezvous sites that are primarily in boulder, talus, and cliff areas (Copeland et al., 2010). Wolverine den sites may not occur in the same exact spot year after year, and specific maternal and/or natal den sites on the Forest are unknown.

Research on wolverines in Glacier National Park (adjacent to the Forest) has been conducted in the last decade or so (Copeland & Yates, 2006; J. R. Squires et al., 2007). Copeland and Yates found that wolverines were constantly on the move, with adult females having home ranges that averaged 55 square miles. Adult males ranged over an even larger area, including lands outside the park, with home ranges that averaged 193 square miles (Copeland & Yates, 2006). Home range boundaries are dynamic, as are population demographics. Prior to the Glacier National Park study, not much was known about the den sites of reproductive female wolverines in Montana because den sites of reproductive females are often in remote terrain that is very difficult to study. During the first three years of the study, data was collected for 19 wolverines, and information about reproductive dens was obtained for two adult females that raised four offspring (kits). Females used two to three different dens prior to the weaning of kits at six to seven months of age. Abandonment of natal and maternal dens may be a preemptive strategy that confers an advantage to females if prolonged use of the same den makes a den more evident to predators (USFWS, 2013a). Survival of young was low, even in the national park setting where trapping is not allowed and motorized disturbance does not occur in winter or spring.

The Forest is within wolverine management unit 1 (northwest Montana), which had a trapping quota of three wolverines (with a maximum of one female) in 2010 and has had a quota of 0 since then (MTFWP, 2017).

Habitat

Copeland stated that wolverine year-round habitat use takes place almost entirely within the area defined by deep persistent spring snow (Copeland et al., 2010). Copeland and others defined snow persisting to mid-May and accumulating to depths greater than 5 feet as persistent spring snow, stating that this factor

appears to be a requirement for denning by reproductive females. Year-round habitat is found at high elevations where rocky alpine habitats, glacial cirque basins, and avalanche chutes provide food sources such as marmots, voles, and carrion (Copeland et al., 2007; Hornocker & Hash, 1981; Robert M. Inman et al., 2007; Magoun & Copeland, 1998). Wolverines appear to rely on the cold and snow to cache carrion (Robert M. Inman, Magoun, Persson, & Mattisson, 2012). Wolverines also travel through the area where snow persists through mid-May when dispersing; they minimize travel through low-elevation habitat (McKelvey et al., 2011). A new study by Webb and others (2016) found that wolverines in the boreal forest region of northern Alberta were not as closely associated with persistent spring snow as wolverines in the Rocky Mountains and suggested that these two very different habitats should be separated for analysis purposes and for the study of climate change effects.

Wolverine habitat is also characterized primarily by low levels of human development (Copeland, 1996; Hornocker & Hash, 1981; Krebs, Lofroth, & Parfitt, 2007; USFWS, 2013a). This negative association with frequent human presence is sometimes interpreted as active avoidance of human disturbance, but it may simply reflect the wolverine's preference for cold, snowy, and high-elevation habitat that humans do not often develop.

The USFWS assessed the effects of a variety of human activities that can affect wolverines and their use of habitat. The USFWS stated:

> Few effects to wolverines from land management actions such as grazing, timber harvest, and prescribed fire have been documented. Wolverines in British Columbia used recently logged areas in the summer and moose winter ranges for foraging (Krebs et al., 2007, pp. 2189-2190). Males did not appear to be influenced strongly by the presence of roadless areas (Krebs et al., 2007, pp. 2189-2190). In Idaho, wolverines used recently burned areas despite the loss of canopy cover (Copeland, 1996). . . .
>
> Intensive management activities such as timber harvest and prescribed fire do occur in wolverine habitat; however, for the most part, wolverine habitat tends to be located at high elevations and in rugged topography that is unsuitable for intensive timber management. . . . Wolverines are not thought to be dependent on specific vegetation or habitat features that might be manipulated by land management activities, nor is there evidence to suggest that land management activities are a threat to the conservation of the species. (USFWS, 2013a, p. 7879)

The USFWS also stated that it is unlikely that wolverines avoid the type of low-use forest roads that generally are found in wolverine habitat. Based on the best available science, the USFWS concluded that wolverines do not avoid human development of the types that occur within suitable wolverine habitat and that there is no evidence that wolverine dispersal is affected by infrastructure development (USFWS, 2013a).

Krebs and others (2007) modeled male vs. female wolverine habitat selection in British Columbia, hypothesizing that food, predation risk, and human disturbance affected habitat selection. Krebs and others based their model on 39 adult wolverines (23 females and 16 males) that were located a total of 2,125 times within two study areas. These authors modeled selection in two time periods: winter and nonwinter. The winter season was defined as the period when there was persistent snow cover at treeline. Human use variables included in the models they tested included those associated with winter recreation activity, roads, and timber harvesting. Winter recreation data included estimates of snowmobile primary use sites, locations of runs for two helicopter skiing companies in the Columbia Mountains study area, and backcountry ski use centered on the Trans-Canada Highway corridor within and adjacent to Mount Revelstoke and Glacier National Parks. These authors stated that extensive timber harvesting had occurred within a large portion of the study area.

Krebs and others (2007) concluded that male wolverines were most closely associated with food availability in both summer and winter. Moose winter ranges, valley bottom forests, and avalanche terrain were positively associated with winter male wolverine use. Habitat use by male wolverines in winter was also negatively associated with helicopter skiing areas in the Columbia Mountains. The authors stated:

> Habitat associations of females were more complex; combinations of variables supporting food, predation risk, or human disturbance hypotheses were included in most supported models from both summer and winter in both study areas. Females were associated with alpine and avalanche environments where hoary marmot and Columbia ground squirrel prey are found in summer. Roaded and recently logged areas were negatively associated with female wolverines in summer. In the Columbia Mountains, where winter recreation was widespread, females were negatively associated with helicopter and backcountry skiing. Moose winter ranges within rugged landscapes were positively associated with females during winter. Our analysis suggests wolverines were negatively responding to human disturbance within occupied habitat. The population consequences of these functional habitat relationships will require additional focused research. Our spatially explicit models can be used to support conservation planning for resource extraction and tourism industries operating in landscapes occupied by wolverines. (abstract)

Recreational use in wolverine habitat: Some scientists have expressed concern about the effects of human activities on female wolverines with young kits during the mid-February to mid-May time period because food resources are scarce for foraging females. As the kits mature, the mother will leave them for longer periods of time to find food, but until the kits are at least 10 weeks old, they cannot travel with their mother. If a female needs to move kits to a new location, or to another den, she must carry them in her mouth. If the female needs to move the kits very far, the probability of kits dying increases. Reproductive females and kits are at risk of predation (Magoun & Copeland, 1998), and, according to Persson in 2005, females are most vulnerable to energetic pressures due to the high cost of lactation during this period (Krebs et al., 2007). The threshold for the amount of human activity that can occur before it affects male and female wolverine habitat selection is unknown, but the predominant activity in some portions of wolverine habitat during this time period is backcountry recreation.

Winter backcountry opportunities in the northern Rocky Mountains include snowshoeing, snowboarding, skiing, snowcat- or trackster-assisted skiing and snowboarding, snow bikes, and snowmobiling. Heinemeyer and Squires (2015) are investigating winter recreational use (primarily skiing, snowboarding, and snowmobiling) in wolverine habitat in central Idaho and the Yellowstone region of Idaho, Montana, and Wyoming. Heinemeyer and Squires stated that wolverines appear to tolerate many types of winter recreation in their home ranges. Wolverines have been documented to persist and reproduce in habitats with high levels of human use and disturbance, including developed alpine ski areas and areas with motorized snowmobile use (Heinemeyer, 2012; Heinemeyer & Squires, 2013). Heinemeyer and Squires (2014) stated, “Wolverines appear to tolerate winter recreation in their home ranges, including denning females. Based on our preliminary findings, potential wolverine habitats that have even high levels of winter recreation may support resident wolverines despite the potential human disturbance” (p. 4). This suggests that wolverines can survive and reproduce in areas that experience human use and disturbance; however, there is uncertainty with respect to the amount, type, and timing of human recreational use and its effects on female wolverines.

Heinemeyer and Squires (2014) indicated there may be increasing avoidance of winter recreation areas as the amount of an individual wolverine’s home range affected by winter recreation increases. They also noted that the reproductive status of the females may affect their potential response to winter recreation, with reproductive females having higher movement rates when in a high-use recreation zone. In their 2015 annual report, Heinemeyer and Squires (2015) stated that the field data collection for the wolverine

winter recreation project was completed and they were focused on analyzing the responses of wolverines to winter recreation (p. 12). The response of individual wolverines to human disturbance is still being analyzed.

The Flathead National Forest has approximately 1.7 million acres of modeled wolverine habitat (USFWS, 2013e), based upon the composite Inman/Copeland model (USFWS, 2013a, 2014b; Woods, Morey, & Mitchell, 2014). The majority of the modeled habitat occurs in the Bob Marshall Wilderness Complex in the South Fork and Middle Fork geographic areas, with lesser amounts in the Swan and Mission Mountain portions of the Swan Valley geographic area as well as the Whitefish Range portion of the North Fork and Salish Mountains geographic areas.

On the Forest, about 59 percent of modeled year-round wolverine habitat (USFWS, 2013a, 2014b) is in designated wilderness, where motorized uses (including snowmobiling, helicopter-assisted skiing or snowboarding, and trackster-assisted skiing or snowboarding) are not allowed. Nonmotorized uses such as backcountry skiing are not restricted, but because much of the wilderness area on the Forest is large and remote, it is also difficult to access for nonmotorized winter recreation. Wilderness areas provide habitat where the risk of human disturbance to wolverines is very low during the time period when females have dependent young. In addition, about 25 percent of modeled wolverine habitat is in inventoried roadless areas, where road building is not allowed and timber harvest is restricted. Glacier National Park, adjacent to the Forest, provides over 1 million acres that is closed to motorized over-snow vehicle use. In combination with wilderness areas on the Forest to the south, there are over 2 million acres of habitat available to wolverines where there is no motorized over-snow vehicle use allowed and where ungulates are present to provide sources of carrion. In addition, wolverine movement is not impeded by topography. Research in Glacier National Park has shown that wolverines can rapidly ascend very steep terrain through deep snow.

Some of the modeled wolverine habitat on the Forest has developed recreation and motorized accress. Much of Whitefish Mountain Resort is in an area of persistent spring snow, but it is unlikely that a wolverine would den there due to the high level of human activity. However, wolverines may feed there. In the past decade, skiers riding the lift observed a wolverine as it fed on carrion. Blacktail Mountain Ski Area has a small amount of modeled maternal denning habitat, but because it is small and widely separated from other areas of wolverine habitat, it is unlikely to receive wolverine denning use. In areas open to motorized over-snow vehicle use, the amount of use has likely increased over the last few decades due to technical advances in motorized over-snow vehicles and human population growth in the Flathead Valley. Backcountry skiing has also increased in popularity. Outside wilderness areas, restrictions on motor vehicle and motorized over-snow vehicle use provide habitat for wolverines with a low risk of human disturbance during time periods when wolverines may be sensitive—particularly in the North Fork geographic area, where use of motorized over-snow vehicles is restricted to specific routes in much of the area (table 98).

Changing climate in wolverine habitat: Across the northern Rockies as a whole, losses of current levels of persistent spring snowpack are estimated to be around 30 percent by mid-century (NRAP, 2015). McKelvey and others (2011) stated: “Although wolverine distribution is closely tied to persistent spring snow cover (Copeland et al. 2010), we do not know how fine-scale changes in snow patterns within wolverine home range may affect population persistence” (p. 2895). The USFWS concurred with this finding, stating that “an improved understanding of how microclimatic variation alters the habitat associations of wolverines at fine spatial scales is needed” (USFWS, 2014b, p. 47527). At a regionwide scale, the preliminary Northern Rockies Adaptation Partnership risk assessment for the wolverine (NRAP, 2015) states that there is no evidence that wolverines in the northern Rocky Mountains can persist in areas distant from extensive areas of spring snow, and thus their adaptive capacity appears to be low. The

authors estimated that the magnitude of effects would be low in 2030 and moderate in 2050, with a high likelihood of effects across all time periods.

According to the models used in an assessment by McKelvey and others (2011), northern Montana (including the Forest), the southern Bitterroot Mountains, and the Greater Yellowstone Ecosystem retain significant spring snow in the next 50 years, whereas central Idaho is projected to lose significant spring snow. There are variations in climate models, but models generally indicate earlier snowmelt in the northern Rockies in the future, a pattern that has been ongoing since at least the 1950s. Although wolverines are known to spend the majority of their time at high elevations, the degree to which earlier snowmelt may affect wolverines and the connectivity of metapopulations is also uncertain. Wolverines are a highly wide-ranging species, and recent research in Glacier National Park has demonstrated that habitat connectivity between Glacier National Park, the Forest, and Canada currently wolverine movement (Copeland & Yates, 2006).

*Key **stressors***

Land management: Some commenters expressed concern about winter recreation activities in persistent spring snow habitat on NFS lands. As discussed in the habitat section above, there is scientific uncertainty about the types of winter recreation activities and the amount of disturbance that may affect female wolverines with young kits (Heinemeyer & Squires, 2015; USFWS, 2013a; Woods et al., 2014). Winter motorized access can indirectly affect accessibility during the trapping season.

Trapping: MFWP has authority to set regulations for wolverine trapping.

Highways: Wolverine mortality from collisions with vehicles has occurred, but at low levels. Wolverines use habitats that are not particularly conducive to roads, so they do not usually come into contact with high-traffic-volume roads except in those areas where highways cross over mountain ranges, usually major passes. Wolverines killed on roads in valleys between mountain ranges are likely the result of dispersal attempts by wolverines, but these appear to be rare occurrences (USFWS, 2014b).

Changing climate: The 2013 ruling listing the North American wolverine as a proposed threatened or endangered species identified threats to the long-term persistence of the species. The primary threat was determined to be climate change (USFWS, 2013a).

Key indicators

In addition to the indicators and effects of alternatives on habitat described in section 3.7.4, subsections "High-elevation habitat associates" and "Forest ungulates," the following species-specific indicator applies to the wolverine:

Risk of human disturbance to female wolverines with young in areas of modeled wolverine maternal denning habitat

Environmental consequences

Effects common to all alternatives

As described in the affected environment section above, research results suggest that wolverines are generally tolerant of recreation activities (Heinemeyer & Squires, 2014, p. 4). The thresholds for the amount of development or human recreational use that individual wolverines will tolerate in their home ranges are unknown but are being investigated. Plan components would support key ecosystem characteristics for wolverines because about 59 percent of modeled year-round wolverine habitat (USFWS, 2013a, 2014b) is in designated wilderness, where motorized uses and mechanized transport

such as snowmobiling, helicopter-assisted skiing or snowboarding, and snow bikes are not allowed. Nonmotorized and non-mechanized transport on the Forest are not restricted. Because much of the designated wilderness area on the Forest is remote, it is difficult to access for nonmotorized and nonmechanized winter recreation.

Summary of modeled alternative consequences

The natural range of variation for persistent spring snow on the Forest is unknown. For effects on maternal denning habitat, the Forest used the model developed by Copeland and others (2010). Modeled maternal denning habitat encompasses about 655,000 acres or about 27 percent of all Forest lands. Table 98 displays the consequences of the alternatives resulting from the combined effects of management areas and suitability for motorized over-snow vehicle use (see figures 1-18 through 1-21).

Table 1. Modeled maternal denning habitat by alternative with persistent spring snow (at least five years out of seven)

Motorized over-snow vehicle use suitability in modeled denning habitat with persistent snow at least five years out of seven	Alternative A	Alternative B modified	Alternative C	Alternative D
Acres where motorized over-snow vehicle use is suitable	74,048	71,547	18,051	77,257
Acres where motorized over-snow vehicle use is not suitable	580,644	583, 145	636,641	577,435
percent of total where motorized over-snow vehicle use is suitable	11%	11%	3%	12%

As shown in table 98, alternative C would have the lowest percentage of modeled wolverine denning habitat where motorized over-snow vehicle use would be suitable, and alternative D would have a slightly higher percentage. Alternatives A and B modified both maintain the existing percentage but shift where it is located on the Forest (see figures 1-18 through 1-25). Alternative B would change an area in lower Big Creek to suitable, but the majority of the area added is not in modeled maternal denning habitat. The area in Sullivan Creek that would become unsuitable is in modeled maternal denning habitat, resulting in a slight net decrease in modeled maternal denning habitat that is suitable for motorized over-snow vehicle use. The thresholds for levels of human disturbance in habitats where female wolverines give birth to and raise dependent offspring are unknown at this time, but plan components for all alternatives would limit the risk. Motorized over-snow vehicle use would be suitable on no more than 12 percent of modeled maternal denning habitat under alternative D, 11 percent under alternatives A and B modified, and 3 percent under alternative C.

Alternative A

Amendment 24 (USDA, 2006) designated specific routes, areas, and seasons for motorized over-snow vehicle use per the Travel Management Rule (§ 212.81). New scientific information about the effects of human disturbance indicates that wolverines are generally tolerant of many types of human recreational use, as described in the affected environment section. Plan components related to motorized over-snow vehicle use would support key ecosystem characteristics for wolverines because activities that have a risk of disturbing reproductive females with offspring would be suitable on no more than 11 percent of modeled maternal denning habitat. Under this alternative, about 9 percent of modeled wolverine maternal denning habitat is in recommended wilderness (management area 1b) and would not be suitable for motorized use, so the risk of disturbance to female wolverines with dependent offspring would be low (see figure 1-01 and section 3.15 for more details). Under this alternative, areas suitable for motorized

over-snow vehicle use would not change the risk of disturbance to female wolverines with dependent offspring (see figure 1-19).

Alternative B modified

The effects displayed above in the wolverine section titled "Summary of Modeled Alternative Consequences" apply to alternative B modified. In addition, the action alternatives include guidelines FW-GDL-WL-04 and FW-GDL-REC-04, which limit the risk of cumulative impacts to female wolverines with dependent young by limiting or mitigating the risk of helicopter disturbance and motorized over-snow vehicle use.

The proposed action also includes a guideline that would benefit the wolverine by limiting the risk of other types of human activities that might cause disturbance in modeled maternal denning habitat. FW-GDL-WL-04 states, "To limit or mitigate the risk of impacts to species that may be sensitive to helicopter disturbance, new projects or activity authorizations should include strategies or design features that protect key habitats during key time periods listed in table 41. This guideline does not apply to low-altitude helicopter flights or landings for emergency purposes, approved site maintenance, or other approved administrative activities."

Table 2. Key habitats and key time periods for wolverine

Species	Key Habitat	Time period
Wolverine	Modeled wolverine maternal denning habitat identified in cooperation with U.S. Fish and Wildlife Service and the USFS Rocky Mountain Research Station	February 15 to May 15

FW-GDL-REC-04 states, "To limit the risk of cumulative impacts to female wolverines with dependent young, there should be no net increase in percentage of modeled wolverine maternal denning habitat where motorized over-snow vehicle use would be suitable on NFS lands at a forestwide scale. Specific locations of routes or areas suitable for motorized over-snow vehicle use are specified in figure B-11."

Under alternative B modified, about 15 percent of modeled wolverine maternal denning habitat is in recommended wilderness (management area 1b) (see figure 1-02), and it would not be suitable for motorized uses or mechanized transport (see section 3.15 for more details). Under this alternative, changes in areas suitable for motorized over-snow vehicle use would slightly decrease the risk of disturbance to female wolverines with dependent offspring when future site-specific decisions are implemented (see figure 1-19).

Taken together, programmatic plan components to reduce the risk of human disturbance and additional areas of management area 1b would benefit female wolverines with dependent offspring when future site-specific decisions are implemented.

Plan components support connectivity of wolverine habitat by (1) providing for ecological conditions that meet subsistence and movement needs in connectivity areas, (2) limiting mortality risk through management of motorized access (see section 3.7.5, subsection "Grizzly bear," for more details), and (3) working with adjacent landowners and other interested parties to improve connectivity and linkage opportunities across multiple jurisdictions (e.g., cooperative agreements, highway approaches and crossings, and land consolidations, exchanges, acquisitions, and easements). Some of the key plan components for connectivity are FW-GDL-IFS-12; GA-HH-DC-03, GA-MF-DC-04, GA-NF-DC-06 through 08, GA-SM-DC-03, and GA-SV-DC-09. For example, GA-HH-DC-03 states that the Coram connectivity area provides habitat connectivity for a north-south movement corridor for wide-ranging

species (e.g., grizzly bear, Canada lynx, wolverine) moving between the southern and northern watersheds on the Forest.

Alternative C

Many of the forestwide plan components and their consequences under alternative C are the same as under alternative B modified. The following section discusses key differences. This alternative has the largest amount of wolverine maternal denning habitat in recommended wilderness (management area 1b), about 31 percent, which would not be suitable for motorized uses or mechanized transport (see figure 1-03; also see section 3.15for more details). Under alternative C, three of the areas open to motorized over-snow vehicle use during the time period when female wolverines with offspring may be more sensitive to human disturbance would be virtually eliminated due to changes in suitability and management direction for recommended wilderness (management area 1b) in areas that are currently open (see figure 1-20). Taken together, additional areas of management area 1b and programmatic plan components to reduce the risk of human disturbance would benefit female wolverines with dependent offspring the most of all the alternatives when future site-specific decisions are implemented.

Alternative D

Many of the plan components under alternative D are the same as under alternative B modified. A key difference is that alternative D has no recommended wilderness (management area 1b) but has more acres in a variety of backcountry management areas (management area 5) (see figure 1-04 and section 3.15 for more details). Under this alternative, changes in areas suitable for motorized over-snow vehicle use would slightly increase the risk of disturbance to female wolverines with dependent offspring as future site-specific decisions are implemented (see figure 1-21).

Cumulative effects

Land management

The majority of wolverine habitat is located in higher-elevation areas that are largely designated wilderness, recommended wilderness and inventoried roadless areas, or lands that are relatively unavailable for development. Forest plan direction for other national forests in the northern Rocky Mountains (for activities such as timber harvest, livestock grazing, and motorized use of forest roads and trails) are not expected to negatively affect wolverines or their habitat. The USFWS concurred with the Northern Region determination that national forest management activities would not jeopardize the wolverine (USFWS, 2014e). Lands managed by the Confederated Salish and Kootenai Tribes include the Mission Mountains Tribal Wilderness Area and the South Fork Jocko Primitive Area. Cumulative adverse effects to the wolverine are not expected as a result of management actions on tribal lands. Private lands are not generally located in modeled wolverine habitat on the Flathead National Forest. Increasing residential development along highways that cross wolverine habitat may result in disturbance or habitat fragmentation. The Forest and Montana Department of Natural Resources and Conservation recently completed the Montana Legacy Project land acquisition in the Swan Valley geographic area of the Forest. This acquisition and other conservation easements on private lands may benefit wolverines in the future by limiting the density of permanent human developments and facilitating movement between mountain ranges. Squires and others suggested that connectivity for wolverines may be facilitated by limiting permanent developments through conservation easements and land purchases (J. R. Squires et al., 2007).

Highways

With respect to connectivity and highways on the Forest, there is one high-elevation paved highway (U.S. Highway 2) along the border between the Forest and Glacier National Park. Since 2011, two wolverines have been killed by vehicles in MFWP Region 1 (T. Thier, MFWP, personal communication, 2016).

Squires and others concluded that wolverine movements are unpredictable and are therefore not easy to incorporate in the planning of structural highway mitigation projects (J. R. Squires et al., 2007).

Trapping

In 2008, further analysis tied to the genetic makeup of the Montana wolverine population, the issue of maintaining population connectivity, and recognizing the core population areas of three major ecosystems led to additional regulation changes. These adjustments included delineating four wildlife management units and reducing quotas to a statewide total of five animals, to promote population connectivity among the three major ecosystems in the state where harvest is allowed (Giddings, 2009, pp. 35-39). In December 2012, a state district court judge in Helena granted a temporary restraining order that blocked the opening of Montana's 2012-2013 wolverine trapping season, and it remained closed with a quota of 0 in 2013–2014, 2014–2015, and 2015-2016. The future of wolverine trapping is unknown. The Forest is within wolverine management unit 1 (northwest Montana), which had a quota of three wolverines (with a maximum of one female) in 2010 and has had a quota of 0 since then (MTFWP, 2015a). Since trapping was suspended in 2011, there has been one wolverine trapped accidentally (T. Thier, MFWP, personal communication, 2016). Glacier National Park, encompassing about one million acres adjacent to the Forest, is closed to trapping. Access during the winter season (discussed under sections on affects of alternatives) may indirectly affect the area accessible for trapping. Any cumulative effects to the wolverine resulting from trapping and winter recreation access on all lands are not available at this time, but investigations by multiple states in the Rocky Mountains are ongoing.

Changing climate

The proposed alternatives would not have an effect on the extent of persistent spring snow. At a regionwide scale, the preliminary Northern Region Adaptation Partnership risk assessment for the wolverine (NRAP, 2015) states that there is no evidence that wolverines can persist in areas distant from extensive areas of spring snow, and thus their adaptive capacity appears to be low. The authors estimated that the magnitude of effects would be low in 2030 and moderate in 2050, with a high likelihood of effects across all time periods. Across the Northern Region as a whole, losses of current levels of persistent spring snowpack are estimated to be around 30 percent by mid-century (NRAP, 2015). McKelvey and others (2011) stated: "Although wolverine distribution is closely tied to persistent spring snow cover (Copeland et al. 2010), we do not know how fine-scale changes in snow patterns within wolverine home range may affect population persistence." The USFWS concurred with this finding, stating that "an improved understanding of how microclimatic variation alters the habitat associations of wolverines at fine spatial scales is needed" (USFWS, 2014b, p. 47527).

At the more localized scale of the northern Rockies, the models indicate that northern Montana (including the Forest), the southern Bitterroot Mountains, and the Greater Yellowstone Ecosystem retain significant spring snow in the next 50 years whereas central Idaho is projected to lose significant spring snow (McKelvey et al., 2011). There are variations in climate models, but models generally indicate earlier snowmelt in the northern Rockies in the future, a pattern that has been ongoing since at least the 1950s. Although wolverines are known to spend the majority of their time at high elevations, the degree to which earlier snowmelt may affect wolverines and the connectivity of metapopulations is uncertain. Wolverines are a highly wide-ranging species. Recent research in Glacier National Park has demonstrated that habitat connectivity between Glacier National Park, the Forest, and Canada currently provides for wolverine movement (Copeland & Yates, 2006). Diverse prey items are available for wolverines throughout the cumulative effects analysis area, so prey should continue to be available.

Some members of the public expressed a concern about the cumulative consequences of climate change combined with increases in recreational activities (see section 3.10 for more details). Glacier National

Park provides over 1 million acres that is closed to motorized over-snow vehicle use, and much of the Park provides wolverine habitat. In combination, Glacier National Park, wilderness areas on adjacent national forests and tribal lands, and designated wilderness areas on the Flathead National Forest provide over 2 million acres of habitat available to wolverines that is remote and difficult to access by any means during the time periods when wolverines may be sensitive to disturbance. As explained in the affected environment section, research in Glacier National Park has shown that wolverines can rapidly ascend very steep terrain through deep snow, so it is likely that they can avoid people if they choose to.

Preferred alternative determination for the North American wolverine

Key ecosystem characteristics for the wolverine include high elevations with persistent spring snow for travel and dispersal where rocky alpine habitats, glacial cirque basins, and avalanche chutes provide food sources such as marmots, voles, and carrion. Maternal and natal denning habitat with relatively low levels of human development are important, although the thresholds are unknown.

The northern Rocky Mountains portion of the North American wolverine distinct population segment is thought to be the largest subpopulation and the most genetically resilient of the current subpopulations (USFWS, 2013a). Alternative B modified, the preferred alternative, has plan components, including standards and guidelines, to maintain, improve, or restore ecological conditions within the plan area to contribute to maintaining a viable population of the species within its range (2012 planning rule, 36 CFR § 219.9). In their concurrence letter for the programmatic biological assessment on the North American wolverine for the USDA Forest Service Northern Region, the USFWS (2014e) concurred that potential projects routinely conducted on National Forest Service lands are not likely to jeopardize the wolverine. All action alternatives include monitoring items MON-WL-14 and 17, which address the wolverine and its habitat (see chapter 5 of the revised plan for more details). The Forest does not anticipate substantial changes to wolverine maternal or natal denning habitat over the anticipated life of the plan, but if conditions change in the future, or if research or monitoring indicates there is a need to address specific threats that are within Forest Service authority or capability to manage, the forest plan may be amended or revised in the future if necessary.

1.1.1 Wildlife habitat connectivity

Introduction

During the planning process, the distribution and connectivity of ecosystems and associated wildlife was examined at multiple scales, in multiple ways, using multiple models and analyses (see Kuennen, 2017b). The wealth of information on connectivity is abundant, but more information is needed to determine the most appropriate use of each publication, model, or data set (T. Graves, Chandler, Royle, Beier, & Kendall, 2014; McClure et al., 2016).

The 2012 planning rule defines connectivity as follows:

> Ecological conditions that exist at several spatial and temporal scales that provide landscape linkages that permit the exchange of flow, sediments, and nutrients; the daily and seasonal movements of animals within home ranges; the dispersal and genetic interchange between populations; and the long distance range shifts of species, such as in response to climate change. (36 CFR § 219.19).

Haber and Nelson (2015) stated that it is useful to think of connectivity as contributing to both the structure and function of ecosystems and landscapes. Structural connectivity is the physical relationship between patches of habitat or other ecological units; functional connectivity is the degree to which landscapes actually facilitate or impede the movement of organisms and processes of ecosystems (Ament, Callahan, McClure, Reuling, & Tabor, 2014).

Connectivity can take several forms, from linear corridors to stepping stones of suitable habitat and from managing for specific linkage areas to managing the landscape as a whole so that movement is facilitated without the need for a "corridor." As summarized by Haber and Nelson (2015), key terms related to connectivity and wildlife movements are

• **corridor.** A distinct component of the landscape that provides connectivity (such as a linear patch).

• **linkage area or zone**. Broader regions of connectivity important to maintain ecological processes and facilitate the movement of multiple species.

As summarized by Ament and others (2014):

• **permeability.** The degree to which landscapes are conducive to wildlife movement and sustain ecological processes.

Wildlife and natural ecosystem processes occur irrespective of political boundaries. The Flathead National Forest is contiguous with the Kootenai National Forest to the west, Canada to the north, the Helena-Lewis and Clark National Forest to the east, the Lolo National Forest and tribal lands of the Confederated Salish and Kootenai Tribes to the south, and Glacier National Park to the north and east. On the Flathead National Fortest, connectivity has been influenced by natural ecosystem processes as well as by human developments such as road construction, ski area development, timber harvest, utility corridors, and private land development.

As recommended in Haber and Nelson (2015), the Forest's planning process takes connectivity into account by:

- recognizing that sustainability depends in part on how the plan area influences and is influenced by the broader landscape (36 CFR § 219.8(a)(1)(ii) and (iii)) (see cumulative effects and landscape context sections throughout the Forest'd assessment (USDA, 2014b); sections 3.7.4 and 3.7.5 and chapter 6 of this final EIS);
- assessing conditions, trends, and sustainability in the context of the broader landscape (36 CFR § 219.5(a)(1)) (see the Forest's assessment; cumulative effects and landscape context sections throughout sections 3.7.4 and 3.7.5 and chapter 6 of this final EIS; and MFWP (2014));
- evaluating system drivers (e.g., climate change) and stressors (e.g., barriers to connectivity) (36 CFR § 219.6 (b)(3) (see sections 3.7.4 and 3.7.5 and appendices 2, 3, and 7; and USDA (2014b, pp. 48-87; 2016d));
- including plan components to coordinate with other land managers relevant to populations of at-risk species (36 CFR § 219.9(b)(2)(ii)) (see revised forest plan section "Partnerships and Coordination" and chapter 5);
- including plan components that address key characteristics for connectivity, composition, structure, and function (36 CFR § 219.8 (a)(1) (see revised forest plan sections "Aquatic Ecosystems," "Terrestrial Ecosystems and Vegetation" and "Wildlife"; sections 3.2, 3.3, 3.7.4, and 3.7.5 in this final EIS);
- modeling and assessing the natural range of variation for vegetation on the Forest (36 CFR § 219.19) (the Forest modeled the natural range of variation over the past 1,000 years and modeled the effects of the alternatives for 50 years into the future, considering potential future climate—see sections 3.3, 3.7.4, 3.7.5, and appendices 2 and 3 of this final EIS); and
- assessing the cumulative effects of the plans and land use policies of others (36 CFR § 219.4(b)) (see sections 3.2.12 and 3.3.11 in this final EIS; see the cumulative effects sections throughout 3.7.4 and 3.7.5 and also chapter 6).

The revised forest plan includes forestwide plan components that promote long-term ecological integrity, ecosystem diversity, and wildlife sustainability. These include plan components for and assessment of a variety of aspects of connectivity such as riparian management zones, human uses, minerals, grazing,

special uses, connectivity standards for Canada lynx, access standards and demographic connectivity for grizzly bears, management area allocations such as wilderness (management area 1a) or recommended wilderness (management area 1b), and the cumulative effects of activities on other land ownerships (Kuennen, 2017b). The natural range of variation analysis is the source for both current and historical conditions related to the evaluation of alternatives upon forested connectivity, which is one aspect of connectivity (see appendices 2 and 3). The Forest assessed how its management can contribute to connectivity by addressing permeability between Forest lands and adjacent lands. For landscape-scale connectivity, the Forest considered developments and other stressors within the plan area and permanent developments on private lands and major public highways. Impacts to connectivity can include those that affect the distribution, pattern, quality, and quantity of habitat as well as how human presence and disturbance influence an animal's ability to move through and use that habitat.

Connectivity models and analyses

Several connectivity models and analyses were considered in assessing connectivity (Kuennen, 2017b). A variety of models showed that the same or similar areas were often important for multiple species. The Forest reviewed connectivity models and conducted an analysis of key areas for connectivity, connectivity of cover, connectivity as affected by roads and highways, and other conditions that may affect habitat and the genetic and demographic connectivity of species. The Forest evaluated where it would be important to provide for habitat connectivity as a conservation strategy to promote population resiliency and adaptability in the face of climate change, considering ecosystems as well as specific species (see also appendices 2, 3, 4, 5, and 7).

Key stressors on connectivity

Key stressors include:

• Vegetation and fire management (e.g., timber harvest, fuels reduction, fire suppression) on NFS lands and other lands

• Access and human disturbance on NFS lands and other lands

• Private land development

• Changing climate

Key indicators for analysis

The effects of vegetation and fire management, access, private land development, and changing climate are discussed throughout sections 3.7.4 and 3.7.5, for key ecosystems as well as for specific species. The following section discusses the results of modeling for connectivity of forest cover.

Environmental consequences

Summary of modeled alternative consequences

Ecosystem Research Group modeled connectivity of forest cover within areas (called polygons) identified and defined by American Wildlands (see appendix 3 for more details).. These areas represent about 1.16 million acres, including NFS, State, and other lands. Additionally, changes in mean patch size were modeled to show how disturbances (fire, insects, disease, or human activities) might affect the size of those patches over time.

Recognizing that connectivity for some species is affected by a lack of or loss of habitat components that take a long period of time to restore (Haber & Nelson, 2015), connectivity across the Forest was modeled using the query design for marten because marten is a species that is more limited by the amount and

arrangement of mature tree cover. As a means of assessing long-term habitat connectivity and the benefits of permanent cover reserves, sample landscapes at years 2015 and 2065 were compared by acres of marten habitat, average patch size, and percent habitat occurring in 2015 against the modeled habitat that still remained fifty years in the future at 2065 (see appendix 3 for more details). Figure B-30 in the revised forest plan and figure 2 in appendix 3 display the geographic connectivity areas in the vicinity of the Forest and those selected for this analysis. These areas were selected because they span the valleys where lands managed by the Forest are intermingled with other landownership.

Within the American Wildlands areas used for analysis, NFS lands total about 782,000 acres (about 33 percent of the Forest). Mature forest is currently present on about 35 percent of the connectivity areas at present, and modeling indicates it would drop to about 28 percent in the fifth decade, based upon a "worst-case scenario" for the combined effects of wildfire and insects and disease. Levels of mature forest cover within the American Wildlands areas declines by about 75,000 acres out of about 400,000 acres by the end of decade 5 for all alternatives. The model predicts that alternatives A, B modified, C, and D provide approximately the same levels of habitat in all decades, indicating that vegetation management activities associated with each alternative play a minor role compared to natural disturbances (see appendix 3 for more details).

In addition, Ecosystem Research Group modeled the number of mature forest patches and the mean patch size within the American Wildlands areas used to assess connectivity of forest cover. Mean patch size for mature forest cover declines in decades 3 through 5, with a corresponding increase in the number of patches. Declines in patch size, accompanied by an increase in the number of patches, are presumed to have negative effects on some interior forest species (e.g., marten, fisher) because patches have more edge where these species may be more vulnerable to predation. Mature forest patch sizes in alternatives B modified, C, and D show little difference between alternatives by the end of the fifth decade. Alternative A shows slightly less of a decline in mature forest patch size, presumably because alternative A was modeled without prescribed burning to match the 1986 forest plan. Most of the area in the American Wildlands areas is in the wildland-urban interface (see figure 1-13). The wildland-urban interface is where vegetation management would be emphasized and where wildfires would be likely to be suppressed. Even if fires are suppressed, the model estimates that disease and insect infestations will increase with expected warmer, drier climates. Insects and disease within mixed-species forests tend to create numerous small patches.

Prescribed fire and mixed-severity fires also create a small-patch mosaic and are anticipated to be present in the warm-dry and warm-moist potential vegetation types. Larger, more severe stand-replacing fires could result in some very large, even-aged, early seral patches and reduce the size of mature forest patches, especially in the cool-moist and cold potential vegetation types. Modeling suggests that fire coverage and severity, as affected by slope, aspect, and fire suppression, often cumulatively result in a small-patch mosaic. Modeling over several decades generally predicts that disturbances tend to reoccur on previously disturbed acres, which adds additional complexity to existing patterns of forest cover. For instance, severe burns may be followed by reburns 15-25 years later, after forest debris accumulates on the forest floor. Moderate-severity burns are often followed by bark beetle attacks on weakened, surviving trees, which may add to the patchiness of forest patterns. These modeled results suggest that the current mix of patch sizes is likely due to a century-long absence of stand-replacing fire, which has allowed stands to reach large or very large size classes and high densities where the boundaries between them become relatively indiscernible.

Alternative A

Management direction provides for key ecosystem characteristics for wildlife connectivity. Management direction specific to connectivity is included in the lynx standards and guidelines ALL 01, ALL S1, ALL

G1, LINK 01, LINK S1, LINK G1, and LINK G2, the old-growth standards, and the riparian habitat conservation area standards.

Alternatives B modified, C, and D

Management direction incorporated throughout the action alternatives provides for key ecosystem characteristics for wildlife connectivity, as discussed in sections 3.7.4 and 3.7.5 and Kuennen (2017b).

Key plan components for alternative B modified are as follows:

- Infrastructure standard FW-STD-IFS-02 limits increases in motorized access, and guideline FW-GDL-IFS-12 specifies that within areas specifically identified as being important for wildlife connectivity across highways (see table 18 in revised forest plan), the Forest should cooperate with highway managers and other landowners to design approaches and crossings that contribute to wildlife and public safety.

- Desired condition FW-DC-TE&V-14 provides for connectivity of old-growth forests, and FW-DC-TE&V-19 specifies that forest patterns contribute to the connectivity of habitat for wildlife (e.g., Canada lynx, marten), movement within and between home ranges, and dispersal between populations. FW-STD-TE&V-01 and 03 and guidelines FW-GDL-TE&V-06 through 09 provide for connectivity of old growth, large live trees, snags, and downed woody material. Downed woody material, for example, contributes to habitat connectivity for amphibian and small mammal species.

- Wildlife guideline FW-GDL-WL DIV-06 provides for retention of cover so that connectivity of cover is not severed by vegetation management activities.

- Energy and minerals standards FW-STD-E&M-08 and 09 contribute to connectivity. For example, mineral development is not allowed in areas withdrawn from mineral entry.

- Desired condition FW-DC-LSU-01 specifies that land ownership adjustments, through purchase, donation, exchange, or other authority, improve national forest management by consolidating ownership, reducing wildlife-human conflicts, providing for wildlife habitat connectivity, improving public access to public lands, and retaining or acquiring key lands for wildlife and fish and lands within wild and scenic river corridors.

- Desired condition FW-DC-P&C-01 specifies that the Forest work towards an all-lands approach to management, in cooperation with other land managers, such as by mitigating threats or stressors, providing for wildlife and fish habitat connectivity, and providing social, economic, and ecological conditions that contribute to mutual objectives.

- Several geographic area plan components provide for connectivity, incorporating areas where connectivity across highways is emphasized in several models: GA-HH-DC-03, GA-MF-DC-04, GA-NF-DC-06 and 07, GA-SM-DC-03, and GA-SV-DC-09, GA-MF-OBJ-01, GA-NF-OBJ-03, and GA-SM-OBJ-04.

- Several plan components provide for riparian connectivity (FW-DC-WTR-02 and FW-DC-RMZ-06; FW-STD-RMZ-01, 05, and 06; FW-GDL-RMZ-08 through 15; FW-SUIT-RMZ-01). For example, FW-RMZ-GDL-09 states that if new openings are created in riparian management zones through even-aged regeneration harvest or fuels reduction activities, the created opening's distance to cover (see glossary) should not exceed 350 feet to provide wildlife habitat structural diversity, connectivity, and cover. This guideline is consistent with findings by Squires and others

(2013) regarding lynx avoidance of areas more than 364 feet to cover and so would benefit lynx as well as meeting distances to cover for marten.

- Management area suitability also contributes to connectivity. For example, management areas 1a, 1b, 2a, 2b, 4a, 5a, and 5c are not suitable for permanent road construction, wheeled motor vehicles, or timber production (see revised forest plan table 34).

For key differences between alternatives B modified, C, and D see the sections on individual species.

Cumulative effects

In the southern end of the Salish Mountains and Swan Valley geographic areas, many sections of forest land (a section is one square mile of land, which is 640 acres) that were managed by a private timber company were treated with regeneration harvest during the last few decades, resulting in a high density of roads in those sections and a "checkerboard" pattern of cover and non-cover, reducing connectivity. As discussed in detail in section 3.7.5, subsection "Grizzly bear," the Forest has now acquired thousands of acres of these lands in the Swan Valley through the Montana Legacy Project, so connecitivity is anticipated to improve in the future.

In the cool-moist and cold potential vegetation types of the North Fork geographic area, NFS lands as well as adjacent lands in Glacier National Park were regenerated by very large wildfires, also reducing connectivity for species associated with forest cover but in this case in a pattern of much larger openings. Vegetation modeling has shown that these effects will persist for the next one to three decades but that regrowth of cover due to forest succession would then occur and forested connectivity would increase, provided there are not new large stand-replacing wildfires.

The connectivity areas (identified in appendix 3, figure 2) include all land ownerships, and the Forest is not able to predict how, when, or where these lands may be affected by vegetation management, road access, or development. However, even if vegetation management activities on all lands are planned to maintain, restore, or improve connectivity, it is not possible to predict exactly where or when wildfires, insect infestations, or disease would occur, or if forest succession (which creates cover for connectivity) would outpace loss of cover due to these factors. For these reasons, connectivity would need to be assessed at the project level at a particular point in time.

The revised plan includes numerous plan components for wildlife connectivity, but as monitoring of forest conditions in recent decades has shown, extensive stand-replacing wildfires, insect infestations, and disease can reduce cover for connectivity across large areas encompassing all lands (USDA, 2014b). Based upon the warmer and drier summer climate predicted by most climate models, large stand-replacing wildfires are likely to continue to occur in the future and can be expected to affect connectivity of forest cover between NFS lands and surrounding lands.

Forestwide desired condition FW-DC-P&C-01 places emphasis on the Forest cooperating with other land managers, including efforts to mitigate threats or stressors, provide for wildlife and fish habitat connectivity, and to promote ecological conditions that contribute to mutual objectives. Where there are willing landowners, the revised forest plan also emphasizes future connectivity through desired condition FW-DC-LSU-01, which states that land ownership adjustments, through purchase, donation, exchange, or other authority, improve national forest management by consolidating ownership, reducing wildlife-human conflicts, providing for wildlife habitat connectivity, improving public access to public lands, and retaining or acquiring key lands for wildlife and fish and within wild and scenic river corridors. This would reduce the risk that private lands in key connectivity areas would be commercially developed or subdivided for residences in the future, which would permanently reduce connectivity. The Forest's desired conditions complement those of governments and agencies (such as MFWP, Missoula County,

and the City of Whitefish), as well as those of non-government organizations and businesses (such as the Flathead Land Trust, The Nature Conservancy, and F. H. Stoltze Land & Lumber Company), that are working together to maintain connectivity in key areas.

Several scientists identified strategies and key locations for highway crossings, eight of which are within Flathead National Forest geographic areas. Because the Forest does not have authority over highways but does manage some lands adjacent to highways, guideline FW-GDL-IFS-12 states that the Forest should cooperate with highway managers and other landowners to design approaches and crossings that contribute to wildlife and public safety within areas specifically identified as being important for wildlife connectivity across highways. These areas are identified in a table under the guideline and include portions of the following highways: U.S. Highway 2, U.S. Highway 93, Montana Highway 83, and Montana Highway 486.

In addition to forestwide and geographic area desired conditions, standards, guidelines, and suitability, the mix of management area allocations for the revised forest plan provides for long-distance range shifts of species by providing large areas of habitat with relatively low levels of human development and disturbance (such as management areas 1a, 1b, and 5) with linkage to tribal wilderness areas, Glacier National Park, and north into Canada.

In summary, plan components for the Forest, in the context of all lands of the larger landscape, contribute to the ecological conditions of habitats that provide connectivity for animals. Plan components limit road access, help to provide cover for connectivity in a vast network of riparian areas and other key areas of the Forest where present, and promote cooperation with other agencies and landowners on activities such as highway crossings and conservation easements that benefit numerous species. Although the Forest Service does not have authority over all the stressors that affect connectivity, NFS lands would help to promote the connectivity of habitats with tribal lands of the Confederated Salish and Kootenai Tribes, Glacier National Park, Canada, and adjacent national forests.

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From: Grizzle, Betty
To: Kuennen, Reed -FS
Subject: Re: Wolverine info - Flathead NF
Date: Friday, September 8, 2017 4:17:49 PM
Attachments: image002.png
image003.png

Yes, that should work (since documents are available online).
Thanks!

On Fri, Sep 8, 2017 at 3:11 PM, Kuennen, Reed -FS <rkuennen@fs.fed.us> wrote:

> Can you reference it like this, or something similar?
>
> USDA Forest Service. 2017. Flathead National Forest Revised Forest Plan, Environmental Impact Statement, and Biological Assessment
>
> available at https://www.fs.usda.gov/detailfull/flathead/home/?cid=stelprdb5422786&width=full
>
> These documents are available in draft form now, but we anticipate they will be posted on this website in final form by the end of October
>
> **From:** Grizzle, Betty [mailto:betty_grizzle@fws.gov]
> **Sent:** Friday, September 08, 2017 12:45 PM
> **To:** Kuennen, Reed -FS <rkuennen@fs.fed.us>
> **Subject:** Re: Wolverine info - Flathead NF
>
> Likely toward the middle of October, but we don't have a firm date. This will be a specie status assessment, not a proposed/final rule (or another withdrawal). That will come early next year.
>
> On Fri, Sep 8, 2017 at 11:28 AM, Kuennen, Reed -FS <rkuennen@fs.fed.us> wrote:
>
> > Will you be publishing before the end of October or after do you think?
> >
> > **From:** Grizzle, Betty [mailto:betty_grizzle@fws.gov]

Sent: Friday, September 08, 2017 9:58 AM
To: Kuennen, Reed -FS <rkuennen@fs.fed.us>
Subject: Re: Wolverine info - Flathead NF

Thank you, Reed, for sending this information.

I have another document to get through today, so I may not get to this until Monday. One quick question - How should I cite these (i.e., USFS Draft EIS 2017; USFS Final BA)?

On Thu, Sep 7, 2017 at 4:25 PM, Kuennen, Reed -FS <rkuennen@fs.fed.us> wrote:

> Hi Betty. Attached is the final draft of the wolverine section of our revised forest plan EIS and the wolverine section of the BA we submitted to the USFWS, as requested for the species status review you are compiling. I have also included the section providing a summary of plan components for connectivity, since some of these plan components are referenced in the wolverine section. Our references are linked from the text to the endnote references section, so I have also included an excerpt of wildlife references.
>
> Our preferred alternative is B modified. Please feed to call me if you have questions or anything you would like to discuss. If there is information I need to correct or update, including our science citations, please let me know.
>
> I can provide you with figures cited if you need them (they are still highlighted in yellow in the attached text since we are now in the process of producing final maps and figure numbers).
>
> **Thanks!**

M. Reed Kuennen
Wildlife Biologist
Forest Service

Flathead National Forest
p: 406-758-5256
c: 406-862-6716
f: 406-758-5367
rkuennen@fs.fed.us
650 Wolfpack Way
Kalispell, MT 59937
www.fs.fed.us

Caring for the land and serving people

From: Grizzle, Betty [mailto:betty_grizzle@fws.gov]
Sent: Thursday, September 07, 2017 4:31 PM
To: Kuennen, Reed -FS <rkuennen@fs.fed.us>
Subject: Wolverine info - Flathead NF

Hi Reed - Sorry I missed your phone call. Yes, if you have an updated section that you can send, that would be very helpful.

I will be in the office tomorrow (7:15 am PDT) so I may call you if I have other questions.

Thanks for your help in collecting this information

Betty

--

Betty J. Grizzle, D.Env.

Fish and Wildlife Biologist

U.S. Fish and Wildlife Service

Carlsbad Fish and Wildlife Office

2177 Salk Ave, Suite 250

Carlsbad, CA 92008

760-431-9440, ext. 215

760-431-5901 fax

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Betty J. Grizzle, D.Env.

Fish and Wildlife Biologist

U.S. Fish and Wildlife Service

Carlsbad Fish and Wildlife Office

2177 Salk Ave, Suite 250

Carlsbad, CA 92008

760-431-9440, ext. 215

760-431-5901 fax

--

Betty J. Grizzle, D.Env.

Fish and Wildlife Biologist

U.S. Fish and Wildlife Service

Carlsbad Fish and Wildlife Office

> 2177 Salk Ave, Suite 250
>
> Carlsbad, CA 92008
>
> 760-431-9440, ext. 215
>
> 760-431-5901 fax

--

Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

From:	Shoemaker, Justin
To:	Sarah Fierce
Subject:	Fwd: AMEC -Request for Proposal, Reference Number 0092717001 for PEER Review of the Draft Species Status Assessment Report for the North American Wolverine
Date:	Tuesday, October 17, 2017 12:00:03 PM
Attachments:	20170921_Wolverine peer review Statement of Work_Draft Final.docx Score Shee Wolverine .doc AmecFW Cover Letter - USFWS Wolverine SSA_10-16-2017 FINAL.pdf AmecFW Proposal - USFWS Wolverine SSA_10-16-2017 FINAL.pdf Compiled_COIs signed.pdf (b)(3)(b)(3)(b)(3)(b)(3)(b)(3)(b)(3)

Sarah,

Here's the wolverine peer review stuff. Let me know if you have questions. We'd like to get the scoring done in a day or so.

Justin Shoemaker
Classification and Recovery Biologist
U.S. Fish and Wildlife Service, Region 6
Phone: 309-757-5800 x214
Email: justin_shoemaker@fws.gov

---------- Forwarded message ----------
From: **Bush, Jodi** <jodi_bush@fws.gov>
Date: Tue, Oct 17, 2017 at 12:00 PM
Subject: Fwd: AMEC -Request for Proposal, Reference Number 0092717001 for PEER Review of the Draft Species Status Assessment Report for the North American Wolverine
To: Justin Shoemaker <justin_shoemaker@fws.gov>

Can you share with Sarah. I will work on this now. The sooner we can a these back to Steve - the sooner we can award the contract and send out the Report. JB

Jodi L. Bush
Office Supervisor
Montana State Ecological Services Office
585 Shepard Way, Suite 1
Helena, MT 59601
(406) 449-5225, ext.205

---------- Forwarded message ----------
From: **Steve Gess** <steve_gess@fws.gov>
Date: Tue, Oct 17, 2017 at 10:47 AM
Subject: RE: AMEC -Request for Proposal, Reference Number 0092717001 for PEER Review of the Draft Species Status Assessment Report for the North American Wolverine
To: Jodi Bush <jodi_bush@fws.gov>
Cc: Justin Shoemaker <justin_shoemaker@fws.gov>

Jodi and Justin, Here are the two proposals—please use the attached score

sheet to score the qualifications and approach/timeline for each proposal—I don't think we will need a third person unless you have someone lined up--

The ratings are included with the score sheets—(1-10 with definitions) and here is an example of how it works: you feel offeror #1 is a 9 on their Qualifications and a 8 on their approach—the multiplier for Qualifications is 4.0 so you score then multiply it by 4.0 and their score is 36 , the multiplier for Approach and time is 2.0 you multiply the 8 you gave them by 2 and their score for that area is 16 . I will score the cost based on the percentage difference. But I can tell you we have one at $27,000 + or – and the other is in the $40's , But I need to go through the reviews in case the low price is not technically acceptable.

If you have any questions let me know—otherwise I would like to get your review scores by Thursday mid morning or sooner..Thanks

From: Bush, Jodi [mailto:jodi_bush@fws.gov]
Sent: Tuesday, October 17, 2017 8:12 AM
To: Steve Gess
Cc: Justin Shoemaker
Subject: Re: AMEC -Request for Proposal, Reference Number 0092717001 for PEER Review of the Draft Species Status Assessment Report for the North American Wolverine

Thanks Steve. I have my AO working with the RO on getting the money to contracting asap. We appreciate the extenuating circumstances in this instance only. And understand that this is not normal procedures.

We await the proposals. Thanks. JB

Jodi L. Bush

Office Supervisor

Montana State Ecological Services Office

585 Shepard Way, Suite 1

Helena, MT 59601

(406) 449-5225, ext.205

On Tue, Oct 17, 2017 at 7:18 AM, Steve Gess <steve_gess@fws.gov> wrote:

Jodi, I received two proposals yesterday- AMEC and Atkins—I was looking in the system and I still do not see a Funded requisition or a Government estimate from anyone on this requirement. Just so you know for future information, since I most likely will not be your Contracting Officer on these requirements (someone else in my office most likely will be) . Technically its illegal for us to request and receive proposals without funds. So the normal package you send in to get proposals must include an estimate, SOW, and a funded requisition. I know you asked me to get this started at fiscal yearend with the understanding someone would send me a requisition. But I don't want you to think this is the normal practice.. I bend the rules sometimes and that might not be the case with the next Contracting officer..

I will send you the technical proposals in the next hour or so—you will be required to review and score them and send me back your scores and review comments—I would like to have 3 reviewers review the technical proposals—I will prepare the score sheets for you to use..

From: Bush, Jodi [mailto:jodi_bush@fws.gov]
Sent: Monday, October 16, 2017 11:12 AM
To: Steve Gess
Cc: Justin Shoemaker
Subject: Re: AMEC -Request for Proposal, Reference Number 0092717001 for PEER Review of the Draft Species Status Assessment Report for the North American Wolverine

Hi Steve. I know the wolverine proposals are due today (October 16). I assume we give them to the end of the day to respond but wondering if you have heard anything yet? Thanks .JB

Jodi L. Bush

Office Supervisor

Montana State Ecological Services Office

585 Shepard Way, Suite 1

Helena, MT 59601

(406) 449-5225, ext.205

On Wed, Sep 27, 2017 at 1:33 PM, Bush, Jodi <jodi_bush@fws.gov> wrote:

Awesome Steve. Thank you! JB

Jodi L. Bush

Office Supervisor

Montana State Ecological Services Office

585 Shepard Way, Suite 1

Helena, MT 59601

(406) 449-5225, ext.205

On Wed, Sep 27, 2017 at 1:28 PM, Steve Gess <steve_gess@fws.gov> wrote:

Dawn, Region 6 US FWS received permission to use the new Scientific Studies BPA,AMEC was awarded recently. As a result I am requesting a formal proposal to conduct a PEER review on the subject Daft Specifies status assessment for the North American Wolverine. The RFP and Statement of work are attached. Proposals are due October 16, 2017.This will be a competitive process.

Please let me know if you have any questions.

Steven C. Gess, CPPO

Contracting Officer

US Fish & Wildlife Service

Region 6 Lakewood CO.

303-236-4334

Steve_gess@fws.gov

Statement of Work
Peer Review of the Draft Species Status Assessment Report for the North American Wolverine

Date: September 21, 2017

1. Introduction/Background

The Service has drafted a Species Status Assessment (SSA) report to inform an evaluation of the status of the North American wolverine (*Gulo gulo luscus*) under the Endangered Species Act of 1973, as amended (Act). The SSA report is a comprehensive evaluation of the biological status of the North American wolverine and its viability as a species. The SSA report considers the ecological needs as well as current and forecasted future conditions for the species. We are seeking peer review on the SSA report.

In compliance with a Court order that remanded our previous withdrawal of a proposed rule to list a Distinct Population Segment of the North American wolverine (79 FR 47522; August 13, 2014), the Service will prepare either a revised proposed rule to list as a threatened or endangered species under the Act, or a revised withdrawal of the previous proposed rule (78 FR 7864; February 4, 2013). The SSA report will be used to inform a decision (to be published in the *Federal Register*) to classify the North American wolverine as threatened, endangered or "not warranted" under the Act.

The wolverine is the largest terrestrial member of the family Mustelidae. In North America, wolverines occur within a wide variety of habitats, primarily boreal forests, tundra, and western mountains throughout Alaska and Canada; however, the southern portion of the range extends into the contiguous United States. Currently, wolverines are found in the North Cascades in Washington and the Northern Rocky Mountains in Idaho, Montana, and, parts of Washington and Oregon, and Wyoming. Individual wolverines have recently dispersed into their historical range in the Sierra Nevada Mountains of California and the Southern Rocky Mountains of Colorado, but have not established breeding populations in these areas.

2. Description of Review

As part of the Service's peer review policy we are requesting peer review of the draft Species Status Assessment report. The purpose of the peer review is to help us ensure that we are using the best scientific and commercial information in the SSA report. Thus, we are looking for independent scientific perspectives on the draft SSA report. Peer Reviewers should be advised that they are not to provide advice on policy.

3. Methods, Protocols and/or Scientific Standards

1. Each reviewer must have a Ph.D. or a Master's with significant experience in Wildlife Ecology, Ecology, or Wildlife Management; and

2. In combination, the expertise of the qualified reviewers shall include the following;

however, each individual is not required to meet all qualifications:

a. Experience or expertise with carnivore management, especially wolverines;

b. Expert knowledge of wildlife biology, wildlife management, demographic management of mammals (especially mesocarnivores), genetics, population modeling and/or scientific literature on wolverines or other mustelids;

c. Expert knowledge of the effects of climate change and climate change modeling, specifically in the Mountain West area of the United States, which includes the northern Rocky Mountains, the North Cascades, or the southern Rocky Mountains;

d. Expert knowledge of genetics of metapopulations;

e. Experience as a peer reviewer for scientific publications;

f. Knowledge of wolverine management in Canada, Alaska, and/or Europe.

The Contractor shall ensure the peer review process complies with the Service's July 1, 1994 peer review policy (59 FR 34270), the Service's August 22, 2016 Director's Memo on the Peer Review Process, and the Office of Management and Budget's December 16, 2004 Final Information Quality Bulletin for Peer Review. For example, potential conflicts of interest should be avoided, if possible and disclosed if not possible. Potential conflicts of interest would likely include: employment or affiliation with the Service, the States of California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, or Wyoming, or the Canadian Federal government; and peer reviewers, who have been or are directly or indirectly employed by any organization that has either litigated the federal government concerning wolverines or taken a position on one side or the other about the status of the North American wolverine in the contiguous United States. In addition, individuals who served as peer reviewers for previous proposed rules or who were participants in the April 2-3, 2014 facilitated wolverine workshop held by the Service should be disqualified from this peer review process. Finally, the reviewers should have no financial or other conflicts of interest with the outcome or implications of the report. The contractor will be responsible for selecting reviewers and obtaining the individual written peer reviews from 3-5 well-qualified reviewers.

Peer Reviewers will provide individual, written responses. Peer Reviewers will be advised that their reviews, including their names and affiliations, will (1) be included in our administrative record, and (2) will be made available to the public. We will summarize and respond to the issues raised by the peer reviewers in the administrative record and address these concerns in the SSA report, as appropriate.

The Service will have an opportunity to seek clarification on any review comments through the contractor (Task 003.1), for a period of 15 days, starting immediately after the Service receives the reviews from the contractor. Peer reviewers will be advised that they are not to provide advice on policy. Rather, they should focus their review on identifying and characterizing scientific uncertainties. Peer reviewers will be asked to answer questions pertaining to the logic of our assumptions, arguments, and conclusions and to provide any other relevant comments,

criticisms, or thoughts. Collectively, the review should cover, but not be limited to, the topics listed below. Reviewers should comment on areas within their expertise, and may choose to abstain from other areas including restricting your technical comments to your area of expertise, but feel free to render opinions or raise questions about larger scientific issues that may be relevant. To the extent possible, justify your comments with supporting evidence just as you would do when presenting your own scientific work. Please do not refrain from offering relevant opinions, but also label them as such. Test your comments for fairness, objectivity and tone of delivery by asking yourself if you would be comfortable presenting your comments, face-to-face, to the author and a panel of your peers.

Peer reviewers will be asked to complete and sign a Conflict of Interest form (see Paragraph 8).

Available Data

(1) Please identify any oversights or omissions of data or information, and their relevance to the assessment. Are there other sources of information or studies that were not included that are relevant to assessing current and future threats to this species and not repetitive of other information or studies already included? What are they and how are they relevant?

(2) Provide advice on the overall strengths and limitations of the scientific data used in the document. Is the information presented in the SSA report explicit about assumptions and limitations of, and concerns regarding, the data, and are these appropriately qualified or explained? Are there concerns that the Service did not identify, and if so, how relevant are these concerns to the assessment of the North American wolverine? Are there any inconsistencies in how the data are presented or assessed?

Analysis of Available Data

(3) Have the assumptions and methods used in the SSA report been clearly and logically stated in light of the best available information? If not, please identify the specific assumptions and methods that are unclear or illogical.

(4) Are there demonstrable errors of fact or interpretation? Have the authors of the SSA report provided reasonable and scientifically sound interpretations and syntheses from the scientific information presented in the report? Are there instances in the SSA report where a different but equally reasonable and sound interpretation might be reached that differs from that provided by the Service? If any instances are found where this is the case, please provide the specifics regarding those particular concerns.

(5) Provide feedback on the inclusion and portrayal of uncertainty in the SSA report. Have the scientific uncertainties presented and the analyses conducted been clearly identified and has the degree of uncertainty been appropriately characterized? If not, please identify any specific concerns.

(6) Does the SSA report adequately consider what the species needs to maintain viability in terms of resiliency, redundancy, and representation?

In accordance with the agreement terms and Performance Work Statement, the contractor(s) is (are) reminded of the requirements to protect information and that the services provided shall consist of unbiased assessments through proper management and enforcement of scientific integrity standards, to avoid any conflict of interest.

4. **Required Service (Work) Items - Task Line Item Numbers (TLIN):** As described in the agreement's Performance Work Statement, paragraph 2B, the below TLINs are required in the performance of this project. The TLINs are different, but interrelated to the tasks listed in task/deliverable and payment schedule**:**

TLIN 001: Selecting for peer reviewers or review panels, or for task orders to provide scientific support.
TLIN 002: Organizing, structuring, leading, and managing the scientific reviews and task order products.
TLIN 003: Managing and producing a final product.
TLIN 004: Responding to any follow-up questions from the Service on original review comments (not to exceed 15 consecutive days).
TLIN 005: Maintaining an official record for peer reviews or task orders.

5. Deliverables
The following deliverables are in addition to the agreement's Performance Work Statement paragraph 3, which states, "The Contractor shall provide the Contracting Officer Representative with three key deliverables: (1) Proposed Timeline, (2) Original individual scientific reviews and a transmittal letter to the Service (to Regional Director, Noreen Walsh), and (3) Complete Official Record." Original individual scientific reviews will be provided to the Contracting Officer Representative electronically in both Word and pdf format.

There are no additional deliverables. However, the contractor will be required to respond to questions, inquiries, or other related requests, and final acceptance, as needed. These request(s) will be by the Contracting Officer Representative (COR) (XXXX), in coordination with the Contracting Officer (XXXX). Inquiries or requests are limited to the products provided, and work performed under this contract (order).

Responses include, but not limited to: phone calls, written responses, and/or meetings.

Review comments by the COR will be provided to the contractor via the Contracting Officer.

6. Task Schedule
The period of performance shall not exceed the contract expiration date without a contract modification. In accordance with the terms of the contract, the contractor shall notify the Contracting Officer of any delays. Delays by the Government or Contractor must be rectified by accelerating the next deliverable on a one to one basis (i.e., if the delay was 2 days then the next deliverable must be submitted 2 days early). Deliverables that fall on a holiday or weekend must be delivered on the first work day after the weekend or holiday. The period of performance (contract expiration date) includes all possible holidays or weekend deliveries:

TASK/DELIVERABLE	CALENDAR DAYS AFTER AWARD
Task 1: The Service's COR will provide access to materials needed for the review.	1 (On XXXX)
Task 2: The contractor(s) shall manage a thorough, objective peer review of the Service's draft Species Status Assessment report for the North American wolverine.	31 (30 days after XXXX)
Task 3: The contractor(s) will provide 3-5 expert peer reviews and a transmittal letter to the Service (to Regional Director, Noreen Walsh).	33 (2 days)
Task 4: The contractor facilitates specific follow-up questions/answers between the Service and the reviewers (task limited to a 10-day period, 60 days after delivering initial review comments to the Service).	43 (10 days)
Task 5: The contractor will provide all applicable official records to the Service's COR.	45 (2 days)

7. Official Administrative Record
The Contractor is required to prepare an official record.

8. Information Sources
The key information sources and links for this review will include: (1) the draft North American wolverine species status assessment. Pertinent literature will be provided, as well as any relevant background information. The Service will provide a Conflict of Interest form for each peer reviewer to complete (attached).

9. Payment Schedule:

The payment schedule is as follows: 100 percent upon completion of Task 5 above.

10. Points of Contact:
Contracting Officers, Mr. Steve Gess, (R6) 303-236-4334 or email: steve_gess@fws.gov;

Contracting Officer Representative/Project Lead: Justin Shoemaker, Classification and Recovery Biologist, 309-757-5800 ext. 214 or email: justin_shoemaker@fws.gov

11. List of Enclosures/Attachments
1) Draft North American wolverine Species Status Assessment
2) Electronic or cd copies of literature cited in the above document
3) Conflict of Interest form

12. Evaluation Criteria (This paragraph will be deleted upon award)
This requirement will be awarded based on best value. Best value will take into consideration price (to include the level of effort applied to each major task), approach (to include the labor categories, TLINs applied to each major task, and the reviewer's resumes (reference paragraph

3). Price must detail cost in accordance with the agreement. The approach must include a detailed/ proposed schedule (timeline), and the disciplines/skill mix of reviewers. The approach should be no more than 2 pages (8 1/2" x 11", 12 point font), excluding information on costs. All contractors must propose five reviewers. Be sure to include the discipline/skills of all reviewers (e.g., a resume or CV).

REQUEST FOR PROPOSAL - EVALUATION FORM
WOLVERINE PEER REVIEW

Date Evaluated:	Evaluator:

Firm Name:

Category	Rating: 1 (poor) - 10 (excellent)	Weight	Score
A. COST PROPOSAL • Cost Proposal (Contracting Officer will conduct the initial evaluation of cost submittals) Leave score blank until Contracting officer provides this information • Score will be based on whether the percentage of price submitted is above the lowest reasonablel price submitted.		**4.0**	
• **QUALIFICATIONS** 1. Each reviewer must have a Ph.D. or a Master's with significant experience in Wildlife Ecology, Ecology, or Wildlife Management; and 2. In combination, the expertise of the qualified reviewers shall include the following; however, each individual is not required to meet all qualifications: a. Experience or expertise with carnivore management, especially wolverines; b. Expert knowledge of wildlife biology, wildlife management, demographic management of mammals (especially mesocarnivores), genetics, population modeling and/or scientific literature on wolverines or other mustelids; c. Expert knowledge of the effects of climate change and climate change modeling, specifically in the Mountain West area of the United States, which includes the northern Rocky Mountains, the North Cascades, or the southern Rocky Mountains; d. Expert knowledge of genetics of metapopulations; e. Experience as a peer reviewer for scientific publications; f. Knowledge of wolverine management in Canada, Alaska, and/or Europe. • **In addition, the reviewers shall have no financial or other conflicts of interest with the outcome or implications**		**4.0**	

B. PROJECT APPROACH • Number of reviewers • Assumptions • Timeline • Other TECHNICAL Considerations -		**2.0**	
	TOTAL SCORE **(**100 points possible**)**		

Continued on Page 2

Page 2 – Evaluation Form –Wolverine PEER

Comments – Cost Proposal:

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Comments –Approach_____

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Comments – Capabilities/ Past performance

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Evaluation Standards

For purposes of this solicitation, numeric ratings of 1 through 10 (one being the lowest and 10 being the highest) will be used in conjunction with narratives to evaluate each of the evaluation criteria categories listed above. These ratings will then be multiplied by a weight factor given to each criteria category. Once each category total has been calculated, they will be added together for a final total score. This process will repeat itself for each evaluated proposal. The following are explanations of the numeric ratings that will be used to evaluate the technical proposals:

1. **10-9:** Information submitted demonstrates offeror's potential to significantly exceed performance or capability

standards. The offeror has clearly demonstrated an understanding of all aspects of the requirements to the extent that timely and highest quality performance is anticipated. Have exceptional strengths that will significantly benefit the Government. The offeror's qualifications exceed the fullest expectations of the Government. The offeror has convincingly demonstrated that the RFP requirements have been analyzed, evaluated, and synthesized into approaches, plans, and techniques that, when implemented, should result in outstanding, effective, efficient, and economical performance under the contract. Significantly exceeds most or all solicitation requirements. **Very high probability of success.**

2. **8-7:** Information submitted demonstrates offeror's potential to exceed performance or capability standards. Have one or more strengths that will benefit the Government. The areas in which the offeror exceeds the requirements are anticipated to result in a high level of efficiency or productivity or quality. The offeror's qualifications meet and slightly exceed requirements. The submittal contains excellent features that will likely produce results very beneficial to the Government. Fully meets all RFP requirements and significantly exceed many of the RFP requirements. Disadvantages are minimal. **High probability of success.**

3. **6-5:** Information submitted demonstrates offeror's potential to meet performance or capability standards. Acceptable solution. Either meets all RFP requirements for the criterion (or sub-criteria) or contains weaknesses in some areas that are offset by strengths in other areas. This rating indicates that, in terms of the specific criterion (or sub-criteria), the offeror has a good probability of success, as there is sufficient confidence that a fully compliant level of performance will be achieved. The proposal demonstrates an adequate understanding of the scope and depth of the RFP requirements. No significant advantages or disadvantages. Equates to neutral. **Good probability of success.**

4. **4-3:** The submittal is not adequately responsive or does not address the specific criterion (or sub-criteria). The offeror's interpretation of the Government's requirements is so superficial, incomplete, vague, incompatible, incomprehensible, or incorrect as to be considered deficient. Proposal does not meet some of the minimum requirements. The assignment of a rating within the bounds of "Marginal" indicates that mandatory corrective action would be required to prevent significant deficiencies from affecting the overall project. The offeror's qualifications, plans or approach will likely result in questionable quality of performance, which represents a moderate level of risk to the Government. Low probability of success although the submittal has a reasonable chance of becoming at least acceptable. **Significant disadvantages.**

5. **2-1:** Fails to meet performance or capability standards. Unacceptable. Requirements can only be met with major changes to the submittal. There is no reasonable expectation that acceptable performance would be achieved. The proposal contains many deficiencies and/or gross omissions; fails to provide a reasonable, logical approach to fulfilling much of the Government's requirements; and/or fails to meet most or all of the minimum requirements. **Very significant disadvantage.**

October 16, 2017

Mr. Steve Gess
Contracting Officer
US Fish & Wildlife Service
134 Union Boulevard
Lakewood, CO 80228

SUBJECT: Amec Foster Wheeler Proposal – October 16, 2017
USFWS Request for Proposal dated September 27, 2017
Reference Number: 0092717001
Project: Peer Review of the Draft Species Status Assessment Report for the North American Wolverine
GSA Contract Number: GS-00F-314CA
USFWS Agreement Number: F17PA00026
USFWS Agreement Name: USFWS Scientific, Technical and Advisory Services

Dear Mr. Gess,

In accordance with the Request for Proposal received via email on September 27, 2017, Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) is pleased to submit our proposal for the following project: *Peer Review of the Draft Species Status Assessment Report for the North American Wolverine*. This proposal includes a team of peer reviewers meeting the requirements identified in the Statement of Work dated September 21, 2017.

Please contact Dawn Johnson at (805) 252-4370 if you have any questions or need additional information.

Respectfully submitted,

Aaron Goldschmidt
Principal

Cc: Cuong Vu – Amec Foster Wheeler Environment & Infrastructure, Inc.

104 West Anapamu Street, Suite 204A
Santa Barbara, CA 93101
(805) 962-0992

Proposal for: Peer Review for Draft Species Status Assessment for the North American Wolverine

US Fish & Wildlife Service

To:	Steve Gess US Fish & Wildlife Service
Re:	Request for Proposal, Reference Number 0092717001
Date:	October 16, 2017
From:	Dawn L. Johnson, PhD Amec Foster Wheeler Environment & Infrastructure, Inc.

1.0 Project Approach

Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) proposes to provide support to the US Fish & Wildlife Service (Service) for a peer review of the draft Species Status Assessment of the North American wolverine (*Gulo gulo luscus*). The project will include (1) assembling a panel of four peer reviewers; (2) conducting individual peer reviews without attribution; and (3) providing all peer reviews with a transmittal letter, along with an official record. Amec Foster Wheeler will provide a senior biologist as Project Manager (PM) to facilitate the peer review and ensure completion of the peer review, with experience in leading and facilitating peer reviews and expert panels.

In order to meet the requirements of the Office of Management and Budget (OMB) *Final Information Quality Bulletin for Peer Review* (December 2004) and avoid conflicts of interest, Amec Foster Wheeler selected the reviewers and identified a process to ensure scientific and process integrity. Each reviewer was provided with the OMB Bulletin language on independence and conflicts of interest, along with the conflict of interest considerations provided by the Service in the Statement of Work (SOW). This peer review is part of a larger process being undertaken by the Service to respond to litigation and petitions related to this distinct population segment (DPS) of the wolverine. As required by the SOW dated March 28, 2016, Amec Foster Wheeler will provide four peer reviewers with experience with mesocarnivores and their conservation and management, genetics, population modeling, and climate change (see 3.0 *Project Team*). The Amec Foster Wheeler team will provide services as defined in the SOW with a summary by Task below.

Task 1 (Provide Materials) ***Deliverables:*** **Timeline.**
The PM will coordinate with the Service to receive all materials to be evaluated during the peer review. The PM will distribute these materials and questions from the SOW to the peer reviewers. After award and receipt of all materials, the PM will provide an updated Timeline.

Task 2 (Peer Review) ***Deliverables:*** **None.**
The PM will provide a template for the peer reviewers to use for their responses to questions and facilitate any questions from the reviewers for the Service. The peer reviewers will evaluate materials provided with the intent to answer questions provided by the Service.

Task 3 (Provide Individual Reviews) ***Deliverables:*** **Individual Reviews, Letter Report.**
The PM will collect each individual review, copy edit and standardize formatting, and assign a random number so that each review has no attribution. The PM will then provide a transmittal letter, each individual review without attribution, and the reviewers' CVs to the Service.

Task 4 (Q&A Period) ***Deliverables:*** **Comment Matrix, if applicable.**

The PM will facilitate any clarification required from peer reviewers based on Service comments on the individual reviews. This will be limited to requests for clarification or additional information. If appropriate (i.e., comments are more than typographical/clarification), a comment matrix summarizing comment(s) and response(s) will be provided.

Task 5 (Official Record) ***Deliverables:*** **Final Reviews, Final Letter Report, Final Comment Matrix (if any).**

2.0 Schedule

Amec Foster Wheeler proposes the following schedule, which will be updated and finalized once the project is awarded.

Task	Calendar Days After Award (Previous Task)	Due Date (Assuming 1 November Award)
Task 1 (Provide Materials)	1 (-)	2 November
Task 2 (Peer Review)	31 (30)	1 December
Task 3 (Provide Reviews)	34 (3)	4 December
Task 4 (Q&A Period)	44 (10)	14 December
Task 5 (Official Record)	45 (1)	15 December

3.0 Project Team

The Amec Foster Wheeler Team consists of a PM and four peer reviewers. The PM has overseen and facilitated many expert panels for Department of Interior agencies, as well as for Department of Defense agencies. The PM and all peer reviewers have a PhD in biology, with expertise in ecology and evolution.

All of the peer reviewers are associated with universities, with one located in Montana. All of the peer reviewers have experience with small carnivore biology, including mustelids, but also conservation and ecology of mammals generally. One of the peer reviewers have experience with boreal forest climate change and wildlife populations, while another has experience with anthropogenic changes in northern forests and mustelid and other small carnivore populations.

All peer reviewers have at least 15 years of experience since their undergraduate degree with numerous publications, experience with conservation of mammals, and experience with peer reviews (both for journals and relating to rare species). None of the peer reviewers have a conflict of interest relating to the wolverine or the Service. None are known for any advocacy positions regarding wolverines. The following table provides a brief synopsis of their experience and general areas of expertise, with full CVs for each proposed peer reviewer attached.

Name & Project Role	Relevant Experience
Dawn L. Johnson, PhD Project Manager Amec Foster Wheeler	▶ 22 years of experience, as a biologist (ecology and evolution) ▶ Experience facilitating peer reviews and expert panels for Department of Interior agencies
James Beasley, PhD Carnivore Biologist Savannah River Ecology Lab University of Georgia	▶ 15 years of experience with mammals, including small carnivores ▶ Expertise in spatial ecology, genetics, population dynamics, wildlife diseases, and anthropogenic stressors ▶ Particular expertise in diverse methods of population estimation and genetics
Mark Boyce, PhD Wildlife Biologist University of Alberta	▶ 45 years of experience with carnivore conservation, management, and ecology, including with wolverines ▶ Emphasis on conservation, landscape ecology, and climate change in western US and Canada
Jennifer Frey, PhD Wildlife Biologist New Mexico State University	▶ 31 years of experience with mammals, including small carnivores ▶ Emphasis on conservation genetics, phylogeography, and natural history of mammals

Name & Project Role	Relevant Experience
Dan Harrison Carnivore Biologist University of Maine	► 37 years of experience with mammals, primarily with carnivores ► Experience with a range of mustelids and other small carnivores ► Expertise in management, population modeling, habitat selection, and anthropogenic change in northern forests

4.0 Price and Assumptions

The price proposal for this technical proposal is $27,829.09 for four peer reviewers. The following assumptions apply to this technical proposal and price proposal.

- There are no in-person meetings. Any meetings will be completed via conference call.
- The full list of references cited in the draft SSA, along with digital copies for all references for which they are available, will be provided to the reviewers.
- Delays by the Service do not accelerate Amec Foster Wheeler deliverables.

CURRICULUM VITAE

JAMES C. BEASLEY

Savannah River Ecology Lab
P.O. Drawer E
Aiken, SC 29802

Phone: (803) 725-5113
Fax: (803) 725-3309
Email: beasley@srel.uga.edu

RESEARCH INTERESTS

Spatial ecology and population dynamics of carnivores, effects of anthropogenic stressors on wildlife, wild pig ecology and management, human-wildlife conflicts, wildlife disease ecology, scavenging ecology

EDUCATION:

Ph.D., Wildlife Ecology, Purdue University (b) (6)
Advisor: Dr. Olin Rhodes, Jr.

M.S., Wildlife Ecology, Purdue University (b) (6)
Advisor: Dr. Olin Rhodes, Jr.

B.S., Wildlife Management, SUNY ESF (b) (6)
Advisor: Dr. William Shields

A.A.S., Pre-Professional Forestry, Paul Smith's College (b) (6)

PROFESSIONAL EXPERIENCE

2015-present	Assistant Professor – University of Georgia, Savannah River Ecology Laboratory, Warnell School of Forestry and Natural Resources
2014-present	International Atomic Energy Agency's Wildlife Advisor to the Fukushima Prefecture, Japan
2012-2015	Assistant Research Scientist – University of Georgia, Savannah River Ecology Laboratory, Warnell School of Forestry and Natural Resources
2011-2012	Visiting Assistant Professor – Department of Forestry and Natural Resources, Purdue University
2010-2011	Postdoctoral Research Associate – Department of Forestry and Natural Resources, Purdue University
2006-2010	Graduate Research Assistant – Department of Forestry and Natural Resources, Purdue University

2003-2005 Graduate Research Assistant – Department of Forestry and Natural Resources, Purdue University

PUBLICATIONS (Total of 78)

Peer-Reviewed Journal Articles (68)

78.) DeVault, T.L., T. Seamans, K. Linnell, D. Sparks, and J.C. Beasley. *In Press*. Scavenger removal of bird carcasses at simulated wind turbines: does carcass type matter? ***Ecosphere***

77.) Abernethy, E.F., K.L. Turner, J.C. Beasley, and O.E. Rhodes, Jr. *In Press*. Scavenging dynamics of reptile and amphibian carrion in a temperate ecosystem. ***Ecosphere***

76.) Smith, J.B., L.J. Laatsch, and J.C. Beasley. 2017. Spatial complexity of carcass location influences vertebrate scavenger efficiency and species composition. ***Scientific Reports*** 7:10250, DOI: 10.1038/s41598-017-10046-1

75.) Keiter, D.A., A.J. Davis, O.E. Rhodes, Jr., F.L. Cunningham, J.C. Kilgo, K.M. Pepin, and J.C. Beasley. 2017. Comparison of wildlife population density estimators under field and simulated conditions. ***Scientific Reports*** 7:9446, DOI: 10.1038/s41598-017-09746-5

74.) Webster, S.C., F.L. Cunningham, J.C. Kilgo, M. Vukovich, O.E. Rhodes, Jr., and J.C. Beasley. *In Press*. Minimum effective dose and persistence of Rhodamine-B in wild pig (*Sus scrofa*) vibrissae. ***Wildlife Society Bulletin***

73.) Turner, K.L., E.F. Abernethy, L.M. Conner, O.E. Rhodes, Jr., and J.C. Beasley. 2017. Abiotic and biotic factors modulate carrion fate and scavenging community dynamics. ***Ecology*** 98(9):2413-2424

72.) Oldenkamp, R.E., A.L. Bryan, Jr., R.A. Kennamer, J.C. Leaphart, S.C. Webster, and J.C. Beasley. 2017. Trace elements and radiocesium in game species near contaminated sites. ***Journal of Wildlife Management***

71.) Holland, A.E., M.E. Byrne, A.L. Bryan, T.L. DeVault, O. Rhodes, Jr. and J.C. Beasley. 2017. Fine-scale assessment of monthly home ranges and activity patterns of resident Black (*Coragyps atratus*) and Turkey (*Cathartes aura*) Vultures. ***PLoS One*** 12(7): e0179819

70.) Schlichting, P, A. Holland, J.C. Beasley, A. Bryan, R. Kennamer, T. DeVault, B. Blackwell, and O.E. Rhodes, Jr. 2017. Efficacy of an acoustic hailing device as an avian dispersal tool. ***Wildlife Society Bulletin*** 41(3):453-460

69.) Kay, S, J. Fischer, A. Monaghan, J.C. Beasley, R. Boughton, T. Campbell, S. Cooper, S. Ditchkoff, S. Hartley, J. Kilgo, S. Wisely, C. Wyckoff, K. Vercauteren, and K. Pepin. 2017. Quantifying drivers of wild pig movement across multiple spatial and temporal scales. ***Movement Ecology*** 5(14): 1-15

68.) Byrne, M.E., A.E. Holland, A.L. Bryan, and J.C. Beasley. 2017. Influence of environmental conditions and animal behavior on performance of solar-powered GPS/GSM avian transmitters. ***Condor*** 119(3)389-404

67.) Keiter, D.A., J.C. Kilgo, M.A. Vukovich, F.L. Cunningham, and J.C. Beasley. 2017. Development of known-fate survival monitoring techniques for juvenile wild pigs (*Sus scrofa*). ***Wildlife Research*** 44(2)165-173

66.) Kennamer, R, R. Oldenkamp, J.C. Leaphart, J. King, A.L. Bryan, and J.C. Beasley. 2017. Radiocesium in migratory aquatic game birds using contaminated U.S. Department of Energy reactor-cooling reservoirs: a long-term perspective. ***Journal of Environmental Radioactivity*** 171:189-199

65.) Hernandez, F., R. Oldenkamp, S. Webster, J.C. Beasley, L.L. Farina, and S.M. Wisely. 2017. Raccoons (*Procyon lotor*) as sentinels of trace element contamination and physiological effects of exposure to coal fly ash. ***Archives of Environmental Contamination and Toxicology*** 72:235-246

64.) Keiter, D.A., and J.C. Beasley. 2017. Hog heaven? Challenges of managing introduced wild pigs in natural areas. ***Natural Areas Journal*** 37(1): 6-16 - Invited Paper

63.) Smith, J.B., K.L. Turner, J.C. Beasley, W.C. Pitt, T.L. DeVault, and O.E. Rhodes, Jr. 2016. Location of brown treesnake (*Boiga irregularis*) carcasses following exposure to acetaminophen. ***Ecotoxicology*** 25: 1556-1562

62.) Abernethy, E., K. Turner, J. Beasley, T. DeVault, W. Pitt, and O. Rhodes, Jr. 2016. Carcasses of invasive species are primarily utilized by invasive scavengers in an island ecosystem. ***Ecosphere*** 7(10) e01496

61.) Webster, S.C., M. Hamilton, J.C. Beasley. 2016. ALLIGATOR MISSISSIPPIENSIS (American Alligator) DIET. ***Herpetological Review*** 47(2):291-292

60.) Brechignac, F., D. Oughton, C. Mays, L. Barnthouse, J.C. Beasley, A. Bonisoli-Alquati, C. Bradshaw, J. Brown, S. Dray, S. Geraskin, T. Glenn, K. Higley, K. Ishida, L. Kapustka, U. Kautsky, W. Kuhne, M. Lynch, T. Mappes, S. Mihok, A. Moller, C. Mothersill, T.A. Mousseau, J. Otaki, E. Prayakhin, O.E. Rhodes, Jr., B. Salbu, P. Strand, and H. Tsukada. 2016. Addressing ecological effects of radiation on populations and ecosystems to

improve protection of the environment against radiation. ***Journal of Environmental Radioactivity*** 158-159: 21-29

59.) Kierepka, E.M., S.D. Unger, D.A. Keiter, J.C. Beasley, O.E. Rhodes, Jr., F.L. Cunningham, A.J. Piaggio. 2016. Identification of robust microsatellite markers for wild pig fecal DNA in humid climates. ***Journal of Wildlife Management***, 80(6):1120-1128

58.) Beatty, W.S., J.C. Beasley, Z.H. Olson, and O.E. Rhodes, Jr. 2016. Influence of habitat attributes on the density of Virginia opossums (*Didelphis virginiana*) in agricultural ecosystems. ***Canadian Journal of Zoology*** 94:411-419

57.) Keiter, D, F.L. Cunningham, O.E. Rhodes, Jr., B.J. Irwin, and J.C. Beasley. 2016. Optimization of scat detection methods for social ungulates and evaluation of factors affecting human detection of scat: Wild pigs as a case study. ***PlosOne*** 11(5): e0155615

56.) Tannenbaum, L.V., and J.C. Beasley. 2016. Validating mammalian resistance to stressor-mediated reproductive impact using rodent sperm analysis. ***Ecotoxicology*** 25(3):584-593

55.) Olson, Z.H., J.C. Beasley, and O.E. Rhodes, Jr. 2016. Carcass type affects local scavenger guilds more than habitat connectivity. ***PlosOne*** 11(2):e0147798

54.) Keiter, D, J.J. Mayer, and J.C. Beasley. 2016. What's in a "common" name? A call for consistent terminology for referring to non-native *Sus scrofa*. ***Wildlife Society Bulletin*** 40(2): 384-387

53.) Webster, S.C., M.E. Byrne, S.L. Lance, C.L. Love, T. Hinton, D. Shamovich, and J.C. Beasley. 2016. Where the wild things are: Influence of radiation on the distribution of mammalian species within the Chernobyl Exclusion Zone. ***Frontiers in Ecology and the Environment*** 14(4): 1-6

52.) Dharmarajan, G., J.C. Beasley, W.S. Beatty, Z.H. Olson, J.A. Fike, and O.E. Rhodes, Jr. 2016. Genetic co-structuring in host-parasite systems: Empirical data from raccoons (*Procyon lotor*) and raccoon ticks (*Ixodes texanus*). ***Ecosphere*** 7(3):e01269

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37.) Dharmarajan, G., J.C. Beasley, J.A. Fike, E.A. Raizman, C.C. Wu, R.M. Pogranichniy, and O.E. Rhodes, Jr. 2012. Effects of kin-structure on disease dynamics in raccoons (*Procyon lotor*) inhabiting a fragmented landscape. ***Basic and Applied Ecology*** 13:560-567.

36.) Beasley, J.C., and O.E. Rhodes, Jr. 2012. Are raccoons limited by the availability of breeding resources? Evidence of variability in fecundity at fine spatial scales. ***Journal of Wildlife Management*** 76:1718-1724.

35.) Beasley, J.C., W.S. Beatty, T. Attwood, S. Johnson, O.E. Rhodes, Jr. 2012. A Comparison of Methods for Estimating Raccoon Abundance: Implications for Disease Vaccination Programs. ***Journal of Wildlife Management*** 76:1021-1026.

34.) Beasley, J.C., Z.H. Olson, and T.L. DeVault. 2012. Carrion cycling in food webs: comparisons among terrestrial and marine ecosystems. ***Oikos*** 121:1021-1026.

33.) Beatty, W.S., J.C. Beasley, G. Dharmarajan, and O.E. Rhodes, Jr. 2012. Genetic structure of the Virginia Opossum (*Didelphis virginiana*) inhabiting a fragmented agricultural ecosystem. ***Canadian Journal of Zoology*** 90(1):101-109.

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30.) Eagan, T.L., J.C. Beasley, Z.H. Olson, and O.E. Rhodes, Jr. 2011. Response of small-mammal populations to the removal of a generalist mesopredator. ***Canadian Journal of Zoology*** 89(8):724-731.

29.) Page, L.K., J.C. Beasley**,** Z.H. Olson, T.J. Smyser, M. Downey, K.F. Kellner, S.E. McCord, T.S. Eagan, II, and O.E. Rhodes, Jr. 2011. Evaluation of an in situ experimental prevention method for raccoon roundworm (*Baylisascaris procyonis*) via anthelmintic baiting: Implications for the management of Infectious diseases. ***Emerging Infectious Diseases*** 17(1):90-93.

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Ecology 12(3):268-274.

27.) Dharmarajan, G., J.C. Beasley**,** and O.E. Rhodes, Jr. 2011. Heterozygote deficiencies in parasite component populations: An evaluation of interrelated hypotheses in the raccoon tick, *Ixodes texanus*. ***Heredity*** 106(2):253-260.

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23.) Beasley, J.C., W.S. Beatty, Z.H. Olson, and O.E. Rhodes, Jr. 2010. A genetic analysis of the Virginia opossum mating system: evidence of multiple paternity in a highly fragmented landscape. ***Journal of Heredity*** 101(3):368-373.

22.) Dharmarajan, G., J.C. Beasley**,** J.A. Fike, and O.E. Rhodes, Jr. 2009. The population genetic structure of raccoons (*Procyon lotor*) inhabiting a highly fragmented landscape. ***Canadian Journal of Zoology*** 87(9):814-824.

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17.) Retamosa, M.I., L.A. Humberg, J.C. Beasley and O.E. Rhodes, Jr. 2008. Modeling wildlife damage to crops in northern Indiana. ***Human-Wildlife Conflicts*** 2(2):225-239.

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15.) DeVault, T.L., J.C. Beasley, L.A. Humberg, B.J. MacGowan, M.I. Retamosa and O.E. Rhodes, Jr. 2007. Intrafield patterns of wildlife damage to corn and soybean in northern Indiana. ***Human-Wildlife Conflicts*** 1(2):205-213.

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12.) Beasley, J.C., T.L. DeVault, and O.E. Rhodes, Jr. 2007. Home range attributes of raccoons in a fragmented agricultural region of northern Indiana. ***Journal of Wildlife Management*** 71(3):844-850.

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Books (1)

10.) Pitt, W.C., J.C. Beasley, and G.W. Witmer. *In Press*. Ecology and Management of Terrestrial Invasive Species in the United States. CRC Press, Boca Raton, FL, USA.

Book Chapters, and Book Reviews (5)

9.) Beasley, J.C., Z.H. Olson, N. Selva, and T.L. DeVault. *In Press*. Ecological functions of vertebrate scavenging. *In*: Carrion Ecology and Management. P.P. Olea, P. Mateo-Tomas, and J. Sanchez-Zapata. Springer.

8.) Mayer, J.J., and J.C. Beasley. *In Press.* Wild Pigs. *In*: Ecology and Management of Terrestrial Vertebrate Invasive Species in the United States. W.C. Pitt, J.C. Beasley, and G.W. Witmer, editors. CRC Press, Boca Raton, FL, USA.

7.) Beasley, J.C. 2016. Human Diseases from Wildlife. Book Review. ***Journal of Wildlife Management*** 80(1):181-182

6.) DeVault, T.L., J.C. Beasley, Z.H. Olson, M. Moleón, J.A. Sánchez-Zapata, M. Carrete, and A. Margalida. 2016. Ecosystem services provided by avian scavengers. *In*: Why Do Birds Matter? Birds' Ecological Functions and Ecosystem Services. C. H. Şekercioğlu, D. G. Wenny, and C. J. Whelan, eds. University of Chicago Press. pp. 235-270

5.) Beasley, J.C., Z.H. Olson, and T.L. DeVault. 2015. Ecological role of vertebrate scavengers. *In*: Carrion Ecology, Evolution and Their Applications. E.M. Benbow, J. Tomberlin, and A. Tarone, eds. CRC Press, Boca Raton, FL. pp. 107-127

Peer-Reviewed Symposia, Proceedings Articles, and Notes (4)

4.) Abernathy, E.F., K.L. Turner, J.C. Beasley, T.L. DeVault, W.C. Pitt, and O.E. Rhodes, Jr. 2015. Impacts of invasive species on ecosystem energy flow on the big island of Hawai'i: Excuse me but are you going to eat that cane toad? ***Proceedings of the 26th Annual Vertebrate Pest Conference.***

3.) Beasley, J.C., T.E. Grazia, P.E. Johns, and J.J. Mayer. 2014. Characterization of habitat attributes associated with wild pig-vehicle collision locations. ***Proceedings of the 2013 Wildlife Damage Management Conference*** Paper 149.

2.) DeVault, T.L., B.J. MacGowan, J.C. Beasley, L.A. Humberg, M.I. Retamosa, and O.E. Rhodes, Jr. 2008. Evaluation of corn and soybean damage by wildlife in northern Indiana. ***Proceedings of the 12th Wildlife Damage Management Conference***, D. Nolte, ed. Corpus Christi, TX.

1.) Humberg, L.A., T.L. DeVault, B.J. MacGowan, J.C. Beasley, and O.E. Rhodes, Jr. 2007. Crop depredation by wildlife in northcentral Indiana. Pages, 199-205 in the ***Proceedings of the Ninth National Wild Turkey Symposium***, A. Stewart, ed., Grand Rapids, Michigan.

In Review

Smith, J.B., T.D. Tuberville, and J.C. Beasley. *Accepted with Revisions*. Hunting and consumption patterns of southeastern USA hunters and anglers. ***Journal of Fish and Wildlife Management***

Thomas, J., J.C. Beasley, J. Seaman, J.W. Finger Jr., T.J. Kieran, E. Lipp, J. Vaun McArthur, O.E. Rhodes, Jr., and T.C. Glenn. *In Review*. Heavy metals in the environment modulate compositional and functional changes in microbiota of wild *Peromyscus*.

Davis, A.J., D.A. Keiter, E. Kierepka, C. Slootmaker, A.J. Piaggio, J.C. Beasley, and K.M. Pepin. *Accepted with Revisions*. The cost of good information: Trade-offs between cost and quality of common population density estimators. ***Journal of Mammalogy***

Nigenda, S.F., Y. Hu, J.C. Beasley, H. Ruiz-Pina, D. Valenzuela-Galvan, and R.K. Wayne. *In Review*. Transcriptomics of skin pigmentation variation in the Virginia opossum (*Didelphis virginiana*). ***Molecular Ecology***

Byrne, M.E., S.C. Webster, S.L. Lance, C.N. Love, T.G. Hinton, D. Shamovich, and J.C. Beasley. *In Review*. Evidence of long-distance dispersal of a gray wolf from the Chernobyl Exclusion Zone. ***Ecology***

Beasley, J.C., M.J. Lavelle, D.A. Keiter, K.M. Pepin, A.J. Piaggio, J.C. Kilgo, and K.C. VerCauteren. *In Review*. Research Methods. *In*: Ecology and Management of Wild Pigs in North America. K.VerCauteren, J.C. Beasley, J.J. Mayer, B. Strickland, G.J. Roloff, and S. Ditchkoff, editors. CRC Press, Boca Raton, FL, USA

Mayer, J.J., J.C. Beasley, R. K. Boughton, and S.S. Ditchkoff. *In Review*. The South. *In*: Ecology and Management of Wild Pigs in North America. K.VerCauteren, J.C. Beasley, J.J. Mayer, B. Strickland, G.J. Roloff, and S. Ditchkoff, editors. CRC Press, Boca Raton, FL, USA

Snow, N., J.C. Beasley, R. Miller, and K. Pepin. *In Review*. Population Dynamics. *In*: Ecology and Management of Wild Pigs in North America. K.VerCauteren, J.C. Beasley, J.J. Mayer, B. Strickland, G.J. Roloff, and S. Ditchkoff, editors. CRC Press, Boca Raton, FL, USA

Gray, S.M., G.J. Roloff, R.A. Montgomery, J.C. Beasley, and K.M. Pepin. *In Review*. Spatial Ecology and Behaviors. *In*: Ecology and Management of Wild Pigs in North America. K.VerCauteren, J.C. Beasley, J.J. Mayer, B. Strickland, G.J. Roloff, and S. Ditchkoff, editors. CRC Press, Boca Raton, FL, USA

Beasley, J.C., S.S. Ditchkoff, J.J. Mayer, M.D. Smith, and K.C. VerCauteren. *In Review*. Research priorities for managing invasive wild pigs in North America. ***Journal of Wildlife management***

Extension Publications (6)

6.) Beasley, J.C. 2014. SRS, the eagles have landed! The Grapevine. University of Georgia, Savannah River Ecology Lab, Aiken, SC.

5.) Bryan, A., A.E. Holland, J.C. Beasley, and O.E. Rhodes, Jr. 2014. Examining vulture movements and behaviors with GSM/GPS transmitters. Tracker News, Microwave Telemetry, Inc. 1:15.

4.) Beasley, J.C. 2008. Spatial dynamics of raccoons and Virginia opossums in agricultural landscapes. *Compass*. Purdue University, Department of Forestry and Natural Resources, West Lafayette, Indiana.

3.) MacGowan, B.J., L.A. Humberg, J.C. Beasley, and O.E. Rhodes, Jr. 2006. Wildlife CSI: unraveling the mysteries of wildlife crop damage, DVD-FNR-266. Purdue University, Department of Forestry and Natural Resources, West Lafayette, Indiana. DVD.

2.) MacGowan, B.J., L.A. Humberg, J.C. Beasley, and O.E. Rhodes, Jr. 2006. Identification of wildlife crop depredation, FNR-267. Purdue University, Department of Forestry and Natural Resources, West Lafayette, Indiana, 28 pp.

1.) MacGowan, B.J., L.A. Humberg, J.C. Beasley, T.L. DeVault, and O.E. Rhodes, Jr. 2006. Corn and soybean crop depredation by wildlife, FNR-265-W. Purdue University, Department of Forestry and Natural Resources, West Lafayette, Indiana, 13 pp. http://www.agriculture.purdue.edu/fnr/cropdamage/resources.htm.

GRANTS – [*$2,389,404 received, $885,871 pending*]

(Grants in italics indicate proposals currently in review)

- *Dharmarajan, G (PI), R Ostfeld (co-PI), and **JC Beasley** (Co-PI). 2017. Hosts as heterogeneous landscapes: Interspecific competition between ticks and its effects on tick-borne disease. National Science Foundation-DEB. In Review* (*$675,242*)
- ***Beasley, JC** (PI) and P. Schlichting (co-PI). 2017. Przewalski's wild horse population status and use of abandoned buildings by wildlife in Chernobyl. Riverbanks Zoo. In Review: $4,825*
- ***Beasley, JC** (PI) and P. Schlichting (co-PI). 2017. Przewalski's wild horse population status and use of abandoned buildings by wildlife in Chernobyl. National Geographic Society. In Review: $29,514*

- ***Beasley, JC** (PI) and AL Bryan (co-PI). 2017. Contaminants in wild pigs and eastern wild turkeys. US Department of Energy. In Review: $176,290*
- **Beasley, JC** (PI). 2017. Crop depredation by wild pigs in the southeastern US. USDA Animal Plant Health Inspection Service. Awarded: $36,000
- **Beasley, JC** (PI). 2017. Radioactive wildlife: disentangling the confounding effects of radiation exposure and human abandonment on wildlife in Fukushima. UGA OVPR. Awarded: $9,681
- **Beasley, JC** (PI). 2017. Effects of low dose radiation exposure on wildlife inhabiting the Fukushima Exclusion Zone, Japan. University of Georgia OIP. Awarded: $5,500
- **Beasley, JC** (PI). 2017. Analysis of wild pig genetic samples. Noble Foundation. Awarded: $4,500
- Bryan, AL (PI) and **Beasley JC** (co-PI). 2017. Movement of wood storks associated with colony modifications at the Savannah International Airport. USFWS. Awarded: $49,280
- Hernandez, SM (PI), **JC Beasley** (co-PI), and M Yabsley (co-PI). 2015. Understanding and managing coyote colonization of Sanibel Island, FL. Sanibel Island City Council. Awarded: $18,882
- **Beasley, JC** (PI) and AL Bryan (co-PI). 2016. Contaminants in wild turkeys. US DOE. Awarded: $32,000
- **Beasley, JC** (PI). 2016. Chernobyl wolves. Living Planet Productions Ltd. Awarded: $2,500
- **Beasley, JC** (PI). Inter and intra-sounder contact structure in wild pigs. USDA Animal Plant Health Inspection Service. Awarded: $112,800
- **Beasley JC** (PI) and OE Rhodes (co-PI). 2016. Spatial ecology of wild pigs subsequent to management activities. USDA Animal Plant Health Inspection Service. Awarded: $70,852
- Rhodes, OE (PI), G Dharmarajan (co-PI), and **JC Beasley** (co-PI). 2017. Ecological factors affecting success of rabies elimination in the southeastern U.S. USDA APHIS. Awarded: $76,913
- **Beasley, JC** (PI) and AL Bryan (co-PI). 2016. Sub-lethal effects of chronic exposure to contaminants: Evaluation of heavy metal, stress, and parasite burdens in beaver, raccoon and river otter inhabiting contaminated wetlands on the Savannah River Site. US DOE. Awarded: $130,000
- **Beasley, JC** (PI) and S Lance (co-PI). 2015. Chernobyl Wolves. Georgia Funder. Awarded: $2,895
- **Beasley, JC** (PI). 2015. Post-translocation movement behavior of wild pigs. USDA Animal Plant Health Inspection Service. Awarded: $62,480
- Kennamer, R (PI) and **JC Beasley** (co-PI). 2015. Monticello Reservoir and Parr Reservoir waterfowl survey. Kleinschmidt Associates. Awarded: $21,628
- Bryan AL (PI) and **JC Beasley** (co-PI). 2015. ^{137}Cs in Biota of R Canal. US DOE. Awarded: $58,000
- **Beasley JC** (PI), RA Kennamer (co-PI), and AL Bryan (co-PI). 2015. Recalculating ecological half-lives for American Coots on Par Pond. US Department of Energy. Awarded: $41,500
- **Beasley JC** (PI) and OE Rhodes (co-PI). 2014. Calibrating efficient methods of estimating feral swine population size. USDA Animal Plant Health Inspection Service. Awarded: $78,815

- Rhodes, OE (PI) and **JC Beasley** (co-PI). 2014. Indirect transfer of acetaminophen/rodenticides to non-target organism through scavenging during BTS and rodent control operations. U.S. Department of Defense/USDA Animal Plant Health Inspection Service. Awarded: $586,628
- **Beasley JC** (PI). 2014. Survival and cause-specific mortality of juvenile feral swine. USDA Animal Plant Health Inspection Service. Awarded: $25,300
- **Beasley JC** (PI) and AE Holland (co-PI). 2014. Environmental contaminants and blood parasite loads in black and turkey vultures in the southeastern USA. Georgia Ornithological Society. Awarded: $8,840
- **Beasley JC** (PI). 2014. Translocation movement behavior of feral swine. USDA Animal Plant Health Inspection Service. Awarded: $45,870
- **Beasley JC** (PI). 2014. Reproductive effects of chronic exposure to anthropogenic contaminants in small mammals. U.S. Army Public Health Command. Awarded: $9,000
- Rhodes, OE (PI) and **JC Beasley** (co-PI). 2014. Development of genetic-based mark-recapture tools for feral swine. USDA Animal Plant Health Inspection Service. Awarded: $35,000
- **Beasley JC** (PI) and OE Rhodes (co-PI). 2014. Dose titration and duration of Rhodamine B in feral pigs. USDA Animal Plant Health Inspection Service. Awarded: $14,934
- **Beasley JC** (PI), AL Bryan (co-PI), and R Kennamer (co-PI). 2013. Preliminary contaminant analysis in selected game species on the Savannah River site. US DOE. Awarded: $40,300
- Kennamer, R (PI), **JC Beasley** (co-PI), and AL Bryan (co-PI). 2013. Radiocesium in American coots on Pond B: a long-term perspective. US Department of Energy. Awarded: $43,515
- Hinton, T (PI) and **JC Beasley** (co-PI). 2013. Innovative Technique to Measure Radiation Dose to Free Ranging Wildlife. French Institute of Radioprotection and Nuclear Safety. Awarded: $162,839
- Rhodes, OE (PI) and **JC Beasley** (co-PI). 2013. Experimental Evaluation of Trophic Transfer of Toxicants Used for Insular Rodents. USDA APHIS. Awarded: $29,986
- **Beasley JC** (PI). 2013. Grad Student Support. Jones Ecological Research Center. Awarded: $21,665
- **Beasley JC** (PI) and OE Rhodes (co-PI). 2013. Efficacy of Rhodamine B as a biomarker for bait uptake in feral swine. USDA Animal Plant Health Inspection Service. Awarded: $11,660
- **Beasley JC** (PI) and S Lance (co-PI). 2013. Sub-lethal effects of chronic exposure to radiation in gray wolves (Canis lupus) at Chernobyl. National Geographic Society. Awarded: $22,000
- **Beasley JC** (PI) and S Webster (co-PI). 2013. Chernobyl Wolves. National Geographic Society. Awarded: $8,200
- **Beasley JC** (PI). 2013. Wildlife Damage Management Working Group Travel Grant. The Wildlife Society Wildlife Damage Management Working Group. Awarded: $500
- Rhodes OE (PI), **JC Beasley** (co-PI), BF Blackwell (co-PI), AL Bryan (co-PI), and TL DeVault (co-PI). 2013. Efficacy of the LRAD weapon system as an avian dispersal tool on airports. Federal Avian Administration/USDA Animal Plant Health Inspection Service. Awarded: $352,245

- **Beasley JC** (PI). 2013. Comparison of uptake of different flavors of ONRAB placebo sachets by rabies hosts. USDA Animal Plant Health Inspection Service. Awarded: $16,406
- Bryan AL (PI) and **JC Beasley** (co-PI). 2012. Preliminary contaminant analysis in selected game species on the Savannah River site. US Department of Energy. Awarded: $40,300
- Rhodes OE (PI) and **JC Beasley** (co-PI). 2013. Experimental Evaluation of Trophic Transfer of Toxicants Used for Insular Rodents. USDA APHIS. Awarded: $99,990
- **Beasley JC** (PI). 2012. Purdue Instructional Innovation Grant, "Microscopy and Digital Imaging for Life Science Instruction" ($21,497)
- **Beasley JC** (PI). 2012. Purdue Instructional Innovation Grant, "Digital Remote Camera Units for Wildlife Management Instruction" ($8,160)
- Olin Rhodes, Jr. (PI) and **JC Beasley** (co-PI). 2011. USDA-APHIS, "Evaluation of bait distribution methods" ($38,379)
- Olin Rhodes, Jr. (PI) and **JC Beasley** (co-PI). 2010. USDA-APHIS, "Use of trapping point transect and spatially explicit capture-recapture to estimate the density of raccoons and using spatial data to increase trap-based detection for raccoons" ($26,190)
- Olin Rhodes, Jr. (PI) and **JC Beasley** (co-PI). 2009. USDA-APHIS, "Use of trapping point transect and spatially explicit capture-recapture to estimate the density of raccoons and using spatial data to increase trap-based detection for raccoons" ($22,752)
- **Beasley JC** (PI). 2007. Frederick N. Andrews Environmental Travel Grant Award ($2,000)
- **Beasley JC** (PI). 2007. Indiana Academy of Science, "Ecological response of raccoons to agriculturally induced habitat fragmentation" ($1,250)

AWARDS AND ACTIVITIES

- Certified Wildlife Biologist, The Wildlife Society, 2013
- Howard Hughes Medical Institute faculty learning community – member, 2011-2012
- Chemical Immobilization Certification through Safe Capture International – 2011
- Charles Kirkpatrick Memorial Graduate Student Award, 2010
- Master Trapper, Fur Takers of America Certification, 2010
- 2nd place, Purdue Forestry and Natural Resources Research Symposium, 2010 (Poster)
- Bilsland Dissertation Fellowship, Purdue University, 2009
- Indiana Chapter of the Wildlife Society Best Paper Award, 2008
- Charles Kirkpatrick Memorial Graduate Student Award, 2007
- 1st place, Purdue Forestry and Natural Resources Research Symposium, 2005 (Poster)
- Honorable mention, Purdue FNR Research Symposium 2004, (Poster)

TEACHING EXPERIENCE

University of Georgia

- **WILD/ECOL 3580: Vertebrate Natural History** – Instructor (Fall 2013)

- **WILD 4650/6650: Field & Molecular Techniques in Wildlife Research and Management** – Instructor (Summer 2013-2017)

- **WILD 1100E: Wildlife in America** – Instructor (Summer 2016, 2017, Spring 2017)

Purdue University

- **FNR 240: Wildlife in America** – Instructor (Fall 2011; 120 students)
- **FNR 341: Wildlife Habitat Management** – Instructor (Spring 2012; 50 students)
- **FNR 348: Wildlife Investigational Techniques** – Instructor (Spring 2012; 55 students)
- **FNR 373: Summer Field Practicum** – Instructor (May 2012; 60 students).
- **FNR 241: Ecology and Systematics of Fishes and Mammals** – Graduate Teaching Assistant (Fall 2004, 2006; ~30 students)
- **FNR 548: Wildlife Investigational Techniques** – Graduate Teaching Assistant (Fall 2007, 2008; ~50 students)
- **FNR 240: Wildlife in America** –Guest Lecture (Fall 2006-2008; 250-400 students)

Table 1. Student evaluations

Evaluation Questions	WILD 4650/6650 2013-2017	WILD1100E 2016-2017
Instructor clearly articulated and met course objectives	5.0	4.9
Instructor presented material in a clear and understandable manner	5.0	4.9
Instructor was organized and prepared in class	4.9	4.9
Instructor stimulated my interest in course subject material	5.0	4.9
Instructor motivated me to perform at my highest level	4.9	4.8
Instructor demonstrated concern for student learning	4.9	4.5
Instructor was receptive to questions and independent thought	5.0	4.6
Instructor was available and helpful outside of class	4.6	4.8
Instructor employed grading practices that were clearly explained and fair	4.6	4.9
Instructor effectively utilized in class time (including lectures and laboratories)	5.0	4.9
Considering all factors, the instructor should be commended for his/her efforts in the course	5.0	4.9
This course exposed me to information and/or ideas that expanded and/or altered my perception of the world	4.7	4.9
Average (out of 5)	**4.88**	**4.80**

MEDIA COVERAGE

My research program has received media coverage through a multitude of outlets. Since 2005, aspects of my research program have been highlighted in several hundred local, national and international newspapers (e.g., New York Times, The Washington Post, USA Today, BBC News, The Guardian – front page, The Independent – front page, Aiken Standard – front page), internet news media (e.g., National Geographic Society, UGA Today – front page, Scientific American, The Wildlife Society), magazines (e.g., Hawkmoth, Wprost), radio broadcasts (e.g.,

NPR-weekend addition, FM4-Austria, 720 ABC-Australia), scientific magazines (e.g., Science, Nature), as well as local and cable television networks (e.g., CNN, Animal Planet, Georgia Public Broadcasting, NBC-26 News). In particular, two of my coauthored papers have altmetric scores within the top 5% of all articles ever tracked by altmetric, one of which was included in the best of UGA magazine for being the most widely read news release produced by the University of Georgia in 2016.

PROFESSIONAL PRESENTATIONS

(Invited papers in **bold**; * indicates coauthored presentations $^{\Psi}$ indicates student presentations; $^{¥}$ indicates award received for presentation)

2017 **National Wild Pig Task Force Meeting, Orange Beach, AL**
International Atomic Energy Association Summer Mission, Fukushima, Japan
NNSA SRS Meeting, Aiken, SC
National Academy of Sciences, Minsk, Belarus
Cedar Shoals High School, Athens, GA
Warnell Graduate Student Symposium, Athens, GA (3)$^{\Psi}$
SICB, New Orleans, LA$^{\Psi}$
Ecological Society of America, Portland, OR (2)$^{*\Psi}$
SREL Undergraduate Research Symposium, Aiken, SC (1) $^{\Psi}$
University of South Carolina Summer Research Symposium, Columbia, SC (1)$^{\Psi}$
Wildlife Disease Association Meeting, Chiapas, Mexico*
SREL REU, Aiken, SC (2) $^{\Psi}$
USDA-APHIS-WS NC/SC wild pig technical meeting, Garnett, SC
USDA-APHIS-NWRC, Fort Collins, CO*

2016 Warnell Graduate Student Symposium, Athens, GA (4)$^{\Psi¥¥¥}$
International Atomic Energy Association Summer Mission, Fukushima, Japan
SREL Undergraduate Research Symposium, Aiken, SC (1) $^{\Psi}$
Fukushima University, Fukushima, Japan$^{\Psi}$
SREL REU, Aiken, SC (2) $^{\Psi}$
TEDx, Atlanta, GA
University of South Carolina Summer Research Symposium (1)$^{\Psi}$
International Atomic Energy Association Winter Mission, Fukushima, Japan
SETAC, Orlando, FL (3) $^{\Psi}$
International Wild Pig Conference, Myrtle Beach, SC (6)$^{\Psi}$
USDA-APHIS-WS Annual State Meeting, SC
Georgia Wildlife Society Meeting, Athens, GA $^{\Psi¥}$
South Carolina Wildlife Society Meeting, SC
Wild Pig Workshop at the 23rd Annual National Meeting of the Wildlife Society, Raleigh, NC
Southeastern Society of Parasitologists, Fort Mill, SC$^{\Psi}$
Society for Glycobiology, New Orleans, LA
The 23rd Annual National Meeting of the Wildlife Society, Raleigh, NC (8) $^{\Psi}$

2015 Warnell Graduate Student Symposium, Athens, GA (5)[Ψ¥¥¥¥]
Ichaway Scientific Advisory Committee, Newton, GA [Ψ]
Clemson University, Clemson, SC
Georgia Entomological Society, Jekyll Island, GA (2) [Ψ¥]
American Society of Mammalogists Annual Meeting, Jacksonville, FL (4) [Ψ]
International Atomic Energy Association Mission, Fukushima, Japan
SREL Undergraduate Research Symposium, Aiken, SC (2) [Ψ]
UGA Ecology of Infectious Diseases Symposium, Athens, GA [Ψ]
University of South Carolina Summer Research Symposium (2) [Ψ]
Georgia Wildlife Society Meeting, Athens, GA (3) [Ψ¥¥]
13th International Conference on the Biochemistry of Trace Elements, Fukuoka, Japan*
The 22nd Annual National Meeting of the Wildlife Society, Winnipeg, Canada (6) [Ψ¥]
University of Florida Emerging Pathogens Institute, Gainesville, FL [Ψ]
NSF REU National Symposium, Arlington, VA [Ψ]
International Atomic Energy Association Mission, Fukushima, Japan
Science Media Center, London, UK

2014 **University of Florida, Gainesville, FL**
Warnell Graduate Student Symposium, Athens, GA (3) [Ψ]
Evolution Meeting, Raleigh, NC*
26th Vertebrate Pest Conference, Waikoloa, HI[Ψ]
Animal Movement Symposium, Raleigh, NC[Ψ]
Florida Cooperative Fish and Wildlife Research Unit, Gainesville, FL*
Southeastern Forest Work Conference, Charleston, SC[Ψ]
International Atomic Energy Association Mission, Fukushima, Japan
SREL Undergraduate Research Symposium (2) [Ψ]
SREL Touch an Animal Day (2) [Ψ]
The 21st Annual National Meeting of the Wildlife Society, Pittsburg, PA (2) [Ψ]
Georgia Chapter of the Wildlife Society, Tifton, GA (2) [Ψ¥]
AOU/COS/SCO, Estes Park, CO [Ψ]
South Carolina Wildlife Society Meeting, Clemson, SC*

2013 TWS Wildlife Damage Management Workshop, Clemson, SC
Sierra Club, Aiken, SC
Southeastern Cooperative Wildlife Disease Study, Athens, GA
Savannah River Ecology Lab, Aiken, SC
Ecological Society of America, Minneapolis, MN*
American Society of Mammalogists, Philadelphia, PA*
Student Conference on Conservation Science, New York, NY*
USFS Environmental Sciences Field Station, Aiken, SC (2) [Ψ]
IRSN, France*

2012 **USFWS American Burying Beetle Science Workshop, Pawhuska, OK**
Indiana State University, Terre Haute, IN

Savannah River Ecology Lab, Aiken, SC
University of South Carolina-Aiken, Aiken, SC
University of Georgia, Athens, GA
Jones Center, Newton, GA
EcoSummit, Columbus, OH*

2011 **USDA-APHIS National Wildlife Research Center, Fort Collins, CO**
The 91st Annual Meeting of the Am. Society of Mammalogists, Portland, OR*
The 72nd annual Midwest Fish and Wildlife's conference, Des Moines, IO*
Furtakers of America Prof. Trappers College for Furbearer Mgmt, Wolcottville, IN
The 22nd Annual International Conference on Rabies in the Americas, San Juan, Puerto Rico*

2010 Purdue University Forestry and Natural Resources Symposium, W. Lafayette, IN (2)
The 17th Annual National Meeting of the Wildlife Society, Snowbird, UT (2)
The 21st Annual International Conference on Rabies in the Americas, Guadalajara, Mexico*
Ph.D. Dissertation Presentation, W. Lafayette, IN

2009 The 89th Annual Meeting of the Am. Society of Mammalogists, Fairbanks, AK (3)
Indiana Chapter of the Wildlife Society, Terre Haute, IN*
The 16th Annual National Meeting of the Wildlife Society, Monterey, CA*
Purdue University Forestry and Natural Resources Symposium, W. Lafayette, IN
Furtakers of America Prof. Trappers College for Furbearer Mgmt, Wolcottville, IN

2008 Indiana Chapter of the Wildlife Society, Nashville, IN¥
The Purdue University Chapter of the Wildlife Society, W. Lafayette, IN

2007 Purdue University Forestry and Natural Resources Symposium, W. Lafayette, IN (2)
Purdue Center for the Environment Graduate Research Showcase, W. Lafayette, IN
56th Annual Meeting of the Wildlife Disease Association. Estes Park, CO*
The Purdue University Chapter of the Wildlife Society, W. Lafayette, IN

2006 Purdue University Forestry and Natural Resources Symposium, W. Lafayette, IN (2)
Purdue Center for the Environment Graduate Research Showcase, W. Lafayette, IN
The Purdue University Chapter of the Wildlife Society, W. Lafayette, IN
Midwest Deer and Turkey Group Meeting, Bloomington, IN*

2005 Purdue University Forestry and Natural Resources Symposium, W. Lafayette, IN
M.S. Thesis Presentation, W. Lafayette, IN
The 66th annual Midwest Fish and Wildlife's conference, Grand Rapids, MI
9th National Wild Turkey Symposium, Grand Rapids, MI*

2004 The 11th Annual National Meeting of the Wildlife Society, Calgary, Canada (2)
The 65th Annual Midwest Fish and Wildlife Conference, Indianapolis, IN
Purdue University Forestry and Natural Resources Symposium, W. Lafayette, IN

The Purdue University Chapter of the Wildlife Society, W. Lafayette, IN

GRADUATE STUDENTS SUPERVISED

Theses and Dissertations Supervised

(b) (6)(b) (6)(b) (6)	M.S.	Spatial ecology of black and turkey vultures in the southeastern U.S.; University of Georgia; December 2015
(b) (6)(b) (6)	M.S.	The effect of habitat type, carcass size, and scavenger exclusion on vertebrate scavenging communities in the Coastal Plain of the Southeast; University of Georgia; December 2015
(b) (6)(b) (6)	M.S.	Occupancy, distribution, and abundance of carnivore populations within the Chernobyl Exclusion Zone; University of Georgia; May 2016
(b) (6)(b) (6)(b) (6)	M.S.	Exposure of game species to trace elements and radiocesium on the Savannah River Site in South Carolina; May 2016
(b) (6)(b) (6)	M.S.	Effects of industrial contamination on carrion-associated beetles; December 2016
(b) (6)(b) (6)	M.S.	Development of population monitoring techniques for wild pigs (*Sus Scrofa*); December 2016
(b) (6)(b) (6)	M.S.	Biomagnification of radiocesium within aquatic food webs; to be completed December 2017
(b) (6)(b) (6)	M.S.	Ecotoxicology and disease ecology of semi-aquatic mammals in the southeastern U.S.; to be completed May 2018
(b) (6)(b) (6)	M.S.	Community composition of mammals within the Fukushima Exclusion Zone; to be completed December 2018
(b) (6)(b) (6)	Ph.D.	Niche overlap and competition between gray fox and coyotes in the southeastern U.S.; to be completed December 2020
(b) (6)(b) (6)	M.S.	Spatio-temporal patterns of wild pig depredation to agricultural crops; to be completed May 2019
(b) (6)(b) (6)	Ph.D.	Reproductive ecology of wild pigs in the southeastern U.S.; to be completed December 2022

(b) (6)(b) (6)	M.S.	Distribution and efficiency of vertebrate scavengers across a gradient of human presence in Fukushima, Japan; to be completed December 2019
(b) (6)(b) (6)(b) (6)	M.S.	Co-supervised with Guha Dharmarajan; to be completed December 2019
(b) (6)	M.S.	Co-supervised with Guha Dharmarajan; to be completed December 2019
(b) (6)(b) (6)	Ph.D.	Co-supervised with Guha Dharmarajan; to be completed December 2020

Undergraduate Theses/REU's Supervised

(b) (6)(b) (6)	Fate and scavenging community composition associated with avian nestling carcasses; May 2016
(b) (6)(b) (6)(b) (6)	Surveillance for ticks and *Babesia* infections in wild pigs (*Sus scrofa*) from South Carolina; December 2016
(b) (6)(b) (6)(b) (6)	Bioaccumulation of radiocesium and mercury in diving and dabbling ducks at Four-mile creek on the Savannah River Site; August 2016
(b) (6)(b) (6)	Accumulation of radiocesium in bullfrog tadpoles in a contaminated effluent canal on the SRS; August 2017

Postdocs Supervised

(b) (6)(b) (6)	(2014-2015)	University of Georgia
(b) (6)	(2015-2017)	University of Georgia
(b) (6)(b) (6)(b) (6)	(2016-Present)	University of Georgia

Student Committees

(b) (6)(b) (6)	Ph.D. (2012)	Purdue University
(b) (6)(b) (6)	M.S. (2015)	University of Georgia
(b) (6)(b) (6)(b) (6)	Ph.D. (2017)*	University of Florida
(b) (6)(b) (6)	M.S. (2015)	University of Georgia
(b) (6)(b) (6)	MNR (2016)	University of Georgia
(b) (6)	Ph.D. (2018)*	University of Georgia
(b) (6)(b) (6)	B.S. (2015)¥	University of Georgia
(b) (6)(b) (6)	M.S. (2017)*	University of Georgia
(b) (6)(b) (6)	Ph.D. (2019)*	University of Georgia

(b) (6)(b) (6)(b) (6)	B.S. (2016)¥	University of Georgia
(b) (6)(b) (6)(b) (6)	B.S. (2016)¥	University of Georgia
(b) (6)	Ph.D. (2019)*	Mississippi State University
(b) (6)(b) (6)	Ph.D. (2019)*	University of Georgia
(b) (6)(b) (6)	Ph.D. (2018)*	University of Georgia
(b) (6)(b) (6)	M.S. (2018)	University of Georgia
(b) (6)(b) (6)	MNR (2017)	University of Georgia
(b) (6)(b) (6)	Ph.D. (2021)*	University of Georgia

** indicates anticipated graduation date*

¥ indicates undergraduate student thesis

PROFESSIONAL AFFILIATIONS

The Wildlife Society
American Society of Mammalogists
Ecological Society of America
Sigma Xi

SERVICE (University, Professional, Community)

- Reviewer: Scientific Reports, PlosOne, Wildlife Research, Canadian Journal of Zoology, Human-Wildlife-Interactions, Journal of Mammalogy, Journal of Wildlife Management, Journal of Wildlife Rehabilitation, Mammalian Biology, Wildlife Biology, Landscape Ecology, Ibis, Landscape and Urban Planning, Northeastern Naturalist, Wildlife Damage Management Proceedings (2013), Wildlife Society Bulletin, Polar Biology, American Midland Naturalist
- Associate Editor, Human-Wildlife Interactions (2016-present)
- External Reviewer, 2014 Purdue University Postdoctoral Application Review
- Guest Associate Editor, 2013 Wildlife Damage Management Proceedings
- TWS working group member: Wildlife Damage Management, Wildlife Diseases
- Chair: Research Subcommittee, National Wild Pig Task Force (2015-present)
- Member: SREL/Warnell Energy Ecologist Search Committee (2014)
- Member: Warnell Graduate Affairs Committee (2016-present)
- Member: SREL Animal Care and Use Committee (2013-2016)
- Member: SREL Campus Relations Committee (2016-present)
- Member: SREL Computer Committee (2012-2014)
- Member: SREL GIS Committee (2012-2015)
- Member: SREL Seminar Committee (2012-2015)
- Member: SREL Executive Committee (2015-present)
- Member: SREL Graduate Programs Committee (2015-present)
- Member: SC Wild Pig Task Force (2013-present)

NAME Mark S. Boyce

ADDRESS

Department of Biological Sciences
University of Alberta
Edmonton, AB T6G 2E9
Canada

PHONE

Office: (780)492-0081
Home: (b) (6)(b) (6)
Fax: (780)492-9234
Cell: (b) (6)(b) (6)

e-mail: boyce@ualberta.ca

EDUCATION

(b) (6) Ph.D., Yale University, New Haven, Connecticut.
(b) (6) M.Phil., Yale University, New Haven, Connecticut.
(b) (6) M.S., University of Alaska, Fairbanks.
(b) (6) B.S., Iowa State University, Ames.

ACADEMIC POSITIONS

Professor of Ecology, and Alberta Conservation Association Chair in Fisheries and Wildlife, 1999-present (Endowed Chair renewed 2012 July 1), Department of Biological Sciences, University of Alberta, Edmonton.

Vallier Chair of Ecology, and Wisconsin Distinguished Professor (UW-System), 1993-1999, College of Natural Resources, University of Wisconsin, Stevens Point.

Professor, 1987-1993, Department of Zoology and Physiology, University of Wyoming, Laramie.

Associate Professor, 1981-1987, Department of Zoology and Physiology, University of Wyoming, Laramie.

Visiting Professor, 1984-1985, Department of Mathematics, University of Wyoming, Laramie.

Postdoctoral Research Fellow, 1982-1983, Animal Ecology Research Group, Department of Zoology, University of Oxford.

Assistant Professor, 1977-1981, Department of Zoology and Physiology, University of Wyoming, Laramie.

Instructor, 1976-77, Department of Zoology and Physiology, University of Wyoming, Laramie.

HONORS AND AWARDS

C. Hart Merriam Award, 2017, American Society of Mammalogists, June 24.
Special Recognition Team Award (with Evelyn H. Merrill), 2017, Alberta Chapter of The Wildlife Society, March 11.
Mirosław Romanowski Medal, 2016, Royal Society of Canada, November 18.
ASTech Award, Outstanding Leadership in Alberta Science, 2014, Alberta Science and Technology Leadership Foundation, October.
Fellow, Royal Society of Canada, inducted 2014 November.
President's Award, 2014, Safari Club International, April.
Emerald Award, 2013, Montane Research Program, Province of Alberta, June.
Publication of the Year Award, 2013, Alberta Chapter of The Wildlife Society, March.
TWS Fellow, lifetime award, 2012, The Wildlife Society, Bethesda, Maryland, USA, October.
Best Wildlife Publication Award "Popular Category," 2012, Alberta Chapter of The Wildlife Society, March.
Killam Annual Professorship, 2011-12, University of Alberta.
Publication of the Year Award, 2011, Alberta Chapter of The Wildlife Society.
Award of Merit, 2010, Alberta Trappers Association.
William Rowan Distinguished Service Award, 2008, The Wildlife Society.
International Conservationist of the Year, 2007, Safari Club International Foundation.
Erskine Fellowship, 1999, Canterbury University, Christchurch, New Zealand.
Phi Kappa Phi, 1998, University of Wisconsin-Stevens Point.
University Scholar Award, 1996, University of Wisconsin-Stevens Point.
Chancellor's Merit Award, 1996, University of Wisconsin-Stevens Point.
Faculty Scholar Award, 1994, Sigma Xi-University of Wisconsin-Stevens Point Chapter.
Distinguished Professorship, 1993, 1999 University of Wisconsin System, Madison.
Vallier Chair of Ecology, 1993, University of Wisconsin-Stevens Point.
Outstanding Research Merit Award, 1993, College of Arts and Sciences, Univ. Wyoming.
Fulbright Scholar to India, 1992, U.S. Educational Foundation in India, Bangalore.
Senior Research Fellow, 1991-92, American Institute of Indian Studies, Bangalore.
Kuehn Professorship Award, 1984-85, College of Arts and Sciences, University of Wyoming.
N.A.T.O. Postdoctoral Fellowship, 1982-83, National Science Foundation, Univ. Oxford, UK.
Academy Exchange to Poland, 1982, National Academy of Sciences, Jagiellonian University.
Outstanding Achievement Award, 1974, University of Alaska, Fairbanks.

SABBATICALS

2017, Centre of Excellence for Biosecurity Risk Analysis (CEBRA), University of Melbourne, AUSTRALIA.

2010-11, University of Queensland, Brisbane, AUSTRALIA;
Imperial College London, Silwood Park, U.K.

2003-04, University of British Columbia, Vancouver, CANADA.

1991-92, Fulbright Fellow/American Institute of Indian Studies, Centre for Ecological Sciences and Centre for Theoretical Studies, Indian Institute of Science, Bangalore, INDIA.

1982-83, NATO Postdoctoral Fellowship, Department of Zoology, University of Oxford, U.K.

OTHER POSITIONS

1989-1993, Director, UW-National Park Service Research Center, University of Wyoming.

PUBLICATIONS

Books:

Boyce, M. S., and A. Haney. 1997. *Ecosystem Management: Applications for Sustainable Forest and Wildlife Resources.* Yale University Press, New Haven, Conn. 361pp.

Thorne, E. T., M. S. Boyce, P. Nicoletti, and T. J. Kreeger (eds.). 1997. *Brucellosis, Bison, elk, and Cattle in the Greater Yellowstone Area: Defining the Problem, Exploring the Solutions.*Wyoming Game and Fish Department, Cheyenne, Wyo. 219pp.

Keiter, R. B., and M. S. Boyce. 1991. *The Greater Yellowstone Ecosystem: Redefining America's Wilderness Heritage*. Yale University Press, New Haven, Conn. 425pp.

Boyce, M. S. 1989. *The Jackson Elk Herd: Intensive Wildlife Management in North America.*Cambridge University Press, Cambridge, U.K., 305 pp.

Boyce, M. S., ed. 1988. *Evolution of Life Histories of Mammals*. Yale Univ. Press, New Haven, Conn., 373 pp.

Boyce, M. S., and L. D. Hayden-Wing. 1979. *North American Elk: Ecology, Behavior and Management*. Univ. Wyoming, Laramie, 294pp.

Scientific Articles:

Morehouse, A. T., A. E. Loosen, and M. S. Boyce. 2017. Rubbing behaviour, fitness, and habitat selection in grizzly bears. *Nature* (manuscript).

Ladle, A., R. Steenweg, B. Shepherd, and M. S. Boyce. 2017. The role of human recreation in shaping patterns of grizzly bear-black bear co-occurrence. *PLoS ONE* (submitted).

Loosen, A., A. T. Morehouse, and M. S. Boyce. 2017. Land tenure shapes black bear density and abundance on a multi-use landscape. *J. Wildl. Manage*. (under revision).

Krawchuk, K. E., K. H. Knopff, N. F. Webb, P. J. Jones, M. S. Boyce, and E. H. Merrill. 2017. Is niche separation between wolves (*Canis lupus*) and cougars (*Puma concolor*) realized in the Rocky Mountains of Canada? *Can. J. Zool*. (under revision).

Morehouse, A., J. Tigner, and M. S. Boyce. 2017. Conservation dollars fund livestock depredation compensation. *J. Environ. Manage.* (under revision).

Scrafford, M. A., and M. S. Boyce. 2017. A comparison of wolverine (*Gulo gulo luscus*) movement, foraging, and habitat selection in the home range and during dispersal. *J. Wildl. Manage.* (JWM-17-0337, submitted).

Ladle, A., T. Avgar, M. Wheatley, G. Stenhouse, S. Nielsen, and M. S. Boyce. 2017. Grizzly bear response to spatio-temporally variable human recreational activity. *J. Appl. Ecol*. (under revision, APPL-2017-00331).

Mallory, C., M. Campbell, and M. S. Boyce. 2017. Climate influences body condition and synchrony of herd size in three caribou populations in Arctic Canada. *Polar Biol.* (revision submitted, POBI-D-17-00033R1).

Scrafford, M. A., and M. S. Boyce. 2017. Wolverine foraging plasticity in the northern boreal forest. *J. Mammal*. (under revision).

Scrafford, M. A., T. Avgar, R. Heeres, and M. S. Boyce. 2017. Roads elicit negative movement and habitat selection responses by wolverines (*Gulo gulo luscus*). *Behav. Ecol*. (revision submitted, BEHECO-2017-0279).

Boyce, M. S., and P. Krausman, editors. 2017. Mountain sheep management in the United States of America and Canada. *J. Wildl. Manage.* (in press).

Bowyer, R. T., T. Kingston, J. R. Goheen, J. Rachlow, and M. S. Boyce. 2017. Conservation and management of the world's mammals. *J. Mammal*. (in press).

Boyce, M. S., C. Mallory, A. Morehouse, C. Prokopenko, M. Scrafford, and C. Warbington. 2017. Defining landscapes and scales to model landscape–organism interactions. *Curr. Landsc. Ecol. Reports* (doi: 10.1007/s40823-017-0027-z).

Mallory, C. D., and M. S. Boyce. 2017. Observed and predicted effects of climate change on Arctic caribou and reindeer. *Envir. Rev*. (doi: 10.1139/er-2017-0032).

Morehouse, A. T., and M. S. Boyce 2017. Troublemaking carnivores: conflicts with humans in a diverse assemblage of large carnivores. *Ecol. Soc.* **22**(3):4 (doi.org/10.5751/ES-09415-220304).

Thurfjell, H., S. Ciuti, and M. S. Boyce. 2017. Learning from the mistakes of others: how female elk (*Cervus elaphus*) adjust behaviour with age to avoid hunters. *PLoS ONE* **12**(6): e0178082 (doi.org/10.1371/journal.pone.0178082).

Paton, D. G., S. Ciuti, M. Quinn, and M. S. Boyce. 2017. Hunting exacerbates the response to human disturbance in large herbivores while migrating through a road network. *Ecosphere* **8**(6):e01841. (doi: 10.1002/ecs2.1841).

Morehouse, A., and M. S. Boyce. 2017. Male dominance interferes with intercept feeding of grizzly bears. *Ursus* **28**(1):66–80.

Avgar, T., S. Lele, J. Keim, and M. S. Boyce. 2017. Relative Selection Strength: quantifying effect size in resource- and step-selection inference. *Ecol. Evol*. **7**:5322–5330 (doi: 10.1002/ ece3.3122).

Roberts, D., V. Bahn, S. Ciuti, M. S. Boyce, J. Elith, G. Guillera-Arroita, S. Hauenstein, J. Lahoz-Monfort, B. Schroder, W. Thuiller, D. Warton, B. Wintle, F. Hartig, and C. Dormann. 2017. Cross-validation strategies for data with temporal, spatial, hierarchical, or phylogenetic structure. *Ecography* **40**:913–929 (doi: 10.1111/ecog.02881).

Boyce, M. S. 2017. Beaver population ecology and trapline management. *Internat. Trapper* 2017(spring):10–13.

Erickson, M. E., C. Found-Jackson, and M. S. Boyce. 2017. Habitat associations with counts of declining Western Grebes in Alberta, Canada. *Avian Conserv. Ecol*. **12**(1):12. (doi.org/10.5751/ACE-00980-120112).

Scrafford, M. A., T. Avgar, B. Abercrombie, and M. S. Boyce. 2017. Wolverine habitat selection in response to anthropogenic disturbance in the western Canadian boreal forest. *For. Ecol. Manage.* **395**:27–36.

Prokopenko, C., M. S. Boyce, and T. Avgar. 2017. Characterizing wildlife behavioural responses to roads using integrated step selection analysis. *J. Appl. Ecol.* **54**: 470–479 (doi: 10.1111/1365-2664.12768).

Boyce, M. S., and R. Corrigan. 2017. Moose survey app for population monitoring. *Wildl. Soc. Bull.* **41**(1):125–128 (doi: 10.1002/wsb.732). [cover photo].

Ladle, A., T. Avgar, M. Wheatley, and M. S. Boyce. 2017. Predictive modeling of ecological patterns along linear-feature networks. *Meth. Ecol. Evol*. **8**:329–338. (doi: 10.1111/2041-210X.12660).

Gilbert, S. L., K. J. Hundertmark, D. K. Person, M. S. Lindberg, and M. S. Boyce. 2017. Behavioral plasticity in a variable environment: snow depth and habitat interactions drive deer movement in winter. *J. Mammal*. **98**:246–259.

Prokopenko, C., T. Avgar, and M. S. Boyce. 2017. Extent-dependent habitat selection in a migratory large herbivore: road avoidance across scales. *Landsc. Ecol*. **32**:313–325.

Christie, K., W. F. Jensen, and M. S. Boyce. 2017. Resource selection by pronghorn in relation to land cover, roads, and oil and gas development in North Dakota. *J. Wildl. Manage.* **81**:154–162. [cover photo].

Cristescu, B., G. B. Stenhouse, B. Goski, and M. S. Boyce. 2016. Grizzly bear space use and fitness in relation to human habitation and access. *Human Wildl. Interact*. **10**(2):240–257.

Salari, A., M. Zakaria, and M. S. Boyce. 2016. Habitat use by two tropical waterfowl in central Malaysia. *Wildfowl* **66**:41–59.

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CONTRACTS & GRANTS

Funded Projects as PI

Grant Completed	Amount Awarded	Funding Agency
Lynx cycles and barriers: dispersal versus climate change in flat-lining populations		
03/31/2011	$27,500	Alberta Conservation Association
03/31/2011	$20,000	MEC c/o Red Deer Naturalists
04/30/2013	$10,000	Alberta Biodiversity Monitoring Institute
Grizzly bear response to open-pit mining: implications for management and conservation		
03/31/2011	$4,700	International Assoc. for Bear Research & Management
03/31/2011	$2,500	AB Sports Recreation Parks & Wildlife Foundation
03/31/2011	$31,000	Alberta Conservation Association
04/30/2011	$4,400	Canadian Wildlife Federation
12/02/2011	$6,000	TD Friends of the Environment Foundation
03/31/2012	$2,000	Safari Club International NAB – Hunting Heritage Fund
ICCB 2010 (24th International Congress for Conservation Biology)		
03/03/2011	$99,289	ICCB Registration account
12/31/2013	$90,066	Carbon tax project account
02/03/2011	$234,335	Cash sponsor support (34 sponsors)
02/03/2011	$191,079	In-kind sponsor support
Cougar distribution and prey selection SW Alberta		
03/31/2011	$32,700	Alberta Conservation Association
09/30/2011	$3,000	AB Sports Recreation Parks & Wildlife Foundation
09/30/2012	$1,500	AB Sports Recreation Parks & Wildlife Foundation
Space use of urban deer		
04/30/2011	$2,134	AB Sports Recreation Parks & Wildlife Foundation
03/31/2012	$2,000	Alberta Conservation Association
Ecology of cougar, human and prey interactions in the Cypress Hills		
12/31/2011	$3,000	AB Sports Recreation Parks & Wildlife Foundation
03/31/2012	$20,000	SK Environment & Resource Management Fish &

		Wildlife Division Fund
03/31/2012	$2,000	Safari Club International NAB – Hunting Heritage Fund
03/31/2012	$2,500	Cypress Hills Cottage Assoc Donation
Home range development in elk		
04/22/2013	$9,500	TD Friends of the Environment Foundation
03/31/2013	$5,325	Safari Club International NAB – Hunting Heritage Fund
03/31/2012	$21,500	Alberta Conservation Association
Human access management in central-western Alberta: implications for grizzly bears		
03/31/2013	$5,200	Safari Club International NAB – Hunting Heritage Fund
03/31/2013	$2,000	AB Sports Recreation Parks & Wildlife Foundation
03/31/2013	$33,050	Alberta Conservation Association
03/31/2013	$14,000	AB Fish & Game Assoc. - Minister's Special License
04/22/2013	$10,200	TD Friends of the Environment Foundation
03/31/2014	$5,000	Safari Club International NAB – Hunting Heritage Fund
03/31/2014	$35,000	ATPR
03/31/2014	$3,300	AB Sports Recreation Parks & Wildlife Foundation
03/31/2014	$25,000	Alberta Conservation Association
06/04/2014	$10,600	TD Friends of the Environment Foundation
03/31/2015	$3,650	Safari Club International NAB – Hunting Heritage Fund
03/31/2015	$30,000	Alberta Conservation Association
03/31/2015	$10,115	International Assoc. for Bear Research & Management
08/31/2015	$9,300	AB Fish & Game Assoc. - Minister's Special License
Efficacy of intercept feeding in reducing spring grizzly bear-ranching conflicts		
03/31/2013	$3,480	Safari Club International NAB – Hunting Heritage Fund
04/22/2013	$5,000	TD Friends of the Environment Foundation
03/31/2014	$7,250	International Assoc. for Bear Research & Management
03/31/2014	$3,000	Safari Club International NAB – Hunting Heritage Fund
06/30/2014	$4,500	AB Sports Recreation Parks & Wildlife Foundation
03/31/2015	$6,560	International Assoc. for Bear Research & Management
03/31/2015	$4,100	Safari Club International NAB – Hunting Heritage Fund
Restoring grizzly bear populations to southern Alberta: Monitoring and conflict resolution		
02/28/2014	$12,000	Environment Canada - Science Horizons
11/25/2014	$12,000	Environment Canada - Science Horizons
03/31/2013	$9,020	AB Conservation Association – Grants in Biodiversity
03/31/2014	$19,400	AB Conservation Collaboration – Minister's Special License Program
05/31/2014	$24,393	International Assoc. for Bear Research & Management
06/04/2014	$5,000	TD Friends of the Environment Foundation
03/31/2015	$12,500	AB Fish & Game Assoc. - Minister's Special License
05/31/2015	$26,788	International Assoc. for Bear Research & Management
06/30/2015	$25,240	Safari Club International Foundation
11/01/2014	$177,000	Waterton Biosphere Reserve Association c/o Alberta Innovates
Grizzly Bear Monitoring Project (GBMP)		
06/2013 - 06/2014	$25,000	Disney
04/2013 - 03/2014	$10,000	Nature Conservancy Canada Donations
2014 - 2015	$70,000	Royal Dutch Shell Waterton Gas Plant
2012 - 2014	$12,000	Shell Environment

11/2012	$10,000	CPAWS Donation
Effects of industry on wolverine ecology in the boreal forest of northern Alberta		
03/31/2014	$3,985	Safari Club International NAB – Hunting Heritage Fund
03/31/2014	$19,500	Wildlife Conservation Society of Canada
03/31/2014	$4,893	AB Sports Recreation Parks & Wildlife Foundation
03/31/2014	$20,000	Alberta Conservation Association
06/04/2014	$9,845	TD Friends of the Environment Foundation
01/15/2015	$9,300	Wildlife Conservation Society of Canada
03/31/2015	$75,000	Alberta Conservation Association
07/31/2015	$5,000	AB Fish & Game Assoc. - Minister's Special License
07/31/2015	$4,000	Safari Club International NAB – Hunting Heritage Fund
07/31/2015	$17,575	The Wolverine Foundation
10/31/2015	$11,140	TD Friends of the Environment Fund
12/31/2015	$10,000	Wildlife Conservation Society of Canada
03/31/2016	$68,138	Alberta Conservation Association
05/31/2016	$4,000	Safari Club International NAB – Hunting Heritage Fund
07/2013 - 03/2015	$55,000	Dene Tha First Nations Donation
2014-2016	$45,000	Husky Oil Operations Ltd. Donation
03/31/2016	$12,000	TD Friends of the Environment Fund
04/30/2017	$6,275	The Wolverine Foundation
Access management for wildlife conservation		
05/04/2014	$834,306	Shell's Contribution Can/NSERC CRD
05/04/2014	$699,510	NSERC Collaborative Research & Development Grants
An evaluation of historical mule deer fawn recruitment in North Dakota		
06/30/2014	$38,892	ND Game & Fish Department
Response by elk to vehicle disturbance on winter range		
12/31/2015	$3,600	AB Fish & Game Assoc. - Minister's Special License
12/31/2015	$3,000	Safari Club International NAB – Hunting Heritage Fund
Analysis of bighorn sheep data from Alberta Environment and Parks		
12/31/2015	$4,800	Alberta Professional Outfitters Society
A retrospective analysis of Pronghorn fawn recruitment and demographic data in North Dakota		
12/31/2015	$59,092	ND Game & Fish Department
Hunting for sustainability: Using bear rubs to monitor black bear populations in southwestern Alberta		
03/31/2016	$4,500	Safari Club International NAB – Hunting Heritage Fund
03/31/2016	$15,000	AB Fish & Game Assoc. - Minister's Special License
03/31/2016	$25,000	Alberta Conservation Association
10/01/2016	$10,000	Waterton Biosphere Reserve Association
09/30/2016	$9,500	Alberta Professional Outfitters Society
03/31/2017	$11,300	Alberta Conservation Association
03/13/2017	$6,000	International Assoc. for Bear Research & Management
03/31/2017	$4,150	AB Fish & Game Assoc. - Minister's Special License
Evaluating the efficacy of predator management and nesting structures for duck management in AB		
06/30/2017	$30,353	Delta Waterfowl Foundation
03/31/2017	$7,100	AB Fish & Game Assoc. - Minister's Special License
12/31/2017	$15,000	Mitacs
03/31/2018	$2,500	Safari Club International NAB – Hunting Heritage Fund
Ecology, density, and distribution of sitatunga in central Uganda		
03/31/2016	$2,500	Safari Club International NAB – Hunting Heritage Fund

07/31/2016	$24,911	Dallas Safari Club
10/31/2016	$6,540	Safari Club International - San Diego Chapter
12/23/2017	$15,000	Mitacs
11/01/2017	$26,311	Dallas Safari Club
06/30/2017	$3,000	Safari Club International NAB – Hunting Heritage Fund
03/31/2018	$3,000	Safari Club International NAB – Hunting Heritage Fund
Cougar project in Cadomin, Alberta		
08/31/2018	$40,000	Wild Sheep Foundation of Alberta
03/31/2019	$15,000	AB Conservation Association – Grants in Biodiversity
03/31/2018	$9,000	Safari Club International NAB – Hunting Heritage Fund
Evaluating alternate elk harvest strategies in SW Alberta		
03/31/2018	$7,650	Alberta Conservation Association
03/31/2018	$3,500	Safari Club International NAB – Hunting Heritage Fund
Qamanirjuaq barren-ground caribou habitat use and population ecology		
06/30/2017	$4,000	World Wildlife Fund - Canada
Wildlife in an Increasingly Variable World		
03/31/2016	$447,600	NSERC – Discovery Grants Program
Habitats drive population biology		
03/31/2017	$26,000	NSERC – Discovery Grants Program
Spatial and Temporal Variability Influences on Ecology and Conservation		
03/31/2022	$220,000	NSERC – Discovery Grants Program
Grazing practices influence on carbon sequestration and storage		
03/31/2021	$2,623,444	Agriculture Green-House Gas Program

PROFESSIONAL AFFILIATIONS AND ACTIVITIES

Memberships in professional societies

American Society of Mammalogists (life member).
Canadian Society for Ecology and Evolution.
Ecological Society of America.
Gamma Sigma Delta (honorary).
Phi Kappa Phi (honorary).
Royal Society of Canada; fellow, 2014.
Sigma Xi (associate member 1975, full member 1978, Univ. Alberta Chapter 2000).
Society for Conservation Biology.
The Wildlife Society (Certified Wildlife Biologist, 2000; Fellow, 2012).
Wild Sheep Foundation (life member, 2003).
Willmore Wilderness Foundation (life member, 2007).

Editor-in-Chief: *Journal of Wildlife Management*, 1995-1997.

Editor: *Ecology* and *Ecological Monographs*, 2001-2006.

Associate Editor: *I.M.A. Journal of Mathematics Applied in Medicine and Biology*, 1983-1994.

Associate Editor: *Journal of Wildlife Management*, 2017.

Editorial Board: *Environmental Conservation*, 2007-2010. *Oxford Bibliographies in Ecology*, 2010-present. *Animal Biotelemetry*, 2012-present.

Academic Editor: *PLoS ONE*, 2010-present.

PROFESSIONAL SERVICES (last 5 yrs)

Organized symposium on "Uncertainty in ecology and conservation" for the Canadian Society for Ecology and Evolution and Canadian Section of The Wildlife Society. Victoria, British Columbia, 2017 May 8.
Past-president, Canadian Section of TheWildlife Society, July 2016-May 2017.
President, Canadian Section of The Wildlife Society, March 2015-July 2016.
Program Chair, The Wildlife Society Annual Conference, Winnipeg, October 2015.
Organized symposium on "Movement models to resource selection functions" for the Annual Conference of The Wildlife Society, Winnipeg, October 2015.
Organized symposium on "Understanding individuals to conserve populations" for the Annual Conference of the Canadian Society for Ecology and Evolution, 2015 May 24.
Workshop on Resource Selection Functions, Saskatchewan Chapter of The Wildlife Society, Saskatoon, 2015 March 13.
Banting Postdoctoral Fellowships Review Committee, NSERC, 2011-2014.
Board of Directors, North American Section, Society for Conservation Biology, 2009-present.
Director, Northern Alberta Chapter of the Safari Club International, 2007-present.
Alberta Conservation Association, Board of Directors, 2002-present.
Chair, Operation Standards Review Committee, Board of Directors, Alberta Conservation Association, 2002-present.

INVITED PRESENTATIONS (last 5yrs)

2017, "Predator-prey systems: the wolves in Yellowstone," Royal Society of Victoria, Melbourne, Australia, September 21.
2017, "Topics in non-linear dynamics in population ecology," Quantitative and Applied Ecology (QAEco), School of Biological Sciences, University of Melbourne, Australia, August 17.
2017, "Habitat selection by mammals," Symposium on Telemetry Methods, International Mammalogical Congress, Perth, Australia, July 11.
2017, "Natural selection for life histories in seasonal environments," Symposium on Ecological and Evolutionary Dynamics in Fluctuating Environments for the Canadian Society for Ecology and Evolution, Victoria, BC, May 8.
2016, "Species at risk in Alberta," Inside Education, Edmonton, September 29.
2016, "Neglected but fundamental: 5 understudied topics in population biology," Distinguished Ecologist Lecture, Colorado State University, April 22.
2016, "North America's Energy Policy," Distinguished Ecologist Lecture, Colorado State University, April 21.
2016, "Compensation and density dependence," Invited Keynote Presentation. Predator-prey Conference, Columbia Mountains Institute, Revelstoke, BC, April 5.
2016, "Neglected but fundamental: 5 understudied topics in population biology," Mathematical Biology Seminar, University of Alberta, March 7.

2015, "Spatial ecology meets population biology," Invited Symposium Presentation, Canadian Society for Ecology and Evolution, Saskatoon, May 22.
2015, "Black bears on the tangled bank," Invited Symposium Presentation, Canadian Society for Ecology and Evolution, Saskatoon, May 24.
2015, "Optimizing cervid harvests in variable environments," Plenary address, Western States and Provinces Deer and Elk Conference, Canmore, May 13.
2015, "Canada's Energy Policy, The Urgent Need for Science," Plenary address, Alberta Chapter of The Wildlife Society, Edmonton, March 21.
2015, "Estimating resource selection functions in R," AGM of the Canadian Section of The Wildlife Society, Saskatoon, March 13.
2014, "Canada's Energy Policy: The Urgent Need for Science," Royal Society of Canada, Quebec City, November 20.
2014, "Selection functions: statistics, interpretations, and applications," Webinar for the Alberta Conservation Association, May 12.
2014, "Trophic cascades in Yellowstone," Plenary Address, Alaska Chapter of The Wildlife Society, Anchorage, April 1.
2014, "Workshop on resource selection functions," Alaska Chapter of The Wildlife Society, Anchorage, March 31.
2014, "Does fear reduce effects of ungulates on vegetation?" Gordon Conference on Predator-Prey Interactions, Ventura, California, January 8.
2013, "Moving into the digital age: a moose app for citizen science among hunters," Canadian Section of The Wildlife Society, Symposium on Citizen Science, Canmore, Alberta, March 9.
2013, "Selection functions: statistics, interpretations, and applications," Webinar for the Canadian Section of The Wildlife Society, January 25.
2013, "Selection, occupancy, and persistence," Morrison Lecture, Stanford University, Jan 16.
2012, "Wolf-caused Trophic Cascades in Yellowstone: Torrent or Trickle?" Symposium at The Wildlife Society Annual Conference, Portland, October 19.
2012, "Critical habitats for the critically endangered Greater Sage-Grouse," Plenary Address, CONFOR West, Banff, February 3.

CONTRIBUTED PAPERS (recent)

2016, "Science and bighorn management." Alberta Chapter of The Wildlife Society, Drumheller (March 5).
2015, "Canada's energy policy: the urgent need for science." Canadian Section of The Wildlife Society, Saskatoon, Saskatchewan (March 14).
2014, "Are terrestrial trophic cascades limited to parks and protected areas?" Alberta Chapter of The Wildlife Society, Jasper, Alberta. (March 8).
2014, "Conflicting views on trophic cascades in Yellowstone," Canadian Section of The Wildlife Society, Universite Laval, Quebec City, Quebec (March 29).
2012, "Managing Moose Populations by the Seat of Your Pants," Poster presentation, The Wildlife Society, Portland (Oct 19).
2012, "Managing Moose Populations by the Seat of Your Pants," National Fish and Wildlife Conservation Congress, Ottawa (May 29).

PUBLIC SERVICE/POPULAR PRESENTATIONS (recent)

2017, "Canada's energy policy: the urgent need for science," Mayfield Rotary, Edmonton (January 4).
2016, "Canada's energy policy: the urgent need for science," Edmonton South Rotary Club (November 23).
2016, "Energy development and species at risk in Canada," Sunrise Rotary Club, Fort Edmonton (September 30).
2016, "Moose app for moose management in Alberta," Strathcona Rotary Club, Edmonton (September 6).
2016, "Bighorn management in Alberta," Safari Club International, Edmonton (January).
2015, "Licenced hunting and trapping in Canada: funding for management and research," House of Commons Standing Committee on Environment and Sustainable Development, Ottawa (March 31).
2013, "Bighorn genetics and the effects of selective harvest," Wild Sheep Foundation, Red Deer, Alberta (March)

COMMITTEES (recent)

2016-2017, Search committee, Fisheries biologist, Dept. Biological Sciences, Univ. Alberta.
2015-present. Alberta Game Policy Advisory Council, Alberta Environment & Parks.
2014-2015, Alberta Game Management Advisory Group, Alberta Environment & Parks.
2015-2016, Grizzly bear harvest policy review, British Columbia Department of Environment.
2013-2014, Search Committee for Campus Alberta Innovates Program (CAIP) Chair, University of Alberta.
2012, Chair, Search Committee for Editor-in-Chief, *Conservation Biology*, Society for Conservation Biology.
2007-present, Conservation Committee, Alberta Chapter The Wildlife Society.

CURRICULUM VITAE

JENNIFER K. FREY

PRESENT ADDRESSES:

Department of Fish, Wildlife, and Conservation Ecology
New Mexico State University
P.O. Box 0003, MSC 4901
Las Cruces, New Mexico 88130

Phone: (575) 640-9782
Email: jfrey@nmsu.edu
Web: http://web.nmsu.edu/~jfrey/

Frey Biological Research
PO Box 294
Radium Springs, NM 88054

Phone: (575) 640-9782
Email: Frey_B_R@fastwave.biz

DEGREES:

Ph.D., Biology. University of New Mexico, Albuquerque, New Mexico. Major professor: Terry L. Yates. Dissertation title: Testing among modes of allopatric speciation: a hypothetico-deductive approach. (b) (6)
M.S., Biology. Emporia State University, Emporia, Kansas. Major professor: Dwight W. Moore. Thesis title: Morphologic variation in the Mexican vole (*Microtus mexicanus*). (b) (6)
B.S., Biology (emphasis in Zoology). Emporia State University, Emporia, Kansas. (b) (6)

WILDLIFE CONSULTING COMPANY

Owner, Frey Biological Research. Radium Springs, New Mexico. 2002-present.

FACULTY POSITIONS:

College Professor and Member of the Graduate Faculty. Department of Fish, Wildlife and Conservation Ecology (FWCE), New Mexico State University (NMSU). 2016 – present.
College Associate Professor and Member of the Graduate Faculty. FWCE, NMSU. 2008 – 2016.
College Assistant Professor and Member of the Graduate Faculty. FWCE, MMSU. August 2002 – 2008.
Assistant Professor. Department of Biology, Eastern New Mexico University (ENMU). 1998-2002.
Research Assistant Professor. Department of Biology, University of New Mexico (UNM). 1995-1998.
Postdoctoral Research Associate. Department of Biology, UNM. 1994-1995.

MUSEUM AND CURATORIAL POSITIONS:

Curator. Wildlife Museum, Department of Fish, Wildlife & Conservation Ecology, NMSU. 2014 - present.
Acting Curator. Wildlife Museum, Department of Fishery and Wildlife Sciences, NMSU. September 2003 - 2013.
Adjunct Curator of Mammals. The Vertebrate Museum, Department of Biology, NMSU. 2003 – present.
Committee Member. Center for Natural History Collections, New Mexico State University. 2008-Present
Research Associate. Mammal Division, Museum of Southwestern Biology (MSB), University of New Mexico. Present
Executive Committee Member. Center for Natural History Collections, New Mexico State University. 2006-2008
Director. Eastern New Mexico University Natural History Museum (ENMUNHM). 1998-2002
Curator of Mammals, Birds, and Frozen Tissue. ENMUNHM. 1998-2002
Board of Trustees, New Mexico Museum of Natural History and Science. 2000-2002
Curatorial Associate. Mammal Division, MSB, UNM. 1994-1998.
Collection Assistant. Frozen Tissues & Biological Materials, MSB. 1990-1994.
Curatorial Assistant. Mammal Division, MSB. 1989-1994.
Curatorial Assistant. Schmidt Museum of Natural History, Emporia State University. 1985-1989

PRE-DOCTORAL PROFESSIONAL POSITIONS:

Allozyme Electrophoresis Laboratory Supervisor. UNM. 1991-1994.
DNA and Karyology Laboratory Supervisor. UNM. 1990, 1992-1994.
Research Assistant. UNM. mtDNA and allozyme variation in the Mexican vole (*Microtus mexicanus*). 1992-1994.
Research Assistantships for Minority High School Students Program Assistant. MSB. Assisted directing student research projects and teaching high school students and teachers. 1993.
Computer Lab Coordinator. Biology Department. UNM. 1993.
Research Assistant. UNM. mtDNA and allozyme variation among migratory races of sandhill crane (*Grus canadensis*). 1990-1991.
Parasitologist. Sevilleta Long-term Ecological Research Site, UNM. 1989.
Fisheries Aid. Kansas Department of Wildlife and Parks, Emporia, Kansas. 1988.
Research Assistant. Emporia State University. Karyotypic relationships among populations of short-tailed shrews (*Blarina*). 1987.
Undergraduate Research Assistant. Emporia State University. Predator avoidance in *Diaptomus* (Crustacea: Copepoda). 1985-1986.

GRADUATE STUDENTS:

- (b) (6)(b) (6). Master's in Environmental Education. Eastern New Mexico University. May 2000.
- (b) (6)(b) (6) Master's thesis title: Island biogeography: Focal species models and their implications for system level relationships. Eastern New Mexico University. May 2002.
- (b) (6)(b) (6) Master's thesis title: Distribution, habitat characteristics, and population demographics of snowshoe hare (*Lepus americanus*) at the extreme southern edge of its geographic range. Eastern New Mexico University. December 2003.
- (b) (6)(b) (6)(b) (6) Master's thesis title: Effects of fuels reduction treatments on mammals in a southwestern mixed coniferous forest. (collaboratively with Jon Boren). New Mexico State University. May 2007.
- (b) (6)(b) (6) Master's thesis title: Mammals of Padre Island National Seashore, Texas. New Mexico State University. May 2008.
- (b) (6)(b) (6)(b) (6) Master's research project topic: Morphologic variation in the gray-footed chipmunk (*Tamias canipes*). New Mexico State University. May 2009.
- (b) (6)(b) (6) Master's thesis title: Elevated surface temperature negatively affects survival of banner-tailed kangaroo rats in the Chihuahuan Desert. (co-advised with Gary Roemer). May 2010.
- (b) (6)(b) (6) Master's thesis title: Multiple scale habitat selection by a small mammal habitat specialist (*Zapus hudsonius luteus*) in a managed floodplain landscape. May 2012.
- (b) (6)(b) (6)(b) (6) Master's thesis title: Effect of forest insect outbreak on the red squirrel (*Tamiasciurus hudsonicus*) in the Sacramento Mountains, New Mexico. December 2012.
- (b) (6)(b) (6) Master's research project topic: Identification of Limiting Factors for the Restoration of Beavers in Northern New Mexico. New Mexico State University. August 2015.
- (b) (6)(b) (6) Master's thesis topic: Predicting spatial factors associated with cattle depredations by the Mexican wolf (*Canis lupus baileyi*) with recommendations for depredation risk modeling. December 2017.
- (b) (6)(b) (6)(b) (6) Master's thesis topic: Using occupancy and species distribution models to identify the distribution and key habitat features of the Oscura Mountains chipmunk and guide monitoring efforts. December 2017.

GRADUATE COMMITTEES:

- (b) (6)(b) (6) Master's thesis title: Ability of western diamondback rattlesnake (*Crotalus atrox*) and prairie rattlesnake (*Crotalus viridis viridis*) to discern the presence of a potential predator based on chemical cues. ENMU. December 2001
- (b) (6)(b) (6) Non-thesis Master's: Applied Ecology. ENMU. May 2002
- (b) (6)(b) (6) Master's thesis title: Conservation genetics of banner-tailed kangaroo rats (*Dipodomys spectabilis*): a molecular ecology perspective. New Mexico State University. Summer 2006.

GRADUATE COMMITTEES (continued):

- (b) (6)(b) (6) Master's thesis topic. Sequencing of Star protein in the endangered Pecos gambusia. Eastern New Mexico University. December 2006.
- (b) (6)(b) (6)(b) (6) Master's thesis title: Development of conservation priority models for the American Pika (*Ochotona princeps*): Implications for conservation. New Mexico State University. May 2010.
- (b) (6)(b) (6) Response of the endangered salt marsh harvest mouse (*Reithrodontomys raviventris*) to tides. Department of Biology, New Mexico State University. May 2012
- (b) (6)(b) (6) An analysis of factors influencing spatial concordance between ecosystem services and biodiversity. Department of Fish, Wildlife and Conservation Ecology, NMSU. December 2013.
- (b) (6)(b) (6) Boldness and natal dispersal in the brush mouse (Peromyscus boylii). Department of Biology, New Mexico State University. May 2014
- (b) (6)(b) (6)(b) (6) Non-thesis masters. Department of Biology, New Mexico State University. May 2014
- (b) (6)(b) (6)(b) (6)(b) (6) The environmental constraints of Rüppell's (*Vulpes rueppellii*), pale (*V. pallida*), and fennec foxes (*V. zerda*), and golden jackals (*Canis aureus*) within the Termit & Tin Toumma Nature Reserve and Cultural Reserve and an analysis of pale fox food habits. Department of Fish, Wildlife and Conservation Ecology, NMSU. May 2014.
- (b) (6)(b) (6)(b) (6) Characterization of vegetation and small mammal communities in Chihuahuan Desert grasslands. Department of Range and Animal Science, New Mexico State University. December 2014.
- (b) (6)(b) (6) Burrowing owl ecology during the post fledging period in an urban and agricultural interface of southern New Mexico. Department of Fish, Wildlife and Conservation Ecology, NMSU. December 2014.
- (b) (6)(b) (6) Distribution of resources for nectar-feeding bats (*Leptonycteris*) in southwestern New Mexico (non-thesis). Department of Fish, Wildlife and Conservation Ecology, NMSU. May 2016.
- (b) (6)(b) (6) Evaluating the performance of satellite tracked and citizen science derived species distribution models to inform the conservation of band-tailed pigeons (*Patagioenas fasciata*). Department of Fish, Wildlife and Conservation Ecology, NMSU. May 2017.
- (b) (6)(b) (6) Distribution and niche partitioning of *Leptonycteris* bats. Department of Fish, Wildlife and Conservation Ecology, NMSU. Current.
- (b) (6)(b) (6) Influence of natural and anthropogenic disturbances on multi-scale black bear (*Ursus americanus*) habitat selection in the Jemez Mountains, New Mexico. Department of Fish, Wildlife and Conservation Ecology, NMSU. Current
- (b) (6)(b) (6) Differential distribution patterns and germination rates of zoochorous dispersed one-seed juniper (*Juniperus monosperma)* seeds. Department of Range and Animal Science, New Mexico State University. Current
- (b) (6)(b) (6) Diet of long-nosed bats (*Leptonycteris*) in New Mexico. Department of Fish, Wildlife and Conservation Ecology, NMSU. Current

UNDERGRADUATE SENIOR HONORS THESIS STUDENT

- (b) (6)(b) (6)(b) (6) Distribution and habitat modeling of the white-nosed coati (*Nasua narica*) in New Mexico. Howard Hughes Medical Institute, Undergraduate Research Scholars Program, New Mexico State University. December 2010.

CAREER STUDENT MENTORING:

Educational Coordinator. New Mexico-Puerto Rico Natural Resource Career Track Program, New Mexico State University. 2012-2013

DISTANCE EDUCATION PROGRAM DEVELOPMENT:

Distance Education Program Developer. Department of Fish, Wildlife and Conservation Ecology, New Mexico State University. 2017-current

TEACHING EXPERIENCE:

New Mexico State University

Undergraduate:

- Introduction to Natural Resources Management; a distance education course (often taught concurrently on NMSU main and branch campuses; Spring 2003-Fall 2004, Fall 2005-2015)
- Contemporary Issues in Wildlife and Natural Resources Management (Fall 2016)
- Ecology and Management of Southwest Ecosystems (Summer 2012)
- Principles of Fish and Wildlife Management (Spring 2011, 2013-2017)
- Wildlife Ecology (Fall 2011)
- Museum Methods (Spring 2006)
- Undergraduate Problems

Graduate/Undergraduate:

- Systems Ecology in Wildlife Management and Laboratory (Fall 2002)
- Advanced Techniques for the Study of Mammalian Diversity (Spring 2004)
- Nongame Wildlife Conservation and Management (Spring 2004)
- Wildlife Damage Management (Spring 2011-2017)
- The Natural History Museum in Modern Society (Spring 2014)
- Wildlife Museum Internship (Fall 2014, Spring/Fall 2016)
- Independent Studies (Graduate Problems, Non-thesis Project, Master's thesis)

Eastern New Mexico University (exclusive of special problems, thesis, etc)

Undergraduate:

- Wildlife Biology (Fall 1998, Spring 1999)
- Introduction to Wildlife and Fisheries Science (each semester 1999-2002)
- Vertebrate Zoology/Vertebrate Zoology Laboratory (Spring 2002)

Graduate/Undergraduate:

- Mammalogy/Mammalogy Laboratory (annual 1998-2001)
- Ornithology/Ornithology Laboratory (annual 1999-2002)

- Wildlife Management/ Wildlife Management Laboratory (annual 1998-2001)

Graduate:

- Biogeography (Spring 1999, Fall 2000)
- Conservation Biology (Fall 1999, 2001)
- Biological Literature (Fall 2001)

University of New Mexico (exclusive of special problems, thesis, etc)

- Mammalogy, lecturer and laboratory assistant
- General Biology Laboratory, instructor
- Biology for Health Related Sciences Laboratory, instructor

Emporia State University

- Ornithology, teaching and laboratory assistant
- General Biology Laboratory, instructor
- Field and Lab Biology, teaching and laboratory assistant

CURRENT UNIVERSITY SERVICE

- College of Agriculture and Home Economics, Distance Education Committee
- Dept. Fish, Wildlife, Conservation Ecology, Curriculum Committee
- Dept. Fish, Wildlife, Conservation Ecology, Curator of Wildlife Museum

PRIOR UNIVERSITY SERVICE (Partial Listing):

- Dept. Fish, Wildlife, Conservation Ecology, Assessment Committee (NMSU 2015-2017)
- College of Agriculture and Home Economics, Assessment Liason (NMSU 2015-2017
- University-wide, Advocates for Scholarly Teaching Committee (NMSU 2017)
- Dept. Fish, Wildlife, Conservation Ecology, Museum Committee, NMSU 2008-2013
- Dept. Fishery & Wildlife Sciences, Graduate Committee, NMSU
- Dept. Fishery & Wildlife Sciences, Freshman advisor, NMSU
- NMSU, Center for Natural History Collections, Executive Committee
- Director of the Natural History Museum, ENMU
- Revised Wildlife and Fishery undergraduate curriculum, ENMU
- Developed graduate program in Applied Ecology, ENMU
- Faculty advisor to pre-professional Fish and Wildlife Club, ENMU
- Numerous faculty search committees, ENMU
- President - Biology Graduate Student Association, UNM.
- Graduate Policy Committee, Department of Biology, UNM.
- Graduate Research Allocations Committee, Dept. Biology, UNM.

CURRENT PROFESSIONAL SERVICE:

- Middle Rio Grande Project, subject matter experts group for New Mexico meadow jumping mouse
- Conservation Committee, Southwestern Association of Naturalists
- Riparian Rodent Advisory Committee, New Mexico Department of Game and Fish

- Peer Reviewer for: National Science Foundation, Journal of Mammalogy, Diversity and Distributions, Journal of Biogeography, Forest Ecology & Management, Global Change Biology, Canadian Journal of Zoology, Ecological Applications, Southwestern Naturalist, Western North American Naturalist; Canadian Field Naturalist; Comparative Medicine;

PRIOR PROFESSIONAL SERVICE (Partial Listing):

- Associate Editor, The Southwestern Naturalist (2008-2015)
- New Mexico Chapter of The Wildlife Society; Local Committee for 2015 meeting
- Share With Wildlife Task Force, New Mexico Department of Game and Fish
- Board of Directors, New Mexico Chapter of the Wildlife Society
- Scientific advisor groups: NM Bat Working Group; NM River Otter; NM Beaver
- Forest Service Region 3 Mammal Sensitive Species Experts Group
- Board of Trustees, New Mexico Museum of Natural History and Science.
- IUCN, Species Survival Commission, Rodent Specialist Group for North America.
- Board of Directors, Southwestern Association of Naturalists.
- Chair, Conservation Committee, Southwestern Association of Naturalists.
- Resolutions Committee, American Society of Mammalogists.
- Education and Graduate Student Committee, American Society of Mammalogists.
- Committee on Women and Minority Issues, American Society of Mammalogists.
- Secretary - Zoology Section, Southwestern and Rocky Mountain Division, AAAS.

PROFESSIONAL SOCIETY AFFILIATIONS:

- American Society of Mammalogists
- International Biogeography Society
- The Wildlife Society
    - Southwest Section
    - New Mexico Chapter
- Southwestern Association of Naturalists
    - Conservation Committee

HONORS AND AWARDS:

Faculty Merit Award. For excellence in teaching, scholarship and service. Eastern New Mexico University. 2001

James H. Nakano Citation Award. For the outstanding scientific paper published in 1994. National Center for Infectious Diseases and Centers for Disease Control and Prevention, 1995.

Albert R. and Alma E. Shadle Fellowship in Mammalogy. The highest annual award given to a single graduate student or recent PhD graduate who has demonstrated a productive and important role in professional mammalogy. American Society of Mammalogists and the Buffalo Foundation, 1992.

University of New Mexico Graduate Achievement Award. Award presented to the two most outstanding graduate students at the University of New Mexico, 1991.

Robert I. Larus Award. For the outstanding student paper presented in 1990. American Association for the Advancement of Science, 1990.

Outstanding Presentation Award. For an outstanding graduate student research paper competition. Southwestern and Rocky Mountain Division, American Association for the Advancement of Science, 1988.

Emporia State University Graduate Achievement Award. Award presented to the outstanding graduate student at Emporia State University, 1987, 1988.

GRANTS AND CONTRACTS (Total = $ 2,346,819^{oo}):

- $32,199 – New Mexico Department of Game and Fish. Distribution, abundance, and habitat selection of the Penasco least chipmunk (*Tamias minimus atristriatus*). 2017
- $ 61,925 - White Sands Missile Range. Oscura Mountain chipmunk monitoring. 2016
- $ 19,772 – New Mexico Department of Game and Fish. Survey for the Penasco least chipmunk (*Tamias minimus atristriatus*). 2015
- $ 62,125 – White Sands Missile Range. Oscura Mountain chipmunk monitoring. 2015
- $ 7,500 - White Sands Missile Range. Survey for meadow jumping mouse (*Zapus hudsonius luteus*). 2015
- $ 59,562 – White Sands Missile Range. Oscura Mountain chipmunk monitoring. 2014
- $ 50,500 – White Sands Missile Range. Survey for meadow jumping mouse (*Zapus hudsonius luteus*). 2014
- $ 6,246 – Marron and Associates. Survey for the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*) at Coyote Creek, Mora County, New Mexico. 2014
- $ 4,000 – The Nature Conservancy. Evaluation of flow-ecology relationships for mammals in the Gila River. 2013-2014.
- $ 10,412 – Bureau of Land Management. Survey for meadow jumping mouse (*Zapus hudsonius luteus*) on the Sacramento River. 2013
- $ 6,450 – New Mexico Department of Game and Fish. Draft survey protocol for the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*). 2012-2013
- $ 19,688 –Evaluation of meadow jumping mouse habitat on Middle Rio Grande. Bureau of Reclamation. 2012-2013
- $ 4,803 – Marron and Associates. Survey for the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*) at Coyote Creek, Mora County, New Mexico. 2012
- $ 15,000 – Carson National Forest. New Mexico meadow jumping mouse surveys. 2011
- $ 11,000 – New Mexico Department of Game and Fish, Share with Wildlife. Development of a habitat suitability model for the Organ Mountain chipmunk & jumping mouse survey of Casa Colorado WMA. 2011
- $ 14,000 – New Mexico Department of Game and Fish, Share with Wildlife. Development of non-invasive monitoring protocols for the Organ Mountain chipmunk. 2010
- $19,924 – U.S. Fish and Wildlife Service. Using pocket gophers to enhance habitat for the endangered Sacramento prickly poppy. 2010.
- $ 4,000 – Review of ecosystem services of the American beaver. WildEarth Guardians. 2010.
- $ 4,999 – Colorado Division of Wildlife. New Mexican meadow jumping mouse survey. 2010
- $ 38,880 – San Juan Public Lands. New Mexican meadow jumping mouse survey.

2009-2010

- $ 25,571 – New Mexico Department of Game and Fish, Share with Wildlife. Cool season activity of the meadow jumping mouse in the Middle Rio Grande (with G. Wright). 2009-2011
- $ 22,647 – Carson National Forest. Abert's squirrel monitoring, 2009. 2009
- $ 25,239 – Carson National Forest. Red squirrel monitoring, 2008. 2009
- $ 20,000 – New Mexico Department of Game and Fish, Share with Wildlife. Montane mammal museum studies. 2008-2010
- $138,807 – U.S. Fish and Wildlife Service/Bureau of Reclamation. Response of the meadow jumping mouse to wetland management in the Middle Rio Grande, New Mexico. 2009-2011.
- $128,948 - Arizona Game and Fish Heritage Grants. Inventory of the meadow jumping mouse in Arizona. 2008-2010.
- $ 21,446 - Carson National Forest. Abert's squirrel monitoring, 2008. 2008
- $ 5,870 – Marron and Associates. Mammal survey of Living Desert Zoo State Park. 2008
- $ 2,500 - Modeling with a keystone indicator species: conservation implications for desert grasslands. T&E Inc. (with Martin Moses and Gary Roemer). 2008-2010
- $ 2,500 – New Mexico State Parks. Mammals of Sugarite Canyon State Park. 2007
- $ 24,000 – New Mexico Department of Game and Fish, Share with Wildlife. Morphological and genetic analysis of *Zapus hudsonius luteus*. 2007
- $ 5,900 – New Mexico Department of Game and Fish. Key to the Rodentia of New Mexico. 2007
- $ 2,500 - Modeling with a keystone indicator species: conservation implications for semi-arid grasslands. T&E Inc. (with Martin Moses and Gary Roemer). 2007-2009
- $ 26,460 – New Mexico Department of Game and Fish. Status of the Peñasco least chipmunk. 2006
- $ 26,037 – Lincoln National Forest. Population assessment of the red squirrel. 2006
- $ 700 – Society for Conservation Biology. Peer-review of US Forest Service species assessments for the hog-nosed skunk and pygmy shrew. 2006
- $ 5,250 – Santa Fe National Forest, Jemez Ranger District. Inventory for the meadow jumping mouse. 2006
- $ 29,820 – New Mexico Department of Game and Fish. Status of the meadow jumping mouse in the Sangre de Cristo Mountains. 2006
- $ 2,000 – New Mexico State Parks. Status of the meadow jumping mouse at Sugarite Canyon State Park. 2006.
- $ 20,053 – Carson National Forest. Abert's squirrel monitoring, 2006. 2006
- $ 5,900 - New Mexico Share with Wildlife: Key to the Rodentia of New Mexico, Part II. 2005-2006.
- $ 10,000 – Desert Southwest Cooperative Ecosystem Studies Unit. Literature review on mammalian carnivore use on islands, coyote telemetry methodology, and biology of islands in the Laguna Madre. (with D. Echols, Padre Island National Seashore). 2006
- $ 2,500 - Modeling with a keystone indicator species: conservation implications for desert grasslands. T&E Inc. (with Kristen Otten and Gary Roemer). 2006-2008
- $ 18,651 – New Mexico Department of Game and Fish. Status survey of the least shrew

(Cryptotis parva). 2005

- $ 19,819 – New Mexico Department of Game and Fish. Status survey of the meadow jumping mouse (*Zapus hudsonius*). 2005
- $ 15,564 – Carson National Forest. Abert's squirrel monitoring, 2005. 2005
- $100,000 – International Arid Lands Consortium: Keystone indicator: a tool for semi-desert grassland conservation. (with Gary Roemer and Eli Geffen). 2005-2007
- $160,636 – National Parks Service: Mammal inventory of Padre Island National Seashore. 2004-2007
- $ 10,352 – National Park Service: Data mining and data entry for Vital Signs Monitoring Plan. (with Don Caccamise). 2004-2005
- $ 17,729 – New Mexico Department of Game and Fish. Status of the endangered Arizona montane vole (*Microtus montanus arizonensis*) in New Mexico. 2004
- $ 7,500 – New Mexico Share with Wildlife: Key to the Rodentia of New Mexico. 2004-2005.
- $ 10,000 – New Mexico Share with Wildlife: Habitat and diet of the threatened New Mexico meadow jumping mouse (*Zapus hudsonius luteus*): a spatial and temporal assessment". (with K. Mohrland and D. Jones). 2004-2205
- $ 26,000 – Carson National Forest. Red squirrel and Abert's squirrel monitoring. 2004.
- $ 46,570 – Carson National Forest. Red squirrel and Abert's squirrel monitoring; small mammal surveys. 2003.
- $ 8,998 – BAE Systems Analytical Solutions, Inc. White Sands Missile Range small mammal voucher specimen preparation and identification. 2003-2005.
- $ 98,000 – National Science Foundation. Center for Natural Resource Analysis within New Mexico Experimental Program to Stimulate Competitive Research (EPSCoR). (J.R. Gosz, A.W. Powell, et al.). I was the PI for the ENMU portion of $ 3 million total award. 2002.
- $ 3,335 – ENMU Research and Faculty Development Committee: Ecological segregation of the mountain cottontail (*Sylvilagus nuttallii*) and the snowshoe hare (*Lepus americanus*). 2001.
- $563,389 – Grand Canyon Monitoring and Research Center, USGS: Inventory and monitoring of terrestrial riparian biological resources in Grand Canyon: an integrative approach. (with M.J.C. Kersley, H. Yard, N. Cobb, D.C. Lightfoot, G. Carpenter, and S.L. Brantley). 2001
- $ 7,500 – USDA Forest Service: Expert's Panel on Grazing Impacts on Southwestern Mammals. 2001
- $ 2,000 – New Mexico Natural Heritage Program: White Sands Missile Range Integrated Natural Resources Management Plan: Mammals. 2000-2001.
- $ 4,979 – Lincoln National Forest, USDA Forest Service and ENMU Research and Faculty Development Committee: Status of the endangered Peñasco least chipmunk (*Tamias minimus atristriatus*). 2000.
- $ 17,000 – New Mexico State Land Office: Geospatially referenced database for sensitive mammal, bird, and plant voucher specimens in the ENMU Natural History Museum. 1999-2000.
- $ 5,500 – New Mexico Department of Game and Fish: Lesser prairie chicken lek surveys. 1999-2001.

- $ 1,991 – ENMU Teaching and Technology Instruction: Radiotelemetry equipment and photographic slides of birds and mammals for classroom instruction. 1999.
- $ 15,000 – U.S. Forest Service, in collaboration with the New Mexico Department of Game and Fish. for Relationships among Southwest mammals and GAP vegetation types for the Biotic Information System of New Mexico (BISON-M). 1998.
- $ 9,981 – Turner Biodiversity Division: Mammal survey of the Fra Cristobal Mountains, Armendariz Ranch, Sierra County, New Mexico. 1998.
- $ 49,249 – Animas Foundation: Effects of reintroduced black-tailed prairie dogs on grassland ecology. (with C. Curtin, D. Lightfoot, G. Carpenter, and A. Henry). 1998.
- $ 3,262 – ENMU Research and Faculty Development Committee: Distribution and habitat preference of white-tailed deer in New Mexico. 1998.
- $ 3,000 – Ski Island Alliance, The Wildlands Project: Data compilation of focal species. 1997.
- $ 17,500 – U.S. Geological Survey, Biological Resources Division: Response of southwestern montane mammal communities to global change. (with T. L. Yates) 1997.
- $ 27,180 – National Science Foundation: Joint U.S.-Mexico Workshop on International Ecology and Biodiversity. (with T. L. Yates and G. Ceballos) 1996.
- $ 11,986 – U.S. Forest Service: Mammal survey of the Negrito Creek watershed, Gila National Forest, Catron Co., New Mexico. 1995.
- $ 12,700 – Arizona Game and Fish Department: Mexican vole (*Microtus mexicanus*) genetic analyses. 1992, 1993.
- $ 2,000 – Albuquerque Community Foundation: Wildlife Rescue, Inc. of New Mexico, (with Francisca C. Bermudez and Elizabeth P. Elliston). 1993.
- $ 900 – Sigma Xi; Biology, UNM; GSA, UNM: Dispersal versus vicariance in southwest montane mammals: genetics of long-tailed vole populations. 1991.
- $ 19,500 – New Mexico Game and Fish Department: Allozyme and mtDNA restriction site variation in sandhill crane (*Grus canadensis*). (with T. L. Yates). 1991.
- $ 500 – GRAC; SRAC; Vice President's Graduate Research Fund, Office of Research, UNM: Historical Biogeography of the Mexican Vole (*Microtus mexicanus*). 1990.
- $ 1,226 – Kansas Department of Wildlife and Parks. For Distribution and habitat analysis of the long-tailed shrew in Kansas. (with D. W. Moore). 1987.

PAPERS PRESENTED AT PROFESSIONAL MEETINGS:

1. **Frey**, **J**. **K**. 1987. Nongeographic variation in the Mexican vole (*Microtus mexicanus*). Kansas Academy of Science.
2. **Frey**, **J**. **K**., and D. W. Moore. 1988. Distribution of *Sorex haydeni* in Kansas. Southwestern and Rocky Mountain Division, American Association for the Advancement of Science. **winner Outstanding Presentation Award**
3. **Frey**, **J**. **K**. 1988. Distribution of Hayden's shrew (*Sorex haydeni*) in Kansas. Kansas Academy of Science.
4. **Frey**, **J**. **K**., and D. W. Moore. 1988. Morphologic variation and systematics of the Mexican vole (*Microtus mexicanus*). Southwestern Association of Naturalists.
5. **Frey**, **J**. **K**., and D. W. Moore. 1988. Distribution of *Sorex haydeni* in Kansas. Prairie States Ecology Conclave.

6. **Frey**, **J**. **K**., and D. W. Moore. 1988. Morphologic variation and systematics of the Mexican vole (*Microtus mexicanus*). American Society of Mammalogists.
7. **Frey**, **J**. **K**., and D. W. Moore. 1989. Geographic variation in the Mexican vole (*Microtus mexicanus*). Southwestern and Rocky Mountain Division, American Association for the Advancement of Science.
8. Moore, D. W., G. Ploskey, and **J**. **K**. **Frey**. 1989. Identification of hybrids between sauger and walleye. Southwestern Association of Naturalists.
9. **Frey**, **J**. **K**. 1990. Fluctuation of a mammalian faunal element in response to climatic change. Southwestern Association of Naturalists.
10. **Frey**, **J**. **K**. 1990. Fluctuation of a mammalian faunal element in response to climatic factors. Southwestern and Rocky Mountain Division, American Association for the Advancement of Science. **winner Robert I. Larus Award-best paper**
11. **Frey**, **J**. **K**. 1990. Fluctuation of a mammalian faunal element in response to climatic change. American Society of Mammalogists.
12. **Frey**, **J**. **K**., and D. W. Moore. 1990. Range expansion of the meadow vole (*Microtus pennsylvanicus*) in Kansas. Kansas Mammalogists.
13. **Frey**, **J**. **K**. 1991. Response of a mammalian faunal element to climatic change. American Association for the Advancement of Science. **invited paper**
14. Gannon, W. L., P. J. Glass, **J**. **K**. **Frey**, and T. L. Yates. 1991. Information retrieval of biological materials at the Museum of Southwestern Biology. American Society of Mammalogists.
15. **Frey**, **J**. **K**. 1992. Evolutionary consequences of modes of peripheral isolate formation under alternative modes of speciation and speciation in frogs of the subgenus *Stombus* (Leptodactylidae: genus *Ceratophrys*). Southwestern Association of Naturalists.
16. **Frey**, **J**. **K**. 1992. Evolutionary consequences of modes of peripheral isolate formation under alternative modes of speciation. American Society of Mammalogists.
17. **Frey**, **J**. **K**. 1993. Testing among modes of allopatric speciation: A hypothetico-deductive approach. American Society of Mammalogists. **invited paper in the plenary session for Shadle Award**
18. **Frey**, **J**. **K**., D. J. Hafner, T. L. Yates, and C. G. Schmitt. 1994. Allozyme and mitochondrial DNA variation in migratory sandhill crane (*Grus canadensis*). Southwestern Association of Naturalists.
19. Bermudez, F. C., and **J**. **K**. **Frey**. 1994. Value and potential of wildlife rehabilitation to the zoological sciences. Southwestern Association of Naturalists.
20. **Frey**, **J**. **K**., and M. J. Patrick. 1994. Endoparasites from the endangered Hualapai vole (*Microtus mogollonensis hualpaiensis*). American Society of Mammalogists.
21. Ditto, A. M. and **J**. **K**. **Frey**. 1995. Species diversity and the peninsular effect: non-volant mammals in Chihuahuan Desert habitat peninsulas. Southwestern Association of Naturalists.
22. **Frey**, **J**. **K**. 1995. Homage to Darwin: On the evolution of domestic breeds of standard chickens. Southwestern Association of Naturalists.
23. **Frey**, **J. K**. 1996. Assessing distribution patterns and predicting climate induced extinctions in southwestern montane mammals. Southwestern Association of Naturalists.
24. Ditto, A. M. and **J**. **K**. **Frey**. 1997. Effects of island attributes on genetic variability in southwestern montane mammals. Southwestern Association of Naturalists.

25. **Frey**, **J**. **K**. 1997. A climate induced pump for increased genetic variability in a peripheral isolate of the montane vole? Southwestern Association of Naturalists.
26. Ditto, A. M. and **J. K**. **Frey**. 1997. Effects of island attributes on genetic variability in southwestern montane mammals. American Society of Mammalogists.
27. **Frey, J.K.** 1998. Conservation considerations for the reintroduction of grizzly bears and wolves in the Southwest. Southwestern Association of Naturalists.
28. Fields, S.P., and **J.K. Frey**. 2000. Squamate reptiles in New Mexico: patterns of species richness and provincialism. Southwestern Association of Naturalists.
29. Kendall, J., and **J.K. Frey**. 2000. Hierarchical relationships of bat communities in Arizona, New Mexico, Utah and Colorado. Southwestern Association of Naturalists.
30. Frey, T.C. and **J.K. Frey**. 2000. Railroads: an alternative mechanism for mesquite invasion in the Southwest. Southwestern Association of Naturalists.
31. Hope, A., and **J.K. Frey**. 2000. Biogeographic models of the distribution of Canadian lynx (*Lynx canadensis*) in the western United States with implications for reintroduction and conservation. Southwestern Association of Naturalists.
32. Edgmon, M.G, L. Castillo, and **J.K. Frey**. 2000. Diversity of avian populations in CRP and native grasslands on the Llano Estacado in the Texas Panhandle. Southwestern Association of Naturalists.
33. Hope, A., and **J.K. Frey**. 2001. Biogeographic models of the distribution of Canadian lynx (*Lynx canadensis*) in the western United States with implications for reintroduction and conservation. Joint Arizona-New Mexico Chapters of The Wildlife Society.
34. Kendall, J., and **J.K. Frey**. 2001. Management implications of hierarchical relationships of southwestern bat communities based on Bailey's ecoregions. Joint Arizona-New Mexico Chapters of The Wildlife Society.
35. Hope, A., and **J.K. Frey**. 2001. Biogeographic nestedness and conservation of boreal mammals in the western contiguous United States. Southwestern Association of Naturalists.
    (*winner Clark Hubbs Award-best poster presentation)
36. Hope, A. and **J.K, Frey.** 2001. Biogeographic nestedness and conservation of boreal mammals in the western contiguous United States. American Society of Mammalogists.
37. Malaney, J. and **J.K. Frey**. 2002. Habitat differentiation between snowshoe hare (*Lepus americanus*) and mountain cottontail (*Sylvilagus nuttallii*) in New Mexico. Joint Arizona-New Mexico Chapters of The Wildlife Society.
38. Malaney, J. and **J.K. Frey**. 2003. Snowshoe hare (*Lepus americanus*) population parameters and habitat preferences in New Mexico. Joint Arizona-New Mexico Chapters of The Wildlife Society.
39. Malaney, J. and **J.K. Frey**. 2003. Primary productivity and habitat quality hypotheses for control of snowshoe hare (*Lepus americanus*) demography: a test at the southern range limit and conclusions for conservation. Southwestern Association of Naturalists.
    (*winner Clark Hubbs Award-best poster presentation)
40. Malaney, J. and **J.K. Frey**. 2003. Primary productivity and habitat quality hypotheses for control of snowshoe hare (*Lepus americanus*) demography: a test at the southern range limit and conclusions for conservation. American Society of Mammalogists.
41. **Frey, J.K.** 2003. Vicariance, not dispersal, is the primary mechanism for the distribution of boreal mammals in the American Southwest. American Society of Mammalogists.

42. Kearsley, M., N. Cobb, H. Yard, D. Lightfoot, G. Carpenter, S. Brantley, and **J.K. Frey**. 2003. Inventory and monitoring of terrestrial riparian biological resources in Grand Canyon: an integrative approach. Ecological Society of America.
43. Malaney, J. and **J.K. Frey**. 2004. Habitat differentiation between snowshoe hare (*Lepus americanus*) and mountain cottontail (*Sylvilagus nuttallii*) at their southern zone of sympatry. Southwestern Association of Naturalists.
    (*winner Clark Hubbs Award-best poster presentation)
44. Mathis, V.L. and **J.K. Frey**. 2005. Geographic variation in relictual populations of red squirrel (*Tamiasciurus hudsonicus*) in the American Southwest. Southwestern Association of Naturalists.
45. Malaney, J. and **J.K. Frey**. 2006. Decline of montane populations of the threatened meadow jumping mouse (*Zapus hudsonius luteus*) in New Mexico. Arizona and New Mexico Chapters of The Wildlife Society.
46. Wampler, C.R, **J.K. Frey** and J. Boren. 2006. Effects of silvicultural treatments on the small mammal community in a southwest coniferous forest. Arizona and New Mexico Chapters of The Wildlife Society.
47. Jones, G.D., K.M. Otten, C. R. Wampler, Z. Schwenke, and **J. K. Frey**. 2006. Status and habitats of the threatened least shrew (*Cryptotis parva*) in New Mexico. Arizona and New Mexico Chapters of The Wildlife Society.
48. Wampler, C.R, **J.K. Frey** and J. Boren. 2006. Effects of silvicultural treatments on the small mammal community in a southwest coniferous forest. The Southwestern Association of Naturalists.
49. Montoya, A. and **J.K. Frey**. 2007. Geographic variation and taxonomy of the gray-footed chipmunk (*Tamias canipes*). The Southwestern Association of Naturalists.
50. Wampler, C.R, **J.K. Frey** and J. Boren. 2007. Effects of fuels reduction thinning on the small mammal community in a southwest coniferous forest. The Southwestern Association of Naturalists.
51. Jones, G., and **J.K. Frey**. 2007. An enigma of the species-area relationship: small island effect on coastal Texas islands. American Society of Mammalogists.
52. **Frey, J.K.**, J.L. Malaney, Z. J. Schwenke, and J.A. Cook. 2007. The New Mexico meadow jumping mouse (*Zapus hudsonius luteus*): a declining riparian indicator species. American Society of Mammalogists.
53. Schwenke, Z.J., **J.K. Frey**, and J.R. Choate. 2008. Identifying isolated peripheral populations of the least shrew (*Cryptotis parva*) along the western extent of its range. American Society of Mammalogists.
54. **Frey, J.K.** 2008. Mammals of the Gila: patterns of diversity and species of concern. Natural History of the Gila Symposium, Silver City.
55. Malaney, J.L., **J.K. Frey**, J.A. Cook. 2009. Conservation genetics and phylogeography of the New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*). Arizona and New Mexico Chapters of The Wildlife Society.
56. Moses, M.R., G.W. Roemer, and **J.K. Frey.** 2009. Unraveling sources of variation in annual survival among distinct populations of banner-tailed kangaroo rats in the Chihuahuan Desert. Ecological Society of America, Albuquerque.
57. J.C. Lewis, **J.K. Frey**, R.K. Guy, J.N. Stuart, J.F. Roback, and K.G. Boykin. 2009. White-nosed coati (*Nasua narica*) habitat suitability and distribution in the state of New Mexico. Howard Hughes Medical Institute-NMSU Undergraduate Research Scholar

Symposium, Las Cruces.

58. Wright, G.D., and **J.K. Frey**. 2009. Status of the meadow jumping mouse at Bosque del Apache national Wildlife Refuge. Festival of the Cranes.
59. J.C. Lewis, **J.K. Frey**, R.K. Guy, J.N. Stuart, J.F. Roback, and K.G. Boykin. 2010. Improving ecological niche models; an example based on the white-nosed coati in the southwest. Arizona and New Mexico Chapters of The Wildlife Society.
60. Wright, G.D., and **J.K. Frey**. 2010. The endangered meadow jumping mouse in the Rio Grande Valley; observations of decline, habitat, and behavior. Arizona and New Mexico Chapters of The Wildlife Society.
61. Calkins, M. and **J.K. Frey**. 2010. A revised distribution and habitat associations for the water shrew in the White Mountains, Arizona. Arizona and New Mexico Chapters of The Wildlife Society.
62. **Frey, J.K**. 2010. Status of the meadow jumping mouse in Arizona. Arizona and New Mexico Chapters of The Wildlife Society.
63. Wright, G.D. and **Frey, J.K**. 2010. The endangered meadow jumping mouse at BANWR: observations of occupation, habitat, and behavior. Festival of the Cranes.
64. **Frey, J.K**. 2012. Synopsis of the status and ecology of the meadow jumping mouse (*Zapus hudsonius luteus*): an imperiled species in the American Southwest. Arizona and New Mexico Chapters of The Wildlife Society.
65. **Frey, J.K**. 2013. Ecosystem services of the American beaver: wetland engineer. New Mexico Environment Department Beavers and Wetlands Symposium. Santa Fe.
66. Small, B., I. Barela, **J.K. Frey**. 2014. Status of dam building beaver on public lands in New Mexico: a comparison of occupied and vacant sites. Arizona and New Mexico Chapters of The Wildlife Society.
67. **Frey, J.K.** 2014. The NMSU Wildlife Museum. Department of Fish, Wildlife & Conservation Ecology Alumni and Friends Reception.
68. **Frey, J.**K., P. Castillo, J. Iglesias. 2015. Eastern fox squirrels in the West. Western Pecan Growers.
69. Barela, I. and **J.K. Frey**. 2015 Use of woody forage plants by the American beaver (*Castor canadensis*) in the Chihuahuan Desert. Arizona and New Mexico Chapters of The Wildlife Society.
70. Small, B.A., **J.K. Frey**, C. C. Gard. 2015. Evaluation of habitat suitability for dam-building beaver in northern New Mexico. Arizona and New Mexico Chapters of The Wildlife Society. (best wildlife student paper finalist)
71. Castillo, P., **J.K. Frey**, J. Iglesias. 2015. Damage caused by the eastern fox squirrel (*Sciurus niger*) in pecan orchards in the El Paso Valley. NMSU Undergraduate Research and Creative Arts Symposium.
72. Barela, I. and **J.K. Frey**. 2015 Use of woody forage plants by the American beaver (*Castor canadensis*) in the Chihuahuan Desert. NMSU Undergraduate Research and Creative Arts Symposium.
73. Small, B.A., **J.K. Frey**, C. C. Gard. 2015. Evaluation of habitat suitability for dam-building beaver in northern New Mexico. New Mexico Environment Department Wetlands Roundtable.
74. Youtz, J.A., R. Goljani A., J.K. Frey. 2016. A habitat suitability model for the Dusky Grouse in New Mexico. Arizona and New Mexico Chapters of The Wildlife Society.
75. Perkins-Taylor, I. and J.K. Frey. 2016. Detection rates during surveys of the endangered

New Mexico meadow jumping mouse. Arizona and New Mexico Chapters of The Wildlife Society.

76. Youtz, J.A., R. Goljani A., J.K. Frey. 2016. A habitat suitability model for the Dusky Grouse in New Mexico. Gila Symposium
77. Youtz, J.A., R. Goljani A., J.K. Frey. 2017. A habitat suitability model for the Dusky Grouse in New Mexico. Arizona and New Mexico Chapters of The Wildlife Society.
78. Burke, R., K. Stoner, and J.K. Frey. 2017. Predicting seasonal distribution and migratory pathways for neotropical nectar-feeding bats. Arizona and New Mexico Chapters of The Wildlife Society.
79. Frey, J.K. 2017. Identification, distribution and ecology of the New Mexico meadow jumping mouse in the zone of sympatry with the western jumping mouse. Arizona and New Mexico Chapters of The Wildlife Society.
80. Lehnen, S., J.K. Frey et al. 2017. Use of remote cameras to detect the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*) at Bosque del Apache National Wildlife Refuge. Arizona and New Mexico Chapters of The Wildlife Society.
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Peer-refereed articles = 70
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NOTE: asterisk indicate students I mentored: *=graduate student; **=undergraduate student; *=high school student.**

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BOOK IN PREPARATION:

Cartron, J.E. and **J.K. Frey (editors).** The Carnivores of New Mexico. University of New Mexico Press. Expected publication date January 2019

J.K. Frey authored chapters by include:

- Introduction
- Conservation of Carnivores
- Red fox
- Wolverine
- Ermine
- Long-tailed weasel
- American mink
- White-nosed coati
- Conclusion

SELECTED MANUSCRIPTS IN PREPARATION:

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Burruss, D., A. Matchano, **J.K. Frey**, M. Andersen, C. Sillero-Zubiri. Species distribution models unravel niche partitioning in a Sahelo-Saharan canid community

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Frey, J.K. Habitat partitioning between two species of jumping mice (*Zapus*) in a zone of sympatry. Journal of Mammalogy

Jones, G.D. and **J.K. Frey**. Mammal community structure on a Padre Island: influence of habitat and interspecific interactions. Journal of Mammalogy

Malaney, J.L., and **J.K. Frey**. Demography of snowshoe hare (*Lepus americanus*) at the southern edge of its range. Journal of Mammalogy

Jones, G.D. and **J.K. Frey**. Testing between hypotheses of causal mechanisms for the small island effect. Journal of Biogeography.

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DANIEL J. HARRISON

Department of Wildlife Ecology
University of Maine, 5755 Nutting Hall
Orono, ME 04469-5755
(207) 581-2867 (Work)
(b) (6)(b) (6) (Cell)
harrison@maine.edu

PROFESSIONAL EXPERIENCES

9/2000-8/2013 & 9/2016-present: ***Professor of Wildlife Ecology***, Dept. of Wildlife Ecology, University of Maine; ***Cooperating Professor***, Center for Research on Sustainable Forests (2007-present); ***Cooperating Scientist ,*** Maine Cooperative Forestry Research Unit (1999-present); ***Cooperating Professor***, Department of Forest Ecosystem Science (1999-2005) and Center for Research on Sustainable Forests (2008-present); and ***Faculty Associate***, Maine Cooperative Fish and Wildlife Research Unit, Univ. of Maine (1988-present). Tenured, academic year appointment with shared research (50%) and teaching (50%) responsibilities; appointment changed to 75% research, 25% teaching, effective 9/1/2005. Course instruction: Wildlife-Habitat Relationships (WLE 450, Cr. 4), Introduction to Wildlife Resources (WLE 100, Cr. 1), Graduate Course in Habitat Ecology (WLM 650, Cr. 4; team-taught), Graduate Course in Carnivore Ecology and Management (WLE 565, Cr. 3). Serve as academic advisor to undergraduate students and as thesis advisor for graduate students (Responsible for: base-funded research program in wildlife-forestry relationships supported through the Maine Agricultural and Forest Experiment Station; extramurally funded research program in habitat relationships of forest wildlife and ecology of meso-carnivores and their prey; public service; technology transfer. Provide research advisement and technology transfer to large private forest landowners, state and federal resource management agencies, and NGO's.

9/2013-8/2016: ***Chair, Professor, and Undergraduate Coordinator*****,** Department of Wildlife, Fisheries, and Conservation Biology, University of Maine; 70% administration, 20% research, 10% instruction. Administer an academic department including 7 university faculty, a federal USGS research unit (2-3 scientists), 2 support personnel, post-doctoral scientists, research associates, approximately 25 graduate research and teaching assistants, and 125 undergraduate wildlife majors. Taught co-capstone senior-level undergraduate course, administered and supervise research grants, and led a lab comprised of graduate students, technicians and a post-doctoral scientist.

7/2001-6/2002: ***Interim Chair***, Department of Wildlife Ecology, University of Maine.

9/93-8/00: ***Associate Professor of Wildlife Ecology***, Dept. of Wildlife Ecology, University of Maine; duties listed above plus served as administrator and instructor for mandatory 3-week summer field camp, Wildlife Field Survey (WLE 250, Cr. 3, 1994-97).

1/88-8/93: ***Assistant Professor of Wildlife***, Dept. of Wildlife, University Maine. 50%-50%, shared research-teaching appointment (9-month). Additional responsibilities included serving as advisor to the Student Chapter of The Wildlife Society, and administration and instruction of the summer field camp, Wildlife Field Survey (WLE 250, Cr. 3, 1988-93). Twice served as instructor in senior-capstone course in wildlife policy and administration (Cr. 3). Developed and taught 4 credit undergraduate habitat

course with 2 sections of lab (1988-93), and a graduate course in predator ecology (Cr. 3).

2/86-12/87: ***Wildlife Research Supervisor*** (Staff Associate-Wildlife), Wildlife Bureau, Connecticut Department of Environmental Protection. Responsible for overall supervision, administration, budgeting, and coordination of statewide research and management programs for Nongame and Endangered Species, Upland Wildlife (small game), and Mammals (except deer). Supervised a staff of 6 wildlife biologists and 2 clerical staff.

6/85-2/86: ***Mammal Program Leader*** (Wildlife Biologist I and II), Wildlife Bureau, Connecticut Department of Environmental Protection. Administered statewide research and management programs for 14 species of harvested and non-harvested mammals.

EDUCATION

(b) (6)(b) (6) University of Maine, ***Ph. D. in Wildlife***, August 1986; Dissertation: Coyote Dispersal, Mortality, and Spatial Interactions with Red Foxes in Maine.

(b) (6)(b) (6) University of Maine, ***M.S. in Wildlife Management***, May 1983; Thesis: Denning Ecology, Movements, and Dispersal of Coyotes in Eastern Maine.

(b) (6)(b) (6) University of Wyoming, ***B.S. in Wildlife Management***, May 1980.

PROFESSIONAL SERVICES

Affiliations

Society for Conservation Biology
American Society of Mammalogists
The Wildlife Society (national, section, chapter)
Martes Working Group

Committees/Professional Service

Invited external reviewer, Species Status Assessment for U.S. population of Canada lynx (2017)
Chair of DWFCB Alumni Awards Committee, (2016-present)
Undergraduate Program Coordinator, Dept. Wildlife, Fisheries, and Conserv. Biol. (2013-2015)
Search Committee, Assistant Professor of Wildlife Habitat Ecology, University of Maine (2015)
Institutional Animal Care and Use Committee, University of Maine (2012-2014)
Chair of Search Committee, Assistant Professor of Wildlife Population Ecology (2013)
Peer Committee Chair, Department of Wildlife Ecology, University of Maine (2012-2013)
Faculty Senator, University of Maine (2010-2012)
Financial and Institutional Planning Committee, Faculty Senate (2010-2012)
Board of Directors, The Forest Society of Maine (2008-2011)
Land Conservation Committee, Forest Society of Maine (2009-present)
Scientific Advisor, Carnivores 2006 Conference, St. Petersburg, Florida (2005-06)
External Program Review Team, Dept. Natural Resources, Univ. New Hampshire (2006)
Search Committee for Asst. Professor Fisheries, Dept. Wildlife Ecology, Univ. Maine (2006)
Invited Peer Reviewer, U.S. Fish &Wildlife Service, Critical Habitat Proposal for Lynx (2006)
Research Council, Maine Agricultural and Forest Experiment Station (2005-2008)
Peer Review Team, Endangered Wolf Delisting Proposal, U.S. Fish Wildlife Service, (2004)
Scientific Advisor, Carnivores 2004 Conference, Santa Fe, New Mexico (2003-04)

Cooperating Scientist, Maine Cooperative Forestry Research Unit, (1999-present)
Scientific Advisor to Newfoundland Model Forest, marten research, (1997-2010)
Invited Member, Recovery Team for Endangered Newfoundland Marten, (1998-2010)
University Representative on Northern Maine Landscape Planning Comm. (2002-2008)
Committee of Whole for Curriculum and Graduate Issues, Dept. of Wildlife Ecology (1988-present)
Awards Committee, Maine Chapter of The Wildlife Society, (1992-present)
Peer Review Committee, Dept. Wildlife Ecology, University Maine (1988-present)
Hosted 4 landscape planning workshops for agencies and environmental groups (2002-2010)
Coauthored position on coyote snaring bill, Maine Chapter, The Wildlife Society (2003)
Member of Search Committee, Assistant Coop. Unit Leader for Fisheries (2003)
Invited External Review Participant for Maine Dept. Inland Fisheries and Wildlife (2003)
Nongame/Endangered Species Advisory Council, MDIFW (1999-2002)
Chair, Search Committee for Instructor in Wildlife Ecology (2001-02)
Search Committees for Faculty Sabbatical Replacements (2) (2001-2002)
Co-author on Forestry-Wildlife Alumni Newsletter, Univ. Maine (2002)
U.S.D.A. Forest Service Expert Review Panel for Species at Risk WMNF, GMNF (2002)
Forest Biodiversity Benchmarks Working Group, Maine Forest Service (2001-02)
Advisor to Huber Corp. on forest wildlife habitat supply planning (2001-2002)
Expert Panelist, Eastern Wolf Conference (2002)
Scientific Advisor, Carnivores 2002 Conference, Monteray, California (2001-02)
Program Chair/Co-Convenor, 3rd Int. *Martes* Symp., Newfoundland, (2000)
Consulting Scientist to industry on biocontaminants issues with aquatic mammals, (2000)
Search Committee for Finance/Communications Coordinator, Maine Coop. Forest Res.Unit, (1999)
Search Comm. for Asst. Leader/Wildlife, Maine Coop. Fish and Wildlife Research Unit, (1999)
College Committee for Development of Green Endowment policies (1999)
Research and Public Service Committee, Faculty Senate, (1994-95, 1998-1999)
Forest Research Center Steering Committee, College of NFA (1998-2000)
Restructuring Committee for Maine Cooperative Forestry Research Unit (1998-1999)
Usniversity of Maine Faculty Senate (elected), (1993-1999)
Lynx Research Working Group, MDIFW & USFWS (2000-present)
Timber Wolf Advisory Committee, Maine Dept. Inland Fisheries & Wildlife (1997-2000)
Search Committee for Silvicultural Program Leader, CFRU, (1997-98)
Search Committee for Instructor, Dept. Wildlife Ecology, (1997)
Academic Affairs Committee, Faculty Senate, (1997-98)
Constitution and Bylaws Committee, Faculty Senate, (1996-97)
Search Committee for Program Scientist, CFRU (1996)
Search Committee for Assistant Professor of Wildlife Ecology (1995)
Admissions Committee, Graduate Program in Ecology and Environmental. Sciences, (1994-96)
Forest Ecosystem Research Committee, University Maine, (1993-95)
Auditing Committee, NE Section, The Wildlife Society, (1989-94)
Scholarship Committee, College Forest Resources, (1989-94)
Scholarship Committee, Department of Wildlife Ecology, (1988-96)
University Forest Advisory Committee, College of Forest Resources, (1989-94)
Predator Management Committee, Baxter State Park, (1993)
Presidential Public Service Awards Committee, University Maine, (1993-94)
Faculty Research Funds Committee, University Maine, (1988-91), Chair, (1990-91)
Evaluation Committee for Dean of Graduate School, (1991)

Executive Committee of the Graduate School, (elected), (1989-90)
Graduate Board, (elected), University Maine, (1988-91)
Northeast Fur Resource Technical Committee, (1985-1991)
Facilities and Safety Committee, College of Forest Resources, (1988-89)
Cooperative Extension-College of Forest Resources Working Group, (1988-89)
Advisor, Student Chapter of the Wildlife Society, University Maine, (1988-92)
Executive Board (elected), Maine Chapter of The Wildlife Society (1989)

Editorships

-Associate Editor for *Wildlife Biology*, September 2009 – 2012
-Senior Editor for a Contributed book: ***Ecology and management of Martes in human altered landscapes: An International Perspective***. Reviewed, edited, and revised 22 contributed chapters, wrote Preface, and coordinated publication (published by Springer, New York in 2004).
-Guest editor for Northeastern Naturalist (2005-06)
-Consulting Editor for Wildlife Monographs (2000)

Manuscript Reviews (in order of number of manuscripts reviewed: range 1-49)

Journal of Wildlife Management
Wildlife Biology
Journal of Mammalogy
Wildlife Society Bulletin
Forest Ecology and Management
Landscape Ecology
Conservation Biology
Canadian Journal of Zoology
Northeastern Naturalist
Wildlife Monographs
Bioscience
Behavioral Ecology
Ecology
Ecological Applications
Ecography
Environmental Monitoring and Assessment
Southeast Proceedings
Southwest Naturalist
Northeast Wildlife
American Midland Naturalist
Wildlife Biology
Wildlife Research
Proceedings of 5th International *Martes* Symposium
Proceedings of 2nd International *Martes* Symposium
Proceedings of 1st International *Martes* Symposium
Maine Agricultural and Forest Experiment Station Miscellaneous Reports

Other Professional Contributions

Granted > 130 media interviews; contributed to 3 film documentaries, presented legal and public testimony on numerous occasions, have provided technical advice to natural resource agencies and non-governmental organizations in Maine, Alaska, Rocky Mountain states, Ontario, New Brunswick, Nova Scotia and Newfoundland Canada, and Tanzania; hosted numerous field trips for visiting scientists, organizations, and businesses; provided technology transfer (newsletters, phone calls, presentations, field visits) for forest products businesses in Maine, handled hundreds of requests for information from public; presented >100 public talks; frequently review scientific proposals for business, federal agencies, and other universities.

Honors and Awards

2009:	Distinguished Alumnus Award, Department of Wildlife Ecology, University of Maine
2008-2009:	University Research Sabbatical, University of Maine (competitive system-wide award)
2008:	Award of Professional Excellence, Department of Wildlife Ecology, The University of Maine (awarded to alumni)
2007:	Maine Chapter of the Wildlife Society's Meritorious Service Award
2007:	Appointed Cooperating Professor, Center for Research on Sustainable Forests
2006:	G. Peirce and Florence Pitts-Webber Award to the Outstanding Researcher in Forest Resources, University of Maine
2000:	G. Peirce and Florence Pitts-Webber Award to the Outstanding Researcher in Forest Resources, University of Maine
1998:	Appointed Cooperating Scientist, Maine Cooperative Forestry Research Unit
1992:	Distinguished College of Forest Resources Professor of the Year, University of Maine
1985:	Dow-Griffee Award to Outstanding Graduate Students in Agriculture, Forestry and Wildlife at the University of Maine
1984:	New England Outdoor Writer's Scholarship to Outstanding Wildlife Student in New England (selected from regional competition among state-level awardees).
1984:	New England Outdoor Writer's Scholarship to Outstanding Wildlife Student in Maine
1979:	Phi Kappa Phi, University of Wyoming

GRADUATE ADVISING:

-Served as major advisor for 19 M.S., 3 non-thesis Masters and 7 Ph.D. students; 25 dissertations, theses, and final project reports completed to date.
-Served on 42 graduate committees where I did not serve as major advisor.
-Mentored 4 post-doctoral Research Scientists and several post-M.S. Research Associates.

TEACHING EXPERIENCE:

Taught 37 sections of 6 undergraduate semester courses (median instructor rating 1.42; 1=excellent, 5=poor); managed and taught the required 3-week, summer field session for wildlife students annually for 10 years (median instructor rating 1.50); advised 8-33 undergraduate wildlife students annually, taught 12 semesters of graduate courses in Predator Ecology and Habitat Analysis (median instructor rating 1.50), and instructed graduate thesis (54 semesters).

PUBLICATIONS (* = refereed)**:**

Books, Journal Articles, Book Chapters, and Published Conference Proceedings

*xxxx - Loman, Z. G., W. V. Deluca, D. J. Harrison, P. B. Wood, C. S. Loftin, and W. S.Schwenk. Submitted. Forest birds usefulness as representatives using fine scale proxy models. ***Diversity and Distributions***.

*xxxx – Rolek, B. W., D. J. Harrison, C. S. Loftin, and P. B. Wood. Submitted. Regenerating clearcuts and post-harvest treatments promote spruce-fir avian assemblages and richness in managed stands. ***Forest Ecology and Management***

*xxxx – Simons-Legaard, E. M., D.J. Harrison, and K. R. Legaard. Submitted. Efficacy of regulations to reduce winter habitat loss and fragmentation in deer wintering areas. ***Biological Conservation***.

*In press - Loman, Z. G., W. V. Deluca, D. J. Harrison, C. S. Loftin, B. W. Rolek, and P. B. Wood. Submitted. Landscape capability models as a tool to predict fine-scale forest bird occupancy and abundance. ***Landscape Ecology***.

*2017 - Loman, Z. G., E. J. Blomberg, W. V. Deluca, D. J. Harrison, C. S. Loftin, and P. B. Wood. Landscape capability predicts upland game bird abundance and occurrence. ***Journal of Wildlife Management*** DOI:10.1002/jwmg.21265

*2016 – Simons-Legaard, E.M., D.J. Harrison and K.R. Legaard. Habitat monitoring and projections for Canada lynx: linking the Landsat archive with carnivore occurrence and prey density. ***Journal of Applied Ecology*** 53:1260-1269.

*2013 - Fuller, A. K,. and D. J. Harrison. Modeling the influence of forest structure on microsite habitat use by snowshoe hares***.*** ***International Journal of Forestry Research***: Volume 2013, Article ID 892327, 7 pages, http://dx/doi.org/10.1155/2013/892327.

*2013 - Fuller, A. K., S. M. Spohr, D. J. Harrison, and F. A. Servello. Nest survival of wild turkeys in a mixed-use landscape: influences at nest-site and patch scales. ***Wildlife Biology*** 19:138-146.

*2013 - Simons-Legaard, E. M., D. J. Harrison, W. B. Krohn, and J. H. Vashon. Canada lynx occurrence and forest management in the Acadian forest. ***Journal of Wildlife Management*** 77:567-578.

*2012 - I. D. Thompson, J. Fryxell, and D. J. Harrison. Improved insights into use of habitat by American martens, since the 2nd International Martes Symposium in 1991. ***Pages 209 – 229 in K.B. Aubry, W.J. Zielinski, M.G. Raphael, G. Proulx, and S.W. Buskirk,*** **editors,** ***Biology and conservation of martens, sables, and fishers: a new synthesis.*** Cornell University Press, Ithaca, New York, USA.

*2010- Fuller, A. K., and D. J. Harrison. Movement paths reveal scale-dependent habitat decisions by Canada lynx. ***Journal of Mammalogy*** 91:1269-1279.

*2010- Hearn, B. J., D. J. Harrison, A. K. Fuller, C. G. Lundrigan, and W. J. Curran. Paradigm shifts in habitat ecology of threatened Newfoundland martens. ***Journal of Wildlife Management*** 74:719-728.

*2007 - Fuller, A. K., D. J. Harrison, and J. H. Vashon. Winter habitat selection by Canada lynx in Maine: prey abundance or accessibility? ***Journal of Wildlife Management*** 71:1980-1986.

2007 - Harrison, D. J., W. B. Krohn, L. Robinson, A. K. Fuller, and C. L. Hoving. Multi-scalar habitat preferences of snowshoe hares: how does a prey specialist coexist with a specialist predator? Page 175 *in* K. Sjoberg and T. Rooke, editors, ***International Union of Game Biologists Conference Proceedings***, Department of Wildlife, Fish, and Environmental Studies, Swedish University of Agricultural Sciences (SLU), Umea, Sweden.

*2007- Homyack, J. A., D. J. Harrison, and W. B. Krohn. Effects of precommercial thinning on snowshoes hares in Maine. ***Journal of Wildlife Management*** 71: 4-13.

*2006 - Homyack, J.A., D. J. Harrison, J.A. Litvaitis, and W.B. Krohn. Quantifying densities of snowshoe hares in Maine using pellet plots. ***Wildlife Society Bulletin*** 34: 74-80.

*2005 - Fuller, A. K. and D. J. Harrison. Influence of partial timber harvesting on American martens in north-central Maine. ***Journal of Wildlife Management*** 69:710-722.

*2005- Homyack, J. A., D. J. Harrison, and W. B. Krohn. Long-term effects of precommercial thinning on small mammals in northern Maine. ***Forest Ecology and Management***: 205:43-57.

*2005 - Hoving, C. L. D. J. Harrison, W. B. Krohn, R. A. Joseph, and M. O'Brien. Broad-scale predictors of Canada lynx occurrence in eastern North America. ***Journal of Wildlife Management*** 69:739-751.

*2004 - Fuller, A. K., D. J. Harrison, and H. J. Lachowski. Stand-scale effects of partial harvesting and clearcutting on small mammals and forest structure. ***Forest Ecology and Management*** 191:373-386.

*2004 - Harrison, D. J., A. K. Fuller, and G. Proulx. Martens and Fishers (Martes) in Human Altered Environments: An International Perspective***. *Springer, New York, New York (edited, peer-reviewed book).***

*2004 - Homyack, J. A., D. J. Harrison and W. B. Krohn. Structural differences between precommercially thinned and unthinned conifer stands. ***Forest Ecology and Management*** 194:131-143.

*2004 - Hoving, C. L., D. J. Harrison, W. B. Krohn, W. J. Jakubas, and M. A. McCollough. Canada lynx habitat and forest succession in northern Maine, United States. ***Wildlife Biology*** 10(4):285-294.

*2004 - Krohn, W. K., C. L. Hoving, D. J. Harrison, D. Phillips, and H. Frost. Martes foot-loading and snowfall patterns in eastern North America: Implications to broad-scale distributions and interactions of mesocarnivores. Pages 115-131 *in* D. J. Harrison, A. K. Fuller, and G. Proulx, editors, ***Martens and Fishers (Martes) in Human Altered Environments: An International Perspective***. Springer, New York, New York.

*2004 - Payer, D. C. and D. J. Harrison. Relationships between forest structure and habitat use by American martens in Maine, USA. Pages 173-186 i*n* D. J. Harrison, A. K. Fuller, and G. Proulx, editors, ***Martens and Fishers (Martes) in Human Altered Environments: An International***

Perspective. Springer, New York, New York.

*2004 -Payer, D. C., D. J. Harrison, and D. M. Phillips. Territoriality and Home-Range Fidelity of American Martens in Relation to Timber Harvesting and Trapping. Pages 99-114 i*n* D. J. Harrison, A. K. Fuller, and G. Proulx, editors, ***Martens and Fishers (Martes) in Human Altered Environments: An International Perspective***. *Springer,* New York, New York.

*2004 - Spohr, S. M., F. A. Servello, D. J. Harrison, and D. W. May. Survival and reproduction of wild turkey hens in a suburban environment. ***Northeast Naturalist*** 11*: 363-374.*

2003 - Fuller, A. K. and D. J. Harrison. Occurrence, distribution, and survey methods for native terrestrial mammals in Acadia National Park, Mount Desert Island, Maine. ***Maine Agricultural and Forest Experiment Station Miscellaneous Publication 752***, Orono, Maine, 28 pp.

*2003 -- Payer, D. C., and D. J. Harrison. Influence of forest structure on habitat use by American marten in an industrial forest. ***Forest Ecology and Management*** 179:145-156.

*2000 - Payer, D. C., and D. J. Harrison. Structural differences between forests regenerating following spruce budworm infestation and clearcut harvesting: implications for American marten. ***Canadian Journal of Forest Research*** 30:1965-1972.

1999 - Harrison, D. J. Response of wildlife to thinning in forests of the northeastern U.S. Pp. 35-40 *in* ***Proceedings of Conference on Thinning in the Maine Forest***, Cooperative Forestry Research Unit and Office of Professional Development, University of Maine, Orono.

*1998 **-** Harrison, D. J., and T. G. Chapin. Extent and connectivity of habitat for wolves in eastern North America. ***Wildlife Society Bulletin*** 26:767-775.

*1998 **-** Chapin, T. G., D. J. Harrison, and D. D. Katnik. Influence of landscape pattern on habitat use by American marten in an industrial forest. ***Conservation Biology*** 12:1327-1337.

*1998 - Long, R. A., A. F. O'Connell, Jr., and D. J. Harrison. Mortality and survival of white-tailed deer Odocoileus virginianus fawns on a north Atlantic coastal island. ***Wildlife Biology*** 4:237-247.

*1998 - Phillips, D. M., D. J. Harrison, and D. C. Payer. Seasonal changes in home-range area and fidelity of martens. ***Journal of Mammalogy*** 79:180-190.

1997 - Bissonette, J. A., D. J. Harrison, C. D. Hargis, and T. G. Chapin. The influence of spatial scale and scale-sensitive properties on habitat selection by American marten. Pages 368-385 in J.A. Bissonette (editor). ***Wildlife and Landscape Ecology: effects of pattern and scale*****.** Springer-Verlag, New York.

*1997 - Chapin. T. G., D. J. Harrison, and D. M. Phillips. Seasonal habitat selection by marten in an untrapped forest preserve. ***Journal of Wildlife Management*** 61:707-717.

*1997 - Chapin, T. G., D. M. Phillips, D. J. Harrison, and E. C. York. Seasonal selection of habitats by resting marten in Maine. Pages 166-181 *in* G. Proulx, H.N. Bryant, and P.M. Woodard (editors). ***Martes: taxonomy, ecology, techniques and management***. Provincial Museum of Alberta,

Edmonton, Alberta, Canada. 474pp.

*1997 - Hodgman, T. P., D. J. Harrison, D. M. Phillips, and K. D. Elowe. Survival of American marten in an untrapped forest preserve in Maine. Pages 86-99 *in* G. Proulx, H.N. Bryant, and P.M. Woodard (editors). ***Martes: taxonomy, ecology, techniques and management***. Provincial Museum of Alberta, Edmonton, Alberta, Canada. 474pp.

*1996 - Chilelli, M., B. Griffith, and D. J. Harrison. Interstate comparisons of river otter harvest data. ***Wildlife Society Bulletin*** 24(2):238-246.

1995 - Harrison, D. J. Foreword. Pp. 1-4 in G. Parker. ***Eastern coyote: the story of its success***. Chelsea Green Publishing Company, White River Junction, Vermont.

*1994 - Hodgman, T. P., D. J. Harrison, D. D. Katnik, and K. D. Elowe. Survival in an intensively trapped marten population in Maine. ***Journal of Wildlife Management***. 58:593-600.

*1994 - Katnik, D. D., D. J. Harrison, and T. P. Hodgman. Spatial relations in a harvested population of marten in Maine. ***Journal of Wildlife Management*** 58:600-607.

*1992 - Harrison, D. J. Dispersal characteristics of coyotes in Maine. ***Journal of Wildlife Management*** 56:128-138.

*1992 - Harrison, D. J. Social ecology of coyotes in northeastern North America: relationships to dispersal, food resources, and human exploitation. Pages 53-72 *in* A. Boer (editor) ***Ecology and Management of the Eastern Coyote***. Wildlife Research Unit, University of New Brunswick, Frederickton.

1992 - Harrison, D. J., and N. E. Famous. Effects of peat harvesting on a large mammalian carnivore: a case study with coyotes (Canis latrans). Pages 77-96 *in* D. Grubich (editor) ***Peat and Peatlands: the Resource and Its Utilization***. Proceedings International Peat Symposium, Duluth, Minnesota.

*1992 – O'Connell, A. F., Jr., D. J. Harrison, B. Connery, and K.B. Anderson. Food use by an insular population of coyotes. ***Northeast Wildlife*** 49:36-42.

*1991 - Harrison, D. J., J. A. Harrison, and M. O'Donoghue. Pre-dispersal movements of coyote (Canis latrans) pups in eastern Maine. ***Journal of Mammalogy*** **72:**756-763.

*1989 - Harrison, D. J., J. A. Bissonette, and J. A. Sherburne. Spatial relationships among coyotes and red foxes in eastern Maine. ***Journal of Wildlife Management*** 52:181-185.

*1989 - Litvaitis, J. A., and D. J. Harrison. Bobcat-coyote niche relationships during a period of coyote population increase. ***Canadian Journal of Zoology*** 67:1180-1188.

1986 - Harrison, D. J., and W. B. Krohn. Population characteristics of Maine coyotes. ***U.S. Fish and Wildlife Service Research Information Bulletin No. 86***:112.

*1986 - Harrison, D. J. Coyotes in the northeast: their history, origin, and ecology. ***Appalachia*** 46:30-39.

1986 - Major, J. T., J. A. Sherburne, J. A. Litvaitis, and D. J. Harrison. Resource use by and interspecific relations between bobcats and other large mammalian predators in Maine. Pages 291 *in* S.D. Miller and D.D. Everett, (editors) ***Cats of the World: Biology, Conservation and Management***. Natl. Wildlife Federation, Washington, D.C.

*1985 - Harrison, D. J., and J. R. Gilbert. Denning ecology and movements of coyotes in Maine during pup rearing. ***Journal of Mammalogy*** 66:712-719.

*1984 - Harrison, D. J., and J. A. Harrison. Foods of adult Maine coyotes and their known-aged pups. ***Journal of Wildlife Management*** 48:922-926.

1984 - Harrison, D. J. Use of white-tailed deer by coyotes during pup rearing in Maine. ***Transactions of the Northeast Deer Technical Committee*** 20:34-35.

Technical Reports and Miscellaneous Publications:

2017 – Dunham, S. and D. Harrison. Spruce grouse habitat in the Acadian forests of Maine: Results and recommendations for forest managers. CFRU Research Note 17-01, Maine Cooperative Forestry Research Unit. University of Maine. Orono, ME.

2016 – Harrison, D., S. Morano, and S. Olson. Relationships among forest harvesting, snowshoe hares, and Canada lynx in Maine. Pages 52-56 *in* Roth, B.E. (Ed.) Cooperative Forestry Research Unit: 2015 Annual Report. University of Maine. Orono, ME.

2016 – Tebbenkamp, J., E. Blomberg, D. Harrison, and S. Dunham. Population dynamics of spruce grouse in the managed forest landscapes of northern Maine. Pages 57-61 *in* Roth, B.E. (Ed.) Cooperative Forestry Research Unit: 2015 Annual Report. University of Maine. Orono, ME.

2016 – Rolek, B., D. Harrison, C. Loftin, and P. Wood. Bird communities of coniferous forests in the Acadian region: habitat associations and responses to forest management. Pages 57-61 *in* Roth, B.E. (Ed.) Cooperative Forestry Research Unit: 2015 Annual Report. University of Maine. Orono, ME.

2015 – Harrison, D., and S. Olson. Relationships among forest harvesting, snowshoe hares, and Canada lynx in Maine. Pages 68-74 *in* B.E. Roth, editor, Cooperative Forestry Research Unit: 2014 Annual Report, University of Maine, Orono.

2015 – Dunham, S., and D. Harrison. Patch occupancy, habitat use, and population performance of spruce grouse in commercially managed conifer stands. Pages 75-79 *in* B.E. Roth, editor, Cooperative Forestry Research Unit: 2014 Annual Report, University of Maine, Orono.

2015 - Rolek, B., D. Harrison, C. Loftin, and P. Wood. Bird communities of coniferous forests in the Acadian Region: Habitat associations and response of birds to forest management. Pages 80-88 *in* B.E. Roth, editor, Cooperative Forestry Research Unit: 2014 Annual Report, University of Maine, Orono.

2014 – Harrison, D., S. Olson, D. Mallett, A. Fuller, and J. Vashon. Relationships among forest harvesting, snowshoe hares, and Canada lynx in Maine. Pages 57-62 *in* B.E. Roth, editor, Cooperative Forestry

Research Unit: 2013 Annual Report, University of Maine, Orono.

2014 – Dunham, S., and D. Harrison. Patch occupancy, habitat use, and population performance of spruce grouse in commercially managed conifer stands. Pages 63-66 *in* B.E. Roth, editor, Cooperative Forestry Research Unit: 2013 Annual Report, University of Maine, Orono.

2014 – Rolek, B., D. Harrison, and C. Loftin. Bird communities of coniferous forests in the Acadian Region: habitat associations and response of birds to forest management. Pages 67-73 *in* B.E. Roth, editor, Cooperative Forestry Research Unit: 2013 Annual Report, University of Maine, Orono.

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Fuller, A. K., and D. J. Harrison. Effects of habitat loss versus fragmentation on habitat occupancy by endangered Newfoundland martens. ***Conservation Biology*** (in prep).

Harrison, D.J. Influence of dispersal on social ecology of coyotes: do social pressures or prey size promote pack formation? ***Animal Behaviour*** (in preparation).

Hepinstall, J. A., and D. J. Harrison. Prediction and validation of occupancy models for American martens. ***Journal of Wildlife Management*** (draft manuscript complete).

Hearn, B. J. and D. J. Harrison. Home range and body scaling in American martens in Maine and Newfoundland: why are home ranges in Newfoundland so large? ***Oikos*** (draft manuscript complete).

Hearn, B. J. and D. J. Harrison. When the sink becomes the source: survival of martens in relation to timber harvesting in Newfoundland. ***Oikos*** (manuscript in preparation)

Hepinstall, J.A. and D. J. Harrison. The relative effects of habitat loss versus fragmentation in determining habitat occupancy by American marten. ***Conservation Biology*** *(manuscript complete and undergoing pre-submission review).*

D. J. Harrison, W. B. Krohn, S. Scott, and L. D. Robinson. Effects of partial forest harvesting on habitat and densities of snowshoe hares. ***Forest Ecology and Management*** *(manuscript in prep).*

Payer, D.C., and D.J. Harrison. Influences of timber harvesting and trapping on habitat selection and home range characteristics of marten. ***Journal of Wildlife Management*** *(analyses ongoing).*

<u>GRANTS AND PROPOSALS</u>:

External (total funded >4.3 million, direct funding to University of Maine =$3,858,897 and is presented in

bold):

Responses of marten populations to 30 years of habitat change in commercially managed landscapes of northern Maine. Maine Cooperative Forestry Research Unit, 2018-2020, **$79,200**, funded.

Responses of marten populations to 30 years of habitat change in commercially managed landscapes of northern Maine. Matching funds of $67,218 requested from Maine Department of Inland Fisheries and Wildlife, 2018-2020, $67,218, not funded.

Spatio-temporal dynamics of snowshoe hares in northern Maine from 2001-2015. Post-doctoral matching support requested from Maine Department of Inland Fisheries and Wildlife, 2017-2018, $33,250, not funded.

Linking habitat associations with demographics to inform conservation of spruce grouse throughout the Northern Forest. Northeastern States Research Cooperative, Theme Four, not funded, $63,633 requested, Co-investigator with Erik Blomberg.

Studies of snowshoe hare population cycles. U.S. Fish and Wildlife Service, funded **$21,290** 1/15/2015-12/31/2017.

Demography and populations status of spruce grouse in northern Maine forests, Co-investigator with Erik Blomberg, Maine Outdoor Heritage Fund, funded **$17,835**, 2014-2015.

Population dynamics of spruce grouse in the managed forest landscapes of northern Maine. Co-investigator with Erik Blomberg, Maine Cooperative Forestry Research Unit, funded, **$89,238** 2015-2017.

Evaluation of representative bird species Landscape Capability models. Co-investigator with Cynthia Loftin, USGS Science Support Program, funded, **$276,731**, 2015-2017

Effects of forest management practices in the Acadian northern hardwood/conifer forests of Maine on forest bird communities. Co-investigator with Cynthia Loftin. U.S. Fish and Wildlife Service and USGS Science Support Partnership Program, funded, **$380,884**, 2012-2016.

Effects of forest management practices in the Acadian conifer forests of Maine on forest bird communities, with emphasis on species of federal conservation priority. Co-investigator with Cynthia Loftin, **$87,000**, Maine Cooperative Forestry Research Unit, funded 2013-2015.

Studies of snowshoe hare densities and forest succession following forest harvesting. U.S. Fish and Wildlife Service. Cooperative Agreement 2011-2015. **$15,000**, funded.

Long-term studies of snowshoe hares, Canada lynx and forest structure associated with forest succession following clearcutting and various forms of partial harvests. **$157,110**, Maine Cooperative Forestry Research Unit, funded 2012-2015.

Cost-shared funding and base support for a Cooperating Scientist in wildlife-forestry relationships. Proposal to Maine Cooperative Forestry Research Unit, The Nature Conservancy,and other forest stakeholders. $510,000 funded, 2010-2015 – but project cancelled due to candidate taking faculty

position at another university.

Relative densities, patch occupancy, and population performance of spruce grouse in clearcut, precommercially thinned, mid-late successional conifer forests, and in coniferous forested wetlands in northern Maine**. $118,007**, funded, Maine Cooperative Forestry Research Unit, funded 2010 –2013.

Genetic-based analyses of lynx diets from scats collected with aid of detection dogs. Funded $6,812, 2013. Funded by Maine Department of Inland Fisheries and Wildlife and paid directly to genetics subcontractor.

Effectiveness of zoning to protect deer wintering areas**. $17,500** funded by Northeastern States Research Cooperative, USDA Forest Service for 2008-2010.

Trends in habitat supply for wildlife species whose habitat requirements are not addressed using coarse-filter umbrella species approaches, with a focus on deer wintering areas**. $77,000** funded by Maine Cooperative Forestry Research Unit for 2009-2011.

An evaluation of course filter umbrella species for landscape planning: trends in habitat supply for wildlife species whose habitat requirements are not addressed using umbrella species approaches. Pre-proposal submitted to Northeastern States Research Cooperative, Theme 4, USDA Forest Service for 2008-2010, $45,629, not funded.

Long-term monitoring of snowshoe hare populations to inform stand and landscape-scale forest management and the recovery planning for Canada lynx in Maine, and collaboration with Maine Department of Inland Fisheries and Wildlife to address changes in lynx demography and spatial ecology associated with declining hare populations. **$97,083** funded by Maine Cooperative Forestry Research Unit for 2008-2011and **$14,637** funded by U.S. Fish and Wildlife Service.

An evaluation of coarse-filter umbrella species for landscape planning. $59,311 requested from Northeast Regional Conservation Needs Grants Program, not funded.

Long-term habitat management planning for lynx and marten across the managed landscapes of northern Maine. **$265,000** funded by U.S. Natural Resource Conservation Service, Healthy Forest Reserve Program (The Nature Conservancy and Natural Resource Conservation cooperating) for 2007-2010.

Developing a black bear model system of skeletal mechanotransduction. $2,105,885 requested from U.S. Department of Human Services (with R. Seger as lead P.I. and others), not funded.

Forecasting and assessing the future of Maine's forests using LiDAR. $2,098,924 requested from Maine Technology Institute (with B. Wiersma as lead P.I. and others), not funded.

Documenting relationships among forest management and the occurrence patterns of Northern Goshawks in Maine. Proposal to Maine Cooperative Forestry Research Unit, $64,000 for 2008-2009 (not funded).

Application and testing of models to predict probability of occupancy and density of endangered Newfoundland marten. **$26,329** funded by Canadian Forest Service and Newfoundland-Labrador Wildlife Division 2006-2007.

Integrating landscape-scale biodiversity conservation with diverse forest management goals on large ownerships in Maine. **$115,427** funded by Maine Cooperative Forestry Research Unit for 2006-2009 (with Manomet Center for Conservation Sciences).

Responses of snowshoe hares and lynx to forest harvesting across multiple spatial scales. **$96,000** funded by Maine Cooperative Forestry Research Unit, **$20,000** funded by U.S. Fish and Wildlife Service, **$15,000** by National Council for Air and Stream Improvement; 2005 - 2009 (with W. Krohn).

Trends in deer-vegetation relationships in Acadia National Park from 1980-2007: relationships of an unhunted insular deer population to forage carrying capacity. $99,830 requested from U.S. National Park Service (not funded).

Completion of deer studies in Acadia National Park. **$8,900** funded by U.S. National Park Service, 2006.

Support for lynx-hare research at The University of Maine, 2005-2007. **$20,000** in grants funded by International Paper Company through the Department of Industrial Cooperation, University of Maine (with W. Krohn).

Gift from The Nature Conservancy to support lynx-hare research projects, May 2006, **$5,000**.

Predicting responses of forest landscape change on wildlife umbrella species: Modeling future effects of alternative forest harvesting scenarios on vertebrate diversity across multiple spatial scales on commercial forestlands in Maine. **$124,00**0 funded by USDA Forest Service, Agenda 20/20 Program 2005-2007, and **$17,000** funded by Maine Cooperative Forestry Research Unit. This project is in collaboration with Drs. Steve Sader, Jeremy Wilson, and William Krohn and supports 2 graduate students.

Predicting responses of snowshoe hares and lynx to alternative forest harvesting scenarios across spatial multiple scales in northern Maine. Science Support Program, USGS/FWS, **$89,810** funded for 2004-2007 (with W.B. Krohn, MCFWRU, M. McCollough, FWS).

Predicting responses of snowshoe hares and lynx to alternative forest harvesting scenarios across multiple spatial scales. **$50,000** funded by CFRU for 2005-2006, **$10,500** funded by U. S. Fish and Wildlife Service (with W. B. Krohn).

Predicting responses of snowshoe hares and lynx to alternative forest harvesting scenarios across spatial multiple scales. **$30,000** funded by National Council for Air and Stream Improvement and Plum Creek Corporation for 2004-2006 (with W. B. Krohn).

Evaluating the umbrella species approach for biodiversity conservation on commercial forestlands in Maine. **$28,850** funded by CFRU for 2004. This project supported a collaboration with post-doctoral scientist Jeff Hepinstall at the University of Washington, Seattle.

Development of a stand-scale model for predicting snowshoe hare densities for forest measurements. **$22,000** funded by CFRU for 2004 (with W. B. Krohn). This project supported a research collaboration with Jessica Homyack, Research Associate, U.S. Fish and Wildlife Service, Cheyenne, Wyoming.

Gift from The Nature Conservancy to support lynx-hare research projects, August 2004, **$5,000**.

Support for publication of edited book titled: *Martens and Fishers (Martes) in Human-Altered environments: An International Perspective*. Gift of **$8,000** from Canadian Forest Service (2002) and **$3,000** from Newfoundland-Labrador Wildlife Division.

Influence of forest practices on stand- and sub-stand scale habitat selection of lynx in northern Maine. Maine Cooperative Forestry Research Unit, **$63,046**, (funded, 2001-2003), Fraser Paper Company **$3,000**.

Influence of forest practices on stand- and sub-stand scale habitat selection of lynx in northern Maine. U.S. Fish and Wildlife Service and Maine Department of Inland Fisheries and Wildlife, **$12,000** (funded 2001-2003).

Landscape thresholds and response to fragmentation by endangered Newfoundland marten. Canadian Wildlife Service, Canadian Forest Service, Western Newfoundland Model Forest, Parks Canada, Newfoundland Wildlife Division, **$180,600**(US$) (funded, 2002-2007).

National Commission on Science for Sustainable Forestry – authored preproposal in collaboration with Manomet scientists requesting $160,000 to support landscape planning for biodiversity in northern Maine. The preproposal was selected as one of 3 finalists (2 to be funded) nationally and we were invited to develop a full proposal. Preproposal was withdrawn because of administrative responsibilities associated with Interim Chair position.

Lynx research projects in northern Maine. The Nature Conservancy, **$7,000** (gift) in 2003.

Influence of pre-commercial thinning on wildlife habitat in northern Maine, with special emphasis on snowshoe hares. Maine Cooperative Forestry Research Unit, U.S. Fish and Wildlife Service, National Council of the Paper Industry for Air and Stream Improvement, **$177,176** (funded, 2000-2003).

A habitat supply assessment for marten: linking population management alternatives to habitat extent and distribution across northern Maine. Maine Cooperative Forestry Research Unit, **$45,000** (funded 2000-2002).

A habitat supply assessment for marten: linking population management alternatives to habitat extent and distribution across northern Maine. National Council of the Paper Industry for Air and Stream Improvement, $30,000 (not funded).

Marten as a tool for landscape-scale habitat planning in northern Maine. Maine Outdoor Heritage Fund and Maine Dept. Inland Fisheries and Wildlife, **$71,498**, (funded, 1999-2002).

Marten as a tool for landscape-scale habitat planning in northern Maine. Maine Chapter of The Nature Conservancy $15,000 requested, **$7,500** funded, 2000-2002).

A GIS-based evaluation of lynx habitat at multiple spatial scales. National Council of the Paper Industry for Air and Stream Improvement (NCASI), U.S. Fish and Wildlife Service, Maine Dept. Inland Fisheries

and Wildlife $59,503 requested, **($52,003**, funded, 1998-2001), co-investigator: W. Krohn.

Population demography of marten in Newfoundland, Canada. Natural Resources Canada, **$20,000**, (funded 1998-99).

Influence of partial harvesting on habitat selection by marten and primary prey species in northern Maine. Maine Cooperative Forestry Research Unit, **$37,151** (funded, 1997-99).

Effects of timber harvesting and trapping on marten populations in northern Maine: the industrial forest site. Maine Department of Inland Fisheries and Wildlife, **$169,259** direct funding, $60,800 *in-kind* (funded, 1993-99).

Effects of timber harvesting and trapping on marten populations in northern Maine: the forest preserve site. Maine Cooperative Forestry Research Unit, **$90,889** (funded, 1993-98), Maine Forest Service, **$71,689** (funded, 1994-98), Maine Department of Inland Fisheries and Wildlife, $25,500 *in-kind* (funded 1994-98). Influence of microhabitat characteristics on intensity of forest use and productivity of martens in Maine: implications for forest practices. National Council of the Paper Industry for Air and Stream Improvement, **$38,214** (funded, 1995-98).

Factors influencing nesting success of wild turkeys in Connecticut. National Wild Turkey Federation and Wildlife Division, Connecticut Dept. of Environmental Protection **$25,000** + *in-kind* support (funded 1996-98), co-investigator F. Servello.

Potential habitat for wolves in the northeastern U.S. and connectivity with habitat occupied by extant wolf populations in southeastern Canada. Wildlife Conservation Society, **$4,559**, (funded, 1996).

Opportunities for management of habitat of American marten on Crown lands leased and managed by Fraser, Inc., in New Brunswick. Fraser Paper, Inc., New Brunswick, $69,334, (not funded, 1996).

Effects of timber harvesting and residual stand characteristics on habitat selection by martens in northern Maine. National Council for the Paper Industry for Air and Stream Improvement. **$28,232**, (funded 1993-95).

White-tailed deer mortality, population dynamics, movements, and spatial interactions with coyotes in Acadia National Park, Maine. U.S. National Park Service. **$208,547**, (funded 1991-95, 1999-2000), co-investigator A. O'Connell, Jr.

Predation on white-tailed deer fawns by coyotes on Mount Desert Island, Maine. U.S. National Park Service. **$69,103**, (funded 1992-94), co-investigator A. O'Connell.

Influence of trapping and timber harvesting on pine martens in northern Maine. New Brunswick Executive Forest Research Committee, Inc. $248,000, (not funded).

Occurrence, distribution, and interactions among mammalian carnivores in Acadia National Park. U.S. National Park Service, **$59,000**, (funded 1988-90).

Effects of browsing by white-tailed deer and snowshoe hare on vegetation at Acadia National Park. U.S.

National Park Service, **$39,000**, (funded 1988-90).

Fecal nitrogen as an index to white-tailed deer nutritional condition in Acadia National Park. U.S. National Park Service , **$1,300**, (funded 1990).

Interactions among trapping, timber harvesting, and pine marten populations. Submitted to Maine Department of Inland Fisheries and Wildlife; $73,000 contractual requested, **$58,000** of *in kind* were provided (1988-92).

A review of methodologies and harvest data used to manage river otter populations in northeastern North America. N.E. Region, U.S. Fish & Wildlife Service, **$52,000**, (funded 1989-90), Co-investigator with B. Griffith.

Internal

Add $2k support for Zach Loman in June 2017 from CRSF and new M-Stennis project October 2015-September 2020

A very high resolution aircraft mounted digital imaging system for remotely sensing forest vegetation. University of Maine Competitive Research Funds, Co-Investigator with Stephen Sader and Robert Wagner, **$14,972**, funded, 4/2012.

Received a competitive University Sabbatical ($15,000) that funded Linda Ilse as an Adjunct Professor and provided additional funds to DWE during my sabbatical in spring 2008.

Multi-scalar effects of forestry on an early-and a late-successional forest obligate across commercially managed lands in northern Maine: How are densities of snowshoe hares and occurrence patterns of spruce grouse differentially affected by broad-scale forest harvesting. Maine Agricultural and Forest Experiment Station, McIntire-Stennis Project funded October 2010 – September 2015. Funding includes 25-50% of P.I. salary, 1 graduate research assistantship (12 months), and ca. $3,000 in annual support for research expenses.

Secured funding for 50% ($25,000 per year, plus fringe benefits for 2 years) of an Assistant Scientist salary (Erin Simons) from the Center for Research on Sustainable Forest's ForCAST initiative 2008-2009.

Landscape-Scale Effects of Forestry on Forest Carnivores and Other Vertebrates. This project forms the basis for my McIntire-Stennis (MAFES) associated research program and is approved for the period 10/2004-9/2009. Funding includes 50% of P.I. salary, 1 graduate research assistantship (12 months), and ca. $6,000 in annual support for research expenses.

Influence of partial harvesting on American marten and primary prey species. McIntire-Stennis proposal, base funded 1998-2004.

A habitat supply assessment for marten: linking population management alternatives to habitat extent and distribution across northern Maine. $22,500 requested from research and development funding, College of Natural Sciences Forestry and Agriculture, University of Maine (not funded, 2002).

A research scientist to complete analyses and report writing for long-term studies in Acadia National Park. Department of Wildlife Ecology, Office of the Dean of College of Natural Sciences, Forestry and Agriculture, and Office of the Vice Provost for Research and Graduate Studies, Univ. Maine, $15,000, funded, 1999-2000.

A GIS-based evaluation of potential habitat for lynx in eastern North America at geographic and landscape scales. $7,500, funded, 11/98. Competitive funding for research and development, College of Natural Sciences, Forestry and Agriculture, University of Maine.

Synthesis and application of data from long-term studies of mammalian carnivores and prey. $31,980, not funded, 11/98. Competitive funding for research and development, College of Natural Sciences, Forestry and Agriculture, University of Maine.

A real-time, differentially corrected, global positioning system for studying animal movements. $6,500, funded, 12/97. Faculty Research Funds - Equipment Grant Competition, Univ. Maine.

Influence of partial harvesting on American marten and primary prey species. McIntire-Stennis proposal, base funded 1998-2003, included $7,900 in annual research funding, plus a graduate assistantship.

Effects of timber harvesting on population performance and habitat selection by American martens in northern Maine. McIntire-Stennis proposal, base funded, 1993-1998.

Interaction of forest management practices and pine marten populations. McIntire-Stennis proposal, base funded 1989-1993.

Submitted proposals requesting supplemental McIntire-Stennis funding in 1988, 1989, 1990, 1991, 1992: $44,190 requested, $40,310 funded.

Effects of trapping on pine marten populations in northern Maine. $5,000, funded, 1991. Faculty *Research Funds - Summer Research Grant Competition, Univ. Maine.*

SCIENTIFIC PRESENTATIONS (abridged to include January 1988 – June 2017: presenter is listed first):

2016 – Tebbenkamp 2 posters at TWS Conference, October 2016

2017- Dunham, S. W., D. J. Harrison, and E. J. Blomberg. Spruce Grouse Habitat Ecology in Maine's Commercially Managed Acadian Forest. *Presented at the Adapt, Adopt, Advance: Resiliency in Natural Resource Management Conference,* Bangor, Maine. March 9.

2017 - Harrison, D. J., B. W. Rolek, C.S. Loftin, P.B. Wood. Effects of forest management practices in Acadian conifer forests on spruce-fir bird communities. *Presentation to Irving Corporation Wildlife Biologists and Foresters and to the New Brunswick Forest Research Advisory Committee Advisory,* Sainte Anne de Madawaska, New Brunswick, Canada, May 30.

2017 - Harrison, D. J., B. W. Rolek, C.S. Loftin, P.B. Wood. Effects of forest management practices in

Acadian conifer forests on forest bird communities, with emphasis on species of conservation priority. *Presentation to Advisory Committee of Maine Cooperative Forestry Research Unit*, Orono, Maine, April 12.

2017 - Loman, Z., D. Harrison, C. Loftin, P. B. Wood. Validation of Designing Sustainable Landscapes Models using forest game birds, passerine birds, and a representative species approach. *Workshop presented to U.S. Fish and Wildlife Service, Migratory Bird Division.* Hadley, MA, USA. 12 January.

2017 - Loman, Z., D. Harrison, C. Loftin, P. B. Wood. Designing sustainable landscapes evaluation: where we're going and where we've been. USGS Maine Coop Unit Cooperators Meeting. Orono, ME, March 22.

2017 – Loman, Z. G. Loman, .W. V. Deluca, D. J. Harrison, C. S. Loftin,, Petra B. Wood. Do representative forest songbirds effectively predict occurrences of ecologically similar species? *Paper presented at Northeast Association of Fish and Wildlife Agencies Annual Conference, Rayleigh, NC*, April 11.

2017 - Rolek, B.W., D. Harrison, C.S. Loftin, P.B. Wood. Spruce-fir birds and forest management in Northern New England. *Workshop presented to U.S. Fish and Wildlife Service, Migratory Bird Division.* Hadley, MA, USA. 12 January.

2017 - Rolek, B.W., D. Harrison, C.S. Loftin, P.B. Wood. Softwood forest birds and forestry in New England. *Presentation to Cooperating Committee Meeting for Maine Cooperative Fish and Wildlife Research Unit*, Orono, Maine, USA. 22 March.

2016 - Dunham, S.W., and D.J. Harrison. Female spruce grouse habitat selection during the brood-rearing season in managed conifer forests. *Poster. 6th North American Ornithological Conference. Joint meeting of American Ornithological Union, Cooper Ornithological Society, Wilson Ornithological Society, Association of Field Ornithologists, and Society of Canadian Ornithologists. Washington, DC.* August 17.

2016 - Harrison, D. and S. Dunham. Final project report: Relative densities, patch occupancy, and population performance of spruce grouse in managed and unmanaged forests in northern Maine. *Presentation to Advisory Committee of Maine Cooperative Forestry Research Unit*, Orono, Maine, April 20.

2016 - Loman, Z.G., E. J. Blomberg, W. D. Deluca, D. Harrison, C. Loftin, and P. B. Wood. 2016. Landscape capability as a predictor of upland game bird space use in the northeastern United States. *Presentation at The Wildlife Society Annual Conference. Raleigh, North Carolina*, October 15-19.

2016 - Rolek, B.W., D. Harrison, C.S. Loftin, P.B. Wood. Opportunities to enhance habitat for spruce-fir passerines using commercial forest management. *Paper at North American Congress for Conservation Biology, Society for Conservation Biology, Madison, Wisconsin*, July 17-20.

2016 - Rolek, B.W., D. Harrison, C.S. Loftin, P.B. Wood. Softwood forest birds and forestry in New England. *Presentation at Cooperating Committee Meeting for Maine Cooperative Fish and Wildlife Research Unit, Orono, Maine,* March 23.

2016 - N. S. Parkhill, N. S., J. Tebbenkamp, S. Dunham, D. Harrison, and E. Blomberg. Effect of forest structure on nest site selection by spruce grouse across two scales. *Poster presented at The Wildlife Society Annual Conference. Raleigh, North Carolina*, October 15-19.

2016 - Tebbenkamp, J., E.Blomberg, D. Harrison, and R. Holberton. Is autumnal display associated with territorial defense or mate prospecting? A case study with spruce grouse. *Poster presented at The Wildlife Society Annual Conference. Raleigh, North Carolina*, October 15-19.

2015 - Dunham, S. W., D. J. Harrison, and E. J. Blomberg. 2015. Spruce grouse (*Falcipennis canadensis)* patch occupancy and abundance estimates in the commercially managed forests of Maine. *Presentation at the 13th International Grouse Symposium, Reykjavik, Iceland,* September 8.

2015 - Harrison, D. J. Updates on wildlife projects funded by the Maine Cooperative Forestry Research Unit (CFRU). *Presentation at CFRU Advisory Committee Meeting, Houlton, Maine*, October 28, 2015.

2015 - Olson, S. J., D. J. Harrison, A. K. Fuller, J. H. Vashon. Canada lynx food habits responses to seasons, and to low vs. high hare density periods: Always a specialist? *Poster presentation at The Wildlife Society Annual Conference, Winnipeg, Manitoba, Canada*, October 21-22.

2015 - Rolek, B.W., D. Harrison, C.S. Loftin, P.B. Wood. *Workshop on spruce-fir birds and forest management in Northern New England at U.S. Fish and Wildlife Service Migratory Bird Division. Hadley, MA, USA*, October 8.

2015 - Rolek, B.W., C. Loftin, D. Harrison, and P. Wood. Effects of forest management on avian abundance in spruce-fir forests of New England. *Joint Meeting of the Canadian Ornithological Society, Association of Field Ornithologists, and Wilson Ornithological Society. Wolfville, NS*, Canada, July 17.

2015 - Rolek, B.W., C. Loftin, D. Harrison, and P. Wood. Softwood forest birds and silviculture in New England. *Annual Meeting of the Research Committee for Baxter State Park, Augusta, Maine*, March 27.

2014 - Dunham, S. W., and D. J. Harrison. 2014. Spruce grouse breeding season patch occupancy and female home range use across forest management treatments in Maine. *Poster presented at the Annual Conference of The Wildlife Society, Pittsburgh, Pennsylvania,* October 27-28.

2014 – Harrison, D. Origin, spatial and social ecology, and predator-prey relationships of eastern coyotes: a review. *Invited lead presentation in Symposium on Ecology and Management of Coyotes in Eastern North America: Synthesizing Information from Contemporary Studies, The Wildlife Society 21st Annual Conference, Pittsburg, Pennsylvania*, October 27.

2014 – Dunham, S. and D. Harrison. Spruce grouse breeding season patch occupancy and home range comparisons across forest management treatments in Maine. *Presentation at 70th Northeast Fish and Wildlife Conference, Portland, Maine,* April 14.

2014 - Dunham, S. and D. Harrison. Habitat selection of female spruce grouse during brood rearing in commercially managed forests. Presentation at Annual Meeting of the American Ornithologists

Union, Estes Park, Colorado. September 27.

2014 – Harrison D. and E. Blomberg. Population dynamics of spruce grouse on commercially managed forestlands in Maine: a proposal. *Presentation at winter meeting of CFRU Advisory Committee, Orono, Maine,* January 22.

2014 – Harrison, D., S. Olson, S. Dunham, B. Rolek, and C. Loftin. Updates of research findings from studies of snowshoe hares, Canada lynx, spruce grouse and forest songbirds funded by the Maine Cooperative Forestry Research Unit (CFRU). *Presentation at winter meeting of CFRU Advisory Committee, Orono, Maine,* January 22.

2014 – Olson, S. and D. Harrison. Seasonal influences of vegetation on snowshoe hare pellet densities across forest management types in Maine. *Presentation at 70th Northeast Fish and Wildlife Conference, Portland, Maine,* April 14.

2014 – Olson, S. and D. Harrison. Snowshoe hare response to seasonal changes in Acadian managed forests of northern Maine. *Presentation at American Society of Mammalogists Annual Conference, Oklahoma City, Oklahoma*, June 10.

2014 – Parkhill, N. S., D. Harrison, and S. Dunham. Effects of forest vegetation on spruce grouse nest-site selection across 2 spatial scales. *Poster at 70th Northeast Fish and Wildlife Conference, Portland, Maine,* April 14.

2014 – Rolek, B., C. Loftin, D. Harrison, and P. Bohall Wood. The influence of silviculture on New England bird communities in northern coniferous forests. *Presentation at 70th Northeast Fish and Wildlife Conference, Portland, Maine,* April 15.

2014 - Simons-Legaard, E. and D. Harrison. Trends in habitat conditions in LURC-zoned deer wintering Areas: implications for management of deer on commercially-owned forestlands. *Invited presentation and panel discussion at Maine Industrial Forest Forum, Bangor, Maine,* February 16.

2013 – Fuller, A. K. and D. J. Harrison. Trade-offs among forest management objectives, focal wildlife species, and ecological reserves: implications for future forest biodiversity and timber harvests. *Invited Seminar to Department of Wildlife Ecology, University of Maine, Orono, Maine,* October 28.

2013 – Harrison, D., D. Mallett, A. K. Fuller, and J. H. Vashon. Snowshoe hares, forests, and Canada lynx: a dynamic interaction between populations, forestry and habitat. *Presentation at Meeting of Maine Cooperative Forestry Research Unit, Orono, Maine*, April 24.

2013 – Harrison, D.J. Conserving sustainable landscapes: using Canada lynx and American martens as umbrella species to enhance landscape planning. *Invited presentation at 2013 Kennebec Land Trust Lyceum, Wayne, Maine,* March 21.

2013 - Rolek, B., C.S. Loftin, D. Harrison, and P. B. Wood. Softwood forest birds and forest management in New England, *USGS-Maine Cooperative Fish and Wildlife Research Unit Annual Coordinating Committee Meeting, Wells Conference Center, Orono, Maine,* March 21.

2012 – Harrison, D., C. Loftin, and P. Wood. Forestry and forest birds: trends in FWS priority bird species in managed forest landscapes. *Presentation to U.S. Fish and Wildlife Service Refuge Biologists, Portland, Maine*, December 18.

2012 - Harrison, D., and E. Simons-Legaard. 2012. Trends in biodiversity in Maine's northern forest. *Presentation at Annual Program and Executive Board Meeting of The Maine Chapter of The Wildlife Society, Brewer, Maine*, May 10.

2012 - Harrison, D. Effects of forest management on Maine's forest bird communities. *Presentation at Advisory Meeting of the Maine Cooperative Forestry Research Unit, Orono, Maine,* January 25.

2012 - Simons-Legaard, E. and D. Harrison. Trends in habitat conditions in LURC-zoned deer wintering areas. *Presentation at Annual Program and Executive Board Meeting of The Maine Chapter of The Wildlife Society, Brewer, Maine,* May 10.

2012 - Simons-Legaard, E. and D. Harrison. Habitat trends in Maine's LURC-zoned deer wintering areas. *Seminar, Department of Wildlife Ecology, The University of Maine,* October 15.

2011 - Fuller, A., D. Harrison, and W. Krohn. 2011. The role of ecological reserves to maintain American marten and Canada lynx in a working forest landscape. *Poster presented at The Wildlife Society, 18th Annual Conference, Waikoloa, Hawaii,* November 9.

2011 - Fuller, A. and D. Harrison Trade-offs among forest management objectives, focal wildlife species, and ecological reserves: implications for future biodiversity and timber harvests. *Poster presented at the Society of Annual Foresters Annual Conference, Honolulu, Hawaii,* November 4

2011 – Harrison, D., E. Simons, A. Fuller, and W. Krohn. Trends in habitat for forest wildlife in Maine's great north woods: the need for landscape planning. *Invited presentation at U.S. Fish and Wildlife Service Northeast Region Biologists Conference, Baltimore, Maryland*, February 14.

2011- Harrison, D., E. Simons, A. Fuller, and W. Krohn. Habitat planning and assessment for forest vertebrates in northern Maine. *Invited Presentation at Annual Coordinating Committee Meeting of the U. S. Geological Survey, Maine Cooperative Fish and Wildlife Research Unit*, *University of Maine, Orono, Maine,* April 12.

2011 – Harrison, D. J. Effects of wind power development on American martens and Canada lynx: an issue of scale. *Invited Presentation at Wind Energy and Wildlife Forum, The Maine Chapter of The Wildlife Society, Orono, Maine*, May 5.

2011 – Simons-Legaard, E. M., D. J. Harrison, K. Legaard, and S. Sader. The effectiveness of zoning to protect deer wintering areas during the period 1975-2007: Does compromising forest productivity to protect deer habitat achieve desired ecological objectives? *Invited Presentation at Advisory Committee Meeting, Maine Cooperative Forestry Research Unit, University of Maine*, Orono, January 26.

2010 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. Applications of habitat modeling for wildlife umbrella species to landscape planning on commercial forestlands. *Presentation at meeting of Maine Cooperative Forestry Research Unit, Orono, Maine*, April 14.

2010 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. A wildlife-based modeling approach to forest landscape planning. *Presentation at The Wildlife Society Annual Conference, Snowbird, Utah*, October 6.

2010 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. Required steps to develop a habitat classification and structured decision-making framework for use in planning for multiple biodiversity and forest objectives on TNC's St. John Lands. *Presentation at Workshop on Managing Working Forest Landscapes for Multiple Biodiversity and Fiber Objectives Using American Martens and Canada Lynx as Focal Species*, University of Maine, Orono, November 10.

2010 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. Results from a structured process for deciding among alternative management scenarios on TNC's St. John lands: trends in habitat supply for martens and lynx and resulting inventory and forest-related metrics. *Presentation at Workshop on Managing Working Forest Landscapes for Multiple Biodiversity and Fiber Objectives Using American Martens and Canada Lynx as Focal Species*, University of Maine, Orono, November 10.

2010 – Harrison, D., W. Krohn, and S. Scott. Spatio-temporal relationships of snowshoe hare populations to forest harvesting, succession, and natural population cycles: implications for forest managers. *Final project report presentation to Maine Cooperative Forestry Research Unit, Orono, Maine*, January 27.

2010 - Harrison, D., W. Krohn, and S. Scott. Snowshoe hares, forestry and Canada lynx: A dynamic interaction. *Invited Paper presented at Lessons From the Past- Research for the Future: A Workshop for CFRU members*, Orono, Maine, May 20.

2010 - Harrison, D. J. and W.B. Krohn. Ongoing research efforts to link landscape conservation with wildlife habitat planning on commercial forestlands in northern Maine. *Invited Presentation to Directors of Resource Conservation, Wildlife, and Planning, Maine Department of Inland Fisheries and Wildlife, Augusta, Maine,* June 15.

2010 – Harrison, D. J., E. Simons, A. Whitman, J. Wilson. Present and future status of biodiversity on managed forest landscapes in Maine, U.S.A. *Presentation at the Annual Meeting of the Society for Conservation Biology*, Edmonton, Alberta, July 7.

2010 – Harrison, D. J. Incorporating landscape planning into the conservation of sensitive forest wildlife species in the northeastern U.S. *Invited presentation at Landscape Workshop for U.S. Fish and Wildlife Service Refuge Biologists and Refuge Managers, Moosehorn National Wildlife Refuge*, Calais, Maine, August 18.

2010 – Harrison, D. J. Stand- and landscape-scale responses of forest mammals to the various forms of siliviculture applied in the Acadian forests of Maine. *Invited presentation and field tour for U.S. Forest Service biologists, foresters and managers. U.S. Forest Service Northern Forest Research Station*, Bradley, Maine, September 9.

2010 – Harrison, D. J. The need for landscape planning on commercially managed landscapes in Maine: *Presentation at Workshop on Managing Working Forest Landscapes for Multiple Biodiversity and Fiber Objectives Using American Martens and Canada Lynx as Focal Species*, University of Maine, Orono, November 10.

2010 - Mallet, D. G., D. J. Harrison, and A. K. Fuller. Variable fix success of GPS collars across habitats used by Canada lynx: influences of habitat structure, topography, and satellite configuration. *Paper presented at 66th Annual Northeast Fish and Wildlife Conference*, Newton, Massachusetts, April 27.

2010 - Simons, E., D. Harrison, A. Whitman, and J. Wilson. 2010. Quantifying biodiversity: seeing the big picture. *Invited Paper presented at Lessons From the Past- Research for the Future: A Workshop for CFRU members*, Orono, Maine, May 20.

2010 – Simons, E., D. Harrison, A. Whitman, and J. Wilson. Present and future status of biodiversity in Maine's commercial forests as indicated by a suite of condition indicators. *Seminar presented at Department of Wildlife Ecology Spring Seminar Series, University of Maine*, Orono, March 29.

2010 - Simons, E. M., W. B. Krohn, and D. J. Harrison. Influences of past and future forest management on the spatiotemporal dynamics of habitat supply for Canada lynx and American marten. *Invited Presentation at the Cooperators' Meeting, Maine Cooperative Fish and Wildlife Research Unit*, University of Maine, Orono. May 11.

2010 - Simons, E., W. Krohn, and D. Harrison. Predicting responses of forest landscape changes on wildlife umbrella species: future projections results for Canada lynx and American marten. *Poster presented at the Cooperators' Meeting, Maine Cooperative Fish and Wildlife Research Unit*, University of Maine, Orono. May 11.

2010 - Scott, S. A., W. B. Krohn, and D. J. Harrison. Influence of declining snowshoe hare densities on Canada Lynx occurrence in northern Maine. *Poster presented at the Cooperators' Meeting, Maine Cooperative Fish and Wildlife Research Unit*, University of Maine, Orono. May 11.

2009 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. Landscape planning on The Nature Conservancy lands in northern Maine. *Invited presentation to executive director and staff of The Nature Conservancy,* Brunswick, Maine. February 24.

2009 - Fuller, A. K. D. J. Harrison, B. J. Hearn, and J. A. Hepinstall. Spatial responses to habitat loss in two populations of forest martens. Paper presented at *5th International Martes Symposium – Biology and Conservation of Martens: a New Synthesis*, Seattle, Washington. September 10.

2009 – Harrison, D. J. Forests, forest mustelids, and forest fragmentation: what happens when mammals don't read? *Invited presentation at Symposium on Behavioral Ecology of Mammals, W. M. Keck Center for Behavioral Ecology, North Carolina State University*, September 4.

2009 – Harrison, D. J. and B. J. Hearn. Ecological comparisons of home-range characteristics of American martens in Newfoundland and Maine: why are home ranges of threatened Newfoundland martens so large? Paper presented at *5th International Martes Symposium – Biology and Conservation of Martens: a New Synthesis*, Seattle, Washington. September 10.

2009 – Harrison, D. J. and A. K. Fuller. Ecology of white-tailed deer in Acadia National Park: Results from Research Conducted at The University of Maine. *Presentation to Resource Management Staff, Acadia National Park, Bar Harbor, Maine*, November 6.

2009 – Harrison, D .J., E. Simons, A. Whitman, and J. Wilson. Quantifying biodiversity values across managed landscapes in northern and western Maine. *Presentation to the Maine Cooperative Forestry Research Unit, Mars Hill, Maine*, October 28.

2009 – Harrison, D. J. The growing need to fund additional scientists working on forest-wildlife interactions in Maine: a proposal. *Presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine. February 26.

2009 – Harrison, D. J. Forestry and Forest Wildlife, Chaired session at New England Society of American Foresters 89th Winter Meeting**.** Bio: Mass, Fuel, Products, Diversity - Resource Management in a Changing World. Portland, Maine. March 19**.**

2009 – Harrison, D. J., and A. K. Fuller. Relative Densities, Patch Occupancy, and Population Performance of Spruce Grouse in Regenerating Conifer, Precommercially Thinned, Mature Conifer, and Conifer Wetlands Stands: a proposal. *Presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine. April 15.

2009 – Harrison, D. J., E. M. Simons, and W. B. Krohn. Habitat changes for wildlife umbrella species: implications for landscape conservation strategies in northern Maine. *Invited presentation to northern Appalachians landscape conservation committee*, The Nature Conservancy, Brunswick, Maine. May 21.

2009 – Harrison, D. J., W. B. Krohn, and E. M. Simons. Past and future trends in habitat supply for forest carnivores in northern Maine: implications for forest policy. *Invited presentation to leadership of Maine Forest Service, Maine Department of Inalnd Fisheries and Wildlife and Maine Natural Areas Program*, Augusta, Maine. June 30.

2009 - Patterson W. and A. K. Fuller. Silvicultural prescriptions for maintaining marten and lynx habitat requirements. Field tour of the Nature Conservancy St. John ownership for staff of The Nature Conservancy, U.S. Fish and Wildlife Service, and Huber Resources Group. May 4-6.

2009 - Scott, S. A, D.J. Harrison, and W. B. Krohn. The relative effects of forest practices and natural population processes on the temporal dynamics of hare populations in northern Maine. *Invited Paper at New England Society of American Foresters 89th Winter Meeting***,** Portland, Maine. March 19**.**

2009 - Scott, S.A., D.J. Harrison, and W.B. Krohn. Spatio-temporal dynamics of snowshoe hares in northern Maine**.** *Presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine. April 15.

2009 – Scott, S. A., D. J. Harrison, and W. B. Krohn. Spatio-temporal dynamics of snowshoe hares in northern Maine. *Paper presented at Northeast Fish and Wildlife Conference*, Lancaster, Pennsylvania. April 27.

2009 - Simons, E. M., D. J. Harrison, W. B. Krohn, K. R. Legaard, J. S. Wilson, and S. A. Sader. Past and future trends in habitat supply for martens and lynx across the landscapes of northern Maine, 1973-2032. . *Invited Paper at New England Society of American Foresters 89th Winter Meeting*, Portland, Maine. March 19**.**

2009 - Simons, E. M., D. J. Harrison, W. B. Krohn, K. R. Legaard, J. S. Wilson, and S. A. Sader. Past and future trends in habitat supply for martens and lynx across the landscapes of northern Maine, 1973-2032. .

Invited presentation to executive director and staff of The Nature Conservancy, Brunswick, Maine. February 24.

2009 – Simons, E. M. Influences of past and future forest management on the spatiotemporal dynamics of habitat supply for Canada lynx and American martens in northern Maine. *Ph.D. defense seminar, The University of Maine*, Orono. March 25.

2009 - Simons, E. M., J. S. Wilson, D. J. Harrison, W. B. Krohn,. Future trends in habitat supply for martens and lynx across the landscapes of northern Maine under alternative forest management scenarios, 2007-2032. . *Presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine. April 15.

2008 - Fuller, A. K., D. J. Harrison, and B. J. Hearn. 2008. Application and testing of models to predict probability of occupancy and density of endangered Newfoundland martens. *Presentation to Newfoundland Marten Recovery Team*, Corner Brook, Newfoundland. January 4.

2008 - Fuller, A. K., D. J. Harrison, and B. J. Hearn. 2008. Spatial responses to habitat loss in two isolated populations of forest martens. *Invited talk in the Ecology, Evolution, and Behavior seminar series. Virginia Tech. University*, Blacksburg. February 1.

2008 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. Landscape planning initiative for northern Maine using area sensitive umbrella species. *Invited presentation at USDA Natural Resources Conservation Service and U.S. Fish and Wildlife Service workshop on the Healthy Forest Reserve Program in Maine*, Bangor, Maine. July 1.

2008 – Fuller, A. K., D. J. Harrison, B. K. Hearn, and J. A. Hepinstall. Spatial responses to habitat loss in 2 populations of forest martens. *Paper presented at The Wildlife Society 15th Annual Conference*, Miami, Florida. November 11.

2008 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. Applications of lynx and marten models to operational forest management. *Invited presentation at Lynx on the landscape: workshop and fall field tour*, Cooperative Forestry Research Unit, Greenville, Maine. October 28.

2008 – Harrison, D. J., W. B. Krohn, and A. K. Fuller. Long-term monitoring of snowshoe hare populations to inform stand- and landscape-scale forest management and recovery planning for Canada lynx in Maine. *Presentation to Advisory Committee, Maine Cooperative Forestry Research Unit*, Orono. April 9.

2008 – Harrison, D. J., A. K. Fuller, and E. Simons. Trends in habitat supply for wildlife species whose habitat requirements are not addressed using coarse-filter umbrella species approaches, with a focus on deer wintering areas. *Presentation to Advisory Committee, Maine Cooperative Forestry Research Unit*, Orono. April 9.

2008 – Harrison, D. J., W. B. Krohn, S. Scott, A. K. Fuller, and L. Robinson. Stand-scale management to increase hare and lynx populations. *Invited presentation at Bridging Science and Stewardship Workshop*, Maine Cooperative Forestry Research Unit, Brewer, Maine. May 14.

2008 – Harrison, D. J., A. K. Fuller, J. A. Hepinstall, and E. Simons. Forests, forest carnivores, and fragmentation: Wildlife-habitat relationships in the Acadian forests of Maine, USA. *Invited seminar, Department of Ecology and Natural Resource Management*, Norwegian University of Life Sciences, As, Norway. September 16.

2008 – Harrison, D. J., A. K. Fuller, J. A. Hepinstall, and E. Simons. Forests carnivores as a tool for landscape conservation: Case studies focusing on American martens and Canada lynx. *Seminar presented at Grimso Wildlife Research Station*, Lindesberg, Sweden. September 19.

2008 – Harrison, D. J., A. K. Fuller, J. A. Hepinstall, E. Simons, B. J. Hearn, and D. Payer. Forests, forestry, and forest martens: a landscape perspective. *Invited presentation at conference titled: Pour une sylviculture adaptee a al feret irreguliere et sa faune,* Faculty of Forestry, University of Laval, Baie Comeau, Quebec. October 8.

2008 - Krohn W. B., D. J. Harrison, S. A Scott, L. L. Robinson, C. L. Hoving, A. K. Fuller, and E. M. Simons. Variation in snowshoe hare densities as related to Canada lynx and forest management in eastern North America. *Presentation at Eastern CANUSA Forest Science Conference*, Orono, Maine. October 17.

2008 - Scott, S., D.J. Harrison, and W. B. Krohn. Partial harvests: contributing to foraging habitat?. *Presentation at Lynx on the Landscape Workshop*, Maine Cooperative Forestry Research Unit , Workshop. Greenville, ME. October 28.

2008 - Simons, E. M., D. J. Harrison, W. B. Krohn, K. R. Legaard, and S. Sader. Trends in American marten habitat on the commercial forestlands of northern Maine. *Presented at Impact of Wildlife on the Forest Industry Workshop*, New England Regional Council on Forest Engineering, University of Maine, Orono. March 10.

2008 - Simons, E. M., D. J. Harrison, W. B. Krohn, K. R. Legaard, and S. Sader. Predicting responses of forest landscape change on wildlife umbrella species. *Presentation to the Maine Cooperative Forestry Research Unit Advisory Committee*, Orono. April 7.

2008 - Simons, E. M., D. J. Harrison, W. B. Krohn, K. R. Legaard, S. Sader, and J. S. Wilson. Landscape indicators of forest biodiversity: application of American marten, Canada lynx, and snowshoe hares. *Presentation at Bridging Science and Stewardship Workshop*, Maine Cooperative Forestry Research Unit, Brewer. May 14.

2008 - Simons, E. M., D. J. Harrison, W. B. Krohn, K. R. Legaard and S. A. Sader. Ecological factors associated with landscape-scale occurrences of Canada lynx in northern Maine. *Invited Presentation at Lynx on the Landscape: What You Need to Know Workshop and Field Tour*, Maine Cooperative Forestry Research Unit, Greenville, Maine. October 29.

2008 - Simons, E. M., D. J. Harrison, W. B. Krohn, K. R. Legaard, and S. A. Sader. Retrospective changes in habitat supply for Canada lynx and snowshoe hares resulting from timber harvesting: Implications for lynx recovery? *Paper presented at The Wildlife Society 15th Annual Conference*, Miami, Florida. November 9.

2008 - Simons, E. M., K. R. Legaard (Co-Presenters), D. J. Harrison, W. B. Krohn, and S. Sader. Evaluating broad-scale changes in timber harvesting patterns, forest landscape structure, and wildlife habitat supply for umbrella species in northern Maine. *Invited presentation at Friends of ForCAST, Center for Research on Sustainable Forests*, Orono. November 20.

2007 - Fuller, A. K., and D. J. Harrison. "The relative roles of fine- and coarse-grained habitat choices by Canada lynx during winter." *Paper presented at The Wildlife Society 14th Annual Conference*, Tucson, Arizona. September 23.

2007 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. 2007. Landscape planning initiative for northern Maine using area sensitive umbrella species: an overview. *Presented to Beginning with Habitat Steering Committee*, Orono, Maine. October 17.

2007 - Fuller, A. K., and D. J. Harrison. Foraging paths reveal scale-dependent habitat decisions by Canada lynx. *Paper presented at Canada Lynx on the Border, Biological and Political Realities for Conservation Planning: An International Workshop*, Grand Portage, Minnesota. October 26.

2007 - Harrison, D.J. Forest carnivores, forestry, and fragmentation: modeling landscape sustainability using marten and lynx. *Seminar presented to Division of Biological Sciences and School of Forest Resources*, University of Montana, Missoula. April 30.

2007 - Harrison, D. J. The role of predation on population dynamics of white-tailed deer. *Presentation to Commissioner's Task Force to Assess the Northern and Eastern Maine Deer Population*. June 12.

2007 - Harrison, D. J., E. Simons, and K. Legaard. Forest carnivores, forestry and fragmentation: Using American marten as the canary in the coal mine. *Department of Biological Sciences Seminar Series*, University of Maine. May 4.

2007 - Harrison, D. J. and J. McCloskey. Documenting occurrence patterns of northern goshowks in Maine. *Proposal presentation to Advisory Committee, Maine Cooperative Forestry Research Unit*, Orono, Maine. April 25.

2007 - Harrison, D. J., W. B. Krohn, L. Robinson, A. K. Fuller, and C. L. Hoving. 2007. Multi-scalar habitat preferences of snowshoe hares: how does a prey specialist coexist with a specialist predator? Paper *presented at International Union of Game Biologists XXVIII Congress*, Uppsala, Sweden. August 17.

2007 – Harrison, D. J. Effects of forest practices on habitat for wintering deer. *Workshop and Field Tour for Maine Cooperative Forestry Research Unit Advisory Committee*. October 10.

2007 - Harrison, D. J., W. B. Krohn, L. Robinson, S. Scott, A. K. Fuller, and C. L. Hoving. Temporal and spatial variation in snowshoe hare densities in eastern North America: relationships to lynx and forest management. *Invited paper presented at Canada Lynx on the Border, Biological and Political Realities for Conservation Planning: An International Workshop*, Grand Portage, Minnesota. October 26.

2007 – Harrison, D. J. The influence of predators on overwinter deer survival: interactions with habitat. *Invited presentation at Deer Wintering Area Workshop*, Orono, Maine. December 10.

2007 - Hearn, B. J., D. J. Harrison, C. Lundrigan, W. J. Curran, and A. K. Fuller. Multi-scale habitat selection by the endangered Newfoundland marten. *Paper presented at The Wildlife Society 14th Annual Conference*, Tucson, Arizona. September 23.

2007 - Simons, E. M., L. Robinson, D. J. Harrison, W. B. Krohn, and K. R. Legaard. Ecological factors associated with landscape-scale occurrences of Canada lynx in northern Maine. *Paper presented at Canada Lynx on the Border, Biological and Political Realities for Conservation Planning: An International Workshop*, Grand Portage, Minnesota. October 24.

2006 – Fuller, A. K., and D. J. Harrison. Stand-scale habitat relationships of lynx in northern Maine. *Presentation at Maine Lynx Workshop*, Bangor, Maine, December 3.

2006 – Fuller, A. K., and D. J. Harrison. Stand-scale habitat relationships of lynx in northern Maine. *Paper presented at 2006 Carnivores Conference*, St. Petersburg, Florida, November 14.

2006 – Fuller, A. K., and D. J. Harrison. Stand-scale habitat relationships of lynx in northern Maine. *Invited presentation at Forestry Noontime Seminar Series*, University of Maine, Orono, March 3.

2006 – Fuller, A. K., and D. J. Harrison. Stand-scale habitat relationships of lynx in northern Maine. *Final contract report presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine, January 25.

2006 – Harrison, D. J. Interactions among forestry and forest wildlife in the Acadian forest: the need for landscape planning. *Invited lecture in FES 508: Industrial Spruce-Fir Ecosystems*, University of Maine, Orono, December 15.

2006 – Harrison, D. J., W. B. Krohn, J. A. Homyack, L. Robinson, and A. K. Fuller. Temporal and spatial variation in hare populations in relation to forest harvesting in Maine. *Presentation at Maine Lynx Workshop*, Bangor, Maine, December 1.

2006 - Harrison, D. J., W. B. Krohn, A. K. Fuller, and L. Robinson. Hare population dynamics and lynx and hare habitat selection in Maine. *Presentation at National Interagency Lynx Biology Team Meeting, Duluth, MN*. October 20.

2006 - Harrison, D. J. and W. K. Krohn. Long-term results from research on snowshoe hares and lynx in relation to forest management activities in Maine. *Presentation to Advisory Committee, Maine Cooperative Forestry Research Unit*, University of Maine. October 4.

2006 – Harrison, D. J., W. K. Krohn, L. Robinson, J. A. Homyack, and A. K. Fuller. Temporal and spatial variation in hare densities within the geographic range of lynx in Maine. *Invited paper presented at Symposium on Lynx Conservation in the lower 48 states, The Wildlife Society Annual Conference*, Anchorage, Alaska, September 27.

2006 – Harrison, D. J. Managing forest stands and landscapes to maintain wildlife biodiversity. *Invited presentation at Research, Results and the Resource Workshop*, sponsored by Maine Cooperative Forestry Research Unit, Orono, Maine, May 25.

2006 – Harrison, D. J. Research results and applications for management: stand and landscape management for marten and lynx on commercial forestlands in Maine. *Invited presentations and field tour, Annual meeting of Foresters, Wagner Land Management Corp*., Bethel, Maine, May 3.

2006 – Harrison, D. J. Quantifying biodiversity values across managed landscapes in northern and western Maine. *Presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine, April 26.

2006 – Harrison, D. J. Wildlife, forest succession, vegetation management, and biodiversity. *Invited lecture in FES 435/535: Managing Forest Succession*, University of Maine, Orono, April 13.

2006 – Krohn, W. B., D. J. Harrison, C. Hoving and L. Robinson. Factors influencing patterns of lynx occurrence across multiple spatial scales in eastern North America. *Presentation at Maine Lynx Workshop*, Bangor, Maine, December 1.

2006 - Krohn, W. B., D. J. Harrison L. Robinson, and C. Hoving. Results for species occurrence modeling with lynx across 3 spatial scales in Maine. *Presentation at National Interagency Lynx Biology Team Meeting*, Duluth, MN. October 20.

2006 – Robinson, L., D. J. Harrison, W. B. Krohn, J. Vashon, and M. McCollough. Modeling habitat occupancy of lynx in northern Maine. *Paper presented at Carnivores 2006 Conference*, St. Petersburg, Florida, November 14.

2006 – Robinson, L., D. J. Harrison, W. B. Krohn. Ecological relationships between partial harvesting, snowshoe hares, and lynx in Maine. *Presentation and Wiscussion for Forestry and Wildlife Professionals in Maine*, University of Maine, Orono, August 24.

2006 – Simons, E., K. Legaard, D. J. Harrison, S. Sader, and W. B. Krohn. Forest harvesting trends affecting lynx and marten habitat in Maine as revealed by change detection of multiple LANDSAT TM images, 1988-2004. *Presentation at Maine Lynx Workshop*, Bangor, Maine, December 1.

2006 – Simons, E., K. Legaard, D. J. Harrison, S. Sader, and W. B. Krohn. Trends in forest harvesting in Maine as revealed by change detection of multiple LANDSAT TM images. *Poster presented at 2006 CANUSA Conference*, Quebec City, Canada, October.

2005 - Fuller, A. K., D. J. Harrison, and B. J. Hearn. Modeling habitat occupancy of marten in western Newfoundland: management and planning applications. *Invited presentation to the Newfoundland Marten Recovery Team*, Corner Brook, Newfoundland, November 2.

2005 – Fuller, A. K., D. J. Harrison, and B. J. Hearn. Modeling habitat occupancy of marten in western Newfoundland: management and planning applications. *Final contract report presentation to Canadian Forest Service, Western Newfoundland Model Forest, and other project cooperators*, Corner Brook, Newfoundland, November 1.

2005 - Fuller, A. K., D. J. Harrison, and J. Vashon. Stand-scale habitat selection by lynx on commercial forestlands in northern Maine. *New England Chapter of Society of American Foresters Conference*, Portland, ME. March 17.

2005 - Fuller, A. K., D. J. Harrison, and J. H. Vashon. Effects of forest practices on habitat selection by Canada lynx during winter. *Lynx Research Working Group Meeting*, Orono, ME. April 14.

2005 - Harrison, D. J. An overview of the research program in the Department of Wildlife Ecology. Presentation to the *Office of the Vice President for Research*, University of Maine, Orono, ME. February 1.

2005 - Harrison, D. J. Predators, prey, and forestry in northern and eastern Maine: a historical perspective. *University of Maine at Machias Science Club and Downeast Salmon Federation*, Machias, ME. March 2, 2005.

2005 - Harrison, D. J. Overview of research conducted by The University of Maine during 1980-1994 regarding the population status and relationships of deer and vegetation in Acadia National Park. *Acadia National Park Resource Management Staff*, Bar Harbor, ME. July 26.

2005 - Harrison, D. J. and J. A. Hepinstall. Evaluating the utility of forest carnivores as umbrella species to promote biodiversity conservation. Final contract report presentation, *Maine Cooperative Forestry*

Research Unit, University of Maine, Orono, ME. January 26.

2005 - Harrison, D. J., and W. B. Krohn. Relationships among partial harvesting, snowshoe hares, Canada lynx and forest harvesting: a survey of research activities at the University of Maine and Maine Cooperative Fish and Wildlife Research Unit. *National Lynx Biology Team Meeting*, Minneapolis, MN. August 17.

2005 – Harrison, D. J., W. B. Krohn, and J. A. Hepinstall. A landscape planning framework for northern Maine: an overview of recent research results for marten, lynx and other forest vertebrates. *Maine Department of Inland Fisheries and Wildlife*, Augusta, December 21.

2005 - Harrison, D. J. and W. B. Krohn. A summary of preliminary research findings from studies of snowshoe hares and lynx conducted by the University of Maine and the Maine Cooperative Fish and Wildlife Research Unit. *Eastern Science Team, National Council for Air and Stream Improvement*, Sugarloaf, U.S.A. August 24.

2005 - Hearn, B. J., D. J. Harrison, and A.K. Fuller. Landscape-scale habitat selection by Newfoundland marten & an update on efforts to model habitat for Newfoundland marten. *Newfoundland Marten Recovery Team*, Corner Brook, NL. May 17, 2005.

2005 - Homyack, J. A., D. J. Harrison, and W. B. Krohn. Effects of precommercial thinning on snowshoe hares, small mammals, and forest structure in northern Maine. *Department of Fisheries and Wildlife Sciences, Virginia Polytechnic Institute and State University*, Frostburg, VA. April 26.

2004 - Fuller, A. K. and D. J. Harrison. Preliminary results of studies of substand-scale habitat selection by lynx in northern Maine. *Invited presentation at Wildlife Management Institute's Eastern Lynx Workshop*, North Conway, New Hampshire, January 6.

2004 - Fuller, A. K. and D. J. Harrison. Preliminary results of studies of substand-scale habitat selection by lynx in northern Maine. *Presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine, January 21.

2004 – Fuller A. K. and D. J. Harrison. Influence of forest practices on stand-scale habitat selection of lynx in northern Maine. *Paper presented at Eastern CANUSA Forest Science Conference*, Frederickton, New Brunswick, October 15.

2004 - Fuller, A. K. and D. J. Harrison. Stand-scale habitat selection by lynx in northern Maine: preliminary results. *Invited presentation at Fourth Northeastern Mesocarnivore Workshop: Lynx and marten in the northern Appalachians*, Portland, Maine, December 9.

2004 - Harrison, D. J., J. A. Homyack, A. K. Fuller, and W. B. Krohn. Effects of precommercial thinning and partial harvesting on snowshoe hares in Maine. *Invited presentation at Wildlife Management Institute's Eastern Lynx Workshop*, North Conway, New Hampshire, January 6.

2004 - Harrison, D. J., J. A. Homyack, J. A. Litvaitis, and W. B. Krohn. Quantifying densities of snowshoe hare in Maine using pellet plots. *Invited presentation at Wildlife Management Institute's Eastern Lynx Workshop*, North Conway, New Hampshire, January 6.

2004 - Harrison, D. J., C. L. Hoving, and W. B. Krohn. Distribution and extent of lynx habitat in eastern North America and Maine from GIS modeling. *Presentation at Wildlife Management Institute's Eastern Lynx Workshop*, North Conway, New Hampshire, January 7.

2004 - Harrison, D. J. Status of lynx litigation, critical habitat designations, and recovery planning in the U.S. *Presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine, January 21.

2004 - Harrison, D. J. Effects of clearcutting, precommercial thinning, and partial harvesting on forest dependent wildlife species. Invited presentation at workshop on *Managing for Fiber Production, Wildlife Habitat, and Biodiversity: Latest Results from CFRU Research,* Ashland Maine, May 12.

2004 – Harrison, D. J. and J. A. Hepinstall. Predicting marten and lynx occurrences across the landscape: Evaluating the utility of forest carnivores as umbrella species to promote biodiversity conservation. *Wildlife Ecology Seminar Series, University of Maine*, Orono, 6 December.

2004 – Harrison, D. J., W. B. Krohn, L. Robinson, and A. K. Fuller. Lynx and hare research sponsored by the Maine Cooperative Forestry Research Unit. *Field tour at sites in northern Maine for forest industry representatives.* October 28.

2004 – Harrison, D. J. and J. A. Hepinstall. Broad-scale viability habitat modeling, habitat supply trends, and umbrella species applications for marten and lynx in Maine. *Invited presentation at Fourth Northeastern Mesocarnivore Workshop: Lynx and marten in the northern Appalacians, Wildlife Conservation Society*, Portland, Maine, December 9.

2004 – Harrison, D. J., A. K. Fuller, and B. Hearn. Updates of results on habitat selection and fragmentation studies on Newfoundland marten. *Presentation to Newfoundland marten recovery team*, Corner Brook, Newfoundland, December 15.

2004 – Hepinstall, J. A. and D. J. Harrison. Utility of forest carnivores (American marten and Canada lynx) as umbrella species for biodiversity conservation. *Carnivores 2004 Conference*, Sante Fe, New Mexico, November 15.

2004 – Homyack, J. A., D. J. Harrison, W. B. Krohn, A. K. Fuller, and C. L. Hoving. *Comparing conservation issues affecting Canada lynx within the northeastern U.S. and the Rocky mountains*. *Presentation to Wyoming Chapter of The Wildlife Society*, Laramie, November 11.

2004 - Krohn, W. B., D. J. Harrison, and M. A.,McCollough. An overview of the lynx-hare landscape modeling project in northern Maine. *Invited presentation at Wildlife Management Institute's Eastern Lynx Workshop*, North Conway, New Hampshire, January 6.

2003 - Harrison, D.J., and J.A. Hepinstall. Marten as a tool for landscape-scale habitat planning in northern Maine. *Final contract report presentation to Maine Cooperative Forestry Research Unit, Orono, Maine.* January 29.

2003 - Harrison, D.J. Ecological aspects of coyote predation and the potential for effective control of predation via snaring. *Invited presentation and panel discussion at winter meeting of Maine Chapter of The Wildlife Society, Augusta, Maine.* January 30.

2003 - Harrison, D.J. and J.A. Hepinstall. Using marten as a landscape-scale conservation tool for maintaining diversity of forest-dependent vertebrates. *Presentation and workshop conducted for Maine Department of Inland Fisheries and Wildlife Habitat Planning Committee, Bangor, Maine.* March 10.

2003 - Harrison, D.J., and J.A. Hepinstall. Marten as a tool for landscape-scale habitat planning and biodiversity conservation. *Presentation to Recovery Team for the Endangered Newfoundland Marten, Deer Lake, Newfoundland.* April 1.

2003 - Harrison, D.J. Predicting responses of snowshoe hares and lynx to alternative forest harvesting scenarios. *Presentation to Maine Cooperative Forestry Research Unit, Orono, Maine.* April 17.

2003 - Harrison, D.J. Relative densities, habitat selection, and population performance of spruce grouse in clearcut, intensively managed, and "classic" habitat in northern Maine. *Presentation to Maine Cooperative Forestry Research Unit, Orono, Maine.* April 17.

2003 - Harrison, D.J. Evaluating the umbrella species approach for biodiversity conservation on commercial forestlands in Maine. *Presentation to Maine Cooperative Forestry Research Unit, Orono, Maine.* April 17.

2003 - Harrison, D. J. Effects of coyotes on Maine's deer herd: Is there a need for a snaring program. *Talk presented to Student Chapter of The Wildlife Society*, University of Maine, Orono, December 6.

2003 - Harrison, D. J. A. K. Fuller, J. A. Homyack, and W. B. Krohn. How do clearcutting, pre-commercial thinning, and partial harvesting influence wildlife habitat? Invited presentation at workshop on *Managing for Fiber Production, Wildlife Habitat, and Biodiversity: Latest Results from CFRU Research*. Plum Creek Timber Company, Fairfield, Maine, December 16.

2003 - Harrison, D. J. and J. A. Hepinstall. Landscape planning for wildlife. Invited presentation at workshop on *Managing for Fiber Production, Wildlife Habitat, and Biodiversity: Latest Results from CFRU Research*. Plum Creek Timber Company, Fairfield, Maine, December 16.

2003 - Harrison, D. J., D. C. Payer, and A. K. Fuller. Maintaining structural requirements of wildlife within forest stands. Invited presentation at workshop on *Managing for Fiber Production, Wildlife Habitat, and Biodiversity: Latest Results from CFRU Research*. Plum Creek Timber Company, Fairfield, Maine, December 16.

2003 - Hepinstall, J.A., and D. J. Harrison. Predicting habitat supply for American marten using measures of landscape composition and configuration. *Paper presented at Resource Selection Conference, Laramie, Wyoming.* January 5-8.

2003 - Hepinstall, J.A., and D.J. Harrison. Does the umbrella leak?: Biodiversity conservation based on marten habitat. *Paper presented at the 10th Annual Conference of The Wildlife Society, Burlington, VT*. September 9.

2003 - Homyack, J.A. Effects of precommercial thinning on snowshoe hares, small mammals, and forest structure in northern Maine. *Seminar presented to Department of Wildlfe Ecology, University of Maine.* February

27.

2003 - Homyack, J.A., D.J. Harrison, and W.B. Krohn. Effects of precommercial thinning on snowshoe hares, small mammals, and forest structure in northern Maine. *Final contract report presentation to Maine Cooperative Forestry Research Unit, Orono, Maine.* April 17.

2003 - Krohn, W.B., J.A. Homyack,and D.J. Harrison. "Changes in the Acadian Forest: Implications for Wildlife." *Invited paper presented in Special Wildlife Session on Early Successional Habitats: A Critical Problem, 59th Northeast Fish and Wildlife Conference, Newport, Rhode Island*. April 15.

2002 - Fuller, A. K. and D. J. Harrison. "Resource partitioning and interspecific competition between coyotes and red foxes on an island during recent colonization by coyotes." *Paper presented at the Northeast Fish and Wildlife Conference*, Portland, ME. April 23.

2002 - Fuller, A. K., and D.J. Harrison. Resource partitioning and interspecific competition between coyotes and red foxes on an island during recent colonization by coyotes. *Paper presented at Carnivores 2002 Conference, Monteray, California.* November 18.

2002 - Harrison, D.J., and J. A. Hepinstall. "A workshop on approaches to evaluate habitat requirements and to inventory habitat supply for endangered marten in Newfoundland." *Workshop presented to Canadian Forest Service Scientists, Newfoundland Government Scientists, and Western Newfoundland Model Forest Scientists*, Cornerbrook, Newfoundland, January 9.

2002 - Harrison, D.J. "Forestry and forest carnivores: conflict or opportunity." *Talk presented to Student Chapter of The Wildlife Society*, Orono, Maine, February 7.

2002 - Harrison, D.J. "Forestry and forest carnivores: conflict or opportunity." *Department of Biology Seminar Series, Colby College*, Waterville, Maine, March 8.

2002 - Harrison, D.J., C. L. Hoving, A. K. Fuller, and W.B. Krohn. "A summary of research needs for lynx in eastern North America: what do we know, what are we researching, and what is left?" *Presentation at Northern Appalachians Lynx Science Workshop*, Portland, Maine, April 24.

2002 - Harrison, D.J. "Landscape considerations for conserving habitat for wolves, American marten, and lynx in the White and Green Mountain National Forests." *Presentation at Species Viability Workshop, U.S. Forest Service*, Manchester, New Hampshire, May 22.

2002 - Harrison, D. J. and A.K. Fuller. Effects of partial harvesting on forest mammals. *Presentation and field tour for Cooperative Forestry Research Unit, Northern Maine.* October 9.

2002 - Harrison, D.J., and J.A. Hepinstall. Landscape management for fragmentation-sensitive species. *Presentation and field tour for Cooperative Forestry Research Unit, Northern Maine.* October 9.

2002 - Harrison, D.J. and A.K. Fuller. Substand-scale responses of Canada lynx to habitat and prey: an ongoing study. . *Invited presentation at Interagency Lynx Biology Team Meeting, Orono, Maine*. October 22.

2002 - Harrison, D.J., W.B. Krohn, and C. Hoving, Broad-scale habitat ecology of Canada lynx in eastern North

America. *Invited presentation at Interagency Lynx Biology Team Meeting, Orono, Maine*. October 22.

2002 - Harrison, D.J., and J.A. Hepinstall. Modeling habitat supply as a tool for marten conservation. *Invited presentation at Newfoundland Marten Habitat Supply Workshop, Grand Falls, Newfoundland.* December 3.

2002 - Harrison, D.J., and J.A. Hepinstall. Predictive modeling and trends in marten occurrence across the landscape of Northern Maine: marten as a tool for conserving forest biodiversity. *Invited presentation at Wildlife Division Meeting, Maine Department of Inland Fisheries and Wildlife, Bangor, Maine.* December 17.

2002 - Hearn, B., and D.J. Harrison. Home range characteristics of Newfoundland marten. *Invited presentation at Newfoundland Marten Habitat Supply Workshop, Grand Falls, Newfoundland.* December 3.

2002 - Hepinstall, J. A. and D. J. Harrison, and W. B. Krohn. "Spatially explicit wildlife habitat modeling; case studies from Maine." Seminar presented at the *Department of Wildlife Ecology Seminar Series*, Orono, ME. April 8.

2002 - Hepinstall, J. A., D. J. Harrison, D. C. Payer and A. K. Fuller. "Habitat supply modeling for American marten in the managed forests of northern Maine." *Poster presented at the Northeast Fish and Wildlife Conference, Portland, ME*. April 21- 24.

2002 - Hepinstall, J. A., D. J. Harrison, D.C. Payer, and A. K. Fuller. "Can marten serve as an umbrella species for forest management in northern Maine?" *Paper presented at the 17th annual symposium of the International Association for Landscape Ecology – United States Regional Association (US-IALE)*, Lincoln, NE. April 23-27.

2002 - Hepinstall, J. A. and D. J. Harrison. "Applications of Field Research to Forest Landscape Planning: A Case Study Using American Marten in Maine." Paper presented at *Beyond the Data: Integrating Research Findings into Forest Management Planning and Operations,* Moncton, New Brunswick, Canada. May 3-4.

2002 - Hepinstall, J.A., D.J. Harrison, D.C. Payer, and A.K. Fuller. Predicting habitat supply for American marten using measures of landscape composition and configuration. *Poster presented at Eastern Canada-USA (CANUSA) Forest Science Conference, Orono, Maine.* October 20.

2002 - Hepinstall, J.A., D.J. Harrison, D.C. Payer, and A.K. Fuller. Predicting habitat supply for American marten using measures of landscape composition and configuration. *Paper presented at Carnivores 2002 Conference, Monteray, California.* November 19.

2002 - Homyack, J. A., D. J. Harrison, and W. B. Krohn. "Effects of intensive forest management on small mammals and snowshoe hare in northern Maine." *Presentation at the Spring 2002 Evening Seminar Series of the University of Maine Student Chapter of the Wildlife Society, Orono, ME*. April 14.

2002 - Homyack, J. A., D. J. Harrison, and W. B. Krohn. "Effects of precommercial thinning on small mammals in northern Maine." *Paper presented at the Northeast Fish and Wildlife Conference, Portland, ME.* April 23.

2002 - Homyack, J. A., D. J. Harrison, and W. B. Krohn. "Preliminary results of the effects of precommercial thinning on snowshoe hare." *Poster presented at the Northeast Fish and Wildlife Conference, Portland, ME*. April 21- 24.

2002 - Homyack, J. A., D. J. Harrison, and W. B. Krohn. "Effects of precommercial thinning on snowshoe hare in northern Maine." *Paper presented at The Annual Meeting of The Wildlife Society, Bismarck, ND*. September 27.

2002 - Homyack, J. A., D. J. Harrison, and W. B. Krohn. Precommercial thinning effects on hare habitat. *Presentation and field tour for Cooperative Forestry Research Unit, Northern Maine.* October 9.

2002 - Homyack, J.A., D.J. Harrison, and W.B. Krohn. Effects of precommercial thinning on abundance of snowshoe hare in northern Maine. *Paper presented at Eastern Canada-USA (CANUSA) Forest Science Conference, Orono, Maine.* October 20.

2002 - Homyack, J.A., D.J. Harrison, and W.B. Krohn. Effects of precommercial thinning on small mammals in northern Maine. *Paper presented at Eastern Canada-USA (CANUSA) Forest Science Conference, Orono, Maine.* October 20.

2002- Homyack, J.A., D.J. Harrison, and W.B. Krohn. Effects of precommercial thinning on snowshoe hares in northern Maine: implications for Canada lynx. *Invited presentation at Interagency Lynx Biology Team Meeting, Orono, Maine*. October 22.

2002- Homyack, J.A., D.J. Harrison, and W.B. Krohn. Effects of precommercial thinning on snowshoe hare: implications for Canada lynx. *Paper presented at Carnivores 2002 Conference, Monteray, California.* November 19.

2002 - Hoving, C. L., D. J. Harrison, W. B. Krohn, and W. J. Jakubas. "Canada lynx habitat, forest harvest strategies and regeneration in northern Maine." *Paper presented at the Northeast Fish and Wildlife Conference, Portland, ME*. April 24.

2002 – Hoving, C., D.J. Harrison, W.B. Krohn, and W. Jakubas. Canada lynx habitat, forest harvest strategies and regeneration in northern Maine. *Paper presented at Carnivores 2002 Conference, Monteray, California.* November 19.

2002 – Hoving, C., D.J. Harrison, W.B. Krohn, R.A. Joseph, and M. O'Brien. Climate change and lynx: spatial occurrence models for eastern North America. *Poster presented at Carnivores 2002 Conference, Monteray, California.* November 17-20.

2002 - Spohr, S., D.J. Harrison, and F.A. Servello. "Effects of landscape and cover characteristics on nest success of eastern wild turkeys in southeastern Connecticut." *Paper presented at the Northeast Fish and Wildlife Conference*, Portland, Maine, April 23.

2001 - Fuller, A.K., and D.J. Harrison. "Partial harvest guidelines for maintenance of marten in Maine." *Invited lecture presented at the "Newfoundland Marten Endangered Species Recovery Team Meeting*", St. John's, Newfoundland, January 12.

2001 - Harrison, D.J. Landscape scale habitat requirements and fragmentation thresholds of marten. *Lecture at workshop attended by Canada Parks scientists and invited advisors to address habitat needs of endangered marten in western Newfoundland*. Gros Morne National Park Newfoundland, January 9.

2001 – Harrison, D.J., and D.C. Payer "Influences of trapping mortality on current distribution and population dynamics of marten: a biogeographical and empirical perspective." *Invited paper presented at "Newfoundland Marten Accidental Trapping and Snaring Workshop*", St. John's, Newfoundland, January 12.

2001 - Harrison, D.J. An update of lynx and marten issues related to forest management. *Presentation to Advisory Committee, Maine Cooperative Forestry Research Unit,* Orono, January 25.

2001 – Harrison, D. J. "Marten and Forestry: Conflict or Opportunity." *Invited paper presented at J. D. Irving, Limited's 2001 Science Forum*, Frederickton, NB, April 3, 2001.

2001 - Harrison, D.J. "Forestry and Forest Carnivores: Conflict or Opportunity." *Presented at the University of Maine, Forestry Noontime Seminar Series*, April 6.

2001 - Harrison, D.J. Potential forest management issues and research opportunities with federally threatened lynx in Maine. *Presentation to to Advisory Committee, Maine Cooperative Forestry Research Unit*, Orono, Maine, May 3.

2001 – Harrison, D.J. "Extent and distribution of wolf habitat in eastern North America and niche characteristics of wolves versus eastern coyotes." Served as *invited panelist and presenter at Wolf Symposium for invited government agencies, university personnel and non-governmental organizations*, Burlington, VT, May 16.

2001 - Harrison, D. J., D.C. Payer, J. A. Hepinstall, A. K. Fuller and D. J. Katnik. "Landscape thresholds and nonlinear responses to fragmentation by American marten." *Paper presented at 15th Annual Meeting of the Society for Conservation Biology*, Hilo, Hawaii, July 31.

2001 - Harrison, D. J., and J. A. Hepinstall. "Habitat supply planning for American marten in Maine and Newfoundland." *Seminar presented to Canadian Forest Service and Newfoundland Provincial Scientists*, Cornerbrook, Newfoundland, August 26.

2001 - Harrison, D. J. "Marten habitat supply assessment." *Presentation at meeting of Maine Cooperative Forestry Research Unit Advisory Committee*, Millinocket, Maine, October 17.

2001 - Harrison, D.J. "Habitat potential for wolves and niche overlap with eastern coyotes in eastern North America." *Paper presented at Eastern Wolf Workshop*, Dixville Notch, New Hampshire, October 19.

2001 – Hepinstall, J. A., D. J. Harrison, D. C. Payer, A. K. Fuller, and D. D. Katnik. "Using marten as an umbrella species for forest management." *Invited paper presented at the 37th Annual North American Moose Conference and Workshop*, Sugarloaf, ME, May 14, 2001.

2001 - Hepinstall, J.A., D.J. Harrison, D.C. Payer, and A.K. Fuller. Predicting the occurrences of American

marten in harvested landscapes. *Paper presented at the 8th Annual Conference of The Wildlife Society, Reno, Nevada*, September 25-29.

2001 - Homyack, J. A., D. J. Harrison, and W. B. Krohn. "Update on the effects of precommercial thinning on snowshoe hare and small mammals in northern Maine." *Field tour and presention to Advisory Committee, Maine Cooperative Forestry Research Unit*, Millinocket, Maine, October 17.

2001 - Hoving, C. L. "Historical occurrence and habitat ecology of Canada lynx in eastern North America." *Talk presented at the Maine Audubon's Wildlife Conference, Maine Audubon Society*, Falmouth, ME, April 7.

2001 - Hoving, C.L, D. J. Harrison, and W.B. Krohn. Historical occurrence and habitat ecology of Canada lynx in eastern North America. *Final contract seminar to Maine Department of Inland Fisheries and Wildlife*, Bangor, ME, March 22.

2001 - Hoving, C.L. Historical occurrence and habitat ecology of Canada lynx in eastern North America. *Final thesis seminar presented to Department of Wildlife Ecology, University of Maine*, April, 12.

2001 – Hoving, C. L., R. A. Joseph, and W. B. Krohn. "Historical and current distributions of lynx in Maine, 1833-1999." *Paper presented at the 57th Northeast Fish and Wildlife Conference*, Saratoga Springs, NY, April 22-26.

2001 – Hoving, C. L., D. J. Harrison, W. K. Krohn, W. J. Jakubas, R. A. Joseph, R. Lafond, and M. O'Brien. "A probability model of Canada lynx occurrence in eastern North America." *Poster presented at the 57th Northeast Fish and Wildlife Conference*, Saratoga Springs, NY, April 22-26.

2001 - Hoving, C.L., D. J. Harrison and W. B. Krohn. " Habitat ecology of Canada lynx in eastern North America." *Poster presented at the U. S. Fish and Wildlife Service regional office, Hadley, MA*, April 26.

2001 - Hoving, C. L., D. J. Harrison, and W. K. Krohn. " Multi-scale habitat relations of Canada lynx in eastern North America." *Paper presented at the 2001 Meeting of the Northeast Fur Technical Committee*, Providence, Rhode Island, September 13.

2001 - Hoving, C. L., D. J. Harrison, W. K. Krohn, W. J. Jakubas, R. A. Joseph, R. Lafond, and M. O'Brien. "Canada lynx habitat associations in eastern North America." *Paper presented at The Wildlife Society 8th Annual Conference*, Reno, Nevada, September 27.

2001 - Hoving, C. L., D. J. Harrison, and W. B. Krohn. "Canada lynx habitat in eastern North America." *Presented at the Alice Steward Lecture Series, Maine Center for the Arts*, Orono, ME. October 31.

2000 - Fuller, A.K., H. J. Lachowski, and D. J. Harrison. Responses of mammals at two trophic levels to partial harvesting. *Paper presented at 80th Annual Meeting of the American Society of Mammalogists*, University of New Hampshire, Durham, June 19.

2000 - Fuller, A.K. and D.J. Harrison. Influence of partial harvesting on habitat selection by American marten in an industrially forest landscape. . *Paper presented at 3rd International Martes Symposium*, Corner Brook, Newfoundland, August 14.

2000 - Fuller, A., H.J. Lachowski, and D. Harrison. 2000. Stand-level responses of American marten and prey to forest management: do marten respond to distribution of prey? *Paper presented at 3rd International Martes Symposium, Corner Brook*, Newfoundland, August 15.

2000 - Fuller, A.K., and D.J. Harrison. Fuller, A.K. and D.J. Harrison. Influence of partial harvests on American marten habitat selection in Maine. *Final contract seminar presented to Advisory Committee, Maine Cooperative Forestry Research Unit*, Sugarloaf Mountain, Maine, October 3.

2000 - Harrison, D.J. Presented a seminar of final results of 10 year study on effects of forest harvesting and trapping on American martens to Advisory Committee, *Cooperative Forestry Research Unit*, University of Maine, Orono, February 2.

2000 - Harrison, D.J. Extent and distribution of potential wolf habitat in eastern North America; an international issue. *Presentation at "Northeast Wolf Forum: a discussion of issues and concerns"*, Rumford, Maine, July 12.

2000 - Harrison, D.J. Served as Program Chair and provided opening comments for *3rd International Martes Symposium*, Corner Brook, Newfoundland, August 14.

2000 - Harrison, D., D. Payer, A. Fuller, J.Hepinstall, D. Katnik. Landscape thresholds and response to fragmentation by American marten. Paper presented at *3rd International Martes Symposium*, Corner Brook, Newfoundland, August 14.

2000 - Harrison, D. Served as chairperson for session titled: Planning and Managing Landscapes for *Martes*, *3rd International Martes Symposium*, Corner Brook, Newfoundland, August 14.

2000 - Harrison, D. Served as an invited panelist for discussion of : What is suitable habitat for North American *Martes*? *3rd International Martes Symposium*, Corner Brook, Newfoundland, August 15.

2000 - Harrison, D. Chaired plenary session titled: Status of *Martes* and their habitats from a global perspective. *3rd International Martes Symposium*, Corner Brook, Newfoundland, August 15.

2000 - Harrison, D.J. Fragmentation thresholds for American marten: preliminary results. *Presentation to Advisory Committee, Maine Cooperative Forestry Research Unit*, Sugarloaf Mountain, Maine, October 3.

2000 - Harrison, D.J., J.Homyack, and A.K. Fuller. Led a field trip and presented preliminary data on effects of forest harvesting on snowshoe hares and small mammals at field tour for Maine forest industry representatives, *Maine Cooperative Forestry Research Unit Fall Field Tour*, October 4.

2000 - Harrison, D. J. Presentation on wolf ecology , habitat potential in Maine, and behavior of wolf-hybrids. *7th grade science and literature classes at the Reeds Brook Middle School*, Hampden, November 8.

2000 – Harrison, D.J. T.G. Chapin, and C.L. Hoving. Distribution, extent, and connectivity of potential habitat for wolves in Maine and eastern Canada. *Poster presented at Carnivores 2000 Conference*, Denver, Colorado, November 13-15.

2000 - Harrison, D.J. Influence of dispersal on social ecology of coyotes: do social pressures or prey size promote pack formation? *Invited paper at Carnivores 2000 Conference*, Denver, Colorado, November 14.

2000 - Krohn, W.B., C.L. Hoving, D.J. Harrison, D.M. Phillips, and H.C. Frost. Martes foot-loading and snowfall distribution in eastern North America: implications to broad-scale distributions and mesocarnivore interactions. *Paper presented at 3rd International Martes Symposium*, Corner Brook, Newfoundland, August 14.

2000 - Payer, D.C., and D.J. Harrison. Influence of forest structure on habitat use by American marten. *Paper presented at 10th Northern Furbearer Conference*, Fairbanks, Alaska, April 17.

2000 - Payer, D.C., and D.J. Harrison. 2000. Effects of timber harvesting and trapping on demographic characteristics of marten. *10th Northern Furbearer Conference*, Fairbanks, Alaska, April 18.

2000 - Payer, D.C., and D.J. Harrison. Demographic characteristics of American marten in relation to clearcutting and trapping. . *Paper presented at 3rd International Martes Symposium*, Corner Brook, Newfoundland, August 14.

2000 - Payer, D.C., and D.J. Harrison. Effects of timber harvesting and trapping on habitat selection by American marten. *Paper presented at 3rd International Martes Symposium*, Corner Brook, Newfoundland, August 15.

2000 - Payer, D.C., and D.J. Harrison. Territoriality and home-range fidelity of American marten in relation to timber harvesting and trapping. *Paper presented at 3rd International Martes Symposium*, Corner Brook, Newfoundland, August 16.

1999 - Harrison, D.J. Response of wildlife to thinning in forests of the *northeastern U.S. Invited* presentation at *Conference on Thinning in the Maine Forest*, Augusta, Maine. November 15.

1999 - Harrison, D. J. Influence of dispersal on social ecology of coyotes: Comparison of a mainland and island population. *The Wildlife Society 6th Annual Conference*, Austin, Texas. September 11.

1999 - Harrison, D. J. Responses of wide ranging carnivores to forest characteristics at multiple spatial scales. *North American Forest Ecology Workshop*, University of Maine, Orono. June 28.

1999 - Harrison, D. J. Session summary: stand- and landscape-scale responses of wildlife to forest practices. *North American Forest Ecology Workshop*, University of Maine, Orono. June 30.

1999 - Harrison, D. J. Habitat associations of marten in Maine: responses to forestry and trapping. Invited presentation at *Pine Marten Symposium*, Corner Brook, Newfoundland. January 27.

1999 - Fuller, A.K. and D.J. Harrison. Influence of partial harvests on American marten habitat selection in Maine. *The Wildlife Society 6th Annual Conference*, Austin, Texas. September 11.

1999 - Fuller, A.K., H. J. Lachowski, and D. J. Harrison. Responses of mammals at two trophic levels to stand-

scale forest harvesting in Maine. *North American Forest Ecology Workshop*, University of Maine, Orono. June 28.

1998 - Harrison, D. J. Using carnivores as a model for landscape-scale forest planning. Invited paper at *Maine Forest Biodiversity Conference*, Orono, Maine. November 19.

1998 - Harrison, D. J. Wolves, science, and the future of Maine=s forests. Lecture to *Forum for Undergraduate Science Majors*, University of Maine. December 10.

1998 - Harrison, D. J. A summary from 10 years of marten research with a look to the future. Invited seminar presented to *Resource Assessment Staff, Maine Department of Inland Fisheries and Wildlife.* November 19.

1998 - Fuller, A.K., and D.J. Harrison. Use of partially harvested stands by American marten: a preliminary analysis. Poster presented at *Euro-American Mammal Congress*, Santiago de Compostela, Spain. July 23.

1998 - Harrison, D.J. Habitat ecology of American marten: specialist or generalist? Invited Paper presented in symposium: *Mustelids in a Modern World*, Euro-American Mammal Congress, Santiago de Compostela, Spain. July 23.

1998 - Harrison, D.J. A summary of results from ongoing studies of American marten in Maine. Invited presentation at *Newfoundland Marten Recovery Team Meeting*, Grand Falls-Windsor, Newfoundland. May 13.

1998 - Harrison, D.J. Potential habitat for eastern timber wolves in Maine. Invited presentation at *Eastern Wolf Recovery Meeting*, Pinkham Notch, NH. September 29.

1998 - Harrison, D.J. and D.C. Payer. Substand-level habitat use by American marten: recommendations for foresters. Presentation to Advisory Committee, *Maine Cooperative Forestry Research Unit*, Orono, Maine. April 29.

1997 - Harrison, D.J. An assessment of potential habitat for eastern timber wolves in the northeastern United States. Invited presentation at *meeting of eastern wolf experts*, Sherbrook, Quebec. October 23.

1997 - Harrison. D.J. Habitat selection by American marten at multiple spatial scales. Invited seminar presented to *Wildlife Division, Department of Natural Resources, St. Johns, Newfoundland*, Canada, March 3.

1997 - Harrison, D.J. "Results from coyote-deer studies in Acadia National Park: insights into predator social ecology and prey demography." Seminar presented to *Dept. of Wildlife Ecology, Univ. Maine*, Orono, April 7.

1997 - Harrison, D.J. Influence of forest harvesting and trapping on populations of American marten. Invited seminar presented to forest industry personnel*, Corner Brook, Newfoundland*, Canada, March 4.

1997 - Harrison, D.J. Influence of forest harvesting and fur trapping on populations of American marten.

Invited paper presented at *Marten Biology and Habitat Guidelines Workshop*, Sault Ste. Marie, Ontario, Canada, May 28.

1997 - Harrison D.J. Influence of landscape composition and configuration on habitat occupance by American marten. Invited paper presented at *Marten Biology and Habitat Guidelines Workshop*, Sault Ste. Marie, Ontario, Canada, May 28.

1997 - Harrison, D.J. Integrating marten and forest management: the Maine experience. Invited paper presented at *Marten Biology and Habitat Guidelines Workshop*, Sault Ste. Marie, Ontario, Canada, May 28.

1997 - Harrison, D.J. Microhabitat-, stand-, and landscape-scale habitat selection by marten in Maine. Invited paper presented at *Workshop on Lynx and Marten Management in Eastern Boreal Forests*, White Mountain National Forest, Gilead, ME, August 26.

1997 - Harrison, D.J. Results from ongoing studies of American marten on industrial forestland in Maine. Seminar presented to *Advisory Committee, Maine Cooperative Forestry Research Unit*, Orono, ME, January 21.

1997 - Harrison, D.J. Ecology and habitat relationships of American martens in Maine. *Penobscot Valley Chapter, Maine Audubon Society*, February 7.

1997 - Harrison, D.J. "The influence of partial harvesting on American marten: a proposal." Presentation to *Advisory Committee, Cooperative Forestry Research Unit*, Univ. Maine, Orono, April 29, 1997.

1997 - Harrison, D.J., and W.B. Krohn. What do, and don=t, we know about lynx and marten in Maine? Invited paper presented at *Workshop on Lynx and Marten Management in Eastern Boreal Forests*, White Mountain National Forest, Gilead, ME, August 25.

1997 - Payer, D.C., and D.J. Harrison. Influence of site-level habitat characteristics on spatial patterns of habitat use by American marten in an industrial forest and a forest preserve in Maine. *The Wildlife Society National Conference*, Snowmass, Colorado, September 25.

1997 - Payer, D.C. and D.J. Harrison. Influence of microsite characteristics on patterns of habitat occupancy by American marten. Presentation at seminar series sponsored by the *Department of Wildlife Ecology, University of Maine*. November 3.

1997 - Payer, D.C., and D.J. Harrison. Structural differences between forests regenerating following spruce-budworm infestations and clearcutting, with implications for merican marten. Presentation at seminar series sponsored by the *Department of Wildlife Ecology, University of Maine*. November 3.

1996 - Chapin, T. G. and D. J. Harrison. Seasonal Selection of Habitats by Resting Marten in Maine. Paper presented at *52nd Northeast Fish and Wildlife Conference*, Farmington, CT. April 2.

1996 - Chapin, T. G. and D. J. Harrison. Seasonal habitat selection by marten in an untrapped forest preserve. Paper presented at *Ecological Society of America and Society for Conservation Biology*

Meeting, Providence, RI. August 14.

1996 - Harrison, D. J. Habitat requirements of American marten in northeastern forests. Seminar presented to *Fraser Paper, Inc. and J. D. Irving Corporation's foresters*. Edmundston, New Brunswick. February 27.

1996 - Harrison, D. J. Marten, forests, and biodiversity: a model for conservation. Invited presentation at *Maine Forest Biodiversity Conference*, Ellsworth, Maine. March 12.

1996 - Harrison, D. J. Funding, infrastructure, and partnerships for wildlife conservation in the U.S. Invited seminar presented to *Department of Ecosystem Planning*, *Tokyo Noko University*, Japan. March 20.

1996 - Harrison, D. J. Habitat relationships of American marten: specialist or generalist. Seminar presented to *U. S. Forest Service Redwood Sciences Laboratory and College of Natural Resources, Humboldt University*, Arcata, CA. March 28.

1996 - Harrison, D. J. Influence of spatial and body scaling on habitat selection by mammalian carnivores. Seminar presented to *Utah Cooperative Fish and Wildlife Research Unit and Dept. of Fisheries and Wildlife, Utah State University*, Logan. April 5.

1996 - Harrison, D. J. Influence of spatial and body scaling on habitat selection by mammalian carnivores. Seminar presented to *Dept. of Zoology and Physiology, University of Wyoming, Laramie*. April 11.

1996 - Harrison, D. J. Marten as a barometer of forest health in Maine. Seminar presented at *Annual Meeting, Maine Chapter of The Wildlife Society*, Brewer, ME. April 25.

1996 - Harrison, D.J. A conservation model for habitat of American martens in Maine. Seminar presented to *Executive Council, Maine Audubon Society*, Ellsworth, ME, November 11.

1996 - Harrison, D. J., D. Payer, and H. J. Lachowski. Influence of forest harvesting and forest structure on habitat selection by American marten Presentation and field tour to *National Council of the Paper Industry (NCASI)* scientists and other forest industry representatives, Millinocket, ME. August 22.

1996 - Harrison, D. J., and S. L. Glass. Comparative social ecology of coyotes: does large prey cause pack formation? Paper presented at *Ecological Society of America and Society for Conservation Biology Meeting*, Providence, RI. August 13.

1996 - Long, R .A., D. J. Harrison, and A. F. O'Connell, Jr. Survival and cause-specific mortality of white-tailed deer fawns on Mount Desert Island, Maine. Paper presented at *Ecological Society of America and Society for Conservation Biology Meeting*, Providence, RI. August 14.

1995 - Chapin, T.G., and D.J. Harrison. Marten use of residual stands in an industrial forest landscape in Maine. Presented at the *51st Annual Northeast Fish and Wildlife Conference*, Ocean City, MD. April 8-12.

1995 - Chapin, T.G., and D.J. Harrison. Marten use of residual stands in an industrial forest landscape in Maine. Paper presented at the *Second International Martes Symposium,* Edmonton, Alberta. August

12-16.

1995 - Chapin, T.G and D.J. Harrison. Influence of landscape pattern and forest type on use of habitat by marten in Maine. Seminar presented to *Department of Wildlife Ecology, University of Maine*, Orono. June 15.

1995 - Chapin, T. G. and D. J. Harrison. Influence of landscape pattern on spatial us of habitat by marten in an industrial forest. Paper presented at *National Conference of the Society of American Foresters*, Portland, ME, November 1.

1995 - Harrison, D. J. Influence of Forest Harvesting on Marten Populations in Northern Maine. Invited paper presented at *Society of American Foresters National Convention*, Portland, ME. October 28-29.

1995 - Harrison, D. J. Ecology and life history of the northeastern coyote. Invited seminar presented to *Illinois Natural History Museum*, University of Illinois, Urbana. November 14.

1995 - Harrison, D. J. Social ecology and prey relationships of the eastern coyote: the influence of prey size on pack formation. Invited seminar presented to *Dept. of Ecology, Ethology, and Evolution*, University of Illinois, Urbana. November 15.

1995 - Harrison, D. J. Habitat Requirements of American Marten: Reassessing Paradigms. Seminar presented to *Department of Wildlife Ecology, Univ. Maine*, November 28.

1995 - Harrison, D.J. Relative influences of timber harvesting and trapping on marten populations in Maine. Presentation at the *Spring Meeting of Forest Resources Research Advisory Committee*, University of Maine, Orono. April 11.

1995 - Harrison, D.J. Incorporating marten habitat requirements into forest management activities. Presentation and field tour, *Cooperative Forestry Research Unit Annual Conference*, Millinocket, ME. September 20-21.

1995 - Harrison, D.J., D.M. Phillips, T.G. Chapin, D.P. Katnik, and T.P. Hodgman.. Population performance and habitat selection by American marten: a need to reassess accepted paradigms and conservation practices. Invited paper presented at the *Second International Martes Symposium*, Edmonton, Alberta. August 12-16.

1995 - Hodgman, T.P., and D. J. Harrison. 1995. Survival in a heavily harvested marten population: a preliminary assessment. Poster presented at *Annual Conference of the Maine Cooperative Forestry Research Unit*, Millinocket, ME. September 20.

1995 - Hodgman, T.P., D.J. Harrison, D.M. Phillips, and K.D. Elowe. Survival of marten in an untrapped forest preserve in Maine. Paper presented at the *Second International Martes Symposium*, Edmonton, Alberta. August 12-16.

1995 - Long, R.A., S.L. Glass, D.J. Harrison, and A.F. O'Connell. Cause-specific mortality of white-tailed

deer fawns on Mount Desert Island, Maine. Presented at the *51st Annual Conference of the Northeast Fish and Wildlife Conference*, Ocean City, MD. April 9-12.

1995 - Long, R.A., D.J. Harrison, S.L. Glass, and A.F. O'Connell. Annual survival and cause-specific mortality of white-tailed deer fawns on Mount Desert Island, Maine. Paper presented at the *21st Maine Biological and Medical Sciences Symposium*, Bar Harbor, ME. June 8-9.

1995 - Long, R.A., D.J. Harrison, and A.F. O'Connell, Jr. Annual survival and cause-specific mortality of white-tailed deer fawns, and relative abundance of snowshoe hare on Mount Desert Island, Maine. Seminar presented to *Department of Wildlife Ecology, University of Maine, Orono*. June 16.

1995 - Long, R, D.J. Harrison, S. L. Glass, and A. F. O'Connell. Mortality of white-tailed deer fawns in Acadia National Park. Seminar presented to research and management staff, *Acadia National Park*, Bar Harbor, ME. August 30.

1995 - Phillips, D.M., and D.J. Harrison. Seasonal changes in density, range area, and range fidelity of American marten in a forest preserve. Paper presented at *Second International Martes Symposium*, Edmonton, Alberta. August 12-16.

1994 - Chilelli, M., B. Griffith, and D.J. Harrison. Utility of regional furbearer data: the river otter example." Paper presented at *First Annual Conference of The Wildlife Society*, Albuquerque, New Mexico, September 21.

1994 - Harrison, D.J. "A proposal to study the relationships among trapping, forest harvesting, and marten populations in northern Maine." Presentation to *Maine Cooperative Forestry Research Unit Advisory Committee*, University of Maine, January 25.

1994 - Harrison, D.J. "Preliminary results from ongoing research to assess influences of forest harvesting and trapping on marten populations in northern Maine." Invited presentation at *Wildlife Division Meeting, Maine Department of Inland Fisheries and Wildlife*, Rockland, ME, April 14.

1994 - Harrison, D.J. The effects of scale on habitat selection. Guest presentation in graduate course in *Evaluation of Wildlife Habitats*, University of Maine, Orono. October 7.

1994 - Harrison, D.J. Evidence for external regulation in an unmanaged deer population. Paper presented at the *Conference on Science of Overabundance*, Front Royal, VA. November 10-11.

1994 - Harrison, D.J., and T.D. Chapin. "Effects of forest fragmentation on martens in northern Maine: preliminary results from ongoing studies." Presentation to *National Council of the Paper Industry for Air and Stream Improvement*, Albuquerque, NM, September 23.

1994 - Phillips, D.M., and D.J. Harrison. "Density, home-range, and spatial overlap of marten in an industrial forest and forest preserve." Paper presented at *Northeast Fish and Wildlife Conference*, Burlington, VT, May 3.

1993 - Harrison, D.J. "Potential forest management issues associated with habitat requirements of the marten." Presentation to *Maine Chapter, Association of Consulting Foresters*, Bangor, ME,

October 12.

1993 - Harrison, D.J. "Objectives and preliminary results of a study to assess the influence of trapping and forest harvesting on marten populations in northern Maine." Presentation to foresters of *Scott Paper, Inc., Rockwood, Maine*, December 14.

1993 - Harrison, D.J. "Habitat associations of the marten: does the species deserve spotted owl status?" Invited paper presented at *Conserving Species Dependent on Older Forests: a Population Viability Workshop*. Fundy National Park, Alma, New Brunswick, October 27.

1993 - Harrison, D.J. The role and effectiveness of predator control to enhance game populations. Presentation to *Maine Chapter of The Wildlife Society*, April 5.

1993 - Harrison, D.J. Feasibility and issues associated with restoring wolves to Maine. Presentation to *Maine Chapter of The Wildlife Society*, April 5.

1992 - Saeki, M., and D.J. Harrison. Influence of food availability and fire history on dietary quality of white-tailed deer (Odocoileus virginianus). Paper presented at Seventy-second annual meeting of *American Society of Mammalogists*, Salt Lake City, Utah.

1992 - Harrison, D.J. Significance of pine martens to future forest practices in Maine. Presentation to *Woodlands staff, Great Northern Corp*., Millinocket, Maine.

1992 - Harrison, D.J. Pine marten habitat requirements: will the Forest Practices Act safeguard marten habitat? Presentation to *Maine Chapter of The Wildlife Society*, Orono, Maine.

1991 - Harrison, D. J. Chaired session and provided summative comments for session titled: "Habitat management of martens and fishers," *International Symposium on the Biology and Management of Martens and Fishers*, Laramie, Wyoming.

1991 - Harrison, D. J. Coyote social organization and relationships to dispersal and food resources: predictions with an unpredictable animal. Invited paper presented at *Eastern Coyote Symposium*, Fredericton, New Brunswick.

1991 - Harrison, D.J., A.F. O'Connell, and J.A. Subijanto. Seasonal food habits of a recently established insular population of coyotes. Poster presented at *Northeast Fish and Wildlife Conference*, Portland, Maine.

1991 - Harrison, D.J., A.F. O'Connell, Jr., and J. A. Subijanto. Seasonal food habits of a recently established insular coyote population. Invited paper presented at *Second National Park Service Conference on Science and Natural Resource Management in the North Atlantic Region*, Newport, RI.

1991 - Harrison, D.J., and N.E. Famous. Effects of peat harvesting on a large mammalian carnivore: a case study with coyotes (*Canis latrans*). Paper presented at *International Peat Symposium*, Duluth, Minnesota.

1991 - Harrison, D.J., T.P. Hodgman, and D.D. Katnik. Survival in a heavily harvested marten population, a preliminary assessment. Paper presented at *International Symposium on the Biology and Management of Martens and Fishers*, University of Wyoming, Laramie.

1991 - Giuliano, W., and D.J. Harrison. A preliminary assessment of spatial-temporal relationships in an unexploited pine marten population. Poster presented at *International Symposium on the Biology and Management of Martens and Fishers*, University of Wyoming, Laramie.

1991 - Saeki, M. and D. J. Harrison. Trends in browse use and preference in an unhunted deer and hare population. Paper presented at *Second National Park Service Conference on Science and Natural Resource Management in the North Atlantic Region*, Newport, Rhode Island.

1990 - Harrison, D.J. Status of ongoing mammal research. Seminar presented to regional management staff, *Maine Department of Inland Fisheries and Wildlife*, Bar Harbor.

1990 - Harrison, D.J. Status, ecology, and inter-specific relationships of mammalian predators in Acadia National Park. Seminar presented to *North Atlantic Region, science staff, U.S. National Park Service*, Bar Harbor, Maine.

1990 - Harrison, D.J. An abstract of results from ongoing research involving coyote-fox spatial interactions, deer-hare browsing relationships, and marten population characteristics in Maine. Seminar presented at annual Wildlife Division meeting, *Maine Department of Inland Fisheries and Wildlife*, Rockland, Maine.

1990 - Harrison, D.J. Ecology and interspecific relationships among Maine's predators. Seminar presented to faculty and staff, *Suffolk University*, Edmunds, ME.

1990 - Harrison, D.J. Pre-dispersal movements of coyote pups in eastern Maine. Paper presented at *70th annual meeting of the American Society of Mammalogists*, Frostburg, Maryland.

1989 - Harrison, D.J. Dispersal characteristics of juvenile coyotes: implications for social organization. Paper presented at *69th Annual Meeting of the American Society of Mammalogists*, Fairbanks, Alaska.

1989 - Harrison, D.J. Distribution, productivity, and food habits of a recently established coyote population in Connecticut. Paper presented at *Northeast Fish and Wildlife Conference*, Ellenville, NY.

1989 - Harrison, D.J. Spatial dynamics and inter-specific relationships among Maine predators. Seminar presented at *Unity College*, Unity, Maine.

1989 - Harrison, D.J. Ecology and management of coyotes in Maine. Seminar presented to *Department of Animal Science*, University of Maine.

1988 - Harrison, D.J. A proposal to assess the utility and interstate comparability of river otter sex, age, and reproductive data. Invited presentation at *Northeast Furbearer Resources Technical Committee Meeting*, Quebec City.

1988 - Harrison, D.J. Interaction of forest management practices and pine marten populations. Invited presentation at *Northeast Furbearer Resources Technical Committee Meeting*, Quebec City.

1988 - Harrison, D.J. A proposal to reintroduce fishers to northwest Connecticut. Paper presented at *Second Natural Diversity Conference*, Rocky Hill, Connecticut.

1988 - May, D,W., D.J. Harrison, and P. Rego. Characteristics and diet of colonizing coyote populations in Connecticut. Paper presented at *Second Natural Diversity Conference*, Rocky Hill, Connecticut.

Public Talks and Workshops (abridged to include since 2007 only):

2015 - Rolek, B.W., C. Loftin, D. Harrison, and P. Wood. Habitat associations, forestry, and coniferous forest birds. *Downeast Birding Festival. Machias, Maine*, May 2015.

2015- Harrison, D. Eastern coyotes and wolves: their history, origin, and ecology in the northeastern U.S. *Invited presentation at the Maine State Museum, Augusta*, April 8.

2013 – Dunham, S., and D. Harrison. Habitat ecology of the spruce grouse in Maine's northern forests. *Presentation sponsored by the Bangor Nature Club, Bangor, Maine*. May 15.

2013 – Olson, S., and D. Harrison. Seasons of the snowshoe hare. *Presentation at Sunkhaze Café, hosted by Friends of Sunkhaze National Wildlife Refuge, Old Town, Maine*. April 20.

2011 - Harrison, D. J. Lynx, forests, and forestry in northern Maine. *Presentation at SummerMeeting of The Forest Society of Maine*, Greenville, ME. August 15.

2008 – Harrison, D. J. "Wildlife in Winter". *Presentation at Maine Audubon's Fields Pond Nature Center*. January 8.

2007 - Harrison, D. J. "Applying umbrella species as tools for land conservation: case examples using martens and lynx in Maine." Presentation to the Board of Directors, Forest Society of Maine, Falmouth, Maine. September 11.

2007 - Harrison, D. J. "What is a predator ecologist and what does it do?" Presentation to first year students in WLE 100. October 12.

2007 - Harrison, D. J. Co-led a field tour for professional foresters highlighting the management of deer wintering habitat in northern Maine. October 10.

2007 - Harrison, D. J. Presented invited guest lecture in WLE 100. October 12.

2007 – Harrison, D. J., W. B. Krohn, E. Simons and A. K. Fuller. Co-led a northern Maine landscape planning workshop for NGO's and state agency personnel. October 17.

2007- Harrison, D. J., W. B. Krohn, and M. McCollough. Contributed to an article titled "Cats in a Quandry" that highlighted finding from our lynx research and appeared in National Wildlife Magazine December-January 2008 issue.

Conflict of Interest Disclosure Form

Note: A potential or actual conflict of interest exists when commitments and obligations are likely to be compromised by the nominator(s)'other material interests, or relationships (especially economic), particularly if those interests or commitments are not disclosed.

This Conflict of Interest Form should indicate whether the nominator(s) has an economic interest in, or acts as an officer or a director of, any outside entity whose financial interests would reasonably appear to be affected by the addition of the nominated condition to the newborn screening panel. The nominator(s) should also disclose any personal, business, or volunteer affiliations that may give rise to a real or apparent conflict of interest. Relevant Federally and organizationally established regulations and guidelines in financial conflicts must be abided by. Individuals with a conflict of interest should refrain from nominating a condition for screening.

Date: 10/13/2017

Name: James Beasley

Position: Assistant Professor

Please describe below any relationships, transactions, positions you hold (volunteer or otherwise), or circumstances that you believe could contribute to a conflict of interest:

☑ I have no conflict of interest to report.

☐ I have the following conflict of interest to report (please specify other nonprofit and for-profit boards you (and your spouse) sit on, any for-profit businesses for which you or an immediate family member are an officer or director, or a majority shareholder, and the name of your employer and any businesses you or a family member own:

1. _____

2. _____

3. _____

I hereby certify that the information set forth above is true and complete to the best of my knowledge.

Signature: _____

Date: 10/13/2017

Conflict of Interest Disclosure Form

Note: A potential or actual conflict of interest exists when commitments and obligations are likely to be compromised by the nominator(s)'other material interests, or relationships (especially economic), particularly if those interests or commitments are not disclosed.

This Conflict of Interest Form should indicate whether the nominator(s) has an economic interest in, or acts as an officer or a director of, any outside entity whose financial interests would reasonably appear to be affected by the addition of the nominated condition to the newborn screening panel. The nominator(s) should also disclose any personal, business, or volunteer affiliations that may give rise to a real or apparent conflict of interest. Relevant Federally and organizationally established regulations and guidelines in financial conflicts must be abided by. Individuals with a conflict of interest should refrain from nominating a condition for screening.

Date: 10/08/2017

Name: Mark S. Boyce

Position: Professor

Please describe below any relationships, transactions, positions you hold (volunteer or otherwise), or circumstances that you believe could contribute to a conflict of interest:

☑ I have no conflict of interest to report.

☐ I have the following conflict of interest to report (please specify other nonprofit and for-profit boards you (and your spouse) sit on, any for-profit businesses for which you or an immediate family member are an officer or director, or a majority shareholder, and the name of your employer and any businesses you or a family member own:

1. _____

2. _____

3. _____

I hereby certify that the information set forth above is true and complete to the best of my knowledge.

Signature: _____

Date: 10/08/2017

Conflict of Interest Disclosure Form

Note: A potential or actual conflict of interest exists when commitments and obligations are likely to be compromised by the nominator(s)'other material interests, or relationships (especially economic), particularly if those interests or commitments are not disclosed.

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Date: 10/09/2017

Name: Jennifer K. Frey

Position: Professor, New Mexico State University

Please describe below any relationships, transactions, positions you hold (volunteer or otherwise), or circumstances that you believe could contribute to a conflict of interest:

☑ I have no conflict of interest to report.

☐ I have the following conflict of interest to report (please specify other nonprofit and for-profit boards you (and your spouse) sit on, any for-profit businesses for which you or an immediate family member are an officer or director, or a majority shareholder, and the name of your employer and any businesses you or a family member own:

1. _____

2. _____

3. _____

I hereby certify that the information set forth above is true and complete to the best of my knowledge.

Signature: _____

Date: 10/09/2017

Conflict of Interest Disclosure Form

Note: A potential or actual conflict of interest exists when commitments and obligations are likely to be compromised by the nominator(s)'other material interests, or relationships (especially economic), particularly if those interests or commitments are not disclosed.

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Date: 10/13/2017

Name: Daniel J. Harrison

Position: Consulting Scientist

Please describe below any relationships, transactions, positions you hold (volunteer or otherwise), or circumstances that you believe could contribute to a conflict of interest:

☑ I have no conflict of interest to report.

☐ I have the following conflict of interest to report (please specify other nonprofit and for-profit boards you (and your spouse) sit on, any for-profit businesses for which you or an immediate family member are an officer or director, or a majority shareholder, and the name of your employer and any businesses you or a family member own:

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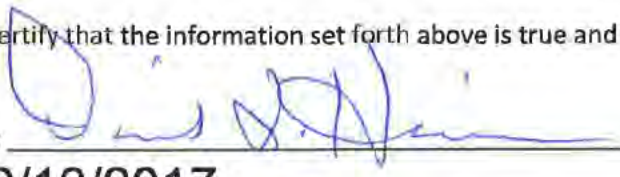
I hereby certify that the information set forth above is true and complete to the best of my knowledge.

Signature: 

Date: 10/13/2017

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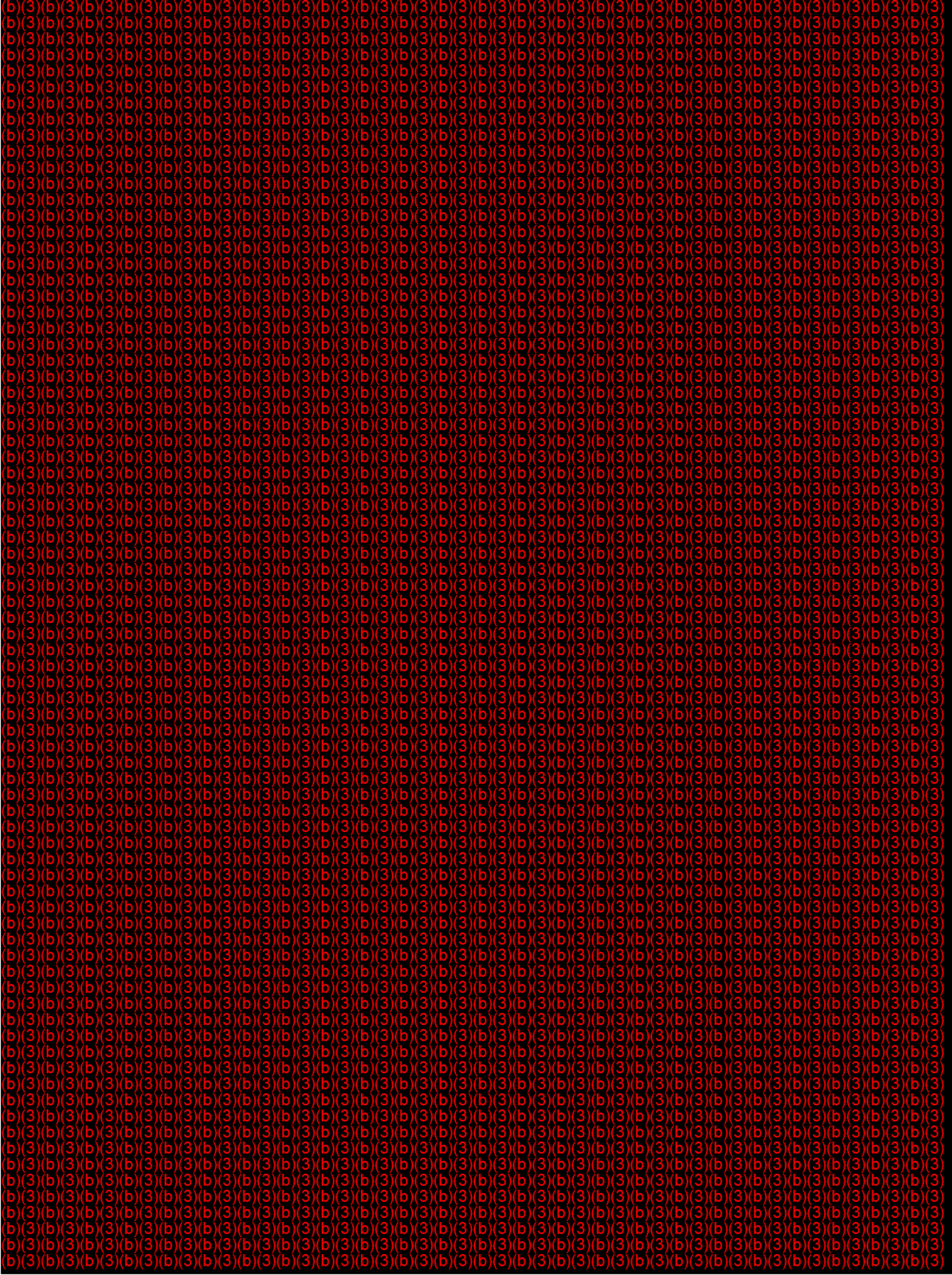
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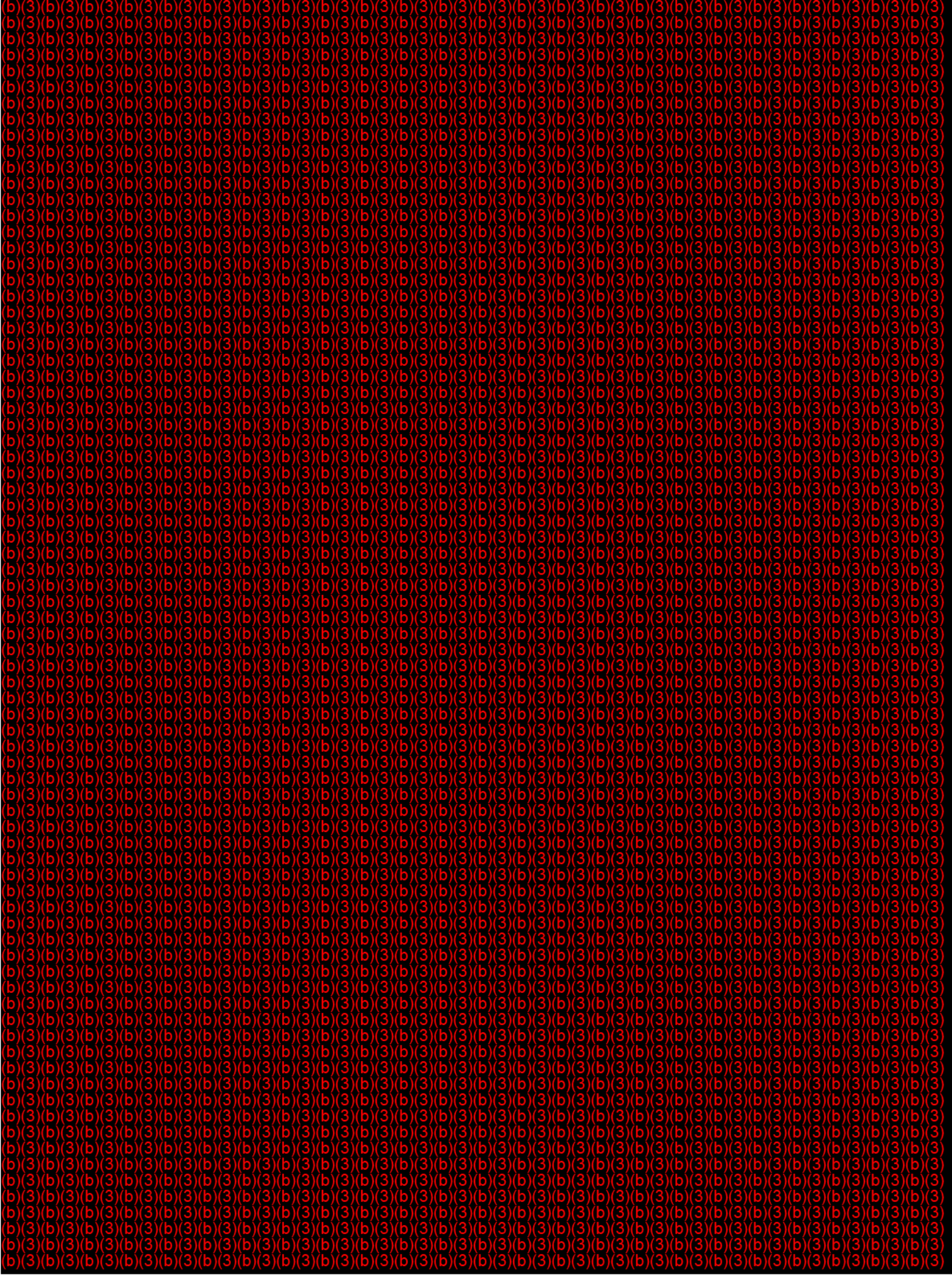
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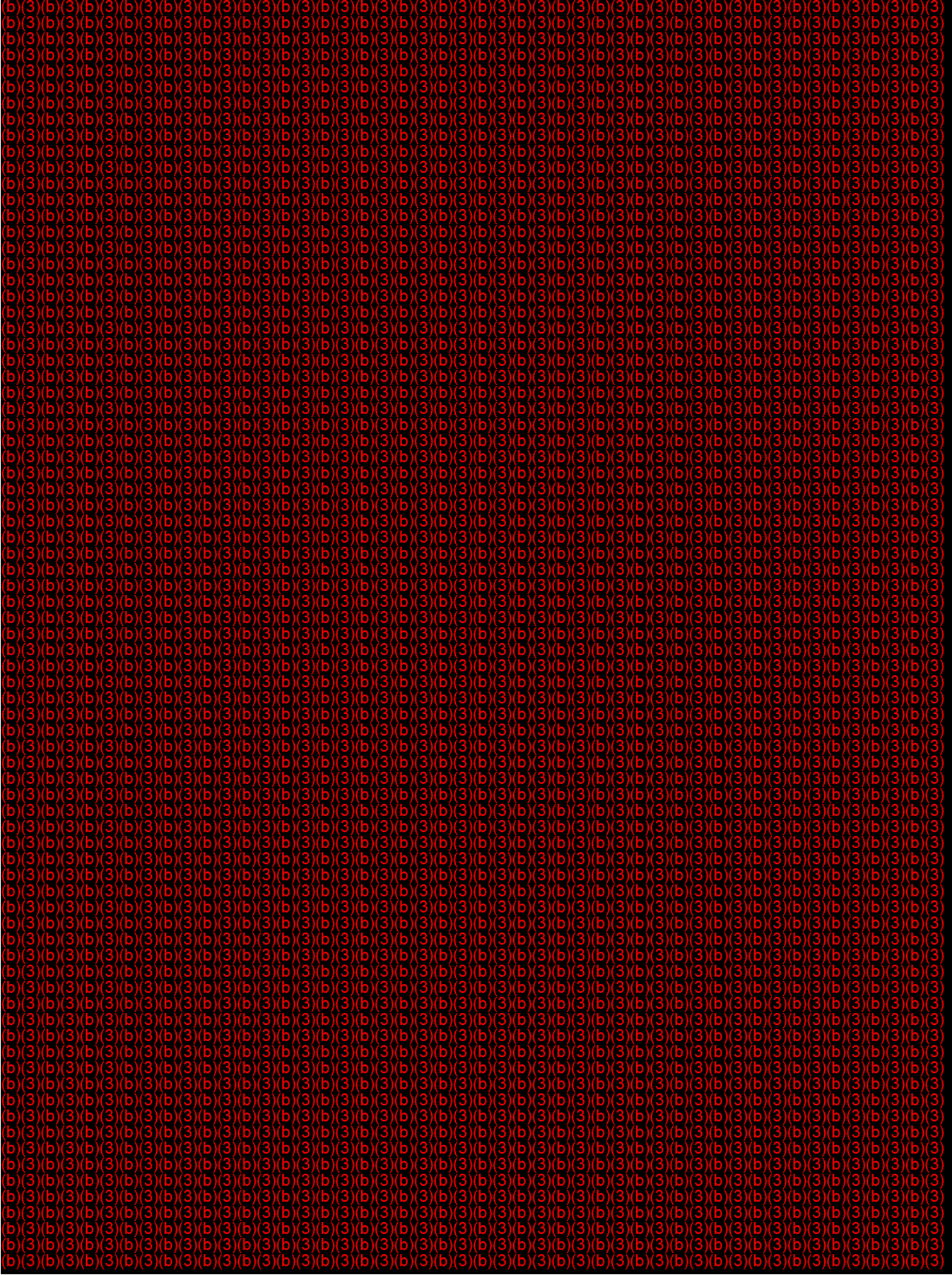
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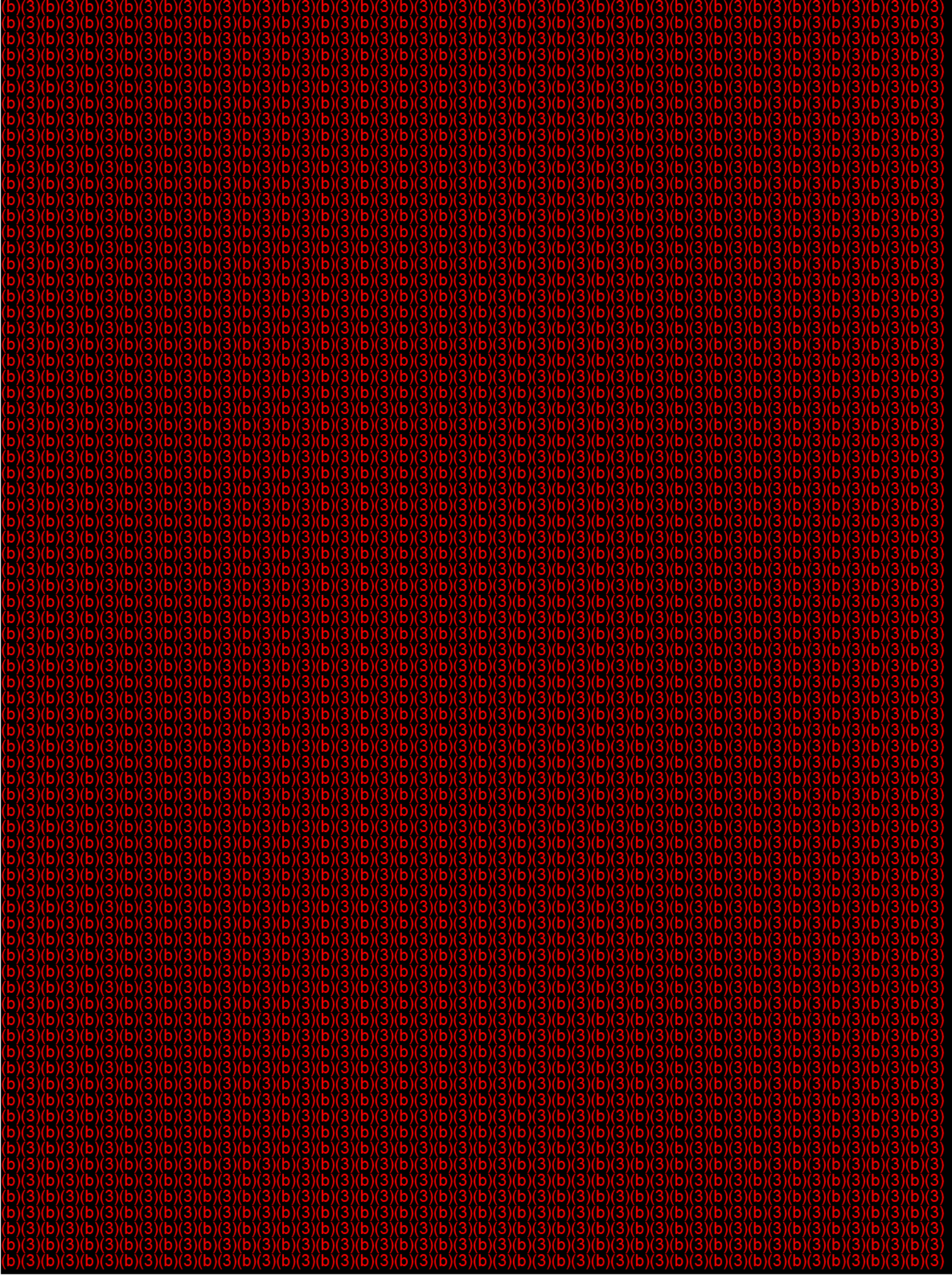
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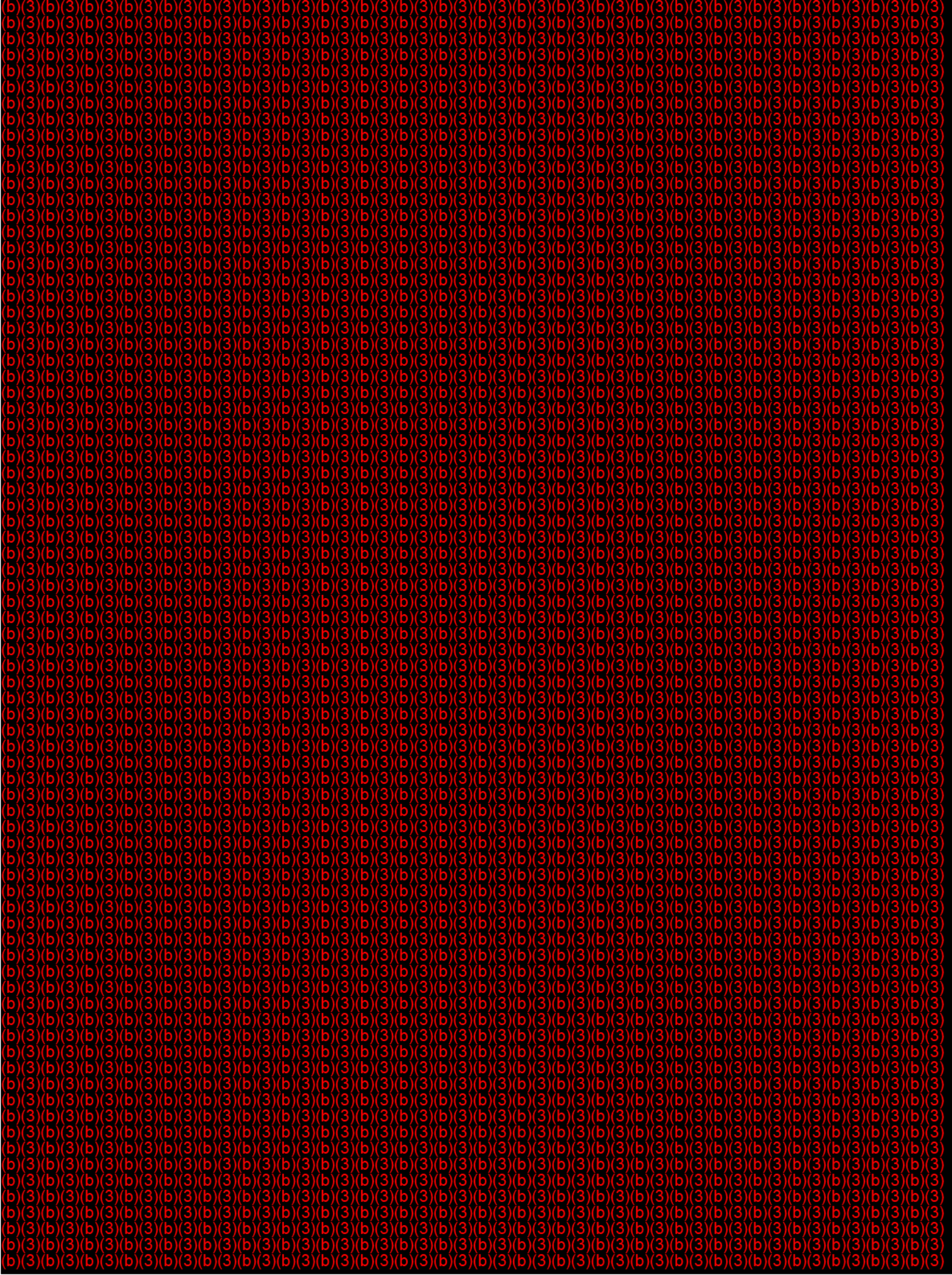
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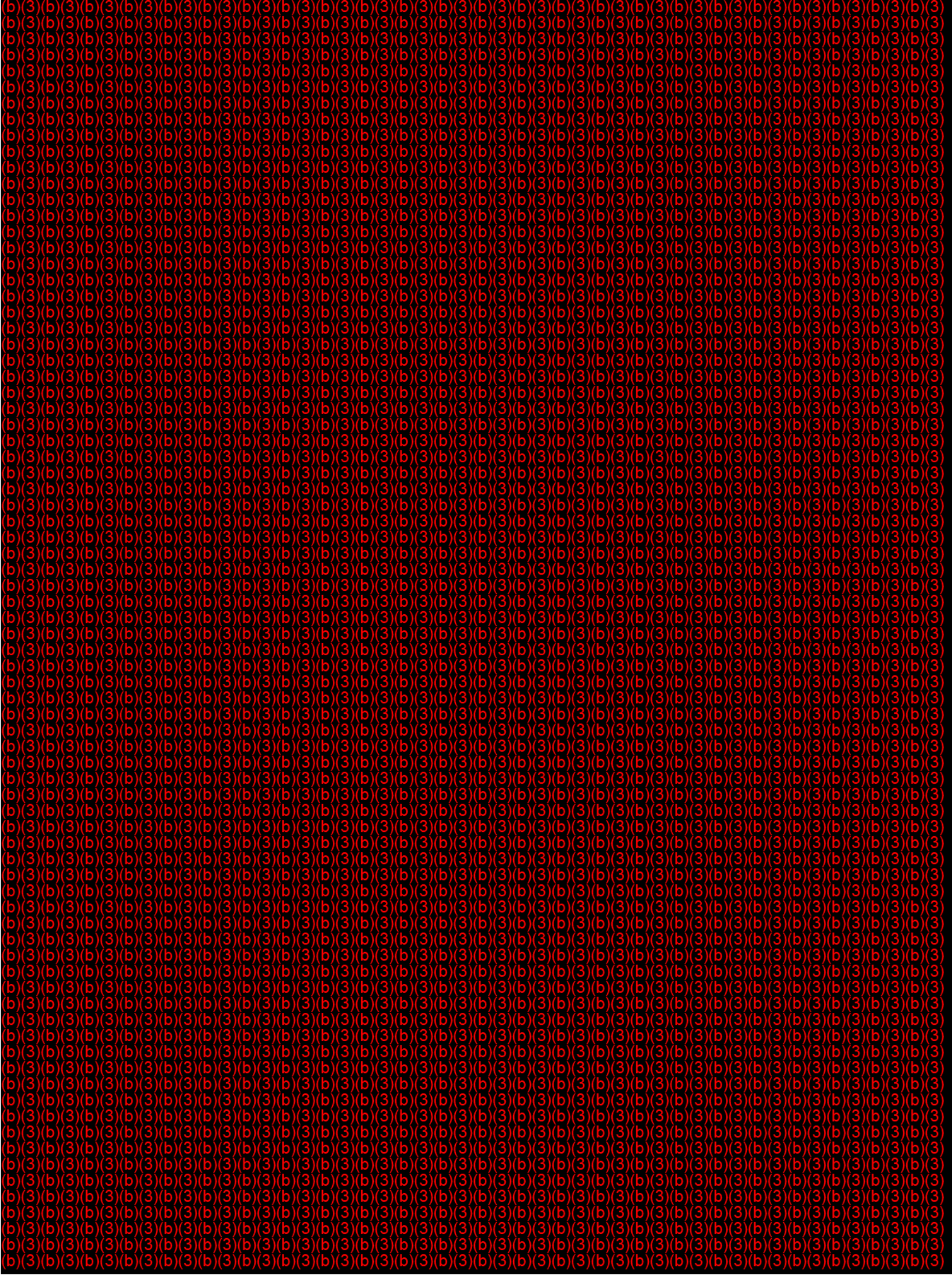
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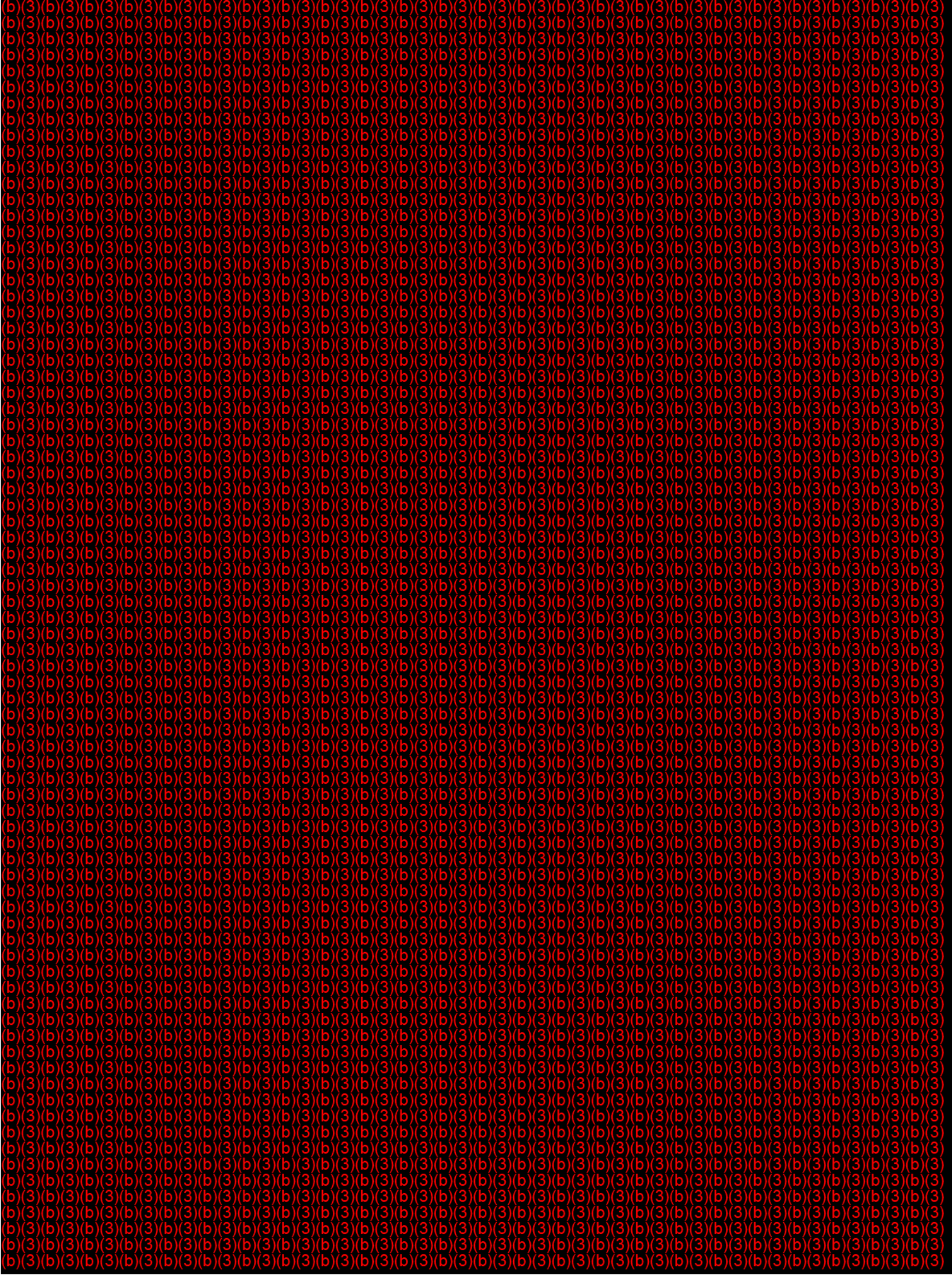
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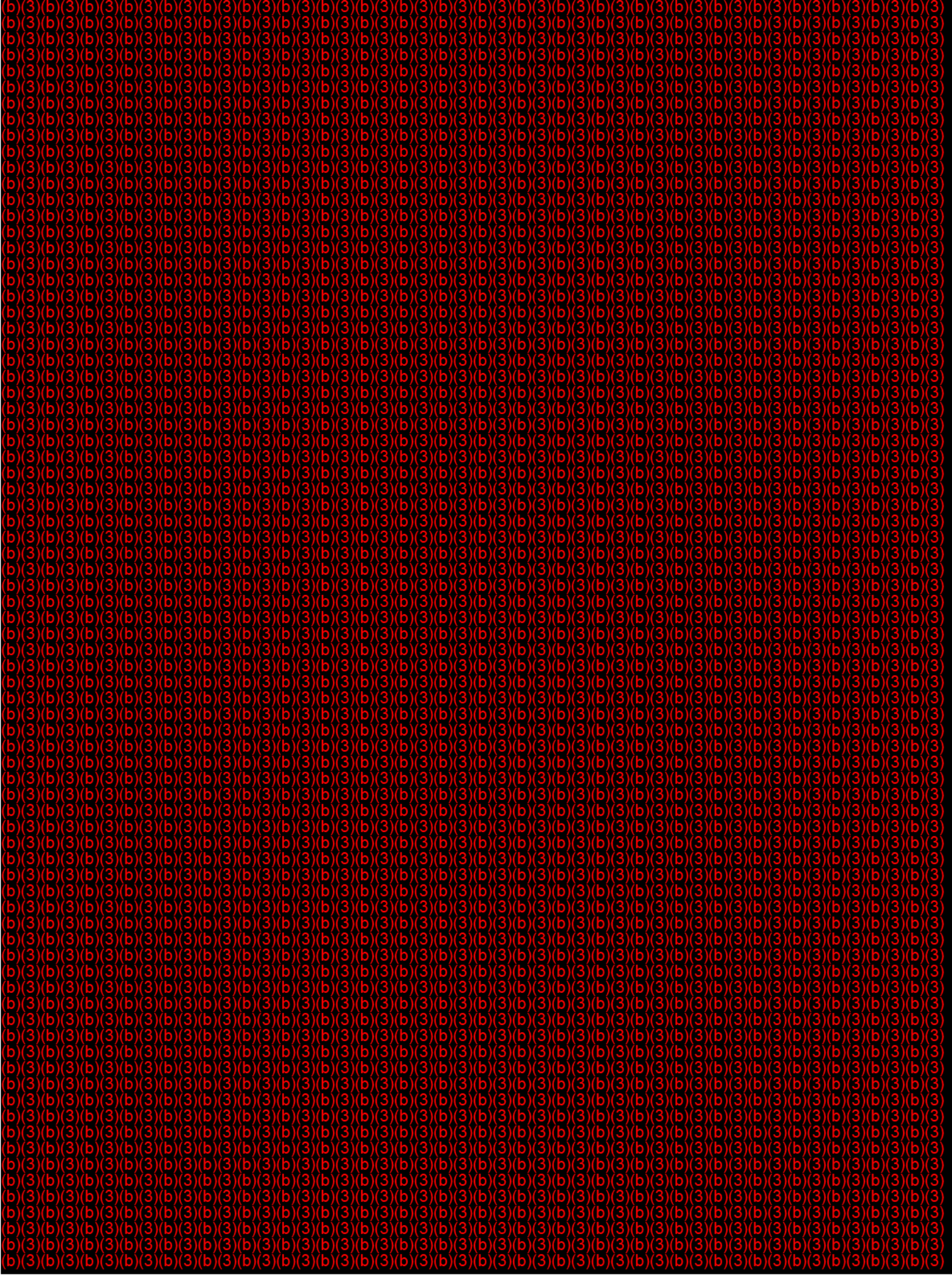
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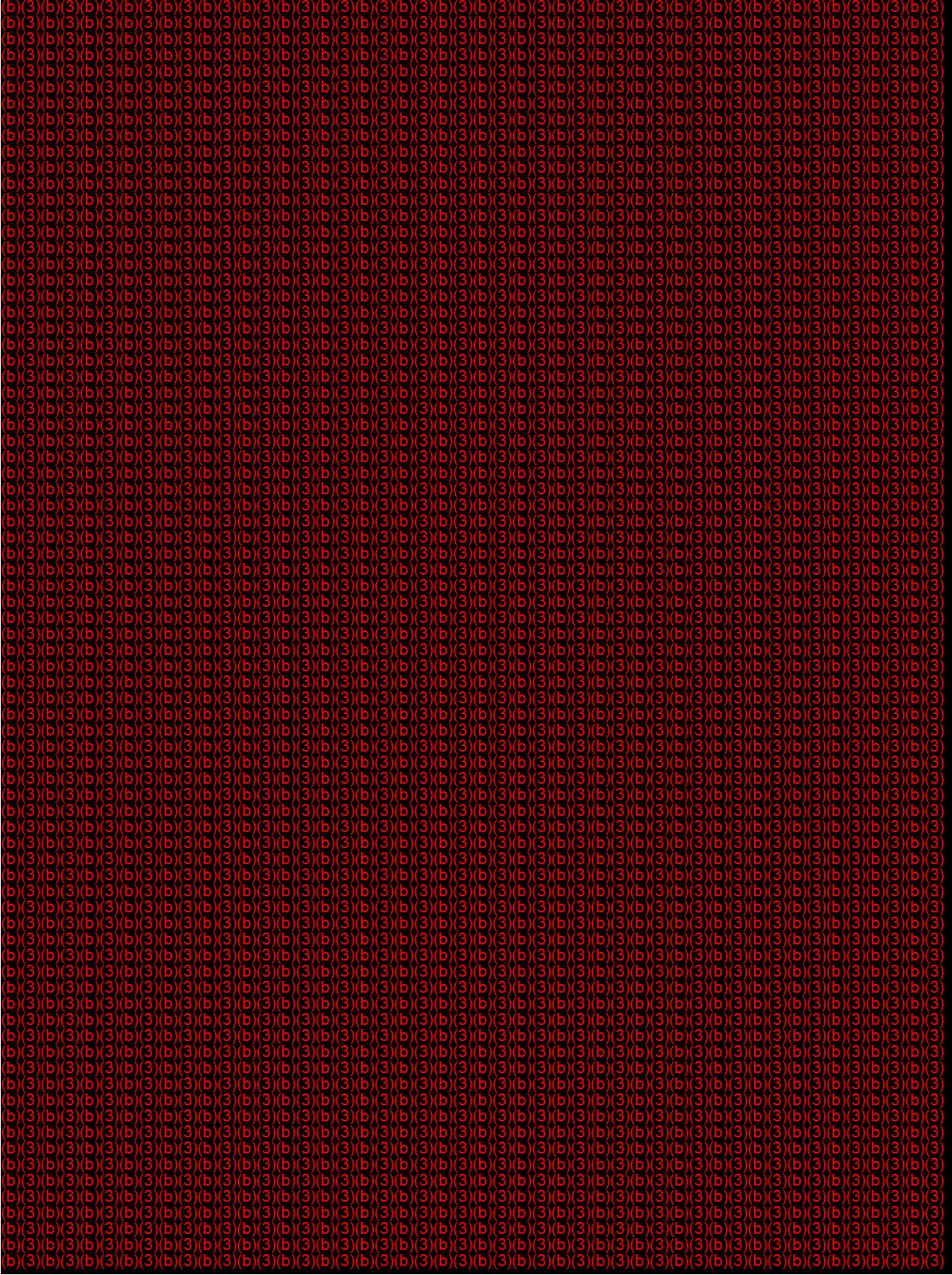
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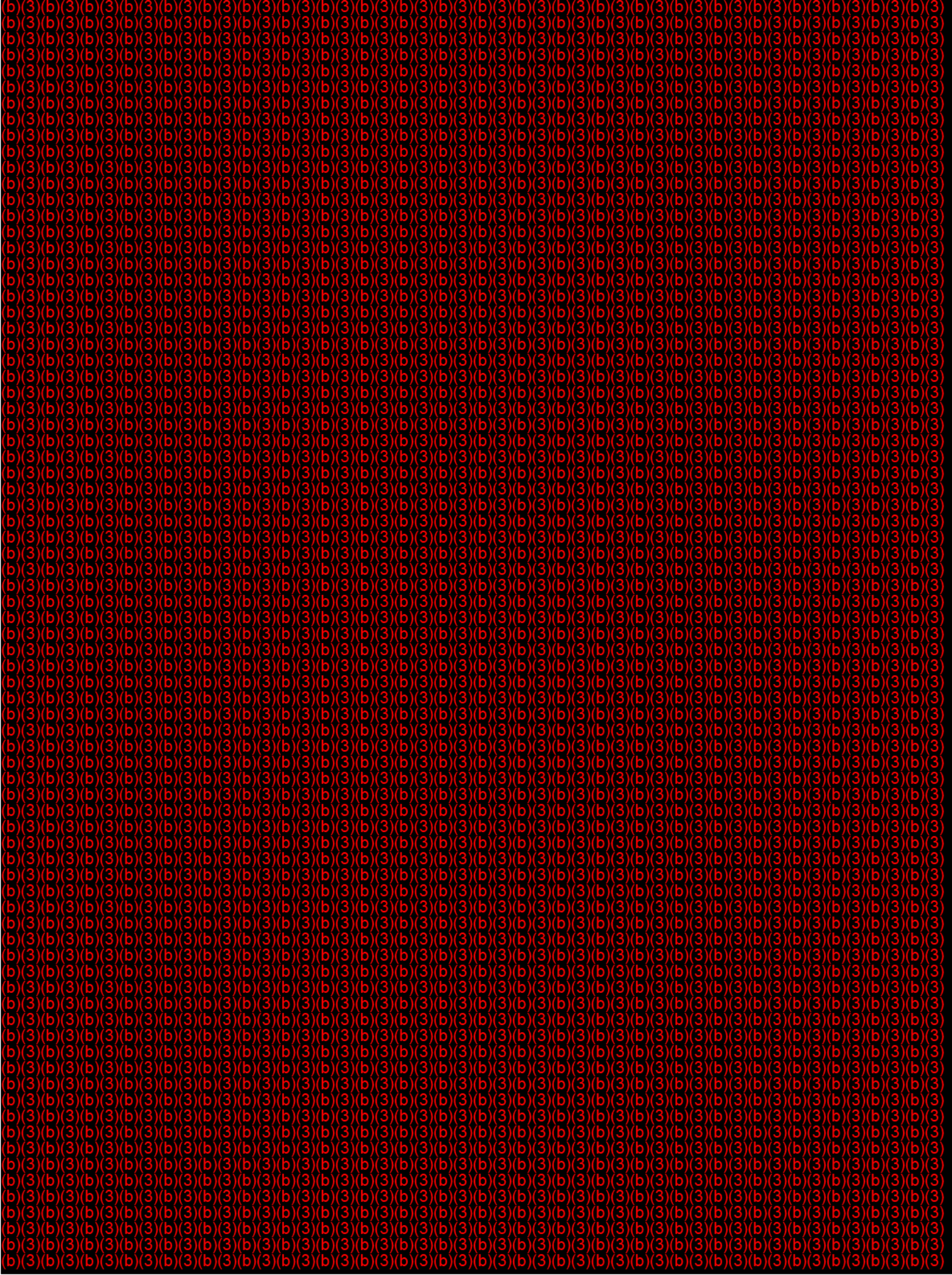
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From: Shoemaker, Justin
To: Jodi Bush
Subject: Wolverine peer review proposal reviews
Date: Tuesday, October 17, 2017 2:48:00 PM
Attachments: Score Sheet Wolverine_J Shoemaker_AMEC.doc
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Mine are attached.

Sarah will have it done by tomorrow am at the latest.

Justin Shoemaker
Classification and Recovery Biologist
U.S. Fish and Wildlife Service, Region 6
Phone: 309-757-5800 x214
Email: justin_shoemaker@fws.gov

REQUEST FOR PROPOSAL - EVALUATION FORM
WOLVERINE PEER REVIEW

Date Evaluated: 10/17/2017	Evaluator: **Justin Shoemaker**

Firm Name:
Amec Foster Wheeler Environment & Infrastructure, Inc.

Category	Rating: 1 (poor) - 10 (excellent)	Weight	Score
A. COST PROPOSAL • Cost Proposal (Contracting Officer will conduct the initial evaluation of cost submittals) Leave score blank until Contracting officer provides this information • Score will be based on whether the percentage of price submitted is above the lowest reasonablel price submitted.		**4.0**	
• **QUALIFICATIONS** 1. Each reviewer must have a Ph.D. or a Master's with significant experience in Wildlife Ecology, Ecology, or Wildlife Management; and 2. In combination, the expertise of the qualified reviewers shall include the following; however, each individual is not required to meet all qualifications: a. Experience or expertise with carnivore management, especially wolverines; b. Expert knowledge of wildlife biology, wildlife management, demographic management of mammals (especially mesocarnivores), genetics, population modeling and/or scientific literature on wolverines or other mustelids; c. Expert knowledge of the effects of climate change and climate change modeling, specifically in the Mountain West area of the United States, which includes the northern Rocky Mountains, the North Cascades, or the southern Rocky Mountains; d. Expert knowledge of genetics of metapopulations; e. Experience as a peer reviewer for scientific publications; f. Knowledge of wolverine management in Canada, Alaska, and/or Europe. • **In addition, the reviewers shall have no financial or other conflicts of interest with the outcome or implications**	**8**	**4.0**	**32**

B. PROJECT APPROACH • Number of reviewers • Assumptions • Timeline • Other TECHNICAL Considerations -	**5**	**2.0**	**10**
	TOTAL SCORE **(**100 points possible**)**		

Continued on Page 2

Comments – Cost Proposal:

_____

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Comments –Approach____Timeline could be shorter, 34 days from submittal of the report to reviewers and us getting the reviews is 4 days too much. _____

_____

_____

_____

_____

Comments – Capabilities/ Past performance

_____

_____

_____

Evaluation Standards

For purposes of this solicitation, numeric ratings of 1 through 10 (one being the lowest and 10 being the highest) will be used in conjunction with narratives to evaluate each of the evaluation criteria categories listed above. These ratings will then be multiplied by a weight factor given to each criteria category. Once each category total has been calculated, they will be added together for a final total score. This process will repeat itself for each evaluated proposal. The following are explanations of the numeric ratings that will be used to evaluate the technical proposals:

1. **10-9:** Information submitted demonstrates offeror's potential to significantly exceed performance or capability standards. The offeror has clearly demonstrated an understanding of all aspects of the requirements to the extent that timely and highest quality performance is anticipated. Have exceptional strengths that will significantly benefit the Government. The offeror's qualifications exceed the fullest expectations of the Government. The offeror has convincingly demonstrated that the RFP requirements have been analyzed, evaluated, and synthesized into approaches, plans, and techniques that, when implemented, should result in outstanding, effective, efficient, and economical performance under the contract. Significantly exceeds most or all solicitation requirements. **Very high probability of success.**

2. **8-7:** Information submitted demonstrates offeror's potential to exceed performance or capability standards. Have one or more strengths that will benefit the Government. The areas in which the offeror exceeds the requirements are anticipated to result in a high level of efficiency or productivity or quality. The offeror's qualifications meet and slightly exceed requirements. The submittal contains excellent features that will likely produce results very beneficial to the Government. Fully meets all RFP requirements and significantly exceed many of the RFP requirements. Disadvantages are minimal. **High probability of success.**

3. **6-5:** Information submitted demonstrates offeror's potential to meet performance or capability standards. Acceptable solution. Either meets all RFP requirements for the criterion (or sub-criteria) or contains weaknesses in some areas that are offset by strengths in other areas. This rating indicates that, in terms of the specific criterion (or sub-criteria), the offeror has a good probability of success, as there is sufficient confidence that a fully compliant level of performance will be achieved. The proposal demonstrates an adequate understanding of the scope and depth of the RFP requirements. No significant advantages or disadvantages. Equates to neutral. **Good probability of success.**

4. **4-3:** The submittal is not adequately responsive or does not address the specific criterion (or sub-criteria). The offeror's interpretation of the Government's requirements is so superficial, incomplete, vague, incompatible, incomprehensible, or incorrect as to be considered deficient. Proposal does not meet some of the minimum requirements. The assignment of a rating within the bounds of "Marginal" indicates that mandatory corrective action would be required to prevent significant deficiencies from affecting the overall project. The offeror's qualifications, plans or approach will likely result in questionable quality of performance, which represents a moderate level of risk to the Government. Low probability of success although the submittal has a reasonable chance of becoming at least acceptable. **Significant disadvantages.**

5. **2-1:** Fails to meet performance or capability standards. Unacceptable. Requirements can only be met with major changes to the submittal. There is no reasonable expectation that acceptable performance would be achieved. The proposal contains many deficiencies and/or gross omissions; fails to provide a reasonable, logical approach to fulfilling much of the Government's requirements; and/or fails to meet most or all of the minimum requirements. **Very significant disadvantage.**

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From: Jodi Bush
To: Shoemaker, Justin
Subject: Re: Wolverine peer review proposal reviews
Date: Tuesday, October 17, 2017 3:10:07 PM

Thanks

Sent from my iPhone

On Oct 17, 2017, at 2:48 PM, Shoemaker, Justin <justin_shoemaker@fws.gov> wrote:

> Mine are attached.
>
> Sarah will have it done by tomorrow am at the latest.
>
> Justin Shoemaker
> Classification and Recovery Biologist
> U.S. Fish and Wildlife Service, Region 6
> Phone: 309-757-5800 x214
> Email: justin_shoemaker@fws.gov
>
> <Score Sheet Wolverine_J Shoemaker_AMEC.doc>
>
> (b)(3)(b)(3)(b)(3)(b)(3)(b)(3)(b)(3)(b)(3)(b)(3)(b)(3)(b)(3)(b)(3)

From: Bush, Jodi
To: Steve Gess
Cc: Justin Shoemaker; Fierce, Sarah
Subject: Fwd: Wolverine peer review proposal reviews
Date: Wednesday, October 18, 2017 9:11:18 AM
Attachments: Score Sheet Wolverine_J Shoemaker_AMEC.doc
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Amec_Score Sheet Wolverine.doc
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Steve. We are still waiting for review from third person (sarah backsen). She will send hers to you directly - later this morning.

Some backstory for my and Justin's scores.

(b)(3)(b)(3)(b)(3)(b)(3)(b)(3)(b)(3)

Classification and Recovery Biologist
U.S. Fish and Wildlife Service, Region 6
Phone: 309-757-5800 x214
Email: justin_shoemaker@fws.gov

REQUEST FOR PROPOSAL - EVALUATION FORM
WOLVERINE PEER REVIEW

Date Evaluated: 10/17/2017	Evaluator: **Justin Shoemaker**

Firm Name:
Amec Foster Wheeler Environment & Infrastructure, Inc.

Category	Rating: 1 (poor) - 10 (excellent)	Weight	Score
A. COST PROPOSAL • Cost Proposal (Contracting Officer will conduct the initial evaluation of cost submittals) Leave score blank until Contracting officer provides this information • Score will be based on whether the percentage of price submitted is above the lowest reasonablel price submitted.		**4.0**	
• **QUALIFICATIONS** 1. Each reviewer must have a Ph.D. or a Master's with significant experience in Wildlife Ecology, Ecology, or Wildlife Management; and 2. In combination, the expertise of the qualified reviewers shall include the following; however, each individual is not required to meet all qualifications: a. Experience or expertise with carnivore management, especially wolverines; b. Expert knowledge of wildlife biology, wildlife management, demographic management of mammals (especially mesocarnivores), genetics, population modeling and/or scientific literature on wolverines or other mustelids; c. Expert knowledge of the effects of climate change and climate change modeling, specifically in the Mountain West area of the United States, which includes the northern Rocky Mountains, the North Cascades, or the southern Rocky Mountains; d. Expert knowledge of genetics of metapopulations; e. Experience as a peer reviewer for scientific publications; f. Knowledge of wolverine management in Canada, Alaska, and/or Europe. • **In addition, the reviewers shall have no financial or other conflicts of interest with the outcome or implications**	**8**	**4.0**	**32**

B. PROJECT APPROACH • Number of reviewers • Assumptions • Timeline • Other TECHNICAL Considerations -	**5**	**2.0**	**10**
	TOTAL SCORE **(**100 points possible**)**		

Continued on Page 2

Comments – Cost Proposal:

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Comments –Approach____Timeline could be shorter, 34 days from submittal of the report to reviewers and us getting the reviews is 4 days too much. _____

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_____

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_____

Comments – Capabilities/ Past performance

_____

_____

_____

Evaluation Standards

For purposes of this solicitation, numeric ratings of 1 through 10 (one being the lowest and 10 being the highest) will be used in conjunction with narratives to evaluate each of the evaluation criteria categories listed above. These ratings will then be multiplied by a weight factor given to each criteria category. Once each category total has been calculated, they will be added together for a final total score. This process will repeat itself for each evaluated proposal. The following are explanations of the numeric ratings that will be used to evaluate the technical proposals:

1. **10-9:** Information submitted demonstrates offeror's potential to significantly exceed performance or capability standards. The offeror has clearly demonstrated an understanding of all aspects of the requirements to the extent that timely and highest quality performance is anticipated. Have exceptional strengths that will significantly benefit the Government. The offeror's qualifications exceed the fullest expectations of the Government. The offeror has convincingly demonstrated that the RFP requirements have been analyzed, evaluated, and synthesized into approaches, plans, and techniques that, when implemented, should result in outstanding, effective, efficient, and economical performance under the contract. Significantly exceeds most or all solicitation requirements. **Very high probability of success.**

2. **8-7:** Information submitted demonstrates offeror's potential to exceed performance or capability standards. Have one or more strengths that will benefit the Government. The areas in which the offeror exceeds the requirements are anticipated to result in a high level of efficiency or productivity or quality. The offeror's qualifications meet and slightly exceed requirements. The submittal contains excellent features that will likely produce results very beneficial to the Government. Fully meets all RFP requirements and significantly exceed many of the RFP requirements. Disadvantages are minimal. **High probability of success.**

3. **6-5:** Information submitted demonstrates offeror's potential to meet performance or capability standards. Acceptable solution. Either meets all RFP requirements for the criterion (or sub-criteria) or contains weaknesses in some areas that are offset by strengths in other areas. This rating indicates that, in terms of the specific criterion (or sub-criteria), the offeror has a good probability of success, as there is sufficient confidence that a fully compliant level of performance will be achieved. The proposal demonstrates an adequate understanding of the scope and depth of the RFP requirements. No significant advantages or disadvantages. Equates to neutral. **Good probability of success.**

4. **4-3:** The submittal is not adequately responsive or does not address the specific criterion (or sub-criteria). The offeror's interpretation of the Government's requirements is so superficial, incomplete, vague, incompatible, incomprehensible, or incorrect as to be considered deficient. Proposal does not meet some of the minimum requirements. The assignment of a rating within the bounds of "Marginal" indicates that mandatory corrective action would be required to prevent significant deficiencies from affecting the overall project. The offeror's qualifications, plans or approach will likely result in questionable quality of performance, which represents a moderate level of risk to the Government. Low probability of success although the submittal has a reasonable chance of becoming at least acceptable. **Significant disadvantages.**

5. **2-1:** Fails to meet performance or capability standards. Unacceptable. Requirements can only be met with major changes to the submittal. There is no reasonable expectation that acceptable performance would be achieved. The proposal contains many deficiencies and/or gross omissions; fails to provide a reasonable, logical approach to fulfilling much of the Government's requirements; and/or fails to meet most or all of the minimum requirements. **Very significant disadvantage.**

b)3(b)3(b)3(

b)3(b)3(b)3(

b)3(b)3(b)3(

REQUEST FOR PROPOSAL - EVALUATION FORM
WOLVERINE PEER REVIEW

Date Evaluated: October 17, 2017	Evaluator: Jodi Bush

Firm Name: **AMEC**

Category	Rating: 1 (poor) - 10 (excellent)	Weight	Score
A. COST PROPOSAL • Cost Proposal (Contracting Officer will conduct the initial evaluation of cost submittals) Leave score blank until Contracting officer provides this information • Score will be based on whether the percentage of price submitted is above the lowest reasonablel price submitted.		**4.0**	
• **QUALIFICATIONS** 1. Each reviewer must have a Ph.D. or a Master's with significant experience in Wildlife Ecology, Ecology, or Wildlife Management; and 2. In combination, the expertise of the qualified reviewers shall include the following; however, each individual is not required to meet all qualifications: a. Experience or expertise with carnivore management, especially wolverines; b. Expert knowledge of wildlife biology, wildlife management, demographic management of mammals (especially mesocarnivores), genetics, population modeling and/or scientific literature on wolverines or other mustelids; c. Expert knowledge of the effects of climate change and climate change modeling, specifically in the Mountain West area of the United States, which includes the northern Rocky Mountains, the North Cascades, or the southern Rocky Mountains; d. Expert knowledge of genetics of metapopulations; e. Experience as a peer reviewer for scientific publications; f. Knowledge of wolverine management in Canada, Alaska, and/or Europe. • **In addition, the reviewers shall have no financial or other conflicts of interest with the outcome or implications**	**8**	**4.0**	**36**

B. PROJECT APPROACH (10) • Number of reviewers (3) • Assumptions (3) • Timeline (3) • Other TECHNICAL Considerations (1) -	**8**	**2.0**	**16**
	TOTAL SCORE **(**100 points possible**)**		

Continued on Page 2

Page 2 – Evaluation Form –Wolverine PEER

Comments – Cost Proposal:

___good_____

_____

_____

_____

_____

Comments –Approach_____

____concerned about timeline. Peer review would not be completed until Dec. 1. Maybe issue for completion of SSA on time. _

_____

_____

_____

Comments – Capabilities/ Past performance

____seems appropriate_____

_____

_____

Evaluation Standards

For purposes of this solicitation, numeric ratings of 1 through 10 (one being the lowest and 10 being the highest) will be used in conjunction with narratives to evaluate each of the evaluation criteria categories listed above. These ratings will then be multiplied by a weight factor given to each criteria category. Once each category total has been calculated, they will be added together for a final total score. This process will repeat itself for each evaluated proposal. The following are explanations of the numeric ratings that will be used to evaluate the technical proposals:

1. **10-9:** Information submitted demonstrates offeror's potential to significantly exceed performance or capability

standards. The offeror has clearly demonstrated an understanding of all aspects of the requirements to the extent that timely and highest quality performance is anticipated. Have exceptional strengths that will significantly benefit the Government. The offeror's qualifications exceed the fullest expectations of the Government. The offeror has convincingly demonstrated that the RFP requirements have been analyzed, evaluated, and synthesized into approaches, plans, and techniques that, when implemented, should result in outstanding, effective, efficient, and economical performance under the contract. Significantly exceeds most or all solicitation requirements. **Very high probability of success.**

2. **8-7:** Information submitted demonstrates offeror's potential to exceed performance or capability standards. Have one or more strengths that will benefit the Government. The areas in which the offeror exceeds the requirements are anticipated to result in a high level of efficiency or productivity or quality. The offeror's qualifications meet and slightly exceed requirements. The submittal contains excellent features that will likely produce results very beneficial to the Government. Fully meets all RFP requirements and significantly exceed many of the RFP requirements. Disadvantages are minimal. **High probability of success.**

3. **6-5:** Information submitted demonstrates offeror's potential to meet performance or capability standards. Acceptable solution. Either meets all RFP requirements for the criterion (or sub-criteria) or contains weaknesses in some areas that are offset by strengths in other areas. This rating indicates that, in terms of the specific criterion (or sub-criteria), the offeror has a good probability of success, as there is sufficient confidence that a fully compliant level of performance will be achieved. The proposal demonstrates an adequate understanding of the scope and depth of the RFP requirements. No significant advantages or disadvantages. Equates to neutral. **Good probability of success.**

4. **4-3:** The submittal is not adequately responsive or does not address the specific criterion (or sub-criteria). The offeror's interpretation of the Government's requirements is so superficial, incomplete, vague, incompatible, incomprehensible, or incorrect as to be considered deficient. Proposal does not meet some of the minimum requirements. The assignment of a rating within the bounds of "Marginal" indicates that mandatory corrective action would be required to prevent significant deficiencies from affecting the overall project. The offeror's qualifications, plans or approach will likely result in questionable quality of performance, which represents a moderate level of risk to the Government. Low probability of success although the submittal has a reasonable chance of becoming at least acceptable. **Significant disadvantages.**

5. **2-1:** Fails to meet performance or capability standards. Unacceptable. Requirements can only be met with major changes to the submittal. There is no reasonable expectation that acceptable performance would be achieved. The proposal contains many deficiencies and/or gross omissions; fails to provide a reasonable, logical approach to fulfilling much of the Government's requirements; and/or fails to meet most or all of the minimum requirements. **Very significant disadvantage.**

b)3(b)3(b)3(

b)3(b)3(b)3(

b)3(b)3(b)3(

From: Backsen, Sarah
To: Bush, Jodi
Cc: Gess, Steve; Justin Shoemaker
Subject: Re: Wolverine peer review proposal reviews
Date: Wednesday, October 18, 2017 10:12:46 AM
Attachments: Score Shee Wolverine - AMEC.doc
(b)(3)(b)(3)(b)(3)(b)(3)

Well, sounds like you may not need these anymore, haha. But for what it's worth, here are my score sheets (sounds like my scores were relatively consistent with Jodi and Justin's anyway).

Thanks,

Sarah Backsen
Classification Biologist
U.S. Fish and Wildlife Service, Region 6
134 Union Blvd., Suite 670
Lakewood, Colorado 80228
303-236-4388
sarah_backsen@fws.gov

On Wed, Oct 18, 2017 at 9:50 AM, Bush, Jodi <jodi_bush@fws.gov> wrote:

> Nope. that works for me. Thanks. JB
>
> Jodi L. Bush
> Office Supervisor
> Montana State Ecological Services Office
> 585 Shepard Way, Suite 1
> Helena, MT 59601
> (406) 449-5225, ext.205
>
> On Wed, Oct 18, 2017 at 9:49 AM, Gess, Steve <steve_gess@fws.gov> wrote:
>
> > Jodi, It appears that AMEC was rated to be be above technically acceptable and they are the lowest prices at $27,829.09 as compared to (b)(3)(b)(3)(b)(3)(b)(3)(b)(3)(b)(3) for scoring purposes on cost AMEC scored 40 points and (b)(3)(b)(3) So when you add those points to each of your scores its a no brainer that AMEC is the BEST Value---I will contact AMEC-Dawn Johnson and ask for a revised timeline based on issuing the TASK order no later than Monday--October 23rd.. Any thoughts--before I contact AMEC.?
> >
> > Steven C. Gess, CPPO
> > Contracting Officer
> > US Fish & Wildlife- Region 6
> > 303-236-4334
> >
> > On Wed, Oct 18, 2017 at 9:10 AM, Bush, Jodi <jodi_bush@fws.gov> wrote:
> >
> > > Steve. We are still waiting for review from third person (sarah backsen). She will send hers to you directly - later this morning.
> > >
> > > Some backstory for my and Justin's scores.
> > >
> > > (b)(3)

(b)(3)

We are concerned with both consultants timelines and are hoping if we select one sooner, we can move up the date that we get reviews back.

(b)(3) I think thats why thier costs are so much higher.

(b)(3) I'm not sure it matters but I'm not sure what the contract requires.

Let me know if you have questions. JB

Jodi L. Bush
Office Supervisor
Montana State Ecological Services Office
585 Shepard Way, Suite 1
Helena, MT 59601
(406) 449-5225, ext.205

---------- Forwarded message ----------
From: **Shoemaker, Justin** <justin_shoemaker@fws.gov>
Date: Tue, Oct 17, 2017 at 2:48 PM
Subject: Wolverine peer review proposal reviews
To: Jodi Bush <jodi_bush@fws.gov>

Mine are attached.

Sarah will have it done by tomorrow am at the latest.

Justin Shoemaker
Classification and Recovery Biologist
U.S. Fish and Wildlife Service, Region 6
Phone: 309-757-5800 x214
Email: justin_shoemaker@fws.gov

REQUEST FOR PROPOSAL - EVALUATION FORM
WOLVERINE PEER REVIEW

Date Evaluated:10/18/2017	Evaluator: Sarah Backsen

Firm Name:
Amec Foster Wheeler

Category	Rating: 1 (poor) - 10 (excellent)	Weight	Score
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B. PROJECT APPROACH • Number of reviewers • Assumptions • Timeline • Other TECHNICAL Considerations -	**8**	**2.0**	**16**
	TOTAL SCORE **(**100 points possible**)**		

Continued on Page 2

Page 2 – Evaluation Form –Wolverine PEER

Comments – Cost Proposal:

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Comments –Approach____Timeline and process seem relatively efficient and simple.

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Comments – Capabilities/ Past performance

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_____

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b)3(b)3(b)3(

b)3(b)3(b)3(

b)3(b)3(b)3(

From: Steve Gess
To: Sarah Backsen; Jodi Bush
Cc: Justin Shoemaker
Subject: RE: Wolverine peer review proposal reviews
Date: Wednesday, October 18, 2017 1:40:39 PM
Attachments: Eval Matrix WOLVERINE PEERs.xls

Here are the results of the evaluations-- Being the prices were $17,331.00 apart—it was an easy matrix—I plan to award to AMEC tomorrow—I am waiting for AMEC to submit a revised timeline showing the start date of OCT 23..

From: Backsen, Sarah [mailto:sarah_backsen@fws.gov]
Sent: Wednesday, October 18, 2017 10:13 AM
To: Bush, Jodi
Cc: Gess, Steve; Justin Shoemaker
Subject: Re: Wolverine peer review proposal reviews

Well, sounds like you may not need these anymore, haha. But for what it's worth, here are my score sheets (sounds like my scores were relatively consistent with Jodi and Justin's anyway).

Thanks,

Sarah Backsen
Classification Biologist
U.S. Fish and Wildlife Service, Region 6
134 Union Blvd., Suite 670
Lakewood, Colorado 80228
303-236-4388
sarah_backsen@fws.gov

On Wed, Oct 18, 2017 at 9:50 AM, Bush, Jodi <jodi_bush@fws.gov> wrote:
Nope. that works for me. Thanks. JB

Jodi L. Bush
Office Supervisor
Montana State Ecological Services Office
585 Shepard Way, Suite 1
Helena, MT 59601
(406) 449-5225, ext.205

On Wed, Oct 18, 2017 at 9:49 AM, Gess, Steve <steve_gess@fws.gov> wrote:
Jodi, It appears that AMEC was rated to be be above technically acceptable and they are the lowest prices at $27,829.09 as compared to (b)(3)(b)(3)(b)(3)(b)(3)(b)(3)(b)(3) for scoring purposes on cost AMEC scored 40 points and (b)(3)(b)(3) So when you add those points to each of your scores its a no brainer that AMEC is the BEST Value---I will contact AMEC-Dawn Johnson and ask for a revised timeline based on issuing the TASK order no later than Monday--October 23rd.. Any thoughts--before I contact AMEC.?

Steven C. Gess, CPPO

Contracting Officer
US Fish & Wildlife- Region 6
303-236-4334

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Steve. We are still waiting for review from third person (sarah backsen). She will send hers to you directly - later this morning.

Some backstory for my and Justin's scores.

[redacted]

We are concerned with both consultants timelines and are hoping if we select one sooner, we can move up the date that we get reviews back.

[redacted] I think thats why thier costs are so much higher.

[redacted]. I'm not sure it matters but I'm not sure what the contract requires.

Let me know if you have questions. JB

Jodi L. Bush
Office Supervisor
Montana State Ecological Services Office
585 Shepard Way, Suite 1
Helena, MT 59601
(406) 449-5225, ext.205

---------- Forwarded message ----------
From: **Shoemaker, Justin** <justin_shoemaker@fws.gov>
Date: Tue, Oct 17, 2017 at 2:48 PM
Subject: Wolverine peer review proposal reviews
To: Jodi Bush <jodi_bush@fws.gov>

Mine are attached.

Sarah will have it done by tomorrow am at the latest.

Justin Shoemaker
Classification and Recovery Biologist
U.S. Fish and Wildlife Service, Region 6
Phone: 309-757-5800 x214
Email: justin_shoemaker@fws.gov

INITIAL PROPOSAL EVALUATION MATRIX FOR :

PO:

Description:
WOLVERINE PEER Review

Vendor
Cost Score/Rank
Tech Score/Rank
Total Proposal Score
Proposal Rank

Scores with Rank Order

Company	Bid Submission	JB	JS	SB	AVG	Total	Rank
AMEC	$ 27,829.00						
Cost Proposal Score Out Of:	40.00	40.00	40.00	40.00	40.00		1
Quals/Experience	4	32.00	32.00	32.00	32.00		1
Project appraoch	2	16.00	10.00	16.00	14.00		1
0							
Criteria #4							
Criteria #5							
Criteria #6							
Criteria #7							
Criteria #8							
Criteria #9							
Criteria #10							
TECH TOTAL SCORE		48.00	42.00	48.00	46.00		1
Total Score (Tech plus Cost)		88.00	82.00	88.00	86.00	258.00	
Proposal Rank		1.00	1.00	1.00	1.00		1

(b)(3)(b)(3)(b)(3)

From:	Johnson, Dawn
To:	Jodi Bush
Cc:	Steve Gess; Justin Shoemaker; betty_grizzle@fws.gov
Subject:	RE: AMEC -Request for Proposal, Reference Number 0092717001 for PEER Review of the Draft Species Status Assessment Report for the North American Wolverine
Date:	Wednesday, December 6, 2017 9:16:28 PM
Attachments:	AmecFW Letter Report - USFWS Wolverine Peer Review_12-6-2017.pdf Compiled_CVs.pdf Individual Review 4_Wolverine SSA_12-2017.pdf Individual Review 1_Wolverine SSA_12-2017.pdf Individual Review 2_Wolverine SSA_12-2017.pdf Individual Review 3_Wolverine SSA_12-2017.pdf

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All-

Here is the official submittal of all four reviews and compiled CVs. Let me know if you have any questions or need any clarifications.

Sincerely,

Dawn Johnson PhD
Senior Biologist
Amec Foster Wheeler Environment & Infrastructure, Inc.
Now owned by Wood plc
Austin/Santa Barbara
D/M 805 252 4370
dawn.johnson@woodplc.com www.**woodplc.com**

From: Johnson, Dawn
Sent: Monday, December 04, 2017 12:23 PM
To: 'Jodi Bush' <jodi_bush@fws.gov>
Cc: Steve Gess <steve_gess@fws.gov>; Justin Shoemaker <justin_shoemaker@fws.gov>; betty_grizzle@fws.gov
Subject: RE: AMEC -Request for Proposal, Reference Number 0092717001 for PEER Review of the Draft Species Status Assessment Report for the North American Wolverine

All – Here are the first three reviews. I'll have the 4th one on Wednesday and will submit the complete package with CVs and cover letter and all 4 reviews then.

Sincerely,

Dawn Johnson PhD
Senior Biologist
Amec Foster Wheeler Environment & Infrastructure, Inc.
Now owned by Wood plc
Austin/Santa Barbara
D/M 805 252 4370
dawn.johnson@woodplc.com www.**woodplc.com**

From: Jodi Bush [mailto:jodi_bush@fws.gov]
Sent: Thursday, November 30, 2017 3:03 PM
To: Johnson, Dawn <dawn.johnson@woodplc.com>
Cc: Steve Gess <steve_gess@fws.gov>; Justin Shoemaker <justin_shoemaker@fws.gov>; betty_grizzle@fws.gov
Subject: Re: AMEC -Request for Proposal, Reference Number 0092717001 for PEER Review of the Draft Species Status Assessment Report for the North American Wolverine

Ok. Thanks. JB

Sent from my iPhone

On Nov 30, 2017, at 12:55 PM, Johnson, Dawn <dawn.johnson@woodplc.com> wrote:

> Jodi-
>
> I have one review back and the 2nd one is almost done. Unfortunately, 2 of the 4 reviewers have had major medical issues the last month. I'll have the 3rd review on Monday and the 4th review Wednesday at the latest. How about I send you the 3 finished ones on Monday and send along the 4th once I have it.
>
> Sincerely,
>
> **Dawn Johnson PhD**
> Senior Biologist
> Amec Foster Wheeler Environment & Infrastructure, Inc.
> ***Now owned by Wood plc***
> Austin/Santa Barbara
> D/M 805 252 4370
> dawn.johnson@woodplc.com www.**woodplc.com**

> **From:** Bush, Jodi [mailto:jodi_bush@fws.gov]
> **Sent:** Tuesday, October 24, 2017 5:25 PM
> **To:** Johnson, Dawn <dawn.johnson@woodplc.com>
> **Cc:** Steve Gess <steve_gess@fws.gov>; Morehouse, Kari <kari.morehouse@woodplc.com>; Justin Shoemaker <justin_shoemaker@fws.gov>
> **Subject:** Re: AMEC -Request for Proposal, Reference Number 0092717001 for PEER Review of the Draft Species Status Assessment Report for the North American Wolverine
>
> We need to proceed asap. We will ask that you send us the reviews as you get

them please so we can start our work. Thanks. JB

Jodi L. Bush
Office Supervisor
Montana State Ecological Services Office
585 Shepard Way, Suite 1
Helena, MT 59601
(406) 449-5225, ext.205

On Mon, Oct 23, 2017 at 5:43 PM, Johnson, Dawn <dawn.johnson@woodplc.com> wrote:

> Two have indicated they need until 1 December.
>
> **Dawn Johnson PhD**
> Senior Biologist
> Amec Foster Wheeler
> Environment & Infrastructure Americas
>
> D 805-252-4370
>
> -------- Original message --------
> From: "Bush, Jodi" <jodi_bush@fws.gov>
> Date: 10/23/2017 17:13 (GMT-06:00)
> To: "Johnson, Dawn" <dawn.johnson@woodplc.com>
> Cc: Steve Gess <steve_gess@fws.gov>, "Morehouse, Kari" <kari.morehouse@woodplc.com>
> Subject: Re: AMEC -Request for Proposal, Reference Number 0092717001 for PEER Review of the Draft Species Status Assessment Report for the North American Wolverine
>
> Dawn. Have you heard anything? We need to get moving on this review. JB
>
> Jodi L. Bush
> Office Supervisor
> Montana State Ecological Services Office
> 585 Shepard Way, Suite 1
> Helena, MT 59601
> (406) 449-5225, ext.205
>
> On Fri, Oct 20, 2017 at 3:03 PM, Johnson, Dawn <dawn.johnson@woodplc.com> wrote:
>
> > Thank you! I'm still waiting on confirmation that all the reviewers can meet the Monday after Thanksgiving deadline.
> >
> > I am sure the reviewers will want access to digital copies of all the references cited like with previous reviews.

Sincerely,

Dawn Johnson PhD
Senior Biologist
Amec Foster Wheeler Environment & Infrastructure, Inc.
Now owned by Wood plc
Austin/Santa Barbara
D/M 805 252 4370
dawn.johnson@woodplc.com www.**woodplc.com**

From: Steve Gess [mailto:steve_gess@fws.gov]
Sent: Thursday, October 19, 2017 11:18 AM
To: Johnson, Dawn <dawn.johnson@woodplc.com>; Vu, Cuong <cuong.vu@woodplc.com>
Cc: Goldschmidt, Aaron P <aaron.goldschmidt@woodplc.com>; Morehouse, Kari <kari.morehouse@woodplc.com>; Jodi Bush <jodi_bush@fws.gov>
Subject: RE: AMEC -Request for Proposal, Reference Number 0092717001 for PEER Review of the Draft Species Status Assessment Report for the North American Wolverine

Dawn, Attached is the executed Task order for the Wolverine SSA PEER review as per your proposal. I will distribute the SSA sometime today when I receive it from Jodi Bush. Please coordinate all of your effort with Jodi bush and her team. This order authorizes you to proceed.

Thanks again.

Steven C. Gess, CPPO
Contracting Officer
US Fish & Wildlife Service
Region 6 Lakewood CO.
303-236-4334
Steve_gess@fws.gov

From: Johnson, Dawn [mailto:dawn.johnson@woodplc.com]
Sent: Wednesday, October 18, 2017 5:31 PM
To: Gess, Steve; Vu, Cuong
Cc: Goldschmidt, Aaron P; Johnson, Dawn; Morehouse, Kari; Jodi Bush

Subject: RE: AMEC -Request for Proposal, Reference Number 0092717001 for PEER Review of the Draft Species Status Assessment Report for the North American Wolverine

Steve-

Thank you! I apologize for not being able to secure a 5th reviewer, but glad it worked out. Here is revised schedule. There are two caveats – the 30 days for reviewers lands delivery right in Thanksgiving, so I moved to Monday after. And I need to check with the reviewers to make sure they can accommodate shifting up a week. I know one had concerns about anything in October or early November. So I provide this with a caveat about the reviewers' confirming it works for them.

Task	Calendar Days After Award (Previous Task)	Due Date (Assuming 23 October Award)
Task 1 (Provide Materials)	1 (-)	24 October
Task 2 (Peer Review)	35 (30 but Thanksgiving)	27 November
Task 3 (Provide Reviews)	38 (3)	30 November
Task 4 (Q&A Period)	48 (10)	11 December
Task 5 (Official Record)	49 (1)	12 December

From: Gess, Steve [mailto:steve_gess@fws.gov]
Sent: Wednesday, October 18, 2017 11:09 AM
To: Vu, Cuong <cuong.vu@woodplc.com>
Cc: Goldschmidt, Aaron P <aaron.goldschmidt@woodplc.com>; Johnson, Dawn <dawn.johnson@woodplc.com>; Morehouse, Kari <kari.morehouse@woodplc.com>; Jodi Bush <jodi_bush@fws.gov>
Subject: Re: AMEC -Request for Proposal, Reference Number 0092717001 for PEER Review of the Draft Species Status Assessment Report for the North American Wolverine

Dawn, Congratulations! AMEC's proposal in response to the RFP for WOLVERINE PEER review was evaluated to be the Best Value to receive the Task order in the amount of your proposal for $27,829.00 . I will prepare the task order in the next day or two but prior to doing so, I am requesting for you to revise your timeline using an OCTOBER 23,2017 start date. Please send me your revised timeline so I can incorporate it into the task order..
Again thanks for your excellent proposal. We look forward to working with you and AMEC on this very important PEER review..

Steven C. Gess, CPPO
Contracting Officer
US Fish & Wildlife- Region 6

303-236-4334

On Mon, Oct 16, 2017 at 1:41 PM, Vu, Cuong <cuong.vu@woodplc.com> wrote:

> Mr. Gess:
>
> Amec Foster Wheeler is pleased to submit its proposal in response to the subject RFP. Our apologies as we were only able to identify four peer reviewers for this requirement.
>
> Please let us know if is acceptable or if you require additional information. Thanks in advance for your consideration.
>
> Regards,
>
> **Cuong Vu**
> Government Contract Manager
> Office: +1 (610) 828-8100
> Direct: +1 (610) 877-6021
> **www.woodplc.com**
>
> ---
>
> **From:** Steve Gess [mailto:steve_gess@fws.gov]
> **Sent:** Wednesday, September 27, 2017 2:28 PM
> **To:** Johnson, Dawn <Dawn.Johnson@amecfw.com>
> **Cc:** Jodi Bush <jodi_bush@fws.gov>; Justin Shoemaker <justin_shoemaker@fws.gov>
> **Subject:** AMEC -Request for Proposal, Reference Number 0092717001 for PEER Review of the Draft Species Status Assessment Report for the North American Wolverine
>
> Dawn, Region 6 US FWS received permission to use the new Scientific Studies BPA,AMEC was awarded recently. As a result I am requesting a formal proposal to conduct a PEER review on the subject Daft Specifies status assessment for the North American Wolverine. The RFP and Statement of work are attached. Proposals are due October 16, 2017.This will be a competitive process.
>
> Please let me know if you have any questions.
>
> Steven C. Gess, CPPO
> Contracting Officer
> US Fish & Wildlife Service
> Region 6 Lakewood CO.
> 303-236-4334

Steve_gess@fws.gov

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December 6, 2017

Ms. Noreen Walsh
Regional Director
US Fish & Wildlife Service
Mountain-Prairie Region
134 Union Boulevard
Lakewood, CO 80228

SUBJECT: Project: Peer Review of the Scientific Findings in Species Status Assessment for the North American Wolverine (*Gulo gulo luscus*).

Dear Ms. Walsh,

In accordance with the Statement of Work dated September 21, 2017, Amec Foster Wheeler Environment & Infrastructure, Inc. (Amec Foster Wheeler) is pleased to submit the completed *Peer Review (without attribution) of the Scientific Findings in U.S. Fish and Wildlife Service's Species Status Assessment for the North American Wolverine (Gulo gulo luscus)*.

The draft Species Status Assessment was provided to four reviewers on October 24, 2017 and the associated literature cited was provided to the reviewers on October 27, 2017. Each reviewer independently evaluated the material and prepared their individual responses to the questions included in the Statement of Work. Each reviewer also provided a signed Conflict of Interest statement during the proposal phase. After receipt of each individual review, I assigned a random number to each review, proofread them, ensured all reviews were in the same format, and coordinated with the reviewer for any clarifications and approval of typographical edits. Individual reviews were received between November 30, 2017 and December 6, 2017.

The four reviewers, all of whom have experience with wolverines and/or similar mustelid species, included:

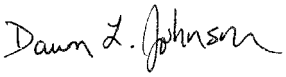
- James Beasley, PhD, affiliated with University of Georgia
- Mark Boyce, PhD, affiliated with University of Alberta
- Jennifer Frey, PhD, affiliated with New Mexico State University
- Daniel Harrison, PhD, affiliated with University of Maine

3755 Capital of Texas Hwy, Suite 375
Austin, TX 78704
512-795-0360
amecfw.com

Continued...

Enclosed with this letter are the four reviews with randomly assigned numbers, along with the resume for each reviewer. The official record will provided after completion of the question and answer (Q&A) period. Please contact Dawn Johnson at (805) 252-4370 if you have any questions or need clarification on the process or for any of the reviews.

Yours sincerely,



Dawn L. Johnson, PhD
Project Manager, Senior Biologist

Enclosures: Individual Reviews and Resumes

Cc: Jodi Bush, USFWS

Peer Review of the Scientific Findings in USFWS Species Status Assessment Evaluating the Status of the North American Wolverine (Gulo gulo luscus)

Reviewer 4
December 2017

Introductory Remarks

The Species Status Assessment (SSA) for the North American wolverine presents a complete, comprehensive, and well-organized and presented summary of the Species Description, Life History and Ecology, Biological Status-Current Condition, and Status – Future Conditions for the subspecies. The status and future temperature and snow conditions relative to climate change and winter snowpack change were particularly comprehensive, well thought out, and objectively presented. The road analyses and summary of current and ongoing research and wolverine monitoring were also up-to-date and provided useful insights. Further, the literature review was comprehensive and included relevant unpublished literature and personal communications. The authors should be commended for their completeness, well organized, and generally (with exceptions noted in subsequent sections) unbiased and scientifically based presentation of available information influencing the current and future status of the subspecies in the western U.S., central and western Canada, and Alaska.

That said, there are areas where the SSA has oversights or omissions (e.g., cumulative impacts of changing snow conditions); has not adequately identified the strength or limitations of available data (e.g., assumptions that reported road kills and incidental reports of trapping or illegal shooting of wolverines are complete and insignificant); where assumptions and methods in the report were not clearly and logically stated (e.g., the consideration of currently unoccupied but historically occupied habitat in California and Colorado, but omission of habitat in Minnesota, Wisconsin, Michigan, and Maine); where there seem to be demonstrable error in fact or interpretation (e.g., that wolverines can quickly change their pelage to respond to increasingly variable temperatures and that increasing temperatures during winter or summer would not stress wolverines); where uncertainty (e.g., uncertainty regarding viability of subpopulations important to persistence of the metapopulation, the role of increasing climate **variability**, and the role of human-induced mortalities on viability of small subpopulations of wolverines) has not been appropriately characterized; and where the SSA does not adequately address what the species needs to maintain redundancy and representation (e.g., are we considering the entire subpopulation or only currently occupied, high elevation habitats in the western mountainous U.S.?). Comments related to those primary issues are presented in the following section of this review.

Available Data:

1. Please identify any oversights or omissions of data or information, and their relevance to the assessment. Are there others sources of information or studies that were not included that are relevant to assessing the viability of this species and not repetitive of other information or studies already included? What are they and how are they relevant?

There is a general omission of data and discussion regarding the importance of unoccupied but potentially suitable habitats in California and Colorado, as well as virtually no discussion of reasons for extirpation in the Midwestern and extreme Northeastern U.S. The report exhibits bias towards well-performing populations in Canada and the U.S., as mentioned above, but seems to give little consideration to habitat identified by the Inman model as suitable and largely unoccupied in the western U.S. Further, we know that remnant populations of wide ranging and uncommon species do not adequately define the range of suitable habitats where the species may occur (i.e., underestimates the benchmark for species representation). For example, the Inman model is largely elevation-based, despite that the subspecies occupies lower elevation boreal forests, taiga, and tundra throughout its currently occupied range in Canada and Alaska. Further the species was extirpated from large areas of southern Ontario, virtually all

of Quebec, and Labrador where elevation was not a detriment to human exploitation. How does the extirpated status in those regions affect current representation within potential suitable habitat in other regions of the U.S.? Is an elevation-based model really supported by the available data for the entire subspecies or is elevation merely a surrogate that explains where remnant population of wolverines persisted in mountainous regions of the western U.S. following a period of intense human exploitation? Elevation could also be correlated with snow and temperature limits for a species at the southern limit of its geographic range (as suggested by negative relationship between elevation at wolverine occurrences and latitude).

2. Provide advice on the overall strengths and limitations of the scientific data used in the document. Is the information presented in the SSA report explicit about assumptions and limitations of, and concerns regarding, the data, and are these appropriately qualified or explained? Are there concerns that the Service did not identify, and if so, how relevant are these concerns to the assessment of the North American wolverine? Are there any inconsistencies in how the data are presented or assessed?

2A) The general assumption that 100% of incidental harvests of wolverines are reported and, as such, shootings and incidental trapping are insignificant risks in the western U.S. seems unsubstantiated. Given the small population size, it appears that additional population viability modeling may be warranted to evaluate potential cumulative risks of incidental trapping (assuming sensitivity of population using available information and a range of assumed reporting rates), road kill (assuming a range of road mortality detection probabilities), and legal and illegal shooting (much of this is likely unreported) on the overall population (given a small effective population size), as well as the viability of small sub-populations.

2B) Although metapopulation processes are assumed in the SSA, the role and risks to subpopulations, as well as the significance to the larger metapopulation of largely unoccupied and isolated habitats in Colorado, California, and southeastern Wyoming are not addressed adequately. There seems to be a general assumption that because the species is mobile, and because individual animals have dispersed to Colorado and California, that the metapopulation is healthy and that the structure and population viability of the metapopulation is at low risk. Single animals do not represent a population, so those areas are effectively unoccupied from the standpoint of representation, resilience, and redundancy.

Analysis of Available Data:

3. Have the assumptions and methods used in the SSA report been clearly and logically stated in light of the best available information? If not, please identify the specific assumptions and methods that are unclear or illogical.

Methods used in the report are clearly and logically stated. Assumptions used to bridge from data presented or cited to conclusions regarding threats, particularly regarding the physical, physiological, and behavioral adaptations of wolverines in response to climate change are unclear. Assumptions regarding the conclusion that there is a lack of threat from incidental trapping, road kills, and legal and illegal shooting on the small subpopulations within the assumed metapopulation are unclear and inadequately documented.

4. Are there demonstrable errors of fact or interpretation? Have the authors of the SSA report provided reasonable and scientifically sound interpretations and syntheses from the scientific information presented in the report? Are there instances in the SSA report where a different but equally reasonable and sound interpretation might be reached that differs from that provided by the Service? If any instances are found where this is the case, please provide the specifics regarding those particular concerns.

4A) The discussion of thermoneutrality in wolverines on pages 10 and 11 of the draft SSA is incomplete and presents an inaccurate picture of thermal stresses facing wolverines in the face of climate change. The assessment in the SSA is based primarily on wide ranges of **Lower** Critical Temperatures of wolverines during winter while in winter pelage compared to summer while in summer pelage. The authors provide weak support for the notion that the **Upper** Critical Temperature for wolverines will not be exceeded in summer because they are "good swimmers", while ignoring uncertainty and the potential effect that increased temperature could have on a wolverine's ability to be metabolically active in habitats (e.g., open area with sun exposure) with optimal foraging opportunities during summer. Particularly, the authors have ignored a significant body of literature suggesting that a combination of temperature and reflected solar radiation off snow can cause well insulated, northern mammals to exceed their **Upper** Critical Temperatures during relatively warm days (but well below 0^{o}C) during winter when solar reflection off snow causes them to retreat to shaded habitats. As such, wolverines may not be able to remain metabolically active in optimal foraging habitats on below freezing but sunny days during winter when their dark coat is absorbing reflected solar radiation and their pelage is thick. The notion by the authors that wolverines have "rapid and seasonal adjustments of fur insulation (page 11, paragraph 6)", despite only 1-2 seasonal molts (page 12, paragraph 2), is misleading and does not consider how increased temperatures during the >6 months when wolverines are in winter coat, as well as how increased variability in winter temperatures (i.e., cold periods requiring dense insulation intermingled with periods of high heat stresses) could affect the ability of wolverines to forage optimally and to reduce energy expenditure for cooling. Further the physiologic ability and costs to wolverines to quickly dissipate heat via energetically costly mechanisms of sweating and panting while in winter pelage has not been addressed.

A relevant example here was published by Parker and Gillingham (1990). They reported that the **Lower** Critical Temperature for mule deer in winter pelage was -19 degrees C (i.e., they are not as well insulated as wolverines). The drawback of that adaption to cold was that deer could exceed their **Upper** Critical Temperature at -25 degrees C with high solar radiation, reflective snow cover, and no wind. This shows how better insulated and cold adapted wolverines might be heat stressed with increased temperature variability and increased mean temperatures when in winter pelage. Thus, the premise of the conclusion of the SSA that wolverines have wide heat tolerances and will compensate behaviorally and physiologically to climate change effects seems without a sound scientific foundation and may be based on flawed logic.

4B) The discussion of "Snow Cover in an Ecological Context", as summarized in Box 1 (page 29) is incomplete and is based solely on relatively old work by Formozov (1961, 1963). Issues related to changes in snow density (affects thermal environment for hibernating marmots and squirrels) and snow wetness (i.e., increased thermal heat loss to water evaporation and due to high specific heat of cold water), and changing snow depth, as well as these effects on snow interception in forested habitats associated with increased firnification (changing density and hardness due to wind, solar radiation, and freeze-thaw) have not been adequately addressed. The discussion of snow seems focused on discounting previously published work (see pages 30- 32), which suggested that den locations were correlated with late spring snow persistence. The SSA does not adequately consider other potential effects of climate warming on snow. Uncertainty related to effects of within-season variability in temperature, sun, and snow characteristics on wolverine foraging behavior, habitat selection, and spatial use is not adequately addressed. Also, effects of changing snow depth, persistence, and characteristics on competition (other

carnivores) and overwinter survival of hibernating (e.g., ground squirrels and marmots) rodents has not been considered.

4C) The SSA goes to great lengths to discount the correlative relationships identified by Copeland et al. (2010) of persistent spring snow with den site locations, yet puts strong support behind correlative evidence from Webb et al. (2016) indicating that harvests of female wolverines (which likely represented many non-reproducing individuals) were not limited to areas of persistent snow. In fact, harvests by human may be biased to lower elevation areas with less snow. The SSA also does not include a recently published paper suggesting that patterns of occupancy of wolverines across a large region of Alberta were positively correlated with persistent spring snow (Heim et al. 2017). Further the authors of the SSA acknowledge the use of structures such as rocks and root masses for denning, as well as the altricial nature of wolverine kits at birth, but fail to acknowledge their earlier statements that temperatures of structures under snow would be 15^{o}C warmer than without snow when kits are born?

I agree that there is great uncertainty regarding the direct effects of snow cover (e.g., versus correlative relationships with elevation or hibernating rodent prey) on wolverine reproductive success and there are certainly examples where wolverines occur and sometimes den in areas without persistent spring snow; however, it appears that the authors have made an inference that climate change is insignificant to wolverines and are going to great lengths to dismiss inconvenient truths. The wording of the text and the use of bold emphasis by authors on pages 30-32 exemplify my concerns with the objectivity of the authors regarding the importance of persistent snow. Alternative explanations (with data) to the observed and published relationships of wolverines to snow and elevation are needed if that relationship is to be discounted. Similar uncertainty regarding the wolverine's ability to deal energetically with elevated winter temperatures and an assumption that incidental trapping is inconsequential seem to be accepted by the authors as they seem to fall in line with the their notion that the subspecies is not at risk. Thus, greater attention to equal and objective treatment of data uncertainty is warranted across all aspects of the report.

It is confusing that, after dismissing the relationships of persistent snow and reproduction, the authors go to great lengths to describe outcomes from a study funded by FWS that demonstrates significant areas of persistent snow in Glacier and Rocky Mountain Parks under potential future climate scenarios. These are encouraging and insightful results, but still seem to imply a lack of objectivity and an apparent effort to dismiss adverse climate effects. The fact that both parks have exceptionally high elevation (and presumably more persistent snow) in comparison to adjacent landscapes where wolverines are present leads to uncertainty regarding the generality of those findings, and those uncertainties seem to have been largely overlooked.

My concerns identified above are exemplified on page v of the Executive Summary. Which states (3: Resiliency: line 80-10) **"… based on available information we have no indication that this species is unable to adapt or adjust to changing (climate) conditions."** This seems to ignore the fact that only 6% of occupied geographic range is south of the U.S. Canada border, that snow (+) and temperature (-) are strongly correlated with elevation, and that elevation of wolverine occurrences increases with decreasing latitude. Further, the climate evaluations all predict increasing temperatures and decreasing snow, yet effects on wolverines are concluded to be insignificant? There is contrary evidence and uncertainty that needs to be acknowledged here.

5. Provide feedback on the inclusion and portrayal of uncertainty in the SSA report. Have the scientific uncertainties presented and the analyses conducted been clearly identified and has the degree of uncertainty been appropriately characterized? If not, please identify any specific concerns.

Refer to comments 2A, 3 and 4C. First, there is inadequate portrayal of uncertainty regarding effects of anthropogenic-related mortality on the metapopulation and subpopulation persistence. Secondly, there is inadequate portrayal of uncertainty that wolverines can respond behaviorally and physiologically to climate stressors and that there is little risk to wolverine persistence as a result of anticipated (and well documented in the SSA) changes in snow persistence and climate. Third, equal treatment of data uncertainty among studies regarding importance of snow persistence is warranted. Finally, further acknowledgment of uncertainty of the conclusion that there will be sufficient persistent snow cover throughout the range of wolverines based on FWS modeling in locally high-elevation national parks is needed.

6. Does the SSA report adequately consider what the species needs to maintain viability in terms of resiliency, redundancy, and representation?

6A) Is future population expansion into Colorado and California required to maintain adequate redundancy? If so, then those populations seem at high risk of extinction. If not, then why is the habitat in those areas included in the report given that it is largely unoccupied except by a couple of aberrant individuals? How are these areas important (or not) to maintain resiliency, redundancy, and representation?

6B) The SSA focuses on the western and northwestern U.S. and seems to ignore the language of the ESA relating to representation of a species in a significant portion of its geographic range. The report is unclear relative to the importance (vis a vis representation and redundancy) of wolverines in California, Colorado, the upper Midwestern U.S., and the extreme Northeastern U.S. (e.g., Maine). On page 15 (paragraph 3) the authors seem to dismiss the Midwestern U.S. as potential wolverine habitat based on a report that wolverines were historically present but "uncommon" in Wisconsin, despite that the same report states that several authenticated records of wolverines were reported along the Wisconsin-Minnesota border. Repeatedly, the SSA establishes that wolverines are uncommon within their currently occupied range and considers potential range in California and Colorado based on occurrence of a single individual in each state? Occurrence of a single individual in northern Michigan is dismissed, why? On page 15 (paragraph 1), the authors indicate that "Our intent…..was to present an overall geographical depiction of the wolverine's estimated range for only the west-northwestern United States…". How was this geographic emphasis decided given that the SSA is for the entire geographic range of the sub-species? How does this decision affect inferences regarding redundancy and representation?

General Comments

The SSA characterizes the wolverine as a food and habitat generalist restricted to boreal forests, tundra, taiga, and high-elevation meadows and boulder/talus. The report also (incorrectly I think) characterizes the wolverine as a species able to tolerate wide temperature extremes (but see comment #4A) and variable snow conditions. Thus, the report does not adequately explain why we are at the current southern range limit (6% of occupied range in coterminous U.S.) or why the geographic range of genus *Gulo* in North America has not included the warmer mixed and deciduous forest regions (e.g., present Appalachian Mountains) currently or since at least the late Pleistocene, despite high food availability? A significant northward shift in the distribution of a highly insulated, climate-restricted, large footed, and snow adapted carnivore like wolverine is certainly plausible under the climate change scenarios so eloquently presented by the authors. That possibility and degree of uncertainty does not come across in the Executive Summary, supporting text, and is in direct contradiction to the conclusions (see page 95, paragraph 2) of the SSA.

Literature Cited

This list includes only the two published studies that were cited above and which were not included in the SSA.

Gillingham, M. P., and K. L. Parker. 1990. Estimates of critical thermal environments for mule deer. Journal of Range Management 43:73-81.

Heim, N., J. T. Fisher, A. Clevenger, J. Paczkowski, and J. Volpe. 2017. Cumulative effects of climate and landscape change drive spatial distribution of Rocky Mountain wolverine (Gulo gulo L.). Ecology and Evolution 7:8903-8914.

Peer Review of the Scientific Findings in USFWS Species Status Assessment Evaluating the Status of the North American Wolverine (Gulo gulo luscus)

Reviewer 1
December 2017

Introductory Remarks

Overall, the SSA report is well written, thorough, and does an excellent job of synthesizing the available information and literature currently in existence for wolverines in the U.S., as well as the rest of the species' range. Below I have provided a number of comments that I hope will aid the USFWS in finalizing this report.

Available Data:

1. Please identify any oversights or omissions of data or information, and their relevance to the assessment. Are there others sources of information or studies that were not included that are relevant to assessing the viability of this species and not repetitive of other information or studies already included? What are they and how are they relevant?

Overall the SSA report provides a comprehensive review and synthesis of the available information on the ecology, biology, and management of wolverines, both within the U.S. but also across the species' range. This includes both the primary literature as well as many sources located within the gray literature and personal communications with wolverine experts. I am not aware of, nor did I find, any published studies that were omitted from the SSA report that provide novel information critical to the assessment of the viability of this species that was not covered to some degree in other sources. However, there are a few additional studies (relatively new studies) relevant to the SSA report that provide additional depth to a few key focal areas of the report.

Specifically, Rauset et al. (2013) tracked Eurasian lynx and wolverines in Sweden that were fitted with GPS collars to elucidate habitat selection and niche partitioning. Results of this study suggest wolverines avoid areas with higher human disturbance. Also, wolverines exhibited much higher individual variation in home range compositions than lynx, ranging from low elevations with large portions of coniferous forests, to higher elevations with large portions of bare rock and glaciers. Wolverines selected for habitats within their home range relative to their availability (i.e. no strong selection). In contrast, lynx had a stronger selection of particular habitats within their home range. Collectively, these data provide further support (with GPS data for which there are limited data available for wolverines) that wolverines are highly adaptable generalists.

Similarly, despite limitations to the study, given the paucity of data available on summer food items used by wolverines, inclusion of the results of Inman et al. (2015) would strengthen the food habits section of this SSA report, especially given that the data were collected in the U.S. Lastly, Ellis et al. (2013) used a simulation-based study to evaluate various sampling protocols to detect a decline in abundance of wolverines in the U.S. These simulation studies suggest most sampling schemes in the U.S. would only able to detect large declines in abundance (50% over 10 years) and small populations would require even more substantial changes to be able to detect a shift. While there are many limitations to this simulation study, the main point that monitoring changes in wolverine populations will require a large, and coordinated, effort is likely valid. Inclusion of this information/study is not essential to the report, but could aid in providing emphasis of the challenges and uncertainties associated with monitoring trends in wolverine populations.

2. Provide advice on the overall strengths and limitations of the scientific data used in the document. Is the information presented in the SSA report explicit about assumptions and limitations of, and concerns regarding, the data, and are these appropriately qualified or explained? Are there concerns that the Service did not identify, and if so, how relevant are these concerns to the assessment of the North American wolverine? Are there any inconsistencies in how the data are presented or assessed?

Overall, this SSA report draws upon a broad range of materials available pertaining to wolverines, including peer-reviewed papers, reports, expert opinions, and other credible sources. As mentioned throughout the report, wolverines are an inherently challenging species to study, and research on this species, particularly in the U.S., is limited at this point. Thus, there are many aspects of wolverine biology, ecology, and management that are understudied, or largely unknown. The authors of the SSA report have done an excellent job synthesizing the available knowledge on wolverines relevant to the topics covered in this report, as well as emphasizing areas where the data are limited. I did not find any inconsistencies in how the data are presented or assessed. Below I have emphasized a few key topics discussed in the report where wolverine ecology is well established, areas where there are current gaps in knowledge, and a few areas where additional clarification in the SSA report could be warranted.

In general, there are several aspects of wolverine ecology that are relatively established, all of which are well characterized in this report with appropriate references. In particular, the available data consistently indicate wolverines are generalists in many aspects of their life history and thus able to exploit a range of habitats and food resources. However, there is consistent agreement that wolverines prefer rugged (high elevations in the U.S.), remote habitats and are typically associated with snow cover persisting late into spring. As highlighted in this report and the available data, there is general agreement wolverines prefer areas of persistent snow into spring, although it appears persistent snow is most critical for wolverine denning associated with rearing young. It also is clear that in most cases wolverines generally avoid areas with potentially greater mortality risk, such as areas with increased activity of predators or human activity (often harvest related). There also is widespread agreement wolverines require large territories and exhibit intrasex territoriality. Wolverines have been reported consuming a wide range of food items and thus require access to a wide variety of seasonally variable food resources, including carrion as wolverines scavenge extensively, especially during winter. All of these aspects of wolverine ecology have been well described in this report, and the authors have appropriately referenced the available literature and current state of knowledge on these topics.

While the aforementioned aspects of wolverine ecology are well recognized, there are many aspects of their ecology (especially in the U.S.) where the data are more limited or non-existent. Furthermore, there are numerous studies that have documented disparate findings (e.g., attraction vs. avoidance of areas of wolf activity), demonstrating the plasticity of the species. For example, although there is general agreement that wolverines prefer areas of persistent snow into spring associated with denning, some natal dens have been reported in areas with less persistent snow cover as well as areas outside modeled projections of snow cover. Thus, it is currently unknown whether wolverines require snow dens for successful reproduction and population viability. Furthermore, snow through May 15th may not be obligatory in wolverines (as suggested by Copeland et al. 2010) as some dens in their study had snow through 15 May in as little as 1 in 7 years (Magoun et al. 2017). It should be noted though that success of litters associated with those dens is unknown. It also is unknown whether females could shift reproductive phenology (given that delayed implantation occurs with this species) in the face of warming climate conditions to alter the timing of birth to better suit earlier snow melt in the future. Unfortunately there are no studies to date that have focused on many of these topics, particularly whether wolverines require persistent snow at the den site and whether this is tied to successful reproduction. Thus, there is a clear need for more information on denning activity, conditions contributing to den abandonment, and whether den type or abiotic/biotic conditions influence any

aspect of reproduction or young survival. These critical data limitations are highlighted in the SSA report.

As discussed throughout the report, there also are critical data gaps for many other aspects of wolverine ecology, such as population demography, vital rates, spatial ecology, population genetics, etc. In particular, there is considerable uncertainty regarding any potential impacts of reduced genetic diversity on U.S. wolverine populations. Much discussion is devoted to these topics in the SSA report. However, as discussed in responses to other questions (see below), the report would benefit from additional statements in the **Biological Status** or **Status-Future Conditions** sections to highlight these current data limitations, particularly genetic diversity in the face of potentially reduced population connectivity resulting from climate change.

Although food availability during denning is critical to both females (due to high energy demands associated with lactation) and their offspring, availability of summer forage should not be overlooked and could be equally important (Inman et al. 2012). In general the importance of summer forage is largely understudied, and would benefit from further research. During summer, young are rapidly growing and need steady food intake. Summer forage also may be critical to improving female body condition heading into winter (i.e. reproduction), although this does not appear to be well studied. This is mentioned in the report (under *diet and feeding* and briefly in *demography*), but only briefly and thus could be further emphasized, particularly under the section on *demography* to expand the current discussion on this topic on page 36.

Page 59, section on predation: Although predation is reported in the literature for wolverines, I would agree with the assessment that the best available data suggest predation does not represent a significant stressor to wolverines at the population level. However, at the individual level there are several studies that speculate wolverines avoid areas of potential predation risk from wolves (e.g., Scrafford et al. 2017). In fact, this is often one of the arguments given for wolverines selecting rugged terrain at high elevations, although there are several other studies that suggest wolverines can be associated with wolves and other predators, presumably to scavenge carcasses of their kills. This paragraph would benefit from the acknowledgement that indirect effects of predators could impact wolverine behavior (i.e. predator avoidance through habitat selection), although this is something that is not fully understood in the literature and the data are somewhat contradictory, suggesting this behavior may be influenced by a multitude of factors.

On page 64 it is stated that “In summary, overutilization does not represent a stressor to the wolverine in the contiguous U.S. at the individual, population, or species level”. However, as stated on page 61, Krebs et al. (2004) suggested harvest of wolverines could represent additive mortality. Although there currently is no wolverine harvest in the U.S., if harvest is reinstated any such harvest could thus provide an additional stressor to an already reduced population. However, as stated in (50 CFR Part 17) such harvest would likely be minimal and thus have limited impact. This SSA report would benefit from similar language as provided in 50 CFR Part 17 to better clarify that any future harvest of wolverine in Montana is likely to have minimal impact on the metapopulation.

Page 72, final sentence of the summary on this page. While these adaptations undoubtedly do allow wolverines to adapt to warming temperatures, other sub-lethal effects (e.g., impacts to reproduction) are not acknowledged here, which are currently unknown. Similarly, the summary on page 73 discusses shifts in vegetation associated with climate change but does not mention corresponding shifts in prey availability in response to changing habitat. It is possible increasing temperatures may favor production of small mammals and other small prey. In contrast, warming temperatures could reduce winter kill of ungulates, which wolverines likely utilize as a source of winter food.

Analysis of Available Data:

3. Have the assumptions and methods used in the SSA report been clearly and logically stated in light of the best available information? If not, please identify the specific assumptions and methods that are unclear or illogical.

After review I found the assumptions and methods used in the SSA report to be clearly and logically stated in light of the best available information with a few minor exceptions. On page 34 the authors introduce an evaluation of snow cover at previously recorded den sites. It is not clear where these den data are derived, or what area of the species distribution they are derived from. Similarly, in Table 9 it appears these same den sites might be used (although this is unclear). However, here only 14 dens are presented so please clarify why the remaining dens were not used, despite there being more than 14 dens presented in Table 3 between 2003 and 2007. These same dens seem to be referenced again on page 54 in the paragraph starting with "We also reviewed den site locations…". It is unclear what dens were used in this analysis, as well as what analysis was performed to make the determination that "…wolverine dens are located in areas with minimal roads, including secondary roads…". Furthermore, results of this analysis may simply reflect a correlation, and not causation. In other words, the wolverines using the dens incorporated in this analysis may simply occupy areas away from roads, rather than those individuals actually exhibiting an avoidance behavior of roads in terms of den selection within their home range. If GPS data are available for these individuals such a determination could be made to better qualify this statement.

4. Are there demonstrable errors of fact or interpretation? Have the authors of the SSA report provided reasonable and scientifically sound interpretations and syntheses from the scientific information presented in the report? Are there instances in the SSA report where a different but equally reasonable and sound interpretation might be reached that differs from that provided by the Service? If any instances are found where this is the case, please provide the specifics regarding those particular concerns.

I did not observe any demonstrable errors of fact or interpretation of the available literature on wolverines in this SSA report. I also found the author's interpretations and syntheses of the available data to be reasonable and scientifically sound. During the initial proposed listing there was emphasis on habitat models generated by Copeland et al. (2010) and McKelvey et al. (2011). The strengths and limitations of the models produced in these studies have been reevaluated in this current SSA report. The current assessment appears to provide appropriate emphasis on both the strengths and limitations of these models, as well as the integration of new studies that are relevant to those prior determinations.

I did identify two aspects of wolverine populations covered in the SSA report that would benefit from additional detail or clarification to support the interpretations of the authors of the available data. In particular, the best available evidence indicates genetic diversity in U.S. wolverine populations is low and in the absence of augmentation (i.e. introductions) this is unlikely to change substantially in the foreseeable future. Furthermore, climate models suggest that while large tracts of wolverine habitat will remain in the future, populations will become increasingly isolated, and some populations could become isolated in terms of female immigration (Inman et al. 2013). Combined, this paints a rather troubling picture for wolverine populations in the future and suggests more active monitoring and management (including introductions) could be warranted. The best available data (which there are very few of) do not indicate wolverine populations are currently being negatively impacted (substantially) by the lack of genetic diversity present, and there is no evidence to suggest the U.S. population is declining. These topics are covered in the SSA report, but I was unable to find any discussion linking these issues under either the **Biological Status** section or the **Status-Future Conditions** section, where such discussion could be beneficial.

Additionally, under "other cumulative effects" on page 89 it is emphasized that a future warming climate could reduce season lengths for winter recreational activities, thus reducing the impact of this stressor. While likely true, it also is likely that given the future reduction in available snow pack there could be increasing overlap in areas used for winter recreation and wolverine activity. In particular, areas suitable for winter recreation could become more likely to encroach upon potential denning habitats if the availability of these habitats is reduced.

5. Provide feedback on the inclusion and portrayal of uncertainty in the SSA report. Have the scientific uncertainties presented and the analyses conducted been clearly identified and has the degree of uncertainty been appropriately characterized? If not, please identify any specific concerns.

Overall there are a considerable number of uncertainties regarding the ecology of wolverine populations, particularly in the U.S., and importantly how future changes in climate/land use could impact populations. However, over the last several years (particularly since the initial proposed listing of the species by the USFWS), there has been a growing number of studies published attempting to address many outstanding questions regarding key ecological and biological attributes of wolverines in the U.S. Despite these additional studies, there remains a paucity of data regarding many aspects of wolverine ecology needed to better understand their ability to maintain viable populations in the face of a multitude of current and future threats, including global climate change. Throughout the SSA report I found the authors very clear in their inclusion and portrayal of uncertainty, particularly where aspects of the ecology of the species are unknown or understudied, and additional data necessary to better inform management decisions for this species. However, below I will highlight one topic in particular that would benefit from further emphasis within the report.

Wolverines currently do not appear to be declining in the U.S. and no impacts of loss of genetic diversity or small population sizes appear to have been documented thus far. Therefore, while genetic integrity and maintenance of robust and healthy populations are a concern for this species over the next century, particularly given the rate of climate change, there currently are insufficient data to suggest an immediate threat to wolverine populations, which is the conclusion stated in the SSA report. It is clear, however, that wolverine populations in the U.S. lack genetic diversity and several potential areas of wolverine habitat are marginally connected to existing populations. Thus, in the absence of population augmentation (i.e. introductions) this species is vulnerable to any factors that negatively impact populations, or connectivity among populations, including the projected reduction in habitat due to global climate change. Given current climate projections, it is possible populations could become smaller and more isolated, even further reducing the amount of genetic exchange (McKelvey et al. 2011, Inman et al. 2013). This likely will be less of a factor in terms of male dispersal, but could isolate core areas of habitat from female dispersal (Inman et al. 2013), and increase inbreeding potential. Small isolated populations also would be subject to high levels of demographic stochasticity. Given that wolverine populations in the U.S. appear to have reduced genetic diversity, any further reduction in connectivity could further impact the genetic integrity of the population. These are plausible scenarios and warrant careful consideration and evaluation moving forward. The lack of genetic data available for wolverines is highlighted in the SSA report, as well as the uncertainties associated with future climate change effects on population connectivity, although it could be beneficial to present these uncertainties together under either the **Biological Status** or the **Status-Future Conditions** sections.

6. Does the SSA report adequately consider what the species needs to maintain viability in terms of resiliency, redundancy, and representation?

The SSA report specifies the physical and ecological needs of wolverines to be 1) large territories in remote landscapes at high elevations, 2) access to a variety of seasonally variable food items, and 3) physical/structural features associated with denning. The report characterizes these needs relative to resiliency, redundancy, and representation of the species well, although below I emphasize a few areas where additional detail or clarification would be beneficial to the report.

In terms of resiliency, there is considerable uncertainty pertaining to many aspects of wolverine demography and population dynamics that require further data. However, as specified in the report, there is no information to suggest populations of wolverines in the U.S. are currently declining. The statement on page 93 that "population size, growth rate, and current population trends are unknown for wolverines…" would benefit from some clarification. Throughout the report there is reference to a population estimate of 318 individuals published by Inman et al. (2013), as well as statements indicating wolverine populations are neither increasing nor decreasing. Thus, there are population-level data available, but perhaps not at the spatial or temporal resolution needed. This should be clarified. This section on page 93 also would benefit from the acknowledgment that genetic diversity is undoubtedly an important attribute to the resiliency of wolverine populations, but it is currently unknown whether there are any impacts of loss of genetic diversity on wolverine populations in the U.S. Nearly a page of text (page 94) is devoted to highlighting aspects of adaptive responses of American pika to climate change effects. This information is relevant and valuable, but are there similar data available for other mustelids, such as marten or fisher that could be highlighted (e.g., Baltensperger et al. 2017, Zielinski et al. 2017)? The report also highlights several additional factors related to resiliency including viable population size and effects of climate change on wolverines through alteration of reproductive success or distribution. Few data are available to inform these aspects of resiliency, which is emphasized in the report.

In terms of redundancy the report states that wolverines are spread across a range of locations and habitats and thus are buffered from catastrophic events; populations in the U.S. also are connected to populations in Canada. However, it should be noted that future model projections suggest that although extensive contiguous areas of wolverine habitat are likely to persist in the next several decades, the available habitat could become more isolated, potentially subjecting smaller populations to increased demographic and genetic stochasticity (McKelvey et al. 2011, Inman et al. 2013). Thus, while the overall metapopulation could be robust to stochastic events, individual pockets of habitats containing wolverines could become increasingly vulnerable in the future. Such effects could be mitigated through active management such as population augmentation (i.e. translocations).

General Comments

In the SSA report the Western States Wolverine Conservation Project is referenced, as is the consideration of population augmentation through translocations. This study undoubtedly will produce a wealth of critical data to inform future management of this species. However, in general there does not seem to be any discussion to indicate under what scenarios future evidence could support further consideration of the listing of this species. This may not be appropriate for this report. But, if appropriate, such information could be valuable in providing benchmarks for future management action. For example, should evidence arise to suggest 1) wolverine populations are suffering from reduced genetic diversity, 2) wolverine reproduction is directly linked to available snow cover and individuals routinely exhibit reproductive failure in the absence of areas with sustained snowpack, 3) the U.S. population begins declining or retracting in range, or 4) that populations in the future could become sufficiently isolated to prevent the maintenance of a natural metapopulation structure, such data could provide sufficient evidence that additional action is needed to protect this species.

Minor Editorial Comments

Page v: under redundancy it is stated that "The wolverine occurs across the contiguous United States". This should be reworded as the wolverine currently does not occur across the contiguous U.S. but rather is restricted to a handful of western states.

GLAC is not listed among the acronyms used.

Page 54: In the last paragraph it is stated that "…the **total** number of wolverine mortalities due to roads from 1972-2016…". This should be changed to …the **minimum** number of wolverine mortalities… as it cannot be certain that all road mortalities have been reported, which undoubtedly they haven't.

On page 91, add "in North America" after "The wolverine's current range".

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Peer Review of the Scientific Findings in USFWS Species Status Assessment Evaluating the Status of the North American Wolverine (Gulo gulo luscus)

Reviewer 2
December 2017

General Comments

1) Ambiguity about what is being evaluated -- A major shortcoming of this Species Status Assessment (SSA) is ambiguity about what exactly is being evaluated. In some instances the evaluation seemed geared towards the entire subspecies, while in many other cases it seemed geared towards the western contiguous USA. For instance, the title implies the whole species, while the description of the wolverine's physical and ecological needs clearly focuses on the western contiguous USA. This pervasive ambiguity led to confusion and misapplication of information. My hunch based on prior listing actions is that the ultimate goal of the assessment was to evaluate status of the wolverine in the western contiguous USA. If that is the case, then it renders many points made in the SSA irrelevant. For instance, lack of a declining trend in density of wolverines in Alaska is largely irrelevant to the status of the species in the western contiguous USA. This confusing and often irrelevant presentation of information significantly clouds the overall analysis. The SSA should carefully define its purpose and then present information that addresses that purpose. This does not mean that information from other regions cannot be included, but the document must make it clear how it is using such information and address any caveats that might exist to applying the information to a different region. For instance, patterns of prey selection in tundra regions may not directly apply to montane regions, although such information might support a premise that carrion can be an important food supply.

2) Scientific rigor -- The SSA is fraught with problems and does not meet the bar of acceptable scientific rigor. Although some pertinent facts are presented, the overall presentation lacks scientific rigor and many conclusions are based on conjecture rather than critical analysis of the facts and how they relate to status of threats to the wolverine. These major shortcomings render all conclusions suspect and give the appearance that the SSA was written from a foregone conclusion. Poor logic and writing style in some sections (e.g., Range and Habitat Use) contribute to the overall failure of the document to lead to convincing conclusion. Where facts are inconvenient to the overall conclusions that there are no significant impacts to redundancy, representation, or resiliency, the SSA seems to go to lengths to justify the conclusions by cherry-picking information that is only tangentially related. An example of this is the lengthy discussion about pikas (pp 93-94) that attempts to justify plasticity of wolverine behavior with respect to climate change. The ecological/evolutionary adaptations of pikas have no bearing on wolverines.

3) Den sites -- This pervasive tendency for cherry-picking information was also used to distort the relative weight of pieces of information in order to support the conclusions of the SSA. For instance, a review of the literature and the opinions of wolverine biologists nearly universally agree that wolverines are a snow-dependent species and snow cover is particularly important during the denning period. However, the SSA presents a confusing portrait of den site selection and misconstrues and often cherry-picks isolated observations to support a conclusion that snow is not needed for denning (e.g., pg. 35). Numerous studies demonstrate that wolverine dens are nearly always in areas that retain snow into the spring. However, the physical features of dens vary. In some cases, where conditions allow, dens are in tunnels dug into deep snow banks. In other cases dens are located in boulders, tree roots, or other physical structures, but within the snow matrix. These two types of dens are not at odds with each other. Wolverines do not den or occur in regions where snowfall does not occur. Use and description of the non-snow physical features of den sites does not detract from the importance of the snow itself, which provides insulation, preservation of carrion, and may be indicative of other important factors such as prey availability (e.g., survival of small mammal prey is benefitted by snow cover) or occurrence of competitors. The SSA distorted information

about dens leads to a conclusion that snow is not important for wolverine denning (e.g., pg 30). For instance, the SSA referenced a den reported by Pulliainen 1968, which the SSA described as "at the base of a tree and not covered by snow" (pg. 30). However, Pulliainen 1968:340 actually described this den:

> "*Den No 25.* I. 1950. Savukoski, Naltiotunturi. One unsexed blind cub was found at the butt of a spruce in a spruce peat-bog (about 3 km from the nearest fell). There was no snow at the butt of the tree. The cub was covered by spruce brush. The lowest spruce twigs were covered with snow."

Thus, this den site was covered by snow in the overhanging branches of the tree. The SSA also cited an unpublished dissertation (Makkonen 2015) apparently as evidence that wolverine dens are not associated with snow. However, the SSA seems to have misconstrued information in Makkonen (2015). That study did not measure the amount of snow present at den sites. Rather, habitat characteristics of the dens were measured after the denning event, sometime many years after. Makkonen (2015) simply found that most wolverine dens in central Sweden had physical structure (e.g, such as bounders and trees) that would protect the den from weather if snow was not present. No data were presented on actual presence or absence of snow.

The SSA misconstrues the findings of Copeland et al (2010) and seems to use this in part as a basis for concluding that wolverines use and den in areas without snow cover. The goal of Copeland et al (2010) was to test the hypothesis that the geographic range (i.e., Johnson's first order selection) is limited by areas with persistent spring snow and the wolverine's upper thermoneutral zone. They did this by creating maps of the distribution of spring snow cover and average maximum August temperatures, which were compared with a map of the current distribution of wolverines and den/telemetry locations. Results strongly supported the broad scale range-wide association of wolverines with areas with spring snow. This is appropriately interpreted that at the range scale, wolverines select for areas with spring snow. That does not mean that every den ever used by wolverines is in a region with persistent snow. On the other hand, any unusual exceptions also do not mean that wolverines are not a habitat specialist of cold climates with spring snow. The association of dens with snow within home range scale has also been well documented in the literature. Thus, the validation of the relationship between wolverine dens and snow at both local and range-wide scales is compelling evidence that spring snow is a key habitat requirement for wolverines. Thus, it is inexplicable that this variable was not included in the wolverine's key physical and ecological needs.

4) Historical and current distribution -- The SSA posits that wolverine populations are currently stable in the contiguous USA (or overall in North America) and that is used as basis for concluding that there is adequate resiliency (e.g., pg 93). This conclusion overlooks several important facts, namely, that the current distribution and abundance of wolverines in the contiguous USA is a fragment of its historical distribution and abundance. For instance, it is estimated that in the contiguous USA there are currently about 318 individual wolverines with an effective population size of < 60. Similarly, the SSA largely ignores and under represents the historical distribution of wolverines in the contiguous USA. There is no evaluation or assessment of the historical distribution in the central Great Plains, Great Lakes, Upper Midwest, or Northeast regions, even given recent observations of wolverines in some of those areas. Given that the SSA is ostensibly an assessment of the North American range of the wolverine, the explanation for why an assessment of these populations in not included is not satisfactory (e.g., pg 15). The current range of wolverine in the contiguous USA is much less than historically. A map of the historical range of the wolverine in the contiguous USA should be included. The conservation biology literature is replete with information about the risk of small population size to the viability of populations, and yet the SSA barely mentions current population size and makes no mention of vast literature on the profound impacts small population size can have on a species.

The map, "Current Range of North American Wolverine" (Figure 3), is a fantasy. This map grossly misrepresents the current range of the wolverine in North America and should not be used for any analyses. For instance, this map shows the Southern Rockies and Sierra Nevada as within the currently occupied range of the wolverine. Range maps depict the usual area occupied by a species. Recent isolated occurrences of wolverines in the Southern Rockies and Sierra Nevada have involved single male individuals. Further, the male that wandered to Colorado eventually wandered to another state where it was killed. There are no known wolverines occurring in Colorado or elsewhere in the Southern Rockies. Using the occurrence of these single animals within a state to shade in large swaths of country as "occupied" is dishonest. These records should more appropriately be considered extralimital occurrence points (mapped as dots) as they occur outside the known breeding range of the species (only specific areas confirmed as breeding range should be shaded). At the same time, the map ignores records of individual wolverines from other locations such as Michigan. This map is a clear example of how the SSA cherry-picks information and makes inappropriate conclusions based on fragmentary information.

Figure 2 is an appropriate representation of the *historical* range of the wolverine in the western contiguous USA, with the caveat that records were apparently not collated based on reliability of the reports and hence may include erroneous records (see Aubry et al. 2017 PLoS ONE 12(6): e0179152 for an example of how using unverified records can change interpretation of species distribution).

5) Roads -- The "assessment" of impacts of roads (pp 52-54) is an example of a section that provides facts, but where conclusions are then drawn based on cherry-picking or misinterpreting facts or without scientific evaluation of facts as they relate to status or stressors on wolverine populations. The SSA cited a large number of studies that clearly demonstrate that wolverines avoid roads (including for den site selection) and that roads can result in direct mortality. Habitat selection studies evaluate the use of habitats relative to their availability. If a habitat is used more frequently than expected based on availability, then that habitat is considered selected by the species. In contrast, if the habitat is used less than availability, then that habitat is considered avoided. May et al (2012) unambiguously demonstrated that wolverines avoid roads and other infrastructure for den site selection:

> "At both the home-range and landscape scales, dens were located far from public roads, and especially at the home-range scale they were also located away from private roads. This supports the hypothesis that wolverines at larger spatial scales may be affected by human activities (e.g. recreation, resource extraction) associated with private roads, which reach farther into wolverine habitat (May *et al*., 2006). Overall, dens were generally located far from infrastructures [7.5 km (0.5 SE) from public roads and 1.4 km (0.1 SE) from private roads and/or recreational cabins], which is difficult considering the almost complete lack of true wilderness areas in modern Norway (see Fig. 1)."

May et al (2012) went on to explain that selection for suitable elevation and topography were the most strongly selected features because wolverines require deep snow for denning. In other words, just because an area is far from a road does not necessarily mean it will have suitable denning habitat; the suitable den site characteristics must come first and within that wolverines select areas relatively far from roads. May concluded that once wolverines find areas that offer suitable den sites (e.g. near treeline), they tend to use the same areas for denning over multiple generations indicating that they are consistently preferred. Thus, the suitable den site characteristics are the overriding factor determining where wolverines den. But, infrastructure also influenced selection, including thresholds a distance below which wolverines did not use sites, although there was a wide range of distances observed. In contrast, the SSA essentially dismissed the findings of May et al (2012) by focusing on the "wide tolerance range" for distance to

infrastructure. In contrast, the fact remains that the May study demonstrated an avoidance of roads by wolverines (as have other studies).

The SSA also presented information on studies that reported observations of wolverines crossing roads. They conclude that these observations indicate that roads do not act as absolute barriers. This conclusion is odd as one would not expect roads to serve as absolute barriers to most species. That is only one of many possible impacts that roads could have on a species. The more important issues are disturbance, altered habitat, increased human access (e.g., Dawson et al (2010) reported hunter killed wolverines were in areas with high road density), increased access by other carnivores, and direct mortality. Those factors were not evaluated in the SSA

Finally, the SSA conducted a flawed evaluation of the impact of major roads on wolverines. This "evaluation" consisted of summing the kilometers of different types of road within modeled primary and female dispersal habitat in the western contiguous USA and within the flawed Current Range map. These "analyses" simply resulted in the reporting of the road density within various regions and by elevation. They conclude that of all roads, there is a low proportion of major highways. This fact is meaningless given that major highways are almost always more rare than smaller roads. Further, some studies have shown that while wolverines are more likely to be killed on larger roads, smaller roads are more numerous and are avoided by wolverines. Similarly, they concluded that there are fewer roads at higher elevations than at lower elevations. Again, this is an almost meaningless statistic. The SSA provides no meaningful scientific evaluation of how these roads might impact wolverine populations. For instance, what proportion of simulated home ranges would be impacted by roads? How does road density influence extent of modeled habitat? etc.

Available Data:

1. Please identify any oversights or omissions of data or information, and their relevance to the assessment. Are there others sources of information or studies that were not included that are relevant to assessing the viability of this species and not repetitive of other information or studies already included? What are they and how are they relevant?

The SSA did not utilize all pertinent information and tended to heavily rely on select references to support conclusions. This was pervasive throughout. See general comments for examples.

2. Provide advice on the overall strengths and limitations of the scientific data used in the document. Is the information presented in the SSA report explicit about assumptions and limitations of, and concerns regarding, the data, and are these appropriately qualified or explained? Are there concerns that the Service did not identify, and if so, how relevant are these concerns to the assessment of the North American wolverine? Are there any inconsistencies in how the data are presented or assessed?

The SSA referenced most relevant papers. However, it misrepresented or cherry-picked information in those papers. See general comments above.

Analysis of Available Data:

3. Have the assumptions and methods used in the SSA report been clearly and logically stated in light of the best available information? If not, please identify the specific assumptions and methods that are unclear or illogical.

The assumptions and methods used in the SSA have not been clearly and logically stated. Conclusions are often made based on little or no scientific evaluation of the information. See general comments above.

4. Are there demonstrable errors of fact or interpretation? Have the authors of the SSA report provided reasonable and scientifically sound interpretations and syntheses from the scientific information presented in the report? Are there instances in the SSA report where a different but equally reasonable and sound interpretation might be reached that differs from that provided by the Service? If any instances are found where this is the case, please provide the specifics regarding those particular concerns.

The SSA suffers from pervasive bias in its use and interpretation of information. There is an overall failure to scientifically evaluate information used to formulate conclusions. See general comments above for more detail.

As another example, the SSA evaluated climate change and future snow cover. Data presented conclusively showed that climate change will reduce snow cover. However, in interpreting this information, the SSA simply concludes “Their results indicate significant areas (several hundred square kilometers (miles) for each site) of future snow (greater than 0.5 m (20 in) in depth) will persist on May 1st at elevations currently used by wolverines for denning”. However, this conclusion discounts the LOSS of snow cover and no analysis is presented on how the loss of habitat will impact wolverines.

5. Provide feedback on the inclusion and portrayal of uncertainty in the SSA report. Have the scientific uncertainties presented and the analyses conducted been clearly identified and has the degree of uncertainty been appropriately characterized? If not, please identify any specific concerns.

Most climate models show major changes to species distributions after about 2050 (e.g. see Johnston et al 2012 for data relevant to wolverine). I am concerned that the SSA limited its analysis to 40-50 years. Proper planning now to identify locations most likely to retain suitable wolverine habitat over the next century will be important in assuring the species does not go extinct. Models indicate significant reductions in suitable habitat after 2050.

Johnston, K.M., K.A. Freund, O.J. Schmitz. 2012. Projecting range shifting by montane mammals under climate change: implications for Cascadia's national Parks. Ecosphere, 3(11):97

6. Does the SSA report adequately consider what the species needs to maintain viability in terms of resiliency, redundancy, and representation?

The three physical and ecological needs described for the wolverine in the western contiguous USA are not adequate:

(1) large territories in remote landscapes; at high elevation (1,800 to 3,500 meters (5,906 to 11,483 feet));
- Need to define what is meant by "remote"

(2) access to a variety of food resources that varies with seasons; and
- This conveys the wrong idea about food requirements; rather, wolverines need access to specific food resources depending on season.

(3) physical/structural features (e.g., talus slopes, rugged terrain) linked to reproductive behavioral patterns.
- The absence of snow from this description seems like a glaring oversight.

The SSA does not adequately consider what the species needs to maintain viability in terms of resiliency, redundancy, and representation:

Resiliency—The definition of resiliency is "having sufficiently large populations for the species to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health; for example, birth versus death rates and population size" (Page 5). Based on this definition, it seems clear the wolverine in the contiguous USA lacks resiliency due to its small overall population size and exceptionally small effective population size. Wolverines have low reproductive rates and human-mediated mortality can be additive. Climate models demonstrate significant loss of future habitat. In contrast, the SSA concludes that wolverines are behaviourally plastic and may adapt or adjust to changing conditions. I find no compelling science-based argument in the SSA to support this view.

Redundancy--The definition of redundancy is "having a sufficient number of populations for the species to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk and can be measured through the duplication and distribution of populations across the range of the species. The greater the number of populations a species has distributed over a larger landscape, the better it can withstand catastrophic events." The Current Range map presented in the SSA grossly over-represents the breeding range of the wolverine in the contiguous USA and no map or analysis is provided of the wolverine's historical distribution. It is currently estimated that there are about 318 individual wolverines in the western contiguous USA with an effective population size of < 60. A wealth of information from conservation biology indicates that populations this small have high extinction risk. The wolverine is functionally extinct from many areas where it historically occurred. In contrast, the SSA concludes that "The wolverine occurs across the contiguous United States within a metapopulation structure. The best available information indicates that

the species continues to expand into historical, previously occupied areas in the contiguous United States following decades of hunting and trapping." The fact that the wolverine occurs as a metapopulation is somewhat irrelevant. The fact is that the entire population in the contiguous USA is very small. First, the dramatic examples of this "expansion" are observations of males that have dispersed from core reproducing populations. No new populations will form unless females also disperse, but which have more limited dispersal potential. Second, it is very likely that these dispersal events (e.g., Colorado, Sierra Nevada) are only now observed due to advances in technology such as pervasive use of remote cameras and satellite GPS. Dispersal of single animals is not necessarily indicative of recolonization. Thus, I find no compelling science-based argument to indicate that wolverines in the contiguous USA have adequate redundancy.

Representation—The definition of representation is "having the breadth of genetic makeup of the species to adapt to changing environmental conditions. Representation can be measured through the genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics within the geographical range." The SSA concludes that "The wolverine is currently found across the west-northwestern United States, as well as much of Canada, and Alaska. The best available information indicates that the species is found across a wide range of habitats. Modeled primary habitat for the wolverine in the contiguous United States has been estimated at 164,125 square kilometers (km2) (63,369 square miles (mi2). " This conclusion is fraught with problems. 1) The wolverine is not "currently found across the west-northwestern United States". Rather, reproductive populations are found in some patches of habitat and it is absent from a large portion of this region. 2) Occurrences in Canada and Alaska are largely irrelevant to its representation in the contiguous USA. 3) The wolverine is largely limited to arctic, boreal, and subalpine biomes. That fact that it can use different microsites within this area is largely irrelevant and does not convey that it is a habitat generalist. 4) The extent of modeled primary habitat is irrelevant because the wolverine does not occur throughout all of the modeled primary habitat. In contrast, reproductive populations only occur in a fraction of the available primary habitat. In contrast to the conclusions of the SSA, genetic studies in conjunction with information on current distribution and abundance of wolverines in the contiguous USA demonstrate that they do not have adequate representation.

Peer Review of the Scientific Findings in USFWS Species Status Assessment Evaluating the Status of the North American Wolverine (Gulo gulo luscus)

Reviewer 3
December 2017

Introductory Remarks
Overall the review appeared to be well done although much longer than necessary and there were a few places that did not make sense. I do not believe that the results of Webb et al. (2016) were fully integrated into this draft, possibly because major sections were written before the Webb et al. paper became available. Some of the comments about population demography were not written by someone grounded in population ecology, and would be best deleted. Nevertheless, I agree with the conclusions of the report that there is no basis for pursuing ESA protection for wolverines in the USA, even though this is not stated explicitly, it is an obvious conclusion.

Available Data:

1. Please identify any oversights or omissions of data or information, and their relevance to the assessment. Are there others sources of information or studies that were not included that are relevant to assessing the viability of this species and not repetitive of other information or studies already included? What are they and how are they relevant?

There is a new paper accepted in *Behavioral Ecology* but it would not have been available when this was written. Otherwise, to my knowledge there were no substantial omissions.

2. Provide advice on the overall strengths and limitations of the scientific data used in the document. Is the information presented in the SSA report explicit about assumptions and limitations of, and concerns regarding, the data, and are these appropriately qualified or explained? Are there concerns that the Service did not identify, and if so, how relevant are these concerns to the assessment of the North American wolverine? Are there any inconsistencies in how the data are presented or assessed?

It would appear that the snow model has not been completely abandoned even though we now have 3 studies showing that it does not restrict the distribution of wolverines. Yet, there may be places in the mountains where late-spring snow is indeed important, and such a proviso would be reasonable. I think that the thorough review of the literature is a strength. There are particular sections identified below (under General Comments) that are in error and should be fixed, e.g., the demography section.

Analysis of Available Data:

3. Have the assumptions and methods used in the SSA report been clearly and logically stated in light of the best available information? If not, please identify the specific assumptions and methods that are unclear or illogical.

Generally I believe that the assumptions have been well identified. I found that the effective population size section and the demography section had flaws but these would not affect overall conclusions relative to the status review.

4. Are there demonstrable errors of fact or interpretation? Have the authors of the SSA report provided reasonable and scientifically sound interpretations and syntheses from the scientific information presented in the report? Are there instances in the SSA report where a different but equally reasonable and sound interpretation might be reached that differs from that provided by the Service? If any instances are found where this is the case, please provide the specifics regarding those particular concerns.

Yes, there are errors and I have identified these in my detailed comments below.

5. Provide feedback on the inclusion and portrayal of uncertainty in the SSA report. Have the scientific uncertainties presented and the analyses conducted been clearly identified and has the degree of uncertainty been appropriately characterized? If not, please identify any specific concerns.

Forecasting climate change scenarios is always burdened with uncertainty, but this was not inappropriately identified. I do not have specific concerns about the manner in which uncertainty was dealt with in the status review.

6. Does the SSA report adequately consider what the species needs to maintain viability in terms of resiliency, redundancy, and representation?

I believe that resiliency was confused with resistance, but again, this had no bearing on the overall conclusions.

General Comments

Page 22, paragraph 2, line 5: that not who—who is for human subjects only.

Page 28, two lines from bottom of page: grammar—also had been found. . .

Page 29 appears to be overkill—probably not necessary for this document.

Pages 28-36 is an exhaustive discussion of snow. But the fact is that although wolverines will use snow to advantage in some habitats, recent results from Alberta (Webb et al.) demonstrate that it is not necessary. Again, this seems excessive when a paragraph would suffice.

Page 38: last sentence in first paragraph: grammar—also may be. . .

Page 42: "Evaluation of genetic material can provide an understanding of population dynamics" This statement is not true. Yes, genetic data can give insights into possible bottlenecks and other mechanisms that might have restricted genetic variability. But it is simply not true that this gives and understanding of population dynamics. Replace the word insight for understanding and I'd be more comfortable with the claim. Even then there are too many unknowns and alternative explanations to make this a very solid statement. I suggest dropping this initial sentence.

Pages 43-44: I think that that the mathematical geneticist Ewens (1990) has a more lucid discussion of effective population size, which depends largely on the structure for the definition. The Ne presented here is narrow in context of the population structure of wolverines and the many factors that could be determining the actual effective population size.

Page 53, line 1: also may affect. . .

Page 54, 2nd line below table: dens usually are located. . . Rainbow Lake, Alberta is a high road density area but with a sizable wolverine population (Webb et al. 2016; Scrafford et al. 2017).

Page 61, last paragraph: If the population is persisting, $\lambda = 1$ over reasonable time scales. Yes, numbers go up and down but this is trivial and should not be reported here. The following sentence is utter nonsense: "Estimated (logistic) rates of population growth (λ) were found to be lower for trapped populations ($\lambda = 0.878$) as compared to untrapped populations ($\lambda = 1.064$) (Krebs et al. 2004, p. 499)." Lambda is a measure of geometric population growth, not a logistic rate of population growth. Likewise, the following sentence cannot be justified because the data are insufficient to determine additive versus compensatory mortality. And again the sentence makes no sense because dispersal is a mechanism that can yield density-dependent compensation.

Page 62, records of fur returns for wolverines exist from 1821 and for BC and Alberta there is no trend in harvests for nearly 200 years. This is as strong a statement about persistence as we can find! At a

finer spatial scale, however, harvests in some localities in southeastern BC would appear unsustainable.

Page 65, end of 2nd paragraph: 6% of the contiguous USA? This is confusing and could use a couple more words of explanation.

Page 90: "Although it has been assumed that wolverines have an obligate relationship with snow for natal denning, the key variables or combination of variables, that defined this relationship have not been empirically analyzed." What's more, the results of Webb et al. (2016) call to question this assumption because we know that wolverines can den successfully in areas w/o late spring snow. Reference to Webb et al. should appear in the next to last paragraph of page 91 as well.

Page 93, resiliency is the ability to rebound after stochastic perturbation in contrast to resistance that is the ability to withstand these perturbations.

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CURRICULUM VITAE

JAMES C. BEASLEY

Savannah River Ecology Lab
P.O. Drawer E
Aiken, SC 29802

Phone: (803) 725-5113
Fax: (803) 725-3309
Email: beasley@srel.uga.edu

RESEARCH INTERESTS

Spatial ecology and population dynamics of carnivores, effects of anthropogenic stressors on wildlife, wild pig ecology and management, human-wildlife conflicts, wildlife disease ecology, scavenging ecology

EDUCATION:

Ph.D., Wildlife Ecology, Purdue University [redacted]
Advisor: Dr. Olin Rhodes, Jr.

M.S., Wildlife Ecology, Purdue University [redacted]
Advisor: Dr. Olin Rhodes, Jr.

B.S., Wildlife Management, SUNY ESF [redacted]
Advisor: Dr. William Shields

A.A.S., Pre-Professional Forestry, Paul Smith's College [redacted]

PROFESSIONAL EXPERIENCE

2015-present	Assistant Professor – University of Georgia, Savannah River Ecology Laboratory, Warnell School of Forestry and Natural Resources
2014-present	International Atomic Energy Agency's Wildlife Advisor to the Fukushima Prefecture, Japan
2012-2015	Assistant Research Scientist – University of Georgia, Savannah River Ecology Laboratory, Warnell School of Forestry and Natural Resources
2011-2012	Visiting Assistant Professor – Department of Forestry and Natural Resources, Purdue University
2010-2011	Postdoctoral Research Associate – Department of Forestry and Natural Resources, Purdue University
2006-2010	Graduate Research Assistant – Department of Forestry and Natural Resources, Purdue University

2003-2005 Graduate Research Assistant – Department of Forestry and Natural Resources, Purdue University

PUBLICATIONS (Total of 78)

Peer-Reviewed Journal Articles (68)

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23.) Beasley, J.C., W.S. Beatty, Z.H. Olson, and O.E. Rhodes, Jr. 2010. A genetic analysis of the Virginia opossum mating system: evidence of multiple paternity in a highly fragmented landscape. ***Journal of Heredity*** 101(3):368-373.

22.) Dharmarajan, G., J.C. Beasley**,** J.A. Fike, and O.E. Rhodes, Jr. 2009. The population genetic structure of raccoons (*Procyon lotor*) inhabiting a highly fragmented landscape. ***Canadian Journal of Zoology*** 87(9):814-824.

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14.) Beasley, J.C., T.L. DeVault, M.I. Retamosa, and O.E. Rhodes, Jr. 2007. A hierarchical analysis of habitat selection by raccoons in northern Indiana. ***Journal of Wildlife Management*** 71(4):1125-1133.

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12.) Beasley, J.C., T.L. DeVault, and O.E. Rhodes, Jr. 2007. Home range attributes of raccoons in a fragmented agricultural region of northern Indiana. ***Journal of Wildlife Management*** 71(3):844-850.

11.) Beasley, J.C., and O.E. Rhodes, Jr. 2007. Effect of tooth removal on recaptures of raccoons. ***Journal of Wildlife Management*** 71(1):266-270.

Books (1)

10.) Pitt, W.C., J.C. Beasley, and G.W. Witmer. *In Press*. Ecology and Management of Terrestrial Invasive Species in the United States. CRC Press, Boca Raton, FL, USA.

Book Chapters, and Book Reviews (5)

9.) Beasley, J.C., Z.H. Olson, N. Selva, and T.L. DeVault. *In Press*. Ecological functions of vertebrate scavenging. *In*: Carrion Ecology and Management. P.P. Olea, P. Mateo-Tomas, and J. Sanchez-Zapata. Springer.

8.) Mayer, J.J., and J.C. Beasley. *In Press.* Wild Pigs. *In*: Ecology and Management of Terrestrial Vertebrate Invasive Species in the United States. W.C. Pitt, J.C. Beasley, and G.W. Witmer, editors. CRC Press, Boca Raton, FL, USA.

7.) Beasley, J.C. 2016. Human Diseases from Wildlife. Book Review. ***Journal of Wildlife Management*** 80(1):181-182

6.) DeVault, T.L., J.C. Beasley, Z.H. Olson, M. Moleón, J.A. Sánchez-Zapata, M. Carrete, and A. Margalida. 2016. Ecosystem services provided by avian scavengers. *In*: Why Do Birds Matter? Birds' Ecological Functions and Ecosystem Services. C. H. Şekercioğlu, D. G. Wenny, and C. J. Whelan, eds. University of Chicago Press. pp. 235-270

5.) Beasley, J.C., Z.H. Olson, and T.L. DeVault. 2015. Ecological role of vertebrate scavengers. *In*: Carrion Ecology, Evolution and Their Applications. E.M. Benbow, J. Tomberlin, and A. Tarone, eds. CRC Press, Boca Raton, FL. pp. 107-127

Peer-Reviewed Symposia, Proceedings Articles, and Notes (4)

4.) Abernathy, E.F., K.L. Turner, J.C. Beasley, T.L. DeVault, W.C. Pitt, and O.E. Rhodes, Jr. 2015. Impacts of invasive species on ecosystem energy flow on the big island of Hawai'i: Excuse me but are you going to eat that cane toad? ***Proceedings of the 26th Annual Vertebrate Pest Conference.***

3.) Beasley, J.C., T.E. Grazia, P.E. Johns, and J.J. Mayer. 2014. Characterization of habitat attributes associated with wild pig-vehicle collision locations. ***Proceedings of the 2013 Wildlife Damage Management Conference*** Paper 149.

2.) DeVault, T.L., B.J. MacGowan, J.C. Beasley, L.A. Humberg, M.I. Retamosa, and O.E. Rhodes, Jr. 2008. Evaluation of corn and soybean damage by wildlife in northern Indiana. ***Proceedings of the 12th Wildlife Damage Management Conference***, D. Nolte, ed. Corpus Christi, TX.

1.) Humberg, L.A., T.L. DeVault, B.J. MacGowan, J.C. Beasley, and O.E. Rhodes, Jr. 2007. Crop depredation by wildlife in northcentral Indiana. Pages, 199-205 in the ***Proceedings of the Ninth National Wild Turkey Symposium***, A. Stewart, ed., Grand Rapids, Michigan.

In Review

Smith, J.B., T.D. Tuberville, and J.C. Beasley. *Accepted with Revisions*. Hunting and consumption patterns of southeastern USA hunters and anglers. ***Journal of Fish and Wildlife Management***

Thomas, J., J.C. Beasley, J. Seaman, J.W. Finger Jr., T.J. Kieran, E. Lipp, J. Vaun McArthur, O.E. Rhodes, Jr., and T.C. Glenn. *In Review*. Heavy metals in the environment modulate compositional and functional changes in microbiota of wild *Peromyscus*.

Davis, A.J., D.A. Keiter, E. Kierepka, C. Slootmaker, A.J. Piaggio, J.C. Beasley, and K.M. Pepin. *Accepted with Revisions*. The cost of good information: Trade-offs between cost and quality of common population density estimators. ***Journal of Mammalogy***

Nigenda, S.F., Y. Hu, J.C. Beasley, H. Ruiz-Pina, D. Valenzuela-Galvan, and R.K. Wayne. *In Review*. Transcriptomics of skin pigmentation variation in the Virginia opossum (*Didelphis virginiana*). ***Molecular Ecology***

Byrne, M.E., S.C. Webster, S.L. Lance, C.N. Love, T.G. Hinton, D. Shamovich, and J.C. Beasley. *In Review*. Evidence of long-distance dispersal of a gray wolf from the Chernobyl Exclusion Zone. ***Ecology***

Beasley, J.C., M.J. Lavelle, D.A. Keiter, K.M. Pepin, A.J. Piaggio, J.C. Kilgo, and K.C. VerCauteren. *In Review*. Research Methods. *In*: Ecology and Management of Wild Pigs in North America. K.VerCauteren, J.C. Beasley, J.J. Mayer, B. Strickland, G.J. Roloff, and S. Ditchkoff, editors. CRC Press, Boca Raton, FL, USA

Mayer, J.J., J.C. Beasley, R. K. Boughton, and S.S. Ditchkoff. *In Review*. The South. *In*: Ecology and Management of Wild Pigs in North America. K.VerCauteren, J.C. Beasley, J.J. Mayer, B. Strickland, G.J. Roloff, and S. Ditchkoff, editors. CRC Press, Boca Raton, FL, USA

Snow, N., J.C. Beasley, R. Miller, and K. Pepin. *In Review*. Population Dynamics. *In*: Ecology and Management of Wild Pigs in North America. K.VerCauteren, J.C. Beasley, J.J. Mayer, B. Strickland, G.J. Roloff, and S. Ditchkoff, editors. CRC Press, Boca Raton, FL, USA

Gray, S.M., G.J. Roloff, R.A. Montgomery, J.C. Beasley, and K.M. Pepin. *In Review*. Spatial Ecology and Behaviors. *In*: Ecology and Management of Wild Pigs in North America. K.VerCauteren, J.C. Beasley, J.J. Mayer, B. Strickland, G.J. Roloff, and S. Ditchkoff, editors. CRC Press, Boca Raton, FL, USA

Beasley, J.C., S.S. Ditchkoff, J.J. Mayer, M.D. Smith, and K.C. VerCauteren. *In Review*. Research priorities for managing invasive wild pigs in North America. ***Journal of Wildlife management***

Extension Publications (6)

6.) Beasley, J.C. 2014. SRS, the eagles have landed! The Grapevine. University of Georgia, Savannah River Ecology Lab, Aiken, SC.

5.) Bryan, A., A.E. Holland, J.C. Beasley, and O.E. Rhodes, Jr. 2014. Examining vulture movements and behaviors with GSM/GPS transmitters. Tracker News, Microwave Telemetry, Inc. 1:15.

4.) Beasley, J.C. 2008. Spatial dynamics of raccoons and Virginia opossums in agricultural landscapes. *Compass*. Purdue University, Department of Forestry and Natural Resources, West Lafayette, Indiana.

3.) MacGowan, B.J., L.A. Humberg, J.C. Beasley, and O.E. Rhodes, Jr. 2006. Wildlife CSI: unraveling the mysteries of wildlife crop damage, DVD-FNR-266. Purdue University, Department of Forestry and Natural Resources, West Lafayette, Indiana. DVD.

2.) MacGowan, B.J., L.A. Humberg, J.C. Beasley, and O.E. Rhodes, Jr. 2006. Identification of wildlife crop depredation, FNR-267. Purdue University, Department of Forestry and Natural Resources, West Lafayette, Indiana, 28 pp.

1.) MacGowan, B.J., L.A. Humberg, J.C. Beasley, T.L. DeVault, and O.E. Rhodes, Jr. 2006. Corn and soybean crop depredation by wildlife, FNR-265-W. Purdue University, Department of Forestry and Natural Resources, West Lafayette, Indiana, 13 pp. http://www.agriculture.purdue.edu/fnr/cropdamage/resources.htm.

GRANTS – [*$2,389,404 received, $885,871 pending*]

(Grants in italics indicate proposals currently in review)

- *Dharmarajan, G (PI), R Ostfeld (co-PI), and **JC Beasley** (Co-PI). 2017. Hosts as heterogeneous landscapes: Interspecific competition between ticks and its effects on tick-borne disease. National Science Foundation-DEB. In Review* (*$675,242*)
- ***Beasley, JC** (PI) and P. Schlichting (co-PI). 2017. Przewalski's wild horse population status and use of abandoned buildings by wildlife in Chernobyl. Riverbanks Zoo. In Review: $4,825*
- ***Beasley, JC** (PI) and P. Schlichting (co-PI). 2017. Przewalski's wild horse population status and use of abandoned buildings by wildlife in Chernobyl. National Geographic Society. In Review: $29,514*

- ***Beasley, JC** (PI) and AL Bryan (co-PI). 2017. Contaminants in wild pigs and eastern wild turkeys. US Department of Energy. In Review: $176,290*
- **Beasley, JC** (PI). 2017. Crop depredation by wild pigs in the southeastern US. USDA Animal Plant Health Inspection Service. Awarded: $36,000
- **Beasley, JC** (PI). 2017. Radioactive wildlife: disentangling the confounding effects of radiation exposure and human abandonment on wildlife in Fukushima. UGA OVPR. Awarded: $9,681
- **Beasley, JC** (PI). 2017. Effects of low dose radiation exposure on wildlife inhabiting the Fukushima Exclusion Zone, Japan. University of Georgia OIP. Awarded: $5,500
- **Beasley, JC** (PI). 2017. Analysis of wild pig genetic samples. Noble Foundation. Awarded: $4,500
- Bryan, AL (PI) and **Beasley JC** (co-PI). 2017. Movement of wood storks associated with colony modifications at the Savannah International Airport. USFWS. Awarded: $49,280
- Hernandez, SM (PI), **JC Beasley** (co-PI), and M Yabsley (co-PI). 2015. Understanding and managing coyote colonization of Sanibel Island, FL. Sanibel Island City Council. Awarded: $18,882
- **Beasley, JC** (PI) and AL Bryan (co-PI). 2016. Contaminants in wild turkeys. US DOE. Awarded: $32,000
- **Beasley, JC** (PI). 2016. Chernobyl wolves. Living Planet Productions Ltd. Awarded: $2,500
- **Beasley, JC** (PI). Inter and intra-sounder contact structure in wild pigs. USDA Animal Plant Health Inspection Service. Awarded: $112,800
- **Beasley JC** (PI) and OE Rhodes (co-PI). 2016. Spatial ecology of wild pigs subsequent to management activities. USDA Animal Plant Health Inspection Service. Awarded: $70,852
- Rhodes, OE (PI), G Dharmarajan (co-PI), and **JC Beasley** (co-PI). 2017. Ecological factors affecting success of rabies elimination in the southeastern U.S. USDA APHIS. Awarded: $76,913
- **Beasley, JC** (PI) and AL Bryan (co-PI). 2016. Sub-lethal effects of chronic exposure to contaminants: Evaluation of heavy metal, stress, and parasite burdens in beaver, raccoon and river otter inhabiting contaminated wetlands on the Savannah River Site. US DOE. Awarded: $130,000
- **Beasley, JC** (PI) and S Lance (co-PI). 2015. Chernobyl Wolves. Georgia Funder. Awarded: $2,895
- **Beasley, JC** (PI). 2015. Post-translocation movement behavior of wild pigs. USDA Animal Plant Health Inspection Service. Awarded: $62,480
- Kennamer, R (PI) and **JC Beasley** (co-PI). 2015. Monticello Reservoir and Parr Reservoir waterfowl survey. Kleinschmidt Associates. Awarded: $21,628
- Bryan AL (PI) and **JC Beasley** (co-PI). 2015. ^{137}Cs in Biota of R Canal. US DOE. Awarded: $58,000
- **Beasley JC** (PI), RA Kennamer (co-PI), and AL Bryan (co-PI). 2015. Recalculating ecological half-lives for American Coots on Par Pond. US Department of Energy. Awarded: $41,500
- **Beasley JC** (PI) and OE Rhodes (co-PI). 2014. Calibrating efficient methods of estimating feral swine population size. USDA Animal Plant Health Inspection Service. Awarded: $78,815

- Rhodes, OE (PI) and **JC Beasley** (co-PI). 2014. Indirect transfer of acetaminophen/rodenticides to non-target organism through scavenging during BTS and rodent control operations. U.S. Department of Defense/USDA Animal Plant Health Inspection Service. Awarded: $586,628
- **Beasley JC** (PI). 2014. Survival and cause-specific mortality of juvenile feral swine. USDA Animal Plant Health Inspection Service. Awarded: $25,300
- **Beasley JC** (PI) and AE Holland (co-PI). 2014. Environmental contaminants and blood parasite loads in black and turkey vultures in the southeastern USA. Georgia Ornithological Society. Awarded: $8,840
- **Beasley JC** (PI). 2014. Translocation movement behavior of feral swine. USDA Animal Plant Health Inspection Service. Awarded: $45,870
- **Beasley JC** (PI). 2014. Reproductive effects of chronic exposure to anthropogenic contaminants in small mammals. U.S. Army Public Health Command. Awarded: $9,000
- Rhodes, OE (PI) and **JC Beasley** (co-PI). 2014. Development of genetic-based mark-recapture tools for feral swine. USDA Animal Plant Health Inspection Service. Awarded: $35,000
- **Beasley JC** (PI) and OE Rhodes (co-PI). 2014. Dose titration and duration of Rhodamine B in feral pigs. USDA Animal Plant Health Inspection Service. Awarded: $14,934
- **Beasley JC** (PI), AL Bryan (co-PI), and R Kennamer (co-PI). 2013. Preliminary contaminant analysis in selected game species on the Savannah River site. US DOE. Awarded: $40,300
- Kennamer, R (PI), **JC Beasley** (co-PI), and AL Bryan (co-PI). 2013. Radiocesium in American coots on Pond B: a long-term perspective. US Department of Energy. Awarded: $43,515
- Hinton, T (PI) and **JC Beasley** (co-PI). 2013. Innovative Technique to Measure Radiation Dose to Free Ranging Wildlife. French Institute of Radioprotection and Nuclear Safety. Awarded: $162,839
- Rhodes, OE (PI) and **JC Beasley** (co-PI). 2013. Experimental Evaluation of Trophic Transfer of Toxicants Used for Insular Rodents. USDA APHIS. Awarded: $29,986
- **Beasley JC** (PI). 2013. Grad Student Support. Jones Ecological Research Center. Awarded: $21,665
- **Beasley JC** (PI) and OE Rhodes (co-PI). 2013. Efficacy of Rhodamine B as a biomarker for bait uptake in feral swine. USDA Animal Plant Health Inspection Service. Awarded: $11,660
- **Beasley JC** (PI) and S Lance (co-PI). 2013. Sub-lethal effects of chronic exposure to radiation in gray wolves (Canis lupus) at Chernobyl. National Geographic Society. Awarded: $22,000
- **Beasley JC** (PI) and S Webster (co-PI). 2013. Chernobyl Wolves. National Geographic Society. Awarded: $8,200
- **Beasley JC** (PI). 2013. Wildlife Damage Management Working Group Travel Grant. The Wildlife Society Wildlife Damage Management Working Group. Awarded: $500
- Rhodes OE (PI), **JC Beasley** (co-PI), BF Blackwell (co-PI), AL Bryan (co-PI), and TL DeVault (co-PI). 2013. Efficacy of the LRAD weapon system as an avian dispersal tool on airports. Federal Avian Administration/USDA Animal Plant Health Inspection Service. Awarded: $352,245

- **Beasley JC** (PI). 2013. Comparison of uptake of different flavors of ONRAB placebo sachets by rabies hosts. USDA Animal Plant Health Inspection Service. Awarded: $16,406
- Bryan AL (PI) and **JC Beasley** (co-PI). 2012. Preliminary contaminant analysis in selected game species on the Savannah River site. US Department of Energy. Awarded: $40,300
- Rhodes OE (PI) and **JC Beasley** (co-PI). 2013. Experimental Evaluation of Trophic Transfer of Toxicants Used for Insular Rodents. USDA APHIS. Awarded: $99,990
- **Beasley JC** (PI). 2012. Purdue Instructional Innovation Grant, "Microscopy and Digital Imaging for Life Science Instruction" ($21,497)
- **Beasley JC** (PI). 2012. Purdue Instructional Innovation Grant, "Digital Remote Camera Units for Wildlife Management Instruction" ($8,160)
- Olin Rhodes, Jr. (PI) and **JC Beasley** (co-PI). 2011. USDA-APHIS, "Evaluation of bait distribution methods" ($38,379)
- Olin Rhodes, Jr. (PI) and **JC Beasley** (co-PI). 2010. USDA-APHIS, "Use of trapping point transect and spatially explicit capture-recapture to estimate the density of raccoons and using spatial data to increase trap-based detection for raccoons" ($26,190)
- Olin Rhodes, Jr. (PI) and **JC Beasley** (co-PI). 2009. USDA-APHIS, "Use of trapping point transect and spatially explicit capture-recapture to estimate the density of raccoons and using spatial data to increase trap-based detection for raccoons" ($22,752)
- **Beasley JC** (PI). 2007. Frederick N. Andrews Environmental Travel Grant Award ($2,000)
- **Beasley JC** (PI). 2007. Indiana Academy of Science, "Ecological response of raccoons to agriculturally induced habitat fragmentation" ($1,250)

AWARDS AND ACTIVITIES

- Certified Wildlife Biologist, The Wildlife Society, 2013
- Howard Hughes Medical Institute faculty learning community – member, 2011-2012
- Chemical Immobilization Certification through Safe Capture International – 2011
- Charles Kirkpatrick Memorial Graduate Student Award, 2010
- Master Trapper, Fur Takers of America Certification, 2010
- 2nd place, Purdue Forestry and Natural Resources Research Symposium, 2010 (Poster)
- Bilsland Dissertation Fellowship, Purdue University, 2009
- Indiana Chapter of the Wildlife Society Best Paper Award, 2008
- Charles Kirkpatrick Memorial Graduate Student Award, 2007
- 1st place, Purdue Forestry and Natural Resources Research Symposium, 2005 (Poster)
- Honorable mention, Purdue FNR Research Symposium 2004, (Poster)

TEACHING EXPERIENCE

University of Georgia

- **WILD/ECOL 3580: Vertebrate Natural History** – Instructor (Fall 2013)

- **WILD 4650/6650: Field & Molecular Techniques in Wildlife Research and Management** – Instructor (Summer 2013-2017)

- **WILD 1100E: Wildlife in America** – Instructor (Summer 2016, 2017, Spring 2017)

Purdue University

- **FNR 240: Wildlife in America** – Instructor (Fall 2011; 120 students)
- **FNR 341: Wildlife Habitat Management** – Instructor (Spring 2012; 50 students)
- **FNR 348: Wildlife Investigational Techniques** – Instructor (Spring 2012; 55 students)
- **FNR 373: Summer Field Practicum** – Instructor (May 2012; 60 students).
- **FNR 241: Ecology and Systematics of Fishes and Mammals** – Graduate Teaching Assistant (Fall 2004, 2006; ~30 students)
- **FNR 548: Wildlife Investigational Techniques** – Graduate Teaching Assistant (Fall 2007, 2008; ~50 students)
- **FNR 240: Wildlife in America** –Guest Lecture (Fall 2006-2008; 250-400 students)

Table 1. Student evaluations

Evaluation Questions	WILD 4650/6650 2013-2017	WILD1100E 2016-2017
Instructor clearly articulated and met course objectives	5.0	4.9
Instructor presented material in a clear and understandable manner	5.0	4.9
Instructor was organized and prepared in class	4.9	4.9
Instructor stimulated my interest in course subject material	5.0	4.9
Instructor motivated me to perform at my highest level	4.9	4.8
Instructor demonstrated concern for student learning	4.9	4.5
Instructor was receptive to questions and independent thought	5.0	4.6
Instructor was available and helpful outside of class	4.6	4.8
Instructor employed grading practices that were clearly explained and fair	4.6	4.9
Instructor effectively utilized in class time (including lectures and laboratories)	5.0	4.9
Considering all factors, the instructor should be commended for his/her efforts in the course	5.0	4.9
This course exposed me to information and/or ideas that expanded and/or altered my perception of the world	4.7	4.9
Average (out of 5)	**4.88**	**4.80**

MEDIA COVERAGE

My research program has received media coverage through a multitude of outlets. Since 2005, aspects of my research program have been highlighted in several hundred local, national and international newspapers (e.g., New York Times, The Washington Post, USA Today, BBC News, The Guardian – front page, The Independent – front page, Aiken Standard – front page), internet news media (e.g., National Geographic Society, UGA Today – front page, Scientific American, The Wildlife Society), magazines (e.g., Hawkmoth, Wprost), radio broadcasts (e.g.,

NPR-weekend addition, FM4-Austria, 720 ABC-Australia), scientific magazines (e.g., Science, Nature), as well as local and cable television networks (e.g., CNN, Animal Planet, Georgia Public Broadcasting, NBC-26 News). In particular, two of my coauthored papers have altmetric scores within the top 5% of all articles ever tracked by altmetric, one of which was included in the best of UGA magazine for being the most widely read news release produced by the University of Georgia in 2016.

PROFESSIONAL PRESENTATIONS

(Invited papers in **bold**; * indicates coauthored presentations $^{\Psi}$ indicates student presentations; $^{¥}$ indicates award received for presentation)

2017 **National Wild Pig Task Force Meeting, Orange Beach, AL**
International Atomic Energy Association Summer Mission, Fukushima, Japan
NNSA SRS Meeting, Aiken, SC
National Academy of Sciences, Minsk, Belarus
Cedar Shoals High School, Athens, GA
Warnell Graduate Student Symposium, Athens, GA (3)$^{\Psi}$
SICB, New Orleans, LA$^{\Psi}$
Ecological Society of America, Portland, OR (2)$^{*\Psi}$
SREL Undergraduate Research Symposium, Aiken, SC (1) $^{\Psi}$
University of South Carolina Summer Research Symposium, Columbia, SC (1)$^{\Psi}$
Wildlife Disease Association Meeting, Chiapas, Mexico*
SREL REU, Aiken, SC (2) $^{\Psi}$
USDA-APHIS-WS NC/SC wild pig technical meeting, Garnett, SC
USDA-APHIS-NWRC, Fort Collins, CO*

2016 Warnell Graduate Student Symposium, Athens, GA (4)$^{\Psi¥¥¥}$
International Atomic Energy Association Summer Mission, Fukushima, Japan
SREL Undergraduate Research Symposium, Aiken, SC (1) $^{\Psi}$
Fukushima University, Fukushima, Japan$^{\Psi}$
SREL REU, Aiken, SC (2) $^{\Psi}$
TEDx, Atlanta, GA
University of South Carolina Summer Research Symposium (1)$^{\Psi}$
International Atomic Energy Association Winter Mission, Fukushima, Japan
SETAC, Orlando, FL (3) $^{\Psi}$
International Wild Pig Conference, Myrtle Beach, SC (6)$^{\Psi}$
USDA-APHIS-WS Annual State Meeting, SC
Georgia Wildlife Society Meeting, Athens, GA $^{\Psi¥}$
South Carolina Wildlife Society Meeting, SC
Wild Pig Workshop at the 23rd Annual National Meeting of the Wildlife Society, Raleigh, NC
Southeastern Society of Parasitologists, Fort Mill, SC$^{\Psi}$
Society for Glycobiology, New Orleans, LA
The 23rd Annual National Meeting of the Wildlife Society, Raleigh, NC (8) $^{\Psi}$

2015 Warnell Graduate Student Symposium, Athens, GA (5)[Ψ¥¥¥¥]
Ichaway Scientific Advisory Committee, Newton, GA [Ψ]
Clemson University, Clemson, SC
Georgia Entomological Society, Jekyll Island, GA (2) [Ψ¥]
American Society of Mammalogists Annual Meeting, Jacksonville, FL (4) [Ψ]
International Atomic Energy Association Mission, Fukushima, Japan
SREL Undergraduate Research Symposium, Aiken, SC (2) [Ψ]
UGA Ecology of Infectious Diseases Symposium, Athens, GA [Ψ]
University of South Carolina Summer Research Symposium (2) [Ψ]
Georgia Wildlife Society Meeting, Athens, GA (3) [Ψ¥¥]
13th International Conference on the Biochemistry of Trace Elements, Fukuoka, Japan*
The 22nd Annual National Meeting of the Wildlife Society, Winnipeg, Canada (6) [Ψ¥]
University of Florida Emerging Pathogens Institute, Gainesville, FL [Ψ]
NSF REU National Symposium, Arlington, VA [Ψ]
International Atomic Energy Association Mission, Fukushima, Japan
Science Media Center, London, UK

2014 **University of Florida, Gainesville, FL**
Warnell Graduate Student Symposium, Athens, GA (3) [Ψ]
Evolution Meeting, Raleigh, NC*
26th Vertebrate Pest Conference, Waikoloa, HI[Ψ]
Animal Movement Symposium, Raleigh, NC[Ψ]
Florida Cooperative Fish and Wildlife Research Unit, Gainesville, FL*
Southeastern Forest Work Conference, Charleston, SC[Ψ]
International Atomic Energy Association Mission, Fukushima, Japan
SREL Undergraduate Research Symposium (2) [Ψ]
SREL Touch an Animal Day (2) [Ψ]
The 21st Annual National Meeting of the Wildlife Society, Pittsburg, PA (2) [Ψ]
Georgia Chapter of the Wildlife Society, Tifton, GA (2) [Ψ¥]
AOU/COS/SCO, Estes Park, CO [Ψ]
South Carolina Wildlife Society Meeting, Clemson, SC*

2013 TWS Wildlife Damage Management Workshop, Clemson, SC
Sierra Club, Aiken, SC
Southeastern Cooperative Wildlife Disease Study, Athens, GA
Savannah River Ecology Lab, Aiken, SC
Ecological Society of America, Minneapolis, MN*
American Society of Mammalogists, Philadelphia, PA*
Student Conference on Conservation Science, New York, NY*
USFS Environmental Sciences Field Station, Aiken, SC (2) [Ψ]
IRSN, France*

2012 **USFWS American Burying Beetle Science Workshop, Pawhuska, OK**
Indiana State University, Terre Haute, IN

Savannah River Ecology Lab, Aiken, SC
University of South Carolina-Aiken, Aiken, SC
University of Georgia, Athens, GA
Jones Center, Newton, GA
EcoSummit, Columbus, OH*

2011 **USDA-APHIS National Wildlife Research Center, Fort Collins, CO**
The 91st Annual Meeting of the Am. Society of Mammalogists, Portland, OR*
The 72nd annual Midwest Fish and Wildlife's conference, Des Moines, IO*
Furtakers of America Prof. Trappers College for Furbearer Mgmt, Wolcottville, IN
The 22nd Annual International Conference on Rabies in the Americas, San Juan, Puerto Rico*

2010 Purdue University Forestry and Natural Resources Symposium, W. Lafayette, IN (2)
The 17th Annual National Meeting of the Wildlife Society, Snowbird, UT (2)
The 21st Annual International Conference on Rabies in the Americas, Guadalajara, Mexico*
Ph.D. Dissertation Presentation, W. Lafayette, IN

2009 The 89th Annual Meeting of the Am. Society of Mammalogists, Fairbanks, AK (3)
Indiana Chapter of the Wildlife Society, Terre Haute, IN*
The 16th Annual National Meeting of the Wildlife Society, Monterey, CA*
Purdue University Forestry and Natural Resources Symposium, W. Lafayette, IN
Furtakers of America Prof. Trappers College for Furbearer Mgmt, Wolcottville, IN

2008 Indiana Chapter of the Wildlife Society, Nashville, IN¥
The Purdue University Chapter of the Wildlife Society, W. Lafayette, IN

2007 Purdue University Forestry and Natural Resources Symposium, W. Lafayette, IN (2)
Purdue Center for the Environment Graduate Research Showcase, W. Lafayette, IN
56th Annual Meeting of the Wildlife Disease Association. Estes Park, CO*
The Purdue University Chapter of the Wildlife Society, W. Lafayette, IN

2006 Purdue University Forestry and Natural Resources Symposium, W. Lafayette, IN (2)
Purdue Center for the Environment Graduate Research Showcase, W. Lafayette, IN
The Purdue University Chapter of the Wildlife Society, W. Lafayette, IN
Midwest Deer and Turkey Group Meeting, Bloomington, IN*

2005 Purdue University Forestry and Natural Resources Symposium, W. Lafayette, IN
M.S. Thesis Presentation, W. Lafayette, IN
The 66th annual Midwest Fish and Wildlife's conference, Grand Rapids, MI
9th National Wild Turkey Symposium, Grand Rapids, MI*

2004 The 11th Annual National Meeting of the Wildlife Society, Calgary, Canada (2)
The 65th Annual Midwest Fish and Wildlife Conference, Indianapolis, IN
Purdue University Forestry and Natural Resources Symposium, W. Lafayette, IN

The Purdue University Chapter of the Wildlife Society, W. Lafayette, IN

GRADUATE STUDENTS SUPERVISED

Theses and Dissertations Supervised

(b) (6)(b) (6)	M.S.	Spatial ecology of black and turkey vultures in the southeastern U.S.; University of Georgia; December 2015
(b) (6)	M.S.	The effect of habitat type, carcass size, and scavenger exclusion on vertebrate scavenging communities in the Coastal Plain of the Southeast; University of Georgia; December 2015
(b) (6)	M.S.	Occupancy, distribution, and abundance of carnivore populations within the Chernobyl Exclusion Zone; University of Georgia; May 2016
(b) (6)(b) (6)	M.S.	Exposure of game species to trace elements and radiocesium on the Savannah River Site in South Carolina; May 2016
(b) (6)	M.S.	Effects of industrial contamination on carrion-associated beetles; December 2016
(b) (6)	M.S.	Development of population monitoring techniques for wild pigs (*Sus Scrofa*); December 2016
(b) (6)	M.S.	Biomagnification of radiocesium within aquatic food webs; to be completed December 2017
(b) (6)	M.S.	Ecotoxicology and disease ecology of semi-aquatic mammals in the southeastern U.S.; to be completed May 2018
(b) (6)	M.S.	Community composition of mammals within the Fukushima Exclusion Zone; to be completed December 2018
(b) (6)	Ph.D.	Niche overlap and competition between gray fox and coyotes in the southeastern U.S.; to be completed December 2020
(b) (6)	M.S.	Spatio-temporal patterns of wild pig depredation to agricultural crops; to be completed May 2019
(b) (6)	Ph.D.	Reproductive ecology of wild pigs in the southeastern U.S.; to be completed December 2022

(b) (6)	M.S.	Distribution and efficiency of vertebrate scavengers across a gradient of human presence in Fukushima, Japan; to be completed December 2019
(b) (6)(b) (6)	M.S.	Co-supervised with Guha Dharmarajan; to be completed December 2019
(b) (6)	M.S.	Co-supervised with Guha Dharmarajan; to be completed December 2019
(b) (6)	Ph.D.	Co-supervised with Guha Dharmarajan; to be completed December 2020

Undergraduate Theses/REU's Supervised

(b) (6)	Fate and scavenging community composition associated with avian nestling carcasses; May 2016
(b) (6)(b) (6)	Surveillance for ticks and *Babesia* infections in wild pigs (*Sus scrofa*) from South Carolina; December 2016
(b) (6)(b) (6)	Bioaccumulation of radiocesium and mercury in diving and dabbling ducks at Four-mile creek on the Savannah River Site; August 2016
(b) (6)	Accumulation of radiocesium in bullfrog tadpoles in a contaminated effluent canal on the SRS; August 2017

Postdocs Supervised

(b) (6)	(2014-2015)	University of Georgia
(b) (6)	(2015-2017)	University of Georgia
(b) (6)(b) (6)	(2016-Present)	University of Georgia

Student Committees

(b) (6)	Ph.D. (2012)	Purdue University
(b) (6)	M.S. (2015)	University of Georgia
(b) (6)(b) (6)	Ph.D. (2017)*	University of Florida
(b) (6)	M.S. (2015)	University of Georgia
(b) (6)	MNR (2016)	University of Georgia
(b) (6)	Ph.D. (2018)*	University of Georgia
(b) (6)	B.S. (2015)¥	University of Georgia
(b) (6)	M.S. (2017)*	University of Georgia
(b) (6)	Ph.D. (2019)*	University of Georgia

(b) (6)(b) (6)	B.S. (2016)¥	University of Georgia
(b) (6)(b) (6)	B.S. (2016)¥	University of Georgia
(b) (6)	Ph.D. (2019)*	Mississippi State University
(b) (6)	Ph.D. (2019)*	University of Georgia
(b) (6)	Ph.D. (2018)*	University of Georgia
(b) (6)	M.S. (2018)	University of Georgia
(b) (6)	MNR (2017)	University of Georgia
(b) (6)	Ph.D. (2021)*	University of Georgia

** indicates anticipated graduation date*

¥ indicates undergraduate student thesis

PROFESSIONAL AFFILIATIONS

The Wildlife Society
American Society of Mammalogists
Ecological Society of America
Sigma Xi

SERVICE (University, Professional, Community)

- Reviewer: Scientific Reports, PlosOne, Wildlife Research, Canadian Journal of Zoology, Human-Wildlife-Interactions, Journal of Mammalogy, Journal of Wildlife Management, Journal of Wildlife Rehabilitation, Mammalian Biology, Wildlife Biology, Landscape Ecology, Ibis, Landscape and Urban Planning, Northeastern Naturalist, Wildlife Damage Management Proceedings (2013), Wildlife Society Bulletin, Polar Biology, American Midland Naturalist
- Associate Editor, Human-Wildlife Interactions (2016-present)
- External Reviewer, 2014 Purdue University Postdoctoral Application Review
- Guest Associate Editor, 2013 Wildlife Damage Management Proceedings
- TWS working group member: Wildlife Damage Management, Wildlife Diseases
- Chair: Research Subcommittee, National Wild Pig Task Force (2015-present)
- Member: SREL/Warnell Energy Ecologist Search Committee (2014)
- Member: Warnell Graduate Affairs Committee (2016-present)
- Member: SREL Animal Care and Use Committee (2013-2016)
- Member: SREL Campus Relations Committee (2016-present)
- Member: SREL Computer Committee (2012-2014)
- Member: SREL GIS Committee (2012-2015)
- Member: SREL Seminar Committee (2012-2015)
- Member: SREL Executive Committee (2015-present)
- Member: SREL Graduate Programs Committee (2015-present)
- Member: SC Wild Pig Task Force (2013-present)

NAME Mark S. Boyce

ADDRESS

Department of Biological Sciences
University of Alberta
Edmonton, AB T6G 2E9
Canada

PHONE

Office: (780)492-0081
Home: (b) (6)(b) (6)
Fax: (780)492-9234
Cell: (b) (6)(b) (6)

e-mail: boyce@ualberta.ca

EDUCATION

(b) (6) Ph.D., Yale University, New Haven, Connecticut.
(b) (6) M.Phil., Yale University, New Haven, Connecticut.
(b) (6) M.S., University of Alaska, Fairbanks.
(b) (6) B.S., Iowa State University, Ames.

ACADEMIC POSITIONS

Professor of Ecology, and Alberta Conservation Association Chair in Fisheries and Wildlife, 1999-present (Endowed Chair renewed 2012 July 1), Department of Biological Sciences, University of Alberta, Edmonton.

Vallier Chair of Ecology, and Wisconsin Distinguished Professor (UW-System), 1993-1999, College of Natural Resources, University of Wisconsin, Stevens Point.

Professor, 1987-1993, Department of Zoology and Physiology, University of Wyoming, Laramie.

Associate Professor, 1981-1987, Department of Zoology and Physiology, University of Wyoming, Laramie.

Visiting Professor, 1984-1985, Department of Mathematics, University of Wyoming, Laramie.

Postdoctoral Research Fellow, 1982-1983, Animal Ecology Research Group, Department of Zoology, University of Oxford.

Assistant Professor, 1977-1981, Department of Zoology and Physiology, University of Wyoming, Laramie.

Instructor, 1976-77, Department of Zoology and Physiology, University of Wyoming, Laramie.

HONORS AND AWARDS

C. Hart Merriam Award, 2017, American Society of Mammalogists, June 24.
Special Recognition Team Award (with Evelyn H. Merrill), 2017, Alberta Chapter of The Wildlife Society, March 11.
Mirosław Romanowski Medal, 2016, Royal Society of Canada, November 18.
ASTech Award, Outstanding Leadership in Alberta Science, 2014, Alberta Science and Technology Leadership Foundation, October.
Fellow, Royal Society of Canada, inducted 2014 November.
President's Award, 2014, Safari Club International, April.
Emerald Award, 2013, Montane Research Program, Province of Alberta, June.
Publication of the Year Award, 2013, Alberta Chapter of The Wildlife Society, March.
TWS Fellow, lifetime award, 2012, The Wildlife Society, Bethesda, Maryland, USA, October.
Best Wildlife Publication Award "Popular Category," 2012, Alberta Chapter of The Wildlife Society, March.
Killam Annual Professorship, 2011-12, University of Alberta.
Publication of the Year Award, 2011, Alberta Chapter of The Wildlife Society.
Award of Merit, 2010, Alberta Trappers Association.
William Rowan Distinguished Service Award, 2008, The Wildlife Society.
International Conservationist of the Year, 2007, Safari Club International Foundation.
Erskine Fellowship, 1999, Canterbury University, Christchurch, New Zealand.
Phi Kappa Phi, 1998, University of Wisconsin-Stevens Point.
University Scholar Award, 1996, University of Wisconsin-Stevens Point.
Chancellor's Merit Award, 1996, University of Wisconsin-Stevens Point.
Faculty Scholar Award, 1994, Sigma Xi-University of Wisconsin-Stevens Point Chapter.
Distinguished Professorship, 1993, 1999 University of Wisconsin System, Madison.
Vallier Chair of Ecology, 1993, University of Wisconsin-Stevens Point.
Outstanding Research Merit Award, 1993, College of Arts and Sciences, Univ. Wyoming.
Fulbright Scholar to India, 1992, U.S. Educational Foundation in India, Bangalore.
Senior Research Fellow, 1991-92, American Institute of Indian Studies, Bangalore.
Kuehn Professorship Award, 1984-85, College of Arts and Sciences, University of Wyoming.
N.A.T.O. Postdoctoral Fellowship, 1982-83, National Science Foundation, Univ. Oxford, UK.
Academy Exchange to Poland, 1982, National Academy of Sciences, Jagiellonian University.
Outstanding Achievement Award, 1974, University of Alaska, Fairbanks.

SABBATICALS

2017, Centre of Excellence for Biosecurity Risk Analysis (CEBRA), University of Melbourne, AUSTRALIA.

2010-11, University of Queensland, Brisbane, AUSTRALIA;
Imperial College London, Silwood Park, U.K.

2003-04, University of British Columbia, Vancouver, CANADA.

1991-92, Fulbright Fellow/American Institute of Indian Studies, Centre for Ecological Sciences and Centre for Theoretical Studies, Indian Institute of Science, Bangalore, INDIA.

1982-83, NATO Postdoctoral Fellowship, Department of Zoology, University of Oxford, U.K.

OTHER POSITIONS

1989-1993, Director, UW-National Park Service Research Center, University of Wyoming.

PUBLICATIONS

Books:

Boyce, M. S., and A. Haney. 1997. *Ecosystem Management: Applications for Sustainable Forest and Wildlife Resources.* Yale University Press, New Haven, Conn. 361pp.

Thorne, E. T., M. S. Boyce, P. Nicoletti, and T. J. Kreeger (eds.). 1997. *Brucellosis, Bison, elk, and Cattle in the Greater Yellowstone Area: Defining the Problem, Exploring the Solutions.*Wyoming Game and Fish Department, Cheyenne, Wyo. 219pp.

Keiter, R. B., and M. S. Boyce. 1991. *The Greater Yellowstone Ecosystem: Redefining America's Wilderness Heritage*. Yale University Press, New Haven, Conn. 425pp.

Boyce, M. S. 1989. *The Jackson Elk Herd: Intensive Wildlife Management in North America.*Cambridge University Press, Cambridge, U.K., 305 pp.

Boyce, M. S., ed. 1988. *Evolution of Life Histories of Mammals*. Yale Univ. Press, New Haven, Conn., 373 pp.

Boyce, M. S., and L. D. Hayden-Wing. 1979. *North American Elk: Ecology, Behavior and Management*. Univ. Wyoming, Laramie, 294pp.

Scientific Articles:

Morehouse, A. T., A. E. Loosen, and M. S. Boyce. 2017. Rubbing behaviour, fitness, and habitat selection in grizzly bears. *Nature* (manuscript).

Ladle, A., R. Steenweg, B. Shepherd, and M. S. Boyce. 2017. The role of human recreation in shaping patterns of grizzly bear-black bear co-occurrence. *PLoS ONE* (submitted).

Loosen, A., A. T. Morehouse, and M. S. Boyce. 2017. Land tenure shapes black bear density and abundance on a multi-use landscape. *J. Wildl. Manage*. (under revision).

Krawchuk, K. E., K. H. Knopff, N. F. Webb, P. J. Jones, M. S. Boyce, and E. H. Merrill. 2017. Is niche separation between wolves (*Canis lupus*) and cougars (*Puma concolor*) realized in the Rocky Mountains of Canada? *Can. J. Zool*. (under revision).

Morehouse, A., J. Tigner, and M. S. Boyce. 2017. Conservation dollars fund livestock depredation compensation. *J. Environ. Manage.* (under revision).

Scrafford, M. A., and M. S. Boyce. 2017. A comparison of wolverine (*Gulo gulo luscus*) movement, foraging, and habitat selection in the home range and during dispersal. *J. Wildl. Manage.* (JWM-17-0337, submitted).

Ladle, A., T. Avgar, M. Wheatley, G. Stenhouse, S. Nielsen, and M. S. Boyce. 2017. Grizzly bear response to spatio-temporally variable human recreational activity. *J. Appl. Ecol*. (under revision, APPL-2017-00331).

Mallory, C., M. Campbell, and M. S. Boyce. 2017. Climate influences body condition and synchrony of herd size in three caribou populations in Arctic Canada. *Polar Biol.* (revision submitted, POBI-D-17-00033R1).

Scrafford, M. A., and M. S. Boyce. 2017. Wolverine foraging plasticity in the northern boreal forest. *J. Mammal*. (under revision).

Scrafford, M. A., T. Avgar, R. Heeres, and M. S. Boyce. 2017. Roads elicit negative movement and habitat selection responses by wolverines (*Gulo gulo luscus*). *Behav. Ecol*. (revision submitted, BEHECO-2017-0279).

Boyce, M. S., and P. Krausman, editors. 2017. Mountain sheep management in the United States of America and Canada. *J. Wildl. Manage.* (in press).

Bowyer, R. T., T. Kingston, J. R. Goheen, J. Rachlow, and M. S. Boyce. 2017. Conservation and management of the world's mammals. *J. Mammal*. (in press).

Boyce, M. S., C. Mallory, A. Morehouse, C. Prokopenko, M. Scrafford, and C. Warbington. 2017. Defining landscapes and scales to model landscape–organism interactions. *Curr. Landsc. Ecol. Reports* (doi: 10.1007/s40823-017-0027-z).

Mallory, C. D., and M. S. Boyce. 2017. Observed and predicted effects of climate change on Arctic caribou and reindeer. *Envir. Rev*. (doi: 10.1139/er-2017-0032).

Morehouse, A. T., and M. S. Boyce 2017. Troublemaking carnivores: conflicts with humans in a diverse assemblage of large carnivores. *Ecol. Soc.* **22**(3):4 (doi.org/10.5751/ES-09415-220304).

Thurfjell, H., S. Ciuti, and M. S. Boyce. 2017. Learning from the mistakes of others: how female elk (*Cervus elaphus*) adjust behaviour with age to avoid hunters. *PLoS ONE* **12**(6): e0178082 (doi.org/10.1371/journal.pone.0178082).

Paton, D. G., S. Ciuti, M. Quinn, and M. S. Boyce. 2017. Hunting exacerbates the response to human disturbance in large herbivores while migrating through a road network. *Ecosphere* **8**(6):e01841. (doi: 10.1002/ecs2.1841).

Morehouse, A., and M. S. Boyce. 2017. Male dominance interferes with intercept feeding of grizzly bears. *Ursus* **28**(1):66–80.

Avgar, T., S. Lele, J. Keim, and M. S. Boyce. 2017. Relative Selection Strength: quantifying effect size in resource- and step-selection inference. *Ecol. Evol*. **7**:5322–5330 (doi: 10.1002/ ece3.3122).

Roberts, D., V. Bahn, S. Ciuti, M. S. Boyce, J. Elith, G. Guillera-Arroita, S. Hauenstein, J. Lahoz-Monfort, B. Schroder, W. Thuiller, D. Warton, B. Wintle, F. Hartig, and C. Dormann. 2017. Cross-validation strategies for data with temporal, spatial, hierarchical, or phylogenetic structure. *Ecography* **40**:913–929 (doi: 10.1111/ecog.02881).

Boyce, M. S. 2017. Beaver population ecology and trapline management. *Internat. Trapper* 2017(spring):10–13.

Erickson, M. E., C. Found-Jackson, and M. S. Boyce. 2017. Habitat associations with counts of declining Western Grebes in Alberta, Canada. *Avian Conserv. Ecol*. **12**(1):12. (doi.org/10.5751/ACE-00980-120112).

Scrafford, M. A., T. Avgar, B. Abercrombie, and M. S. Boyce. 2017. Wolverine habitat selection in response to anthropogenic disturbance in the western Canadian boreal forest. *For. Ecol. Manage.* **395**:27–36.

Prokopenko, C., M. S. Boyce, and T. Avgar. 2017. Characterizing wildlife behavioural responses to roads using integrated step selection analysis. *J. Appl. Ecol.* **54**: 470–479 (doi: 10.1111/1365-2664.12768).

Boyce, M. S., and R. Corrigan. 2017. Moose survey app for population monitoring. *Wildl. Soc. Bull.* **41**(1):125–128 (doi: 10.1002/wsb.732). [cover photo].

Ladle, A., T. Avgar, M. Wheatley, and M. S. Boyce. 2017. Predictive modeling of ecological patterns along linear-feature networks. *Meth. Ecol. Evol*. **8**:329–338. (doi: 10.1111/2041-210X.12660).

Gilbert, S. L., K. J. Hundertmark, D. K. Person, M. S. Lindberg, and M. S. Boyce. 2017. Behavioral plasticity in a variable environment: snow depth and habitat interactions drive deer movement in winter. *J. Mammal*. **98**:246–259.

Prokopenko, C., T. Avgar, and M. S. Boyce. 2017. Extent-dependent habitat selection in a migratory large herbivore: road avoidance across scales. *Landsc. Ecol*. **32**:313–325.

Christie, K., W. F. Jensen, and M. S. Boyce. 2017. Resource selection by pronghorn in relation to land cover, roads, and oil and gas development in North Dakota. *J. Wildl. Manage.* **81**:154–162. [cover photo].

Cristescu, B., G. B. Stenhouse, B. Goski, and M. S. Boyce. 2016. Grizzly bear space use and fitness in relation to human habitation and access. *Human Wildl. Interact*. **10**(2):240–257.

Salari, A., M. Zakaria, and M. S. Boyce. 2016. Habitat use by two tropical waterfowl in central Malaysia. *Wildfowl* **66**:41–59.

Cristescu, B., G. B. Stenhouse, M. Symbaluk, S. E. Nielsen, and M. S. Boyce. 2016. Wildlife habitat selection on landscapes with industrial disturbance. *Environ. Conserv.* **43**(4):327–336.

Morehouse, A., T. Graves, N. Mikle, and M. S. Boyce. 2016. Nature vs. nurture: Evidence for social learning of conflict behaviour in grizzly bears. *PLoS ONE* **11**(11): e0165425.

Webb, S. M., R. B. Anderson, D. L. Manzer, B. Abercrombie, B. Bildson, M. A. Scrafford, and M. S. Boyce. 2016. Distribution of female wolverines relative to snow cover, Alberta, Canada. *J. Wildl. Manage.* **80**(8):1461–1470.

Benz, R., M. S. Boyce, H. Thurfjell, D. G. Paton, M. Musiani, C. Dormann, and S. Ciuti. 2016. Dispersal ecology informs design of large-scale wildlife corridors. *PLoS ONE* **11**(9): e0162989.

Morehouse, A., and M. S. Boyce. 2016. Grizzly bears without borders: spatially explicit capture recapture in southwestern Alberta. *J. Wildl. Manage.* **80**(7):1152–1166 [Featured article]

Boyce, M. S., A. Derocher, and D. L. Garshelis. 2016. *Scientific review of grizzly bear harvest management system in British Columbia.* British Columbia Ministry of Forests, Lands and Natural Resource Operations, Victoria. 56 pp.

Bacon, M. M., and M. S. Boyce. 2016. Landscape of fear for naïve prey: ungulates flee protected area to avoid a re-established predator. *Can. Wildl. Biol. Manage*. 5(1):1–9.

Cristescu, B., G. B. Stenhouse, and M. S. Boyce. 2016. Large omnivore movements in response to surface mining and mine reclamation. *Scientific Reports* **6**:19177, doi: 10.1038/ srep19177.

Avgar, T., J. R. Potts, M. A. Lewis, and M. S. Boyce. 2016. Integrated step selection analysis: bridging the gap between resource selection and animal movement. *Methods Ecol. Evol*. **7**(5):619–630.

Boyce, M. S., C. J. Johnson, E. H. Merrill, S. E. Nielsen, E. J. Solberg, and B. Van Moorter. 2016. Can habitat selection predict abundance? *J. Anim. Ecol*. **85**:11–20.

Seidel, D., and M. S. Boyce. 2016. Varied tastes: home range implications of foraging patch selection. *Oikos* **125**:39–49.

Christie, K., W. F. Jensen, J. H. Schmidt, and M. S. Boyce. 2015. Long-term changes in pronghorn abundance linked to climate and oil development in North Dakota. *Biol. Conserv*. **192**:445–453.

Ciuti, S., W. Jensen, S. E. Nielsen, and M. S. Boyce. 2015. Predicting mule deer recruitment from climate oscillations for harvest management on the northern Great Plains. *J. Wildl. Manage.* **79**(8):1226–1238.

Morrison, C. D., M. S. Boyce, and S. E. Nielsen. 2015. Space-use, movement and dispersal of sub-adult cougars in a geographically isolated population. *PeerJ* **3**:e1118; doi: 10.7717/peerj.1118.

Cristescu, B., G. B. Stenhouse, and M. S. Boyce. 2015. Grizzly bear diet shifting on reclaimed lands. *Global Ecol. & Conserv.* **4**: 207-220.

Seidel, D., and M. S. Boyce. 2015. Patch-use dynamics by a large herbivore. *Movement Ecol.* **3**:7 doi: 10.1186/s40462-015-0035-8.

Proctor, M. F., S. E. Nielsen, W. F. Kasworm, C. Servheen, T. G. Radandt, A. G. MacHutchon, and M. S. Boyce. 2015. Grizzly bear connectivity mapping in the Canada-US trans-border region. *J. Wildl. Manage*. **79**:544-558. doi: 10.1002/jwmg.862. Featured paper.

Cristescu, B., G. B. Stenhouse, and M. S. Boyce. 2015. Predicting multiple behaviors from GPS radiocollar cluster data. *Behav. Ecol.* **26**(2): 452–464. Cover photo.

Morrison, C., M. S. Boyce, S. E. Nielsen, and M. M. Bacon. 2014. Habitat selection of a re-colonized cougar population in response to seasonal fluctuations of human activity. *J. Wildl. Manage.* **78**(8):1394-1403.

Knopff, A. A., K. H. Knopff, M. S. Boyce, and C. C. St. Clair. 2014. Flexible habitat selection by cougars in response to anthropogenic development. *Biol. Conserv*. **178**:136–145.

Ensing, E. P., S. Ciuti, F. A. L. M. de Wijs, D. H. Lentferink, A. ten Hoedt, M. S. Boyce, and R. A. Hut. 2014. GPS based daily activity patterns in European red deer and North American elk (*Cervus elaphus*): indication for a weak circadian clock in ungulates. *PLoS ONE* **9**(9):e106997.

Pruvot, M., D. Seidel, S. Kutz, M. Musiani, A. Massolo, M. S. Boyce, and K. Orsel. 2014. What attracts elk onto cattle pasture? Implications for inter-species disease transmission. *Prev. Vet. Med.* **117**(2):326-339.

Erickson, M. E., C. Found-Jackson, and M. S. Boyce. 2014. Using latent selection difference to model persistence in a declining population. *PLoS ONE* **9**(5): e98126. doi:10.1371/journal.pone.0098126.

Killeen, J., H. Thurfjell, S. Ciuti, D. Paton, M. Musiani, and M. S. Boyce. 2014. Habitat selection during ungulate dispersal at broad and fine scale with implications for conservation management. *Movement Ecol*. **2**:15 (doi:10.1186/s40462-014-0015-4).

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CONTRACTS & GRANTS

Funded Projects as PI

Grant Completed	Amount Awarded	Funding Agency
Lynx cycles and barriers: dispersal versus climate change in flat-lining populations		
03/31/2011	$27,500	Alberta Conservation Association
03/31/2011	$20,000	MEC c/o Red Deer Naturalists
04/30/2013	$10,000	Alberta Biodiversity Monitoring Institute
Grizzly bear response to open-pit mining: implications for management and conservation		
03/31/2011	$4,700	International Assoc. for Bear Research & Management
03/31/2011	$2,500	AB Sports Recreation Parks & Wildlife Foundation
03/31/2011	$31,000	Alberta Conservation Association
04/30/2011	$4,400	Canadian Wildlife Federation
12/02/2011	$6,000	TD Friends of the Environment Foundation
03/31/2012	$2,000	Safari Club International NAB – Hunting Heritage Fund
ICCB 2010 (24th International Congress for Conservation Biology)		
03/03/2011	$99,289	ICCB Registration account
12/31/2013	$90,066	Carbon tax project account
02/03/2011	$234,335	Cash sponsor support (34 sponsors)
02/03/2011	$191,079	In-kind sponsor support
Cougar distribution and prey selection SW Alberta		
03/31/2011	$32,700	Alberta Conservation Association
09/30/2011	$3,000	AB Sports Recreation Parks & Wildlife Foundation
09/30/2012	$1,500	AB Sports Recreation Parks & Wildlife Foundation
Space use of urban deer		
04/30/2011	$2,134	AB Sports Recreation Parks & Wildlife Foundation
03/31/2012	$2,000	Alberta Conservation Association
Ecology of cougar, human and prey interactions in the Cypress Hills		
12/31/2011	$3,000	AB Sports Recreation Parks & Wildlife Foundation
03/31/2012	$20,000	SK Environment & Resource Management Fish &

		Wildlife Division Fund
03/31/2012	$2,000	Safari Club International NAB – Hunting Heritage Fund
03/31/2012	$2,500	Cypress Hills Cottage Assoc Donation
Home range development in elk		
04/22/2013	$9,500	TD Friends of the Environment Foundation
03/31/2013	$5,325	Safari Club International NAB – Hunting Heritage Fund
03/31/2012	$21,500	Alberta Conservation Association
Human access management in central-western Alberta: implications for grizzly bears		
03/31/2013	$5,200	Safari Club International NAB – Hunting Heritage Fund
03/31/2013	$2,000	AB Sports Recreation Parks & Wildlife Foundation
03/31/2013	$33,050	Alberta Conservation Association
03/31/2013	$14,000	AB Fish & Game Assoc. - Minister's Special License
04/22/2013	$10,200	TD Friends of the Environment Foundation
03/31/2014	$5,000	Safari Club International NAB – Hunting Heritage Fund
03/31/2014	$35,000	ATPR
03/31/2014	$3,300	AB Sports Recreation Parks & Wildlife Foundation
03/31/2014	$25,000	Alberta Conservation Association
06/04/2014	$10,600	TD Friends of the Environment Foundation
03/31/2015	$3,650	Safari Club International NAB – Hunting Heritage Fund
03/31/2015	$30,000	Alberta Conservation Association
03/31/2015	$10,115	International Assoc. for Bear Research & Management
08/31/2015	$9,300	AB Fish & Game Assoc. - Minister's Special License
Efficacy of intercept feeding in reducing spring grizzly bear-ranching conflicts		
03/31/2013	$3,480	Safari Club International NAB – Hunting Heritage Fund
04/22/2013	$5,000	TD Friends of the Environment Foundation
03/31/2014	$7,250	International Assoc. for Bear Research & Management
03/31/2014	$3,000	Safari Club International NAB – Hunting Heritage Fund
06/30/2014	$4,500	AB Sports Recreation Parks & Wildlife Foundation
03/31/2015	$6,560	International Assoc. for Bear Research & Management
03/31/2015	$4,100	Safari Club International NAB – Hunting Heritage Fund
Restoring grizzly bear populations to southern Alberta: Monitoring and conflict resolution		
02/28/2014	$12,000	Environment Canada - Science Horizons
11/25/2014	$12,000	Environment Canada - Science Horizons
03/31/2013	$9,020	AB Conservation Association – Grants in Biodiversity
03/31/2014	$19,400	AB Conservation Collaboration – Minister's Special License Program
05/31/2014	$24,393	International Assoc. for Bear Research & Management
06/04/2014	$5,000	TD Friends of the Environment Foundation
03/31/2015	$12,500	AB Fish & Game Assoc. - Minister's Special License
05/31/2015	$26,788	International Assoc. for Bear Research & Management
06/30/2015	$25,240	Safari Club International Foundation
11/01/2014	$177,000	Waterton Biosphere Reserve Association c/o Alberta Innovates
Grizzly Bear Monitoring Project (GBMP)		
06/2013 - 06/2014	$25,000	Disney
04/2013 - 03/2014	$10,000	Nature Conservancy Canada Donations
2014 - 2015	$70,000	Royal Dutch Shell Waterton Gas Plant
2012 - 2014	$12,000	Shell Environment

11/2012	$10,000	CPAWS Donation
Effects of industry on wolverine ecology in the boreal forest of northern Alberta		
03/31/2014	$3,985	Safari Club International NAB – Hunting Heritage Fund
03/31/2014	$19,500	Wildlife Conservation Society of Canada
03/31/2014	$4,893	AB Sports Recreation Parks & Wildlife Foundation
03/31/2014	$20,000	Alberta Conservation Association
06/04/2014	$9,845	TD Friends of the Environment Foundation
01/15/2015	$9,300	Wildlife Conservation Society of Canada
03/31/2015	$75,000	Alberta Conservation Association
07/31/2015	$5,000	AB Fish & Game Assoc. - Minister's Special License
07/31/2015	$4,000	Safari Club International NAB – Hunting Heritage Fund
07/31/2015	$17,575	The Wolverine Foundation
10/31/2015	$11,140	TD Friends of the Environment Fund
12/31/2015	$10,000	Wildlife Conservation Society of Canada
03/31/2016	$68,138	Alberta Conservation Association
05/31/2016	$4,000	Safari Club International NAB – Hunting Heritage Fund
07/2013 - 03/2015	$55,000	Dene Tha First Nations Donation
2014-2016	$45,000	Husky Oil Operations Ltd. Donation
03/31/2016	$12,000	TD Friends of the Environment Fund
04/30/2017	$6,275	The Wolverine Foundation
Access management for wildlife conservation		
05/04/2014	$834,306	Shell's Contribution Can/NSERC CRD
05/04/2014	$699,510	NSERC Collaborative Research & Development Grants
An evaluation of historical mule deer fawn recruitment in North Dakota		
06/30/2014	$38,892	ND Game & Fish Department
Response by elk to vehicle disturbance on winter range		
12/31/2015	$3,600	AB Fish & Game Assoc. - Minister's Special License
12/31/2015	$3,000	Safari Club International NAB – Hunting Heritage Fund
Analysis of bighorn sheep data from Alberta Environment and Parks		
12/31/2015	$4,800	Alberta Professional Outfitters Society
A retrospective analysis of Pronghorn fawn recruitment and demographic data in North Dakota		
12/31/2015	$59,092	ND Game & Fish Department
Hunting for sustainability: Using bear rubs to monitor black bear populations in southwestern Alberta		
03/31/2016	$4,500	Safari Club International NAB – Hunting Heritage Fund
03/31/2016	$15,000	AB Fish & Game Assoc. - Minister's Special License
03/31/2016	$25,000	Alberta Conservation Association
10/01/2016	$10,000	Waterton Biosphere Reserve Association
09/30/2016	$9,500	Alberta Professional Outfitters Society
03/31/2017	$11,300	Alberta Conservation Association
03/13/2017	$6,000	International Assoc. for Bear Research & Management
03/31/2017	$4,150	AB Fish & Game Assoc. - Minister's Special License
Evaluating the efficacy of predator management and nesting structures for duck management in AB		
06/30/2017	$30,353	Delta Waterfowl Foundation
03/31/2017	$7,100	AB Fish & Game Assoc. - Minister's Special License
12/31/2017	$15,000	Mitacs
03/31/2018	$2,500	Safari Club International NAB – Hunting Heritage Fund
Ecology, density, and distribution of sitatunga in central Uganda		
03/31/2016	$2,500	Safari Club International NAB – Hunting Heritage Fund

07/31/2016	$24,911	Dallas Safari Club
10/31/2016	$6,540	Safari Club International - San Diego Chapter
12/23/2017	$15,000	Mitacs
11/01/2017	$26,311	Dallas Safari Club
06/30/2017	$3,000	Safari Club International NAB – Hunting Heritage Fund
03/31/2018	$3,000	Safari Club International NAB – Hunting Heritage Fund
Cougar project in Cadomin, Alberta		
08/31/2018	$40,000	Wild Sheep Foundation of Alberta
03/31/2019	$15,000	AB Conservation Association – Grants in Biodiversity
03/31/2018	$9,000	Safari Club International NAB – Hunting Heritage Fund
Evaluating alternate elk harvest strategies in SW Alberta		
03/31/2018	$7,650	Alberta Conservation Association
03/31/2018	$3,500	Safari Club International NAB – Hunting Heritage Fund
Qamanirjuaq barren-ground caribou habitat use and population ecology		
06/30/2017	$4,000	World Wildlife Fund - Canada
Wildlife in an Increasingly Variable World		
03/31/2016	$447,600	NSERC – Discovery Grants Program
Habitats drive population biology		
03/31/2017	$26,000	NSERC – Discovery Grants Program
Spatial and Temporal Variability Influences on Ecology and Conservation		
03/31/2022	$220,000	NSERC – Discovery Grants Program
Grazing practices influence on carbon sequestration and storage		
03/31/2021	$2,623,444	Agriculture Green-House Gas Program

PROFESSIONAL AFFILIATIONS AND ACTIVITIES

Memberships in professional societies

American Society of Mammalogists (life member).
Canadian Society for Ecology and Evolution.
Ecological Society of America.
Gamma Sigma Delta (honorary).
Phi Kappa Phi (honorary).
Royal Society of Canada; fellow, 2014.
Sigma Xi (associate member 1975, full member 1978, Univ. Alberta Chapter 2000).
Society for Conservation Biology.
The Wildlife Society (Certified Wildlife Biologist, 2000; Fellow, 2012).
Wild Sheep Foundation (life member, 2003).
Willmore Wilderness Foundation (life member, 2007).

Editor-in-Chief: *Journal of Wildlife Management*, 1995-1997.

Editor: *Ecology* and *Ecological Monographs*, 2001-2006.

Associate Editor: *I.M.A. Journal of Mathematics Applied in Medicine and Biology*, 1983-1994.

Associate Editor: *Journal of Wildlife Management*, 2017.

Editorial Board: *Environmental Conservation*, 2007-2010. *Oxford Bibliographies in Ecology*, 2010-present. *Animal Biotelemetry*, 2012-present.

Academic Editor: *PLoS ONE*, 2010-present.

PROFESSIONAL SERVICES (last 5 yrs)

Organized symposium on "Uncertainty in ecology and conservation" for the Canadian Society for Ecology and Evolution and Canadian Section of The Wildlife Society. Victoria, British Columbia, 2017 May 8.
Past-president, Canadian Section of TheWildlife Society, July 2016-May 2017.
President, Canadian Section of The Wildlife Society, March 2015-July 2016.
Program Chair, The Wildlife Society Annual Conference, Winnipeg, October 2015.
Organized symposium on "Movement models to resource selection functions" for the Annual Conference of The Wildlife Society, Winnipeg, October 2015.
Organized symposium on "Understanding individuals to conserve populations" for the Annual Conference of the Canadian Society for Ecology and Evolution, 2015 May 24.
Workshop on Resource Selection Functions, Saskatchewan Chapter of The Wildlife Society, Saskatoon, 2015 March 13.
Banting Postdoctoral Fellowships Review Committee, NSERC, 2011-2014.
Board of Directors, North American Section, Society for Conservation Biology, 2009-present.
Director, Northern Alberta Chapter of the Safari Club International, 2007-present.
Alberta Conservation Association, Board of Directors, 2002-present.
Chair, Operation Standards Review Committee, Board of Directors, Alberta Conservation Association, 2002-present.

INVITED PRESENTATIONS (last 5yrs)

2017, "Predator-prey systems: the wolves in Yellowstone," Royal Society of Victoria, Melbourne, Australia, September 21.
2017, "Topics in non-linear dynamics in population ecology," Quantitative and Applied Ecology (QAEco), School of Biological Sciences, University of Melbourne, Australia, August 17.
2017, "Habitat selection by mammals," Symposium on Telemetry Methods, International Mammalogical Congress, Perth, Australia, July 11.
2017, "Natural selection for life histories in seasonal environments," Symposium on Ecological and Evolutionary Dynamics in Fluctuating Environments for the Canadian Society for Ecology and Evolution, Victoria, BC, May 8.
2016, "Species at risk in Alberta," Inside Education, Edmonton, September 29.
2016, "Neglected but fundamental: 5 understudied topics in population biology," Distinguished Ecologist Lecture, Colorado State University, April 22.
2016, "North America's Energy Policy," Distinguished Ecologist Lecture, Colorado State University, April 21.
2016, "Compensation and density dependence," Invited Keynote Presentation. Predator-prey Conference, Columbia Mountains Institute, Revelstoke, BC, April 5.
2016, "Neglected but fundamental: 5 understudied topics in population biology," Mathematical Biology Seminar, University of Alberta, March 7.

2015, "Spatial ecology meets population biology," Invited Symposium Presentation, Canadian Society for Ecology and Evolution, Saskatoon, May 22.
2015, "Black bears on the tangled bank," Invited Symposium Presentation, Canadian Society for Ecology and Evolution, Saskatoon, May 24.
2015, "Optimizing cervid harvests in variable environments," Plenary address, Western States and Provinces Deer and Elk Conference, Canmore, May 13.
2015, "Canada's Energy Policy, The Urgent Need for Science," Plenary address, Alberta Chapter of The Wildlife Society, Edmonton, March 21.
2015, "Estimating resource selection functions in R," AGM of the Canadian Section of The Wildlife Society, Saskatoon, March 13.
2014, "Canada's Energy Policy: The Urgent Need for Science," Royal Society of Canada, Quebec City, November 20.
2014, "Selection functions: statistics, interpretations, and applications," Webinar for the Alberta Conservation Association, May 12.
2014, "Trophic cascades in Yellowstone," Plenary Address, Alaska Chapter of The Wildlife Society, Anchorage, April 1.
2014, "Workshop on resource selection functions," Alaska Chapter of The Wildlife Society, Anchorage, March 31.
2014, "Does fear reduce effects of ungulates on vegetation?" Gordon Conference on Predator-Prey Interactions, Ventura, California, January 8.
2013, "Moving into the digital age: a moose app for citizen science among hunters," Canadian Section of The Wildlife Society, Symposium on Citizen Science, Canmore, Alberta, March 9.
2013, "Selection functions: statistics, interpretations, and applications," Webinar for the Canadian Section of The Wildlife Society, January 25.
2013, "Selection, occupancy, and persistence," Morrison Lecture, Stanford University, Jan 16.
2012, "Wolf-caused Trophic Cascades in Yellowstone: Torrent or Trickle?" Symposium at The Wildlife Society Annual Conference, Portland, October 19.
2012, "Critical habitats for the critically endangered Greater Sage-Grouse," Plenary Address, CONFOR West, Banff, February 3.

CONTRIBUTED PAPERS (recent)

2016, "Science and bighorn management." Alberta Chapter of The Wildlife Society, Drumheller (March 5).
2015, "Canada's energy policy: the urgent need for science." Canadian Section of The Wildlife Society, Saskatoon, Saskatchewan (March 14).
2014, "Are terrestrial trophic cascades limited to parks and protected areas?" Alberta Chapter of The Wildlife Society, Jasper, Alberta. (March 8).
2014, "Conflicting views on trophic cascades in Yellowstone," Canadian Section of The Wildlife Society, Universite Laval, Quebec City, Quebec (March 29).
2012, "Managing Moose Populations by the Seat of Your Pants," Poster presentation, The Wildlife Society, Portland (Oct 19).
2012, "Managing Moose Populations by the Seat of Your Pants," National Fish and Wildlife Conservation Congress, Ottawa (May 29).

PUBLIC SERVICE/POPULAR PRESENTATIONS (recent)

2017, "Canada's energy policy: the urgent need for science," Mayfield Rotary, Edmonton (January 4).
2016, "Canada's energy policy: the urgent need for science," Edmonton South Rotary Club (November 23).
2016, "Energy development and species at risk in Canada," Sunrise Rotary Club, Fort Edmonton (September 30).
2016, "Moose app for moose management in Alberta," Strathcona Rotary Club, Edmonton (September 6).
2016, "Bighorn management in Alberta," Safari Club International, Edmonton (January).
2015, "Licenced hunting and trapping in Canada: funding for management and research," House of Commons Standing Committee on Environment and Sustainable Development, Ottawa (March 31).
2013, "Bighorn genetics and the effects of selective harvest," Wild Sheep Foundation, Red Deer, Alberta (March)

COMMITTEES (recent)

2016-2017, Search committee, Fisheries biologist, Dept. Biological Sciences, Univ. Alberta.
2015-present. Alberta Game Policy Advisory Council, Alberta Environment & Parks.
2014-2015, Alberta Game Management Advisory Group, Alberta Environment & Parks.
2015-2016, Grizzly bear harvest policy review, British Columbia Department of Environment.
2013-2014, Search Committee for Campus Alberta Innovates Program (CAIP) Chair, University of Alberta.
2012, Chair, Search Committee for Editor-in-Chief, *Conservation Biology*, Society for Conservation Biology.
2007-present, Conservation Committee, Alberta Chapter The Wildlife Society.

CURRICULUM VITAE

JENNIFER K. FREY

PRESENT ADDRESSES:

Department of Fish, Wildlife, and Conservation Ecology
New Mexico State University
P.O. Box 0003, MSC 4901
Las Cruces, New Mexico 88130

Phone: (575) 640-9782
Email: jfrey@nmsu.edu
Web: http://web.nmsu.edu/~jfrey/

Frey Biological Research
PO Box 294
Radium Springs, NM 88054

Phone: (575) 640-9782
Email: Frey_B_R@fastwave.biz

DEGREES:

Ph.D., Biology. University of New Mexico, Albuquerque, New Mexico. Major professor: Terry L. Yates. Dissertation title: Testing among modes of allopatric speciation: a hypothetico-deductive approach. (b) (6)
M.S., Biology. Emporia State University, Emporia, Kansas. Major professor: Dwight W. Moore. Thesis title: Morphologic variation in the Mexican vole (*Microtus mexicanus*). (b) (6)
B.S., Biology (emphasis in Zoology). Emporia State University, Emporia, Kansas. (b) (6)

WILDLIFE CONSULTING COMPANY

Owner, Frey Biological Research. Radium Springs, New Mexico. 2002-present.

FACULTY POSITIONS:

College Professor and Member of the Graduate Faculty. Department of Fish, Wildlife and Conservation Ecology (FWCE), New Mexico State University (NMSU). 2016 – present.
College Associate Professor and Member of the Graduate Faculty. FWCE, NMSU. 2008 – 2016.
College Assistant Professor and Member of the Graduate Faculty. FWCE, MMSU. August 2002 – 2008.
Assistant Professor. Department of Biology, Eastern New Mexico University (ENMU). 1998-2002.
Research Assistant Professor. Department of Biology, University of New Mexico (UNM). 1995-1998.
Postdoctoral Research Associate. Department of Biology, UNM. 1994-1995.

MUSEUM AND CURATORIAL POSITIONS:

Curator. Wildlife Museum, Department of Fish, Wildlife & Conservation Ecology, NMSU. 2014 - present.
Acting Curator. Wildlife Museum, Department of Fishery and Wildlife Sciences, NMSU. September 2003 - 2013.
Adjunct Curator of Mammals. The Vertebrate Museum, Department of Biology, NMSU. 2003 – present.
Committee Member. Center for Natural History Collections, New Mexico State University. 2008-Present
Research Associate. Mammal Division, Museum of Southwestern Biology (MSB), University of New Mexico. Present
Executive Committee Member. Center for Natural History Collections, New Mexico State University. 2006-2008
Director. Eastern New Mexico University Natural History Museum (ENMUNHM). 1998-2002
Curator of Mammals, Birds, and Frozen Tissue. ENMUNHM. 1998-2002
Board of Trustees, New Mexico Museum of Natural History and Science. 2000-2002
Curatorial Associate. Mammal Division, MSB, UNM. 1994-1998.
Collection Assistant. Frozen Tissues & Biological Materials, MSB. 1990-1994.
Curatorial Assistant. Mammal Division, MSB. 1989-1994.
Curatorial Assistant. Schmidt Museum of Natural History, Emporia State University. 1985-1989

PRE-DOCTORAL PROFESSIONAL POSITIONS:

Allozyme Electrophoresis Laboratory Supervisor. UNM. 1991-1994.
DNA and Karyology Laboratory Supervisor. UNM. 1990, 1992-1994.
Research Assistant. UNM. mtDNA and allozyme variation in the Mexican vole (*Microtus mexicanus*). 1992-1994.
Research Assistantships for Minority High School Students Program Assistant. MSB. Assisted directing student research projects and teaching high school students and teachers. 1993.
Computer Lab Coordinator. Biology Department. UNM. 1993.
Research Assistant. UNM. mtDNA and allozyme variation among migratory races of sandhill crane (*Grus canadensis*). 1990-1991.
Parasitologist. Sevilleta Long-term Ecological Research Site, UNM. 1989.
Fisheries Aid. Kansas Department of Wildlife and Parks, Emporia, Kansas. 1988.
Research Assistant. Emporia State University. Karyotypic relationships among populations of short-tailed shrews (*Blarina*). 1987.
Undergraduate Research Assistant. Emporia State University. Predator avoidance in *Diaptomus* (Crustacea: Copepoda). 1985-1986.

GRADUATE STUDENTS:

- (b) (6)(b) (6) Master's in Environmental Education. Eastern New Mexico University. May 2000.
- (b) (6)(b) (6) Master's thesis title: Island biogeography: Focal species models and their implications for system level relationships. Eastern New Mexico University. May 2002.
- (b) (6)(b) (6) Master's thesis title: Distribution, habitat characteristics, and population demographics of snowshoe hare (*Lepus americanus*) at the extreme southern edge of its geographic range. Eastern New Mexico University. December 2003.
- (b) (6)(b) (6)(b) (6) Master's thesis title: Effects of fuels reduction treatments on mammals in a southwestern mixed coniferous forest. (collaboratively with Jon Boren). New Mexico State University. May 2007.
- (b) (6)(b) (6) Master's thesis title: Mammals of Padre Island National Seashore, Texas. New Mexico State University. May 2008.
- (b) (6)(b) (6)(b) (6) Master's research project topic: Morphologic variation in the gray-footed chipmunk (*Tamias canipes*). New Mexico State University. May 2009.
- (b) (6)(b) (6) Master's thesis title: Elevated surface temperature negatively affects survival of banner-tailed kangaroo rats in the Chihuahuan Desert. (co-advised with Gary Roemer). May 2010.
- (b) (6)(b) (6) . Master's thesis title: Multiple scale habitat selection by a small mammal habitat specialist (*Zapus hudsonius luteus*) in a managed floodplain landscape. May 2012.
- (b) (6)(b) (6)(b) (6) Master's thesis title: Effect of forest insect outbreak on the red squirrel (*Tamiasciurus hudsonicus*) in the Sacramento Mountains, New Mexico. December 2012.
- (b) (6)(b) (6) Master's research project topic: Identification of Limiting Factors for the Restoration of Beavers in Northern New Mexico. New Mexico State University. August 2015.
- (b) (6)(b) (6) Master's thesis topic: Predicting spatial factors associated with cattle depredations by the Mexican wolf (*Canis lupus baileyi*) with recommendations for depredation risk modeling. December 2017.
- (b) (6)(b) (6)(b) (6) Master's thesis topic: Using occupancy and species distribution models to identify the distribution and key habitat features of the Oscura Mountains chipmunk and guide monitoring efforts. December 2017.

GRADUATE COMMITTEES:

- (b) (6)(b) (6) Master's thesis title: Ability of western diamondback rattlesnake (*Crotalus atrox*) and prairie rattlesnake (*Crotalus viridis viridis*) to discern the presence of a potential predator based on chemical cues. ENMU. December 2001
- (b) (6)(b) (6) Non-thesis Master's: Applied Ecology. ENMU. May 2002
- (b) (6)(b) (6) Master's thesis title: Conservation genetics of banner-tailed kangaroo rats (*Dipodomys spectabilis*): a molecular ecology perspective. New Mexico State University. Summer 2006.

GRADUATE COMMITTEES (continued):

- (b) (6)(b) (6) Master's thesis topic. Sequencing of Star protein in the endangered Pecos gambusia. Eastern New Mexico University. December 2006.
- (b) (6)(b) (6)(b) (6) Master's thesis title: Development of conservation priority models for the American Pika (*Ochotona princeps*): Implications for conservation. New Mexico State University. May 2010.
- (b) (6)(b) (6) Response of the endangered salt marsh harvest mouse (*Reithrodontomys raviventris*) to tides. Department of Biology, New Mexico State University. May 2012
- (b) (6)(b) (6) An analysis of factors influencing spatial concordance between ecosystem services and biodiversity. Department of Fish, Wildlife and Conservation Ecology, NMSU. December 2013.
- (b) (6)(b) (6) Boldness and natal dispersal in the brush mouse (Peromyscus boylii). Department of Biology, New Mexico State University. May 2014
- (b) (6)(b) (6)(b) (6) Non-thesis masters. Department of Biology, New Mexico State University. May 2014
- (b) (6)(b) (6)(b) (6)(b) (6) The environmental constraints of Rüppell's (*Vulpes rueppellii*), pale (*V. pallida*), and fennec foxes (*V. zerda*), and golden jackals (*Canis aureus*) within the Termit & Tin Toumma Nature Reserve and Cultural Reserve and an analysis of pale fox food habits. Department of Fish, Wildlife and Conservation Ecology, NMSU. May 2014.
- (b) (6)(b) (6)(b) (6) Characterization of vegetation and small mammal communities in Chihuahuan Desert grasslands. Department of Range and Animal Science, New Mexico State University. December 2014.
- (b) (6)(b) (6) Burrowing owl ecology during the post fledging period in an urban and agricultural interface of southern New Mexico. Department of Fish, Wildlife and Conservation Ecology, NMSU. December 2014.
- (b) (6)(b) (6). Distribution of resources for nectar-feeding bats (*Leptonycteris*) in southwestern New Mexico (non-thesis). Department of Fish, Wildlife and Conservation Ecology, NMSU. May 2016.
- (b) (6)(b) (6) Evaluating the performance of satellite tracked and citizen science derived species distribution models to inform the conservation of band-tailed pigeons (*Patagioenas fasciata*). Department of Fish, Wildlife and Conservation Ecology, NMSU. May 2017.
- (b) (6)(b) (6). Distribution and niche partitioning of *Leptonycteris* bats. Department of Fish, Wildlife and Conservation Ecology, NMSU. Current.
- (b) (6)(b) (6) Influence of natural and anthropogenic disturbances on multi-scale black bear (*Ursus americanus*) habitat selection in the Jemez Mountains, New Mexico. Department of Fish, Wildlife and Conservation Ecology, NMSU. Current
- (b) (6)(b) (6). Differential distribution patterns and germination rates of zoochorous dispersed one-seed juniper (*Juniperus monosperma)* seeds. Department of Range and Animal Science, New Mexico State University. Current
- (b) (6)(b) (6). Diet of long-nosed bats (*Leptonycteris*) in New Mexico. Department of Fish, Wildlife and Conservation Ecology, NMSU. Current

UNDERGRADUATE SENIOR HONORS THESIS STUDENT

- (b) (6)(b) (6)(b) (6) Distribution and habitat modeling of the white-nosed coati (*Nasua narica*) in New Mexico. Howard Hughes Medical Institute, Undergraduate Research Scholars Program, New Mexico State University. December 2010.

CAREER STUDENT MENTORING:

Educational Coordinator. New Mexico-Puerto Rico Natural Resource Career Track Program, New Mexico State University. 2012-2013

DISTANCE EDUCATION PROGRAM DEVELOPMENT:

Distance Education Program Developer. Department of Fish, Wildlife and Conservation Ecology, New Mexico State University. 2017-current

TEACHING EXPERIENCE:

New Mexico State University

Undergraduate:

- Introduction to Natural Resources Management; a distance education course (often taught concurrently on NMSU main and branch campuses; Spring 2003-Fall 2004, Fall 2005-2015)
- Contemporary Issues in Wildlife and Natural Resources Management (Fall 2016)
- Ecology and Management of Southwest Ecosystems (Summer 2012)
- Principles of Fish and Wildlife Management (Spring 2011, 2013-2017)
- Wildlife Ecology (Fall 2011)
- Museum Methods (Spring 2006)
- Undergraduate Problems

Graduate/Undergraduate:

- Systems Ecology in Wildlife Management and Laboratory (Fall 2002)
- Advanced Techniques for the Study of Mammalian Diversity (Spring 2004)
- Nongame Wildlife Conservation and Management (Spring 2004)
- Wildlife Damage Management (Spring 2011-2017)
- The Natural History Museum in Modern Society (Spring 2014)
- Wildlife Museum Internship (Fall 2014, Spring/Fall 2016)
- Independent Studies (Graduate Problems, Non-thesis Project, Master's thesis)

Eastern New Mexico University (exclusive of special problems, thesis, etc)

Undergraduate:

- Wildlife Biology (Fall 1998, Spring 1999)
- Introduction to Wildlife and Fisheries Science (each semester 1999-2002)
- Vertebrate Zoology/Vertebrate Zoology Laboratory (Spring 2002)

Graduate/Undergraduate:

- Mammalogy/Mammalogy Laboratory (annual 1998-2001)
- Ornithology/Ornithology Laboratory (annual 1999-2002)

- Wildlife Management/ Wildlife Management Laboratory (annual 1998-2001)

Graduate:

- Biogeography (Spring 1999, Fall 2000)
- Conservation Biology (Fall 1999, 2001)
- Biological Literature (Fall 2001)

University of New Mexico (exclusive of special problems, thesis, etc)

- Mammalogy, lecturer and laboratory assistant
- General Biology Laboratory, instructor
- Biology for Health Related Sciences Laboratory, instructor

Emporia State University

- Ornithology, teaching and laboratory assistant
- General Biology Laboratory, instructor
- Field and Lab Biology, teaching and laboratory assistant

CURRENT UNIVERSITY SERVICE

- College of Agriculture and Home Economics, Distance Education Committee
- Dept. Fish, Wildlife, Conservation Ecology, Curriculum Committee
- Dept. Fish, Wildlife, Conservation Ecology, Curator of Wildlife Museum

PRIOR UNIVERSITY SERVICE (Partial Listing):

- Dept. Fish, Wildlife, Conservation Ecology, Assessment Committee (NMSU 2015-2017)
- College of Agriculture and Home Economics, Assessment Liason (NMSU 2015-2017
- University-wide, Advocates for Scholarly Teaching Committee (NMSU 2017)
- Dept. Fish, Wildlife, Conservation Ecology, Museum Committee, NMSU 2008-2013
- Dept. Fishery & Wildlife Sciences, Graduate Committee, NMSU
- Dept. Fishery & Wildlife Sciences, Freshman advisor, NMSU
- NMSU, Center for Natural History Collections, Executive Committee
- Director of the Natural History Museum, ENMU
- Revised Wildlife and Fishery undergraduate curriculum, ENMU
- Developed graduate program in Applied Ecology, ENMU
- Faculty advisor to pre-professional Fish and Wildlife Club, ENMU
- Numerous faculty search committees, ENMU
- President - Biology Graduate Student Association, UNM.
- Graduate Policy Committee, Department of Biology, UNM.
- Graduate Research Allocations Committee, Dept. Biology, UNM.

CURRENT PROFESSIONAL SERVICE:

- Middle Rio Grande Project, subject matter experts group for New Mexico meadow jumping mouse
- Conservation Committee, Southwestern Association of Naturalists
- Riparian Rodent Advisory Committee, New Mexico Department of Game and Fish

- Peer Reviewer for: National Science Foundation, Journal of Mammalogy, Diversity and Distributions, Journal of Biogeography, Forest Ecology & Management, Global Change Biology, Canadian Journal of Zoology, Ecological Applications, Southwestern Naturalist, Western North American Naturalist; Canadian Field Naturalist; Comparative Medicine;

PRIOR PROFESSIONAL SERVICE (Partial Listing):

- Associate Editor, The Southwestern Naturalist (2008-2015)
- New Mexico Chapter of The Wildlife Society; Local Committee for 2015 meeting
- Share With Wildlife Task Force, New Mexico Department of Game and Fish
- Board of Directors, New Mexico Chapter of the Wildlife Society
- Scientific advisor groups: NM Bat Working Group; NM River Otter; NM Beaver
- Forest Service Region 3 Mammal Sensitive Species Experts Group
- Board of Trustees, New Mexico Museum of Natural History and Science.
- IUCN, Species Survival Commission, Rodent Specialist Group for North America.
- Board of Directors, Southwestern Association of Naturalists.
- Chair, Conservation Committee, Southwestern Association of Naturalists.
- Resolutions Committee, American Society of Mammalogists.
- Education and Graduate Student Committee, American Society of Mammalogists.
- Committee on Women and Minority Issues, American Society of Mammalogists.
- Secretary - Zoology Section, Southwestern and Rocky Mountain Division, AAAS.

PROFESSIONAL SOCIETY AFFILIATIONS:

- American Society of Mammalogists
- International Biogeography Society
- The Wildlife Society
    - Southwest Section
    - New Mexico Chapter
- Southwestern Association of Naturalists
    - Conservation Committee

HONORS AND AWARDS:

Faculty Merit Award. For excellence in teaching, scholarship and service. Eastern New Mexico University. 2001

James H. Nakano Citation Award. For the outstanding scientific paper published in 1994. National Center for Infectious Diseases and Centers for Disease Control and Prevention, 1995.

Albert R. and Alma E. Shadle Fellowship in Mammalogy. The highest annual award given to a single graduate student or recent PhD graduate who has demonstrated a productive and important role in professional mammalogy. American Society of Mammalogists and the Buffalo Foundation, 1992.

University of New Mexico Graduate Achievement Award. Award presented to the two most outstanding graduate students at the University of New Mexico, 1991.

Robert I. Larus Award. For the outstanding student paper presented in 1990. American Association for the Advancement of Science, 1990.

Outstanding Presentation Award. For an outstanding graduate student research paper competition. Southwestern and Rocky Mountain Division, American Association for the Advancement of Science, 1988.

Emporia State University Graduate Achievement Award. Award presented to the outstanding graduate student at Emporia State University, 1987, 1988.

GRANTS AND CONTRACTS (Total = $ 2,346,819^{oo}):

- $32,199 – New Mexico Department of Game and Fish. Distribution, abundance, and habitat selection of the Penasco least chipmunk (*Tamias minimus atristriatus*). 2017
- $ 61,925 - White Sands Missile Range. Oscura Mountain chipmunk monitoring. 2016
- $ 19,772 – New Mexico Department of Game and Fish. Survey for the Penasco least chipmunk (*Tamias minimus atristriatus*). 2015
- $ 62,125 – White Sands Missile Range. Oscura Mountain chipmunk monitoring. 2015
- $ 7,500 - White Sands Missile Range. Survey for meadow jumping mouse (*Zapus hudsonius luteus*). 2015
- $ 59,562 – White Sands Missile Range. Oscura Mountain chipmunk monitoring. 2014
- $ 50,500 – White Sands Missile Range. Survey for meadow jumping mouse (*Zapus hudsonius luteus*). 2014
- $ 6,246 – Marron and Associates. Survey for the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*) at Coyote Creek, Mora County, New Mexico. 2014
- $ 4,000 – The Nature Conservancy. Evaluation of flow-ecology relationships for mammals in the Gila River. 2013-2014.
- $ 10,412 – Bureau of Land Management. Survey for meadow jumping mouse (*Zapus hudsonius luteus*) on the Sacramento River. 2013
- $ 6,450 – New Mexico Department of Game and Fish. Draft survey protocol for the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*). 2012-2013
- $ 19,688 –Evaluation of meadow jumping mouse habitat on Middle Rio Grande. Bureau of Reclamation. 2012-2013
- $ 4,803 – Marron and Associates. Survey for the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*) at Coyote Creek, Mora County, New Mexico. 2012
- $ 15,000 – Carson National Forest. New Mexico meadow jumping mouse surveys. 2011
- $ 11,000 – New Mexico Department of Game and Fish, Share with Wildlife. Development of a habitat suitability model for the Organ Mountain chipmunk & jumping mouse survey of Casa Colorado WMA. 2011
- $ 14,000 – New Mexico Department of Game and Fish, Share with Wildlife. Development of non-invasive monitoring protocols for the Organ Mountain chipmunk. 2010
- $19,924 – U.S. Fish and Wildlife Service. Using pocket gophers to enhance habitat for the endangered Sacramento prickly poppy. 2010.
- $ 4,000 – Review of ecosystem services of the American beaver. WildEarth Guardians. 2010.
- $ 4,999 – Colorado Division of Wildlife. New Mexican meadow jumping mouse survey. 2010
- $ 38,880 – San Juan Public Lands. New Mexican meadow jumping mouse survey.

2009-2010

- $ 25,571 – New Mexico Department of Game and Fish, Share with Wildlife. Cool season activity of the meadow jumping mouse in the Middle Rio Grande (with G. Wright). 2009-2011
- $ 22,647 – Carson National Forest. Abert's squirrel monitoring, 2009. 2009
- $ 25,239 – Carson National Forest. Red squirrel monitoring, 2008. 2009
- $ 20,000 – New Mexico Department of Game and Fish, Share with Wildlife. Montane mammal museum studies. 2008-2010
- $138,807 – U.S. Fish and Wildlife Service/Bureau of Reclamation. Response of the meadow jumping mouse to wetland management in the Middle Rio Grande, New Mexico. 2009-2011.
- $128,948 - Arizona Game and Fish Heritage Grants. Inventory of the meadow jumping mouse in Arizona. 2008-2010.
- $ 21,446 - Carson National Forest. Abert's squirrel monitoring, 2008. 2008
- $ 5,870 – Marron and Associates. Mammal survey of Living Desert Zoo State Park. 2008
- $ 2,500 - Modeling with a keystone indicator species: conservation implications for desert grasslands. T&E Inc. (with Martin Moses and Gary Roemer). 2008-2010
- $ 2,500 – New Mexico State Parks. Mammals of Sugarite Canyon State Park. 2007
- $ 24,000 – New Mexico Department of Game and Fish, Share with Wildlife. Morphological and genetic analysis of *Zapus hudsonius luteus*. 2007
- $ 5,900 – New Mexico Department of Game and Fish. Key to the Rodentia of New Mexico. 2007
- $ 2,500 - Modeling with a keystone indicator species: conservation implications for semi-arid grasslands. T&E Inc. (with Martin Moses and Gary Roemer). 2007-2009
- $ 26,460 – New Mexico Department of Game and Fish. Status of the Peñasco least chipmunk. 2006
- $ 26,037 – Lincoln National Forest. Population assessment of the red squirrel. 2006
- $ 700 – Society for Conservation Biology. Peer-review of US Forest Service species assessments for the hog-nosed skunk and pygmy shrew. 2006
- $ 5,250 – Santa Fe National Forest, Jemez Ranger District. Inventory for the meadow jumping mouse. 2006
- $ 29,820 – New Mexico Department of Game and Fish. Status of the meadow jumping mouse in the Sangre de Cristo Mountains. 2006
- $ 2,000 – New Mexico State Parks. Status of the meadow jumping mouse at Sugarite Canyon State Park. 2006.
- $ 20,053 – Carson National Forest. Abert's squirrel monitoring, 2006. 2006
- $ 5,900 - New Mexico Share with Wildlife: Key to the Rodentia of New Mexico, Part II. 2005-2006.
- $ 10,000 – Desert Southwest Cooperative Ecosystem Studies Unit. Literature review on mammalian carnivore use on islands, coyote telemetry methodology, and biology of islands in the Laguna Madre. (with D. Echols, Padre Island National Seashore). 2006
- $ 2,500 - Modeling with a keystone indicator species: conservation implications for desert grasslands. T&E Inc. (with Kristen Otten and Gary Roemer). 2006-2008
- $ 18,651 – New Mexico Department of Game and Fish. Status survey of the least shrew

(Cryptotis parva). 2005

- $ 19,819 – New Mexico Department of Game and Fish. Status survey of the meadow jumping mouse (*Zapus hudsonius*). 2005
- $ 15,564 – Carson National Forest. Abert's squirrel monitoring, 2005. 2005
- $100,000 – International Arid Lands Consortium: Keystone indicator: a tool for semi-desert grassland conservation. (with Gary Roemer and Eli Geffen). 2005-2007
- $160,636 – National Parks Service: Mammal inventory of Padre Island National Seashore. 2004-2007
- $ 10,352 – National Park Service: Data mining and data entry for Vital Signs Monitoring Plan. (with Don Caccamise). 2004-2005
- $ 17,729 – New Mexico Department of Game and Fish. Status of the endangered Arizona montane vole (*Microtus montanus arizonensis*) in New Mexico. 2004
- $ 7,500 – New Mexico Share with Wildlife: Key to the Rodentia of New Mexico. 2004-2005.
- $ 10,000 – New Mexico Share with Wildlife: Habitat and diet of the threatened New Mexico meadow jumping mouse (*Zapus hudsonius luteus*): a spatial and temporal assessment". (with K. Mohrland and D. Jones). 2004-2205
- $ 26,000 – Carson National Forest. Red squirrel and Abert's squirrel monitoring. 2004.
- $ 46,570 – Carson National Forest. Red squirrel and Abert's squirrel monitoring; small mammal surveys. 2003.
- $ 8,998 – BAE Systems Analytical Solutions, Inc. White Sands Missile Range small mammal voucher specimen preparation and identification. 2003-2005.
- $ 98,000 – National Science Foundation. Center for Natural Resource Analysis within New Mexico Experimental Program to Stimulate Competitive Research (EPSCoR). (J.R. Gosz, A.W. Powell, et al.). I was the PI for the ENMU portion of $ 3 million total award. 2002.
- $ 3,335 – ENMU Research and Faculty Development Committee: Ecological segregation of the mountain cottontail (*Sylvilagus nuttallii*) and the snowshoe hare (*Lepus americanus*). 2001.
- $563,389 – Grand Canyon Monitoring and Research Center, USGS: Inventory and monitoring of terrestrial riparian biological resources in Grand Canyon: an integrative approach. (with M.J.C. Kersley, H. Yard, N. Cobb, D.C. Lightfoot, G. Carpenter, and S.L. Brantley). 2001
- $ 7,500 – USDA Forest Service: Expert's Panel on Grazing Impacts on Southwestern Mammals. 2001
- $ 2,000 – New Mexico Natural Heritage Program: White Sands Missile Range Integrated Natural Resources Management Plan: Mammals. 2000-2001.
- $ 4,979 – Lincoln National Forest, USDA Forest Service and ENMU Research and Faculty Development Committee: Status of the endangered Peñasco least chipmunk (*Tamias minimus atristriatus*). 2000.
- $ 17,000 – New Mexico State Land Office: Geospatially referenced database for sensitive mammal, bird, and plant voucher specimens in the ENMU Natural History Museum. 1999-2000.
- $ 5,500 – New Mexico Department of Game and Fish: Lesser prairie chicken lek surveys. 1999-2001.

- $ 1,991 – ENMU Teaching and Technology Instruction: Radiotelemetry equipment and photographic slides of birds and mammals for classroom instruction. 1999.
- $ 15,000 – U.S. Forest Service, in collaboration with the New Mexico Department of Game and Fish. for Relationships among Southwest mammals and GAP vegetation types for the Biotic Information System of New Mexico (BISON-M). 1998.
- $ 9,981 – Turner Biodiversity Division: Mammal survey of the Fra Cristobal Mountains, Armendariz Ranch, Sierra County, New Mexico. 1998.
- $ 49,249 – Animas Foundation: Effects of reintroduced black-tailed prairie dogs on grassland ecology. (with C. Curtin, D. Lightfoot, G. Carpenter, and A. Henry). 1998.
- $ 3,262 – ENMU Research and Faculty Development Committee: Distribution and habitat preference of white-tailed deer in New Mexico. 1998.
- $ 3,000 – Ski Island Alliance, The Wildlands Project: Data compilation of focal species. 1997.
- $ 17,500 – U.S. Geological Survey, Biological Resources Division: Response of southwestern montane mammal communities to global change. (with T. L. Yates) 1997.
- $ 27,180 – National Science Foundation: Joint U.S.-Mexico Workshop on International Ecology and Biodiversity. (with T. L. Yates and G. Ceballos) 1996.
- $ 11,986 – U.S. Forest Service: Mammal survey of the Negrito Creek watershed, Gila National Forest, Catron Co., New Mexico. 1995.
- $ 12,700 – Arizona Game and Fish Department: Mexican vole (*Microtus mexicanus*) genetic analyses. 1992, 1993.
- $ 2,000 – Albuquerque Community Foundation: Wildlife Rescue, Inc. of New Mexico, (with Francisca C. Bermudez and Elizabeth P. Elliston). 1993.
- $ 900 – Sigma Xi; Biology, UNM; GSA, UNM: Dispersal versus vicariance in southwest montane mammals: genetics of long-tailed vole populations. 1991.
- $ 19,500 – New Mexico Game and Fish Department: Allozyme and mtDNA restriction site variation in sandhill crane (*Grus canadensis*). (with T. L. Yates). 1991.
- $ 500 – GRAC; SRAC; Vice President's Graduate Research Fund, Office of Research, UNM: Historical Biogeography of the Mexican Vole (*Microtus mexicanus*). 1990.
- $ 1,226 – Kansas Department of Wildlife and Parks. For Distribution and habitat analysis of the long-tailed shrew in Kansas. (with D. W. Moore). 1987.

PAPERS PRESENTED AT PROFESSIONAL MEETINGS:

1. **Frey**, **J**. **K**. 1987. Nongeographic variation in the Mexican vole (*Microtus mexicanus*). Kansas Academy of Science.
2. **Frey**, **J**. **K**., and D. W. Moore. 1988. Distribution of *Sorex haydeni* in Kansas. Southwestern and Rocky Mountain Division, American Association for the Advancement of Science. **winner Outstanding Presentation Award**
3. **Frey**, **J**. **K**. 1988. Distribution of Hayden's shrew (*Sorex haydeni*) in Kansas. Kansas Academy of Science.
4. **Frey**, **J**. **K**., and D. W. Moore. 1988. Morphologic variation and systematics of the Mexican vole (*Microtus mexicanus*). Southwestern Association of Naturalists.
5. **Frey**, **J**. **K**., and D. W. Moore. 1988. Distribution of *Sorex haydeni* in Kansas. Prairie States Ecology Conclave.

6. **Frey**, **J**. **K**., and D. W. Moore. 1988. Morphologic variation and systematics of the Mexican vole (*Microtus mexicanus*). American Society of Mammalogists.
7. **Frey**, **J**. **K**., and D. W. Moore. 1989. Geographic variation in the Mexican vole (*Microtus mexicanus*). Southwestern and Rocky Mountain Division, American Association for the Advancement of Science.
8. Moore, D. W., G. Ploskey, and **J**. **K**. **Frey**. 1989. Identification of hybrids between sauger and walleye. Southwestern Association of Naturalists.
9. **Frey**, **J**. **K**. 1990. Fluctuation of a mammalian faunal element in response to climatic change. Southwestern Association of Naturalists.
10. **Frey**, **J**. **K**. 1990. Fluctuation of a mammalian faunal element in response to climatic factors. Southwestern and Rocky Mountain Division, American Association for the Advancement of Science. **winner Robert I. Larus Award-best paper**
11. **Frey**, **J**. **K**. 1990. Fluctuation of a mammalian faunal element in response to climatic change. American Society of Mammalogists.
12. **Frey**, **J**. **K**., and D. W. Moore. 1990. Range expansion of the meadow vole (*Microtus pennsylvanicus*) in Kansas. Kansas Mammalogists.
13. **Frey**, **J**. **K**. 1991. Response of a mammalian faunal element to climatic change. American Association for the Advancement of Science. **invited paper**
14. Gannon, W. L., P. J. Glass, **J**. **K**. **Frey**, and T. L. Yates. 1991. Information retrieval of biological materials at the Museum of Southwestern Biology. American Society of Mammalogists.
15. **Frey**, **J**. **K**. 1992. Evolutionary consequences of modes of peripheral isolate formation under alternative modes of speciation and speciation in frogs of the subgenus *Stombus* (Leptodactylidae: genus *Ceratophrys*). Southwestern Association of Naturalists.
16. **Frey**, **J**. **K**. 1992. Evolutionary consequences of modes of peripheral isolate formation under alternative modes of speciation. American Society of Mammalogists.
17. **Frey**, **J**. **K**. 1993. Testing among modes of allopatric speciation: A hypothetico-deductive approach. American Society of Mammalogists. **invited paper in the plenary session for Shadle Award**
18. **Frey**, **J**. **K**., D. J. Hafner, T. L. Yates, and C. G. Schmitt. 1994. Allozyme and mitochondrial DNA variation in migratory sandhill crane (*Grus canadensis*). Southwestern Association of Naturalists.
19. Bermudez, F. C., and **J**. **K**. **Frey**. 1994. Value and potential of wildlife rehabilitation to the zoological sciences. Southwestern Association of Naturalists.
20. **Frey**, **J**. **K**., and M. J. Patrick. 1994. Endoparasites from the endangered Hualapai vole (*Microtus mogollonensis hualpaiensis*). American Society of Mammalogists.
21. Ditto, A. M. and **J**. **K**. **Frey**. 1995. Species diversity and the peninsular effect: non-volant mammals in Chihuahuan Desert habitat peninsulas. Southwestern Association of Naturalists.
22. **Frey**, **J**. **K**. 1995. Homage to Darwin: On the evolution of domestic breeds of standard chickens. Southwestern Association of Naturalists.
23. **Frey**, **J. K**. 1996. Assessing distribution patterns and predicting climate induced extinctions in southwestern montane mammals. Southwestern Association of Naturalists.
24. Ditto, A. M. and **J**. **K**. **Frey**. 1997. Effects of island attributes on genetic variability in southwestern montane mammals. Southwestern Association of Naturalists.

25. **Frey**, **J**. **K**. 1997. A climate induced pump for increased genetic variability in a peripheral isolate of the montane vole? Southwestern Association of Naturalists.
26. Ditto, A. M. and **J. K**. **Frey**. 1997. Effects of island attributes on genetic variability in southwestern montane mammals. American Society of Mammalogists.
27. **Frey, J.K.** 1998. Conservation considerations for the reintroduction of grizzly bears and wolves in the Southwest. Southwestern Association of Naturalists.
28. Fields, S.P., and **J.K. Frey**. 2000. Squamate reptiles in New Mexico: patterns of species richness and provincialism. Southwestern Association of Naturalists.
29. Kendall, J., and **J.K. Frey**. 2000. Hierarchical relationships of bat communities in Arizona, New Mexico, Utah and Colorado. Southwestern Association of Naturalists.
30. Frey, T.C. and **J.K. Frey**. 2000. Railroads: an alternative mechanism for mesquite invasion in the Southwest. Southwestern Association of Naturalists.
31. Hope, A., and **J.K. Frey**. 2000. Biogeographic models of the distribution of Canadian lynx (*Lynx canadensis*) in the western United States with implications for reintroduction and conservation. Southwestern Association of Naturalists.
32. Edgmon, M.G, L. Castillo, and **J.K. Frey**. 2000. Diversity of avian populations in CRP and native grasslands on the Llano Estacado in the Texas Panhandle. Southwestern Association of Naturalists.
33. Hope, A., and **J.K. Frey**. 2001. Biogeographic models of the distribution of Canadian lynx (*Lynx canadensis*) in the western United States with implications for reintroduction and conservation. Joint Arizona-New Mexico Chapters of The Wildlife Society.
34. Kendall, J., and **J.K. Frey**. 2001. Management implications of hierarchical relationships of southwestern bat communities based on Bailey's ecoregions. Joint Arizona-New Mexico Chapters of The Wildlife Society.
35. Hope, A., and **J.K. Frey**. 2001. Biogeographic nestedness and conservation of boreal mammals in the western contiguous United States. Southwestern Association of Naturalists.
    (*winner Clark Hubbs Award-best poster presentation)
36. Hope, A. and **J.K, Frey.** 2001. Biogeographic nestedness and conservation of boreal mammals in the western contiguous United States. American Society of Mammalogists.
37. Malaney, J. and **J.K. Frey**. 2002. Habitat differentiation between snowshoe hare (*Lepus americanus*) and mountain cottontail (*Sylvilagus nuttallii*) in New Mexico. Joint Arizona-New Mexico Chapters of The Wildlife Society.
38. Malaney, J. and **J.K. Frey**. 2003. Snowshoe hare (*Lepus americanus*) population parameters and habitat preferences in New Mexico. Joint Arizona-New Mexico Chapters of The Wildlife Society.
39. Malaney, J. and **J.K. Frey**. 2003. Primary productivity and habitat quality hypotheses for control of snowshoe hare (*Lepus americanus*) demography: a test at the southern range limit and conclusions for conservation. Southwestern Association of Naturalists.
    (*winner Clark Hubbs Award-best poster presentation)
40. Malaney, J. and **J.K. Frey**. 2003. Primary productivity and habitat quality hypotheses for control of snowshoe hare (*Lepus americanus*) demography: a test at the southern range limit and conclusions for conservation. American Society of Mammalogists.
41. **Frey, J.K.** 2003. Vicariance, not dispersal, is the primary mechanism for the distribution of boreal mammals in the American Southwest. American Society of Mammalogists.

42. Kearsley, M., N. Cobb, H. Yard, D. Lightfoot, G. Carpenter, S. Brantley, and **J.K. Frey**. 2003. Inventory and monitoring of terrestrial riparian biological resources in Grand Canyon: an integrative approach. Ecological Society of America.
43. Malaney, J. and **J.K. Frey**. 2004. Habitat differentiation between snowshoe hare (*Lepus americanus*) and mountain cottontail (*Sylvilagus nuttallii*) at their southern zone of sympatry. Southwestern Association of Naturalists.
    (*winner Clark Hubbs Award-best poster presentation)
44. Mathis, V.L. and **J.K. Frey**. 2005. Geographic variation in relictual populations of red squirrel (*Tamiasciurus hudsonicus*) in the American Southwest. Southwestern Association of Naturalists.
45. Malaney, J. and **J.K. Frey**. 2006. Decline of montane populations of the threatened meadow jumping mouse (*Zapus hudsonius luteus*) in New Mexico. Arizona and New Mexico Chapters of The Wildlife Society.
46. Wampler, C.R, **J.K. Frey** and J. Boren. 2006. Effects of silvicultural treatments on the small mammal community in a southwest coniferous forest. Arizona and New Mexico Chapters of The Wildlife Society.
47. Jones, G.D., K.M. Otten, C. R. Wampler, Z. Schwenke, and **J. K. Frey**. 2006. Status and habitats of the threatened least shrew (*Cryptotis parva*) in New Mexico. Arizona and New Mexico Chapters of The Wildlife Society.
48. Wampler, C.R, **J.K. Frey** and J. Boren. 2006. Effects of silvicultural treatments on the small mammal community in a southwest coniferous forest. The Southwestern Association of Naturalists.
49. Montoya, A. and **J.K. Frey**. 2007. Geographic variation and taxonomy of the gray-footed chipmunk (*Tamias canipes*). The Southwestern Association of Naturalists.
50. Wampler, C.R, **J.K. Frey** and J. Boren. 2007. Effects of fuels reduction thinning on the small mammal community in a southwest coniferous forest. The Southwestern Association of Naturalists.
51. Jones, G., and **J.K. Frey**. 2007. An enigma of the species-area relationship: small island effect on coastal Texas islands. American Society of Mammalogists.
52. **Frey, J.K.**, J.L. Malaney, Z. J. Schwenke, and J.A. Cook. 2007. The New Mexico meadow jumping mouse (*Zapus hudsonius luteus*): a declining riparian indicator species. American Society of Mammalogists.
53. Schwenke, Z.J., **J.K. Frey**, and J.R. Choate. 2008. Identifying isolated peripheral populations of the least shrew (*Cryptotis parva*) along the western extent of its range. American Society of Mammalogists.
54. **Frey, J.K.** 2008. Mammals of the Gila: patterns of diversity and species of concern. Natural History of the Gila Symposium, Silver City.
55. Malaney, J.L., **J.K. Frey**, J.A. Cook. 2009. Conservation genetics and phylogeography of the New Mexico Meadow Jumping Mouse (*Zapus hudsonius luteus*). Arizona and New Mexico Chapters of The Wildlife Society.
56. Moses, M.R., G.W. Roemer, and **J.K. Frey.** 2009. Unraveling sources of variation in annual survival among distinct populations of banner-tailed kangaroo rats in the Chihuahuan Desert. Ecological Society of America, Albuquerque.
57. J.C. Lewis, **J.K. Frey**, R.K. Guy, J.N. Stuart, J.F. Roback, and K.G. Boykin. 2009. White-nosed coati (*Nasua narica*) habitat suitability and distribution in the state of New Mexico. Howard Hughes Medical Institute-NMSU Undergraduate Research Scholar

Symposium, Las Cruces.

58. Wright, G.D., and **J.K. Frey**. 2009. Status of the meadow jumping mouse at Bosque del Apache national Wildlife Refuge. Festival of the Cranes.
59. J.C. Lewis, **J.K. Frey**, R.K. Guy, J.N. Stuart, J.F. Roback, and K.G. Boykin. 2010. Improving ecological niche models; an example based on the white-nosed coati in the southwest. Arizona and New Mexico Chapters of The Wildlife Society.
60. Wright, G.D., and **J.K. Frey**. 2010. The endangered meadow jumping mouse in the Rio Grande Valley; observations of decline, habitat, and behavior. Arizona and New Mexico Chapters of The Wildlife Society.
61. Calkins, M. and **J.K. Frey**. 2010. A revised distribution and habitat associations for the water shrew in the White Mountains, Arizona. Arizona and New Mexico Chapters of The Wildlife Society.
62. **Frey, J.K**. 2010. Status of the meadow jumping mouse in Arizona. Arizona and New Mexico Chapters of The Wildlife Society.
63. Wright, G.D. and **Frey, J.K**. 2010. The endangered meadow jumping mouse at BANWR: observations of occupation, habitat, and behavior. Festival of the Cranes.
64. **Frey, J.K**. 2012. Synopsis of the status and ecology of the meadow jumping mouse (*Zapus hudsonius luteus*): an imperiled species in the American Southwest. Arizona and New Mexico Chapters of The Wildlife Society.
65. **Frey, J.K**. 2013. Ecosystem services of the American beaver: wetland engineer. New Mexico Environment Department Beavers and Wetlands Symposium. Santa Fe.
66. Small, B., I. Barela, **J.K. Frey**. 2014. Status of dam building beaver on public lands in New Mexico: a comparison of occupied and vacant sites. Arizona and New Mexico Chapters of The Wildlife Society.
67. **Frey, J.K.** 2014. The NMSU Wildlife Museum. Department of Fish, Wildlife & Conservation Ecology Alumni and Friends Reception.
68. **Frey, J.**K., P. Castillo, J. Iglesias. 2015. Eastern fox squirrels in the West. Western Pecan Growers.
69. Barela, I. and **J.K. Frey**. 2015 Use of woody forage plants by the American beaver (*Castor canadensis*) in the Chihuahuan Desert. Arizona and New Mexico Chapters of The Wildlife Society.
70. Small, B.A., **J.K. Frey**, C. C. Gard. 2015. Evaluation of habitat suitability for dam-building beaver in northern New Mexico. Arizona and New Mexico Chapters of The Wildlife Society. (best wildlife student paper finalist)
71. Castillo, P., **J.K. Frey**, J. Iglesias. 2015. Damage caused by the eastern fox squirrel (*Sciurus niger*) in pecan orchards in the El Paso Valley. NMSU Undergraduate Research and Creative Arts Symposium.
72. Barela, I. and **J.K. Frey**. 2015 Use of woody forage plants by the American beaver (*Castor canadensis*) in the Chihuahuan Desert. NMSU Undergraduate Research and Creative Arts Symposium.
73. Small, B.A., **J.K. Frey**, C. C. Gard. 2015. Evaluation of habitat suitability for dam-building beaver in northern New Mexico. New Mexico Environment Department Wetlands Roundtable.
74. Youtz, J.A., R. Goljani A., J.K. Frey. 2016. A habitat suitability model for the Dusky Grouse in New Mexico. Arizona and New Mexico Chapters of The Wildlife Society.
75. Perkins-Taylor, I. and J.K. Frey. 2016. Detection rates during surveys of the endangered

New Mexico meadow jumping mouse. Arizona and New Mexico Chapters of The Wildlife Society.

76. Youtz, J.A., R. Goljani A., J.K. Frey. 2016. A habitat suitability model for the Dusky Grouse in New Mexico. Gila Symposium
77. Youtz, J.A., R. Goljani A., J.K. Frey. 2017. A habitat suitability model for the Dusky Grouse in New Mexico. Arizona and New Mexico Chapters of The Wildlife Society.
78. Burke, R., K. Stoner, and J.K. Frey. 2017. Predicting seasonal distribution and migratory pathways for neotropical nectar-feeding bats. Arizona and New Mexico Chapters of The Wildlife Society.
79. Frey, J.K. 2017. Identification, distribution and ecology of the New Mexico meadow jumping mouse in the zone of sympatry with the western jumping mouse. Arizona and New Mexico Chapters of The Wildlife Society.
80. Lehnen, S., J.K. Frey et al. 2017. Use of remote cameras to detect the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*) at Bosque del Apache National Wildlife Refuge. Arizona and New Mexico Chapters of The Wildlife Society.
81. Perkins-Taylor, I. and J.K. Frey. 2017. Developing conservation guidelines for the Oscura Mountain chipmunk using occupancy models. Arizona and New Mexico Chapters of The Wildlife Society.
82. Goljani, R., J.K. Frey, et al. 2017. Predicting spatial factors associated with cattle depredations by the Mexican wolf (*Canis lupus baileyi*) in Arizona and New Mexico. Arizona and New Mexico Chapters of The Wildlife Society.
83. Burke, R., K. Stoner, J.K. Frey, C. P. Brown. 2017. Predicting seasonal distribution and migratory pathways for neotropical nectar-feeding bats. The Wildlife Society.
84. Goljani, R., J.K. Frey, D.L. Bergman, S.W. Breck., J.W. Cain, J. Oakleaf, J.B. Smith. 2017. Predicting spatial factors associated with livestock depredations by the Mexican wolf in Arizona and New Mexico. The Wildlife Society.
85. Perkins-Taylor, I. and J.K. Frey. 2017. Assessing site occupancy of the Oscura Mountains Colorado chipmunk using camera traps. The Wildlife Society.
86. Youtz, J.A., R. Goljani A., J.K. Frey. 2017. Species distribution models for the Dusky Grouse in New Mexico: Implications for conservation and climate change. The Wildlife Society.

SELECTED RECENT TECHNICAL REPORTS:

Frey, J.K. 2003. Baseline inventory of small mammal prey-base communities on Carson National Forest, New Mexico. Final Report submitted to Carson National Forest, 48 pp.

Frey, J.K. 2003. Preliminary investigation of the relationship between montane meadow stubble height and small mammal communities on Cason National Forest, New Mexico. Final Report submitted to Carson National Forest, 14 pp.

Frey, J.K. 2003. Initiation of Abert's squirrel (*Sciurus aberti*) monitoring on Carson National Forest, New Mexico. Final Report submitted to Carson National Forest, 18 pp.

Frey, J.K. 2003. Initiation of red squirrel (*Tamiasciurus hudsonicus*) monitoring on Carson National Forest, New Mexico. Final Report submitted to Carson

National Forest. 38 pp.

SELECTED RECENT TECHNICAL REPORTS (continued):

Frey, J.K. 2004. Abert's squirrel (*Sciurus aberti*) monitoring and habitat analysis on Carson National Forest, New Mexico, 2004. Final Report submitted to Carson National Forest, 21 pp.

Frey, J.K. 2004. Red squirrel (*Tamiasciurus hudsonicus*) monitoring and habitat analysis on Carson National Forest, New Mexico, 2004. Final Report submitted to Carson National Forest, 45 pp.

Frey, J.K. 2005. Status assessment of the Arizona montane vole (*Microtus montanus arizonensis*) in New Mexico. Final Report submitted to New Mexico Department of Game and Fish, 39 pp.

Frey, J.K. 2005. Keys to the squirrels, pocket gophers, New World rats and mice, voles, and jumping mice of New Mexico. Final report submitted to New Mexico Department of Game and Fish, 75 pp.

Frey, J.K. 2005. Abert's squirrel (*Sciurus aberti*) monitoring on Carson National Forest, New Mexico, 2005. Final Report submitted to Carson National Forest, 32 pp.

Frey, J.K. 2005. Status and habitat of the least shrew (*Cryptotis parva)* in New Mexico. Final Report submitted to New Mexico Dept. of Game and Fish, 40 pp.

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Kearsley, M., D. Lightfoot, S. Brantley, J.K. Frey, and H. Yard. 2006. Introduction. Pages 4-31 in M. Kearsley, N. Cobb, H. Yard, D. Lightfoot, G. Carpenter, S. Brantley, and J.K. Frey. Inventory and monitoring of terrestrial riparian resources in the Colorado River corridor of Grand Canyon: an integrative approach. Final report submitted to USGS Grand Canyon monitoring and research Center, 317 pp.

Frey, J.K. 2006. Mammals. Pages 154-177 in M. Kearsley, N. Cobb, H. yard, D. Lightfoot, G. Carpenter, S. Brantley, and J.K. Frey. Inventory and monitoring of terrestrial riparian resources in the Colorado River corridor of Grand Canyon: an integrative approach. Final report submitted to USGS Grand Canyon monitoring and research Center, 317 pp.

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Frey, J.K. 2007. Survey for the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*) at selected locations in the Jemez Ranger District, Santa Fe National Forest, Final Report submitted to Jemez Ranger District, Santa Fe National Forest, 28 pp.

Frey, J.K. 2007. Density and habitat of red squirrel (*Tamiasciurus hudsonicus*) in five study areas on Lincoln National Forest New Mexico. Final Report submitted to Lincoln National Forest, 54 pp.

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SELECTED RECENT TECHNICAL REPORTS (continued):

Frey, J.K. and K. Boykin. 2007. Status assessment of the Peñasco least chipmunk (*Tamias minimus atristriatus*). Final Report submitted to New Mexico Department of Game and Fish, 72 pp.

Frey, J.K. and Z. J. Schwenke. 2007. Mammals of Sugarite Canyon State Park, Colfax County, New Mexico. Final Report submitted to New Mexico State Parks, 49 pp.

Frey, J.K., and G.D. Jones. 2008. Mammal inventory of Padre Island National Seashore. Final Report submitted to Padre Island National Seashore, 271 pp.

Frey, J.K. 2008. Morphology and genetics of the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*). Final Report submitted to New Mexico Department of Game and Fish, 77 pp.

Frey, J.K. 2008. Baseline inventory of the wild mammals of Living Desert Zoo and Gardens State park, Eddy County, New Mexico. Final Report submitted to New Mexico State Parks, 36 pp.

Frey, J.K. 2008. Abert's squirrel (*Sciurus aberti*) monitoring on Carson National Forest, New Mexico, 2008. Final Report submitted to Carson National Forest, 40 pp.

Frey, J.K. 2009. Abert's squirrel (*Sciurus aberti*) monitoring on Carson National Forest, New Mexico, 2009. Final Report submitted to Carson National Forest, 42 pp.

Frey, J.K. 2009. Red squirrel (*Tamiasciurus hudsonicus*) monitoring on Carson National Forest, New Mexico, 2009. Final Report submitted to Carson National Forest, 37 pp.

Frey, J.K., and G.D. Wright. 2010. Rio Grande jumping mouse ecology. Annual Technical Progress Report for 2009 submitted to U.s. Fish and Wildlife Service, Region 2, Albuquerque, New Mexico, revised 23 February 2010, 34 pp.

Wright, G.D., and J.K. Frey. 2010. Cool season activity of the meadow jumping mouse in the Middle Rio Grande. Final Report submitted to New Mexico Department of Game and Fish, Share with Wildlife Program, 16 pp.

Frey, J.K. 2010. Identification of voles from Aragon, Catron county, New Mexico: are they the endangered Arizona montane vole (*Microtus montanus arizonensis*)? Final Report submitted to New Mexico Department of Game and Fish, Share with Wildlife Program, 20 pp.

Frey, J.K. 2010. Identification of chipmunks from the Sacramento Mountains in the Academy of Natural Sciences of Philadelphia: are they the endangered Penasco least chipmunk (*Tamias minimus atristriatus*)? Final Report submitted to New Mexico Department of Game and Fish, Share with Wildlife Program, 22 pp.

Frey, J.K. 2010. Review of the western heather vole (*Phenacomys intermedius*) at its southern range limits. Final Report submitted to New Mexico Department of Game and Fish, Share with Wildlife Program, 46 pp.

Frey, J.K., and M.T. Calkins. 2010. Status of the ermine (*Mustela erminea*) at its southern range limits, New Mexico. Final Report submitted to New Mexico Department of Game and Fish, Share with Wildlife Program, 48 pp.

Frey, J.K. 2011. Survey for the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*) on the San Juan and San Luis Valley Public Lands Centers, Colorado. Final Report submitted to San Juan Public Lands Center, 8 January 2011, 44 pp.

SELECTED RECENT TECHNICAL REPORTS (continued):

Frey, J.K., and G.D. Wright. 2011. Rio Grande jumping mouse ecology. Annual Technical Progress Report for 2010 submitted to U.s. Fish and Wildlife Service, Region 2, Albuquerque, New Mexico, 12 February 2011, 42 pp.

Frey, J.K. 2011. Development of non-invasive monitoring protocols for the Organ Mountains chipmunk. Final Report submitted to New Mexico Department of Game and Fish, Share with Wildlife Program, 41 pp.

Frey, J.K. 2011. Inventory of the meadow jumping mouse in Arizona. Final Report submitted to Arizona Game and Fish Department Heritage Grant I09004, 5 July 2011, 114 pp.

Frey, J.K. and G.D. Wright. 2012. Multiple Scale Habitat Selection by a Small Mammal Habitat Specialist (*Zapus hudsonius luteus*) in a Managed Floodplain Landscape. Final Report submitted to U.S. Fish and Wildlife Service, Cooperative Agreement 201819J806, 16 March 2012, 109 pp.

Frey, J.K. 2012. Survey for the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*) at Coyote Creek, Mora County, New Mexico. Final Report submitted to Marron and Associates, 31 August 2012, 10 pp.

Frey, J.K. 2012. Survey for the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*) on Carson National Forest, New Mexico. Final Report submitted to Carson National Forest, 5 December 2012, 71 pp.

Frey, J.K. 2012f. Survey for the meadow jumping mouse (*Zapus hudsonius luteus*) at Casa Colorada Wildlife Area, Valencia county, New Mexico. Final Report submitted to Share With Wildlife, Conservation Services Division, New Mexico Department of Game and Fish, 10 December 2012, 13 pp.

Frey, J.K. 2013a. Survey for the meadow jumping mouse at Bosque del Apache National Wildlife Refuge. Final Report submitted to US Fish and Wildlife Service, Ecological Services, Southwest Region, 5 June 2013 (revised).

Frey, J.K. 2013b. Draft survey protocol for the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*). Final report submitted to Non-game and T&E Mammal Program, New Mexico Department of Game and Fish, 28 June 2013, 53 pp.

Frey, J.K. 2013c. Survey for the New Mexico meadow jumping mouse on the Sacramento River, Otero County, New Mexico, with recommendations for maintenance of the Sacramento-Orogrande Pipeline. Final report submitted to the Bureau of Land Management, Las Cruces District Office, 24 September 2013.

Frey, J.K., and D.A. Kopp. 2013. Post Track Fire survey for the meadow jumping mouse (*Zapus hudsonius luteus*) at Sugarite Canyon State Park. Report submitted to US Fish and Wildlife Service, 30 July 2013. 11 Pages

Frey, J.K., and D.A. Kopp. 2014. Preliminary assessment of jumping mouse habitat associated with the Middle Rio Grande Project. Final report submitted to U.S. Department of the Interior, Bureau of Reclamation, Albuquerque Area Office. 20 January 2014.

Frey, J.K. 2014. Riparian Mammals of the Gila River, New Mexico: Impacts of Flow Pages 353-356 *In* Gori, D., M.S. Cooper, E.S. Soles, M. Stone, R. Morrison, T.F. Turner, D.L. Propst, G. Garfin, M. Switanek, H. Chang, S. Bassett, J. Haney, D. Lyons, M. Horner, C.N. Dahm, J.K. Frey, K. Kindscher, H.A. Walker, and M.T.

Bogan. Gila River Flow Needs Assessment. A report by The Nature Conservancy. 515 Pp. http://nmconservation.org/Gila/GilaFlowNeedsAssessment.pdf

Frey, J.K., and Q. R. Hays. 2017. Surveys for the Penasco least chipmunk 2016. Final Report submitted to Share With Wildlife, Conservation Services Division, New Mexico Department of Game and Fish, March 2017, 53 pp.

PEER-REVIEWED PUBLICATIONS:

ResearchGate: https://www.researchgate.net/profile/Jennifer_Frey3
Peer-refereed articles = 70
Google Scholar
Citations = 1,369 (420 since 2012)
H-index = 15
I10-index = 23

NOTE: asterisk indicate students I mentored: *=graduate student; **=undergraduate student; *=high school student.**

1. Prophet, C. W., and **J**. **K**. **Frey**. 1987. Capture of *Diaptomus siciloides* and *Diaptomus pallidus* by suction simulator and gizzard shad (*Dorosoma cepedianum*). Journal of Freshwater Ecology, 4:253-258.
2. Tims, T. A., **J**. **K**. **Frey**, T. A. Spradling, and D. W. Moore. 1989. A new locality for the pygmy shrew (*Sorex hoyi winnemana*) in Tennessee. Journal of the Tennessee Academy of Science, 64:240.
3. **Frey**, **J**. **K**., and D. W. Moore. 1990. Status of Hayden's shrew (*Sorex haydeni*) in Kansas. Southwestern Naturalist, 35:84-86.
4. **Frey**, **J**. **K**., and D. W. Moore. 1990. Nongeographic morphologic variation in the Mexican vole (*Microtus mexicanus*). Transactions of the Kansas Academy of Sciences, 93:97-109.
5. **Frey**, **J**. **K**., and D. W. Moore. 1990. Range expansion of the meadow vole (*Microtus pennsylvanicus*) in Kansas. Prairie Naturalist, 22:259-263.
6. Choate, J. R., D. W. Moore, and **J**. **K**. **Frey**. 1991. Dispersal of the meadow jumping mouse in northern Kansas. Prairie Naturalist, 23:127-130.
7. **Frey**, **J**. **K**. 1992. Response of a mammalian faunal element to climatic changes. Journal of Mammalogy, 73:43-50.
8. **Frey**, **J**. **K**., T. L. Yates, D. W. Duszynski, W. L. Gannon, and S. L. Gardner. 1992. Designation and curatorial management of type host specimens (symbiotypes) for new parasite taxa. Journal of Parasitology, 78:930-932.
9. **Frey**, **J**. **K**. 1993. Modes of peripheral isolate formation and speciation. Systematic Biology, 42:373-381.

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10. **Frey**, **J**. **K**., and C. T. LaRue. 1993. Notes on the distribution of the Mogollon vole (*Microtus mogollonensis*) in Arizona and New Mexico. Southwestern Naturalist, 38:176-178.

11. **Frey**, **J**. **K**. 1993. Nocturnal foraging by scissor-tailed flycatchers under artificial light. Western Birds, 24:200.
12. **Frey**, **J**. **K**., and F. C. Bermudez**. 1994. Cordilleran flycatchers nesting within a cave. New Mexico Ornithological Society Bulletin, 22:23-24.
13. Childs, J. E., T. G. Ksiazek, C. F. Spiropoulou, J. W. Krebs, S. Morzunov, G. O. Maupi, K. L. Gage, P. E. Rollin, J. Sarisky, R. E. Enscore, **J**. **K**. **Frey**, C. J. Peters, and S. T. Nichol. 1994. Serologic and genetic identification of *Peromyscus maniculatus* as the primary reservoir for a new hantavirus in the southwestern United States. Journal of Infectious Disease, 169:2171-2180. **Charles C. Shepard Science Award and James H. Nakano Citation candidate**
14. Bermudez**, F. C., J. N. Stuart, **J**. **K**. **Frey**, and R. Valdez. 1995. Distribution and status of the Virginia opossum (*Didelphis virginiana*) in New Mexico. Southwestern Naturalist, 40:336-340.
15. **Frey**, **J**. **K**., and M. J. Patrick. 1995. Endoparasites from the endangered Hualapai vole, *Microtus mogollonensis hualpaiensis* (Rodentia: Cricetidae). Journal of Parasitology, 81:641-643.
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17. **Frey**, **J**. **K**. 1996. Rock Rattlesnake (*Crotalus lepidus*). Aquatic Behavior. Herpetological Review, 27:145.
18. **Frey**, **J**. **K**. 1996. Mammalian type localities in New Mexico. Occasional Papers of the Museum of Southwestern Biology, 7:1-25.
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22. **Frey**, **J**. **K**., and M. L. Campbell**. 1997. Introduced population of fox squirrel (*Sciurus niger*) in Trans-Pecos and Llano Estacado regions of New Mexico and Texas. Southwestern Naturalist, 42:356-358.
23. **Frey**, **J**. **K**., R. D. Fischer, and L. A. Ruedas. 1997. The type locality of *Sylvilagus cognatus* Nelson 1907 (Lagomorpha: Leporidae). Proceedings of the Biological Society of Washington, 110:329-331.
24. **Frey**, **J**. **K**. 1999. Osgood's mouse / *Peromyscus gratus*. Pp. 570-571, in The Smithsonian Book of North American Mammals (D. E. Wilson and S. Ruff, eds.). Smithsonian Institution Press, Washington, D.C., 750 pp.
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26. **Frey, J.K.**, J.J. Root, C.A. Jones, C.H. Calisher, and B. J. Beaty. 2002. New records of the Mogollon vole, *Microtus mogollonensis* (Mearns 1890), in southwestern Colorado. Western North American Naturalist, 62:120-123.

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28. **Frey, J.K.**, R.D. Fisher, M.A. Bogan, C. Jones. 2002**.** First record of the Arizona cotton rat (*Sigmodon arizonae*) in New Mexico. Southwestern Naturalist, 47:491-493.
29. Dunnum, J.L., **J.K. Frey**, D. Tinin, J. Salazar-Bravo, T.L. Yates. 2002**.** Elevational range extension for the hispid cotton rat, *Sigmodon hispidus*, (Rodentia: Muridae). Southwestern Naturalist, 47:637-639.
30. **Frey, J.K.** 2003. Distributional records and natural history notes for uncommon mammals on the Llano Estacado of eastern New Mexico. New Mexico Journal of Science, 43:1-24.
31. **Frey, J.K**. 2004. Taxonomy and distribution of the mammals of New Mexico: an annotated checklist. Occasional Papers, Museum of Texas Tech University, 240:1-32.
32. **Frey, J.K**. 2006. Inferring species distributions in the absence of occurrence records: an example considering wolverine (*Gulo gulo*) and Canada lynx (*Lynx canadensis*) in New Mexico. Biological Conservation, 130:16-24.
33. **Frey, J.K**. 2006. Review of *Mammals of Carlsbad Caverns National Park, New Mexico*, by K.N. Geluso and K. Geluso, 2004. Journal of Mammalogy, 87:817.
34. Malaney*, J.A. and. **J.K. Frey**. 2006. Summer habitat use by snowshoe hare and mountain cottontail at their southern zone of sympatry. Journal of Wildlife Management, 70:877-883.
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36. Ditto*, A. M., and **J**. **K**. **Frey**. 2007. Effects of ecogeographic variables on genetic variation in montane mammals: implications for population survivorship in a global warming scenario. Journal of Biogeography, 34:1136-1149.
37. **Frey, J.K**., T.L. Yates, and M.A. Bogan. 2007. Mountaintop island age determines species richness of boreal mammals in the American Southwest. Ecography, 30:231-240.
38. **Frey, J**.K. 2007. The cliff chipmunk (*Tamias dorsalis*) does not occur in the Sandia Mountains, New Mexico. Western North American Naturalist, 67:611-612.
39. **Frey, J.K.**, M.T. Hill**, B.L. Christman, J.C. Truett, S.O. MacDonald. 2008. Distribution and habitat of the Arizona gray squirrel (*Sciurus arizonensis*) in New Mexico. The Southwestern Naturalist, 53:248-255.
40. Wampler*, C.R., **J.K. Frey**, D.M. VanLeeuwen, J.C. Boren, T.T. Baker. 2008. Mammals in mechanically thinned and non-thinned mixed-coniferous forest in the Sacramento Mountains, New Mexico. The Southwestern Naturalist, 53:431-443.
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43. Stuart, J.N., **J.K. Frey**, Z. J. Schwenke**, and John S. Sherman. 2007 (2009). Status of

the armadillo (*Dasypus novemcinctus*) in New Mexico. Prairie Naturalist, 39:163-169.

44. **Frey, J.K.** 2009. Distinguishing range expansions from previously undocumented populations using background data from museum records. Diversity and Distributions, 15:183-187.
45. **Frey, J.K.**, and J.L. Malaney. 2009. Decline of the meadow jumping mouse (*Zapus hudsonius luteus*) in two mountain ranges in New Mexico. The Southwestern Naturalist, 54:31-44.
46. **Frey, J.K.** 2009. Genetics of allopatric populations of the montane vole (*Microtus montanus*) and Mogollon vole (*Microtus mogollonensis*) in the American Southwest. Western North American Naturalist, 69:215-222.
47. **Frey, J.K.,** R.D. Fisher, and S.C. Peurach. 2009. Capture locations of two endangered rodents during a 1902 exploration of the Sacramento Mountains, New Mexico. Western North American Naturalist, 69:267-271.
48. **Frey, J.K.**, B.J. Frey, and D.W. Moore. 2009. Karyotypes of the long-tailed vole (*Microtus longicaudus*) in isolated mountain ranges of the American Southwest. Western North American Naturalist, 69:388-390.
49. **Frey, J.K.**, and J.N. Stuart. 2009. Nine-banded armadillo (*Dasypus novemcinctus*) records in New Mexico, USA. Edentata, 8-10:54-55.
50. **Frey, J.K.** 2010. Mammals of the upper Gila River watershed, Arizona and New Mexico: patterns of diversity and species of concern. New Mexico Botanist, Special Issue, 2:67-87.
51. Moses*, M.R., **J.K. Frey**, and G. W. Roemer. 2012. Elevated surface temperature depresses survival of banner-tailed kangaroo rats: will climate change cook a desert icon? Oecologia, 168: 257-268.
52. Malaney, J. L., **J. K Frey**, and J. A. Cook. 2012. The biogeographic legacy of an imperilled taxon provides a foundation for assessing lineage diversification, demography, and conservation genetics. Diversity and Distributions, 18:689-703.
53. Calkins*, M.T., E. A. Beever, K..G. Boykin, **J. K. Frey**, and M. C. Andersen. 2012. Not-so-splendid isolation: modeling climate-mediated range collapse of a montane mammal *Ochotona princeps* across numerous ecoregions. Ecography, 35: 780-791.
54. **Frey, J.K.** 2012. Evidence for the historical occurrence of the meadow jumping mouse in the Verde River watershed, Arizona. Western North American Naturalist, 72:257-262.
55. **Frey, J.K.** and Z.J. Schwenke**. 2012. Mammals of Sugarite Canyon State Park, Colfax County, New Mexico. Museum of Texas Tech University, Occasional Papers, 311:1-24.
56. **Frey, J.K.** 2013. Re-evaluation of the evidence for the importation of red foxes from Europe to colonial America: Origins of the southeastern red fox (*Vulpes v. fulva*). Biological Conservation, 158:74-79.

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57. **Frey, J.K.**, J.C. Lewis**, R.K. Guy*, J.S. Stuart. 2013. Use of anecdotal occurrence data in species distribution models: an example based on the white-nosed coati (*Nasua narica*) in the American Southwest. Animals, 3:327-348.

58. Jones*, G.D. and **J.K. Frey**. 2013. Mammals of Padre Island National Seashore. Special Publications, The Museum, Texas Tech University, 61:1-63.
59. **Frey, J.K**., J. Iglesias, K. Herman**. 2013. Eastern fox squirrel (*Sciurus niger*): new threat to pecan orchards in far west Texas. Western North American Naturalist. 73:382-385.
60. **Frey, J.K.**, and M. Calkins*. 2014. Snow cover and riparian habitat determine the distribution of the short-tailed weasel (*Mustela erminea*) at its southern range limits in arid western North America. Mammalia, 78:45-56.
61. Wright*, G. D. and **J.K. Frey**. 2014. Herbeal feeding behavior of the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*). Western North American Naturalist, 74:231-235.
62. Wright*, G. D. and **J.K. Frey**. 2015. Habitat Selection by the Endangered Meadow Jumping Mouse (*Zapus hudsonius luteus*) on an Irrigated floodplain. Journal of Fish and Wildlife Management, 6:112-129.
63. **J.K. Frey**. 2015. Variation in the phenology of hibernation and reproduction in the New Mexico meadow jumping mouse (*Zapus hudsonius luteus*). PeerJ DOI: 10.7717/peerj.1138
64. Small*, B.A., **J.K. Frey**, C.C. Gard. 2016. Livestock grazing limits beaver restoration in northern New Mexico. Journal of Restoration Ecology, 24: 646-655.
65. Barela**, I. and **J.K. Frey**. 2016. Habitat and forage selection by the American beaver (*Castor canadensis*) on a regulated river in the Chihuahuan Desert. The Southwestern Naturalist, 61:286-293.
66. **Frey, J.K**. 2017. Landscape Scale and Microhabitat of the Endangered New Mexico Meadow Jumping Mouse in the White Mountains, Arizona. Journal of Fish and Wildlife Management, .
67. Burruss*, D., A. Matchano, **J.K. Frey**, M. Andersen, C. Sillero-Zubiri. 2017. Food habits of the pale fox in Niger. African Journal of Ecology, **DOI:** 10.1111/aje.12404
68. Coxen,* C.L., **Frey, J.K.**, S.A. Carlton, D.P. Collins. 2017. Species distribution models for a migratory bird based on citizen science and satellite tracking data. Global Ecology and Conservation, 11:298-311.
69. **Frey, JK**. In press. A review and conservation implications of aquatic behaviour (and drowning) in jumping mice (Dipodidae: Zapodinae). Canadian Field Naturalist
70. **Frey, J.K.** In press. Beavers, livestock, and riparian synergies: a small mammal perspective. Chapter in International Riparian Project. US Forest Service, Rocky Mountain Research Station, General Technical Report.

BOOK IN PREPARATION:

Cartron, J.E. and **J.K. Frey (editors).** The Carnivores of New Mexico. University of New Mexico Press. Expected publication date January 2019

J.K. Frey authored chapters by include:

- Introduction
- Conservation of Carnivores
- Red fox
- Wolverine
- Ermine
- Long-tailed weasel
- American mink
- White-nosed coati
- Conclusion

SELECTED MANUSCRIPTS IN PREPARATION:

Perkins-Taylor, I. and **J.K. Frey.** Ecological factors associated with site occupancy of an endemic chipmunk. Journal of Wildlife Management.

Burruss, D., A. Matchano, **J.K. Frey**, M. Andersen, C. Sillero-Zubiri. Species distribution models unravel niche partitioning in a Sahelo-Saharan canid community

Frey, J.K., and M. Calkins. Distribution and habitat of an endangered and isolated population of the northern water shrew (*Sorex palustris*) in Arizona. The Southwestern Naturalist

Frey, J.K. Habitat partitioning between two species of jumping mice (*Zapus*) in a zone of sympatry. Journal of Mammalogy

Jones, G.D. and **J.K. Frey**. Mammal community structure on a Padre Island: influence of habitat and interspecific interactions. Journal of Mammalogy

Malaney, J.L., and **J.K. Frey**. Demography of snowshoe hare (*Lepus americanus*) at the southern edge of its range. Journal of Mammalogy

Jones, G.D. and **J.K. Frey**. Testing between hypotheses of causal mechanisms for the small island effect. Journal of Biogeography.

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DANIEL J. HARRISON

Department of Wildlife Ecology
University of Maine, 5755 Nutting Hall
Orono, ME 04469-5755
(207) 581-2867 (Work)
(b) (6)(b) (6) (Cell)
harrison@maine.edu

PROFESSIONAL EXPERIENCES

9/2000-8/2013 & 9/2016-present: ***Professor of Wildlife Ecology***, Dept. of Wildlife Ecology, University of Maine; ***Cooperating Professor***, Center for Research on Sustainable Forests (2007-present); ***Cooperating Scientist ,*** Maine Cooperative Forestry Research Unit (1999-present); ***Cooperating Professor***, Department of Forest Ecosystem Science (1999-2005) and Center for Research on Sustainable Forests (2008-present); and ***Faculty Associate***, Maine Cooperative Fish and Wildlife Research Unit, Univ. of Maine (1988-present). Tenured, academic year appointment with shared research (50%) and teaching (50%) responsibilities; appointment changed to 75% research, 25% teaching, effective 9/1/2005. Course instruction: Wildlife-Habitat Relationships (WLE 450, Cr. 4), Introduction to Wildlife Resources (WLE 100, Cr. 1), Graduate Course in Habitat Ecology (WLM 650, Cr. 4; team-taught), Graduate Course in Carnivore Ecology and Management (WLE 565, Cr. 3). Serve as academic advisor to undergraduate students and as thesis advisor for graduate students (Responsible for: base-funded research program in wildlife-forestry relationships supported through the Maine Agricultural and Forest Experiment Station; extramurally funded research program in habitat relationships of forest wildlife and ecology of meso-carnivores and their prey; public service; technology transfer. Provide research advisement and technology transfer to large private forest landowners, state and federal resource management agencies, and NGO's.

9/2013-8/2016: ***Chair, Professor, and Undergraduate Coordinator*****,** Department of Wildlife, Fisheries, and Conservation Biology, University of Maine; 70% administration, 20% research, 10% instruction. Administer an academic department including 7 university faculty, a federal USGS research unit (2-3 scientists), 2 support personnel, post-doctoral scientists, research associates, approximately 25 graduate research and teaching assistants, and 125 undergraduate wildlife majors. Taught co-capstone senior-level undergraduate course, administered and supervise research grants, and led a lab comprised of graduate students, technicians and a post-doctoral scientist.

7/2001-6/2002: ***Interim Chair***, Department of Wildlife Ecology, University of Maine.

9/93-8/00: ***Associate Professor of Wildlife Ecology***, Dept. of Wildlife Ecology, University of Maine; duties listed above plus served as administrator and instructor for mandatory 3-week summer field camp, Wildlife Field Survey (WLE 250, Cr. 3, 1994-97).

1/88-8/93: ***Assistant Professor of Wildlife***, Dept. of Wildlife, University Maine. 50%-50%, shared research-teaching appointment (9-month). Additional responsibilities included serving as advisor to the Student Chapter of The Wildlife Society, and administration and instruction of the summer field camp, Wildlife Field Survey (WLE 250, Cr. 3, 1988-93). Twice served as instructor in senior-capstone course in wildlife policy and administration (Cr. 3). Developed and taught 4 credit undergraduate habitat

course with 2 sections of lab (1988-93), and a graduate course in predator ecology (Cr. 3).

2/86-12/87: ***Wildlife Research Supervisor*** (Staff Associate-Wildlife), Wildlife Bureau, Connecticut Department of Environmental Protection. Responsible for overall supervision, administration, budgeting, and coordination of statewide research and management programs for Nongame and Endangered Species, Upland Wildlife (small game), and Mammals (except deer). Supervised a staff of 6 wildlife biologists and 2 clerical staff.

6/85-2/86: ***Mammal Program Leader*** (Wildlife Biologist I and II), Wildlife Bureau, Connecticut Department of Environmental Protection. Administered statewide research and management programs for 14 species of harvested and non-harvested mammals.

EDUCATION

(b) (6): University of Maine, ***Ph. D. in Wildlife***, August 1986; Dissertation: Coyote Dispersal, Mortality, and Spatial Interactions with Red Foxes in Maine.

(b) (6)(b) (6) University of Maine, ***M.S. in Wildlife Management***, May 1983; Thesis: Denning Ecology, Movements, and Dispersal of Coyotes in Eastern Maine.

(b) (6): University of Wyoming, ***B.S. in Wildlife Management***, May 1980.

PROFESSIONAL SERVICES

Affiliations

Society for Conservation Biology
American Society of Mammalogists
The Wildlife Society (national, section, chapter)
Martes Working Group

Committees/Professional Service

Invited external reviewer, Species Status Assessment for U.S. population of Canada lynx (2017)
Chair of DWFCB Alumni Awards Committee, (2016-present)
Undergraduate Program Coordinator, Dept. Wildlife, Fisheries, and Conserv. Biol. (2013-2015)
Search Committee, Assistant Professor of Wildlife Habitat Ecology, University of Maine (2015)
Institutional Animal Care and Use Committee, University of Maine (2012-2014)
Chair of Search Committee, Assistant Professor of Wildlife Population Ecology (2013)
Peer Committee Chair, Department of Wildlife Ecology, University of Maine (2012-2013)
Faculty Senator, University of Maine (2010-2012)
Financial and Institutional Planning Committee, Faculty Senate (2010-2012)
Board of Directors, The Forest Society of Maine (2008-2011)
Land Conservation Committee, Forest Society of Maine (2009-present)
Scientific Advisor, Carnivores 2006 Conference, St. Petersburg, Florida (2005-06)
External Program Review Team, Dept. Natural Resources, Univ. New Hampshire (2006)
Search Committee for Asst. Professor Fisheries, Dept. Wildlife Ecology, Univ. Maine (2006)
Invited Peer Reviewer, U.S. Fish &Wildlife Service, Critical Habitat Proposal for Lynx (2006)
Research Council, Maine Agricultural and Forest Experiment Station (2005-2008)
Peer Review Team, Endangered Wolf Delisting Proposal, U.S. Fish Wildlife Service, (2004)
Scientific Advisor, Carnivores 2004 Conference, Santa Fe, New Mexico (2003-04)

Cooperating Scientist, Maine Cooperative Forestry Research Unit, (1999-present)
Scientific Advisor to Newfoundland Model Forest, marten research, (1997-2010)
Invited Member, Recovery Team for Endangered Newfoundland Marten, (1998-2010)
University Representative on Northern Maine Landscape Planning Comm. (2002-2008)
Committee of Whole for Curriculum and Graduate Issues, Dept. of Wildlife Ecology (1988-present)
Awards Committee, Maine Chapter of The Wildlife Society, (1992-present)
Peer Review Committee, Dept. Wildlife Ecology, University Maine (1988-present)
Hosted 4 landscape planning workshops for agencies and environmental groups (2002-2010)
Coauthored position on coyote snaring bill, Maine Chapter, The Wildlife Society (2003)
Member of Search Committee, Assistant Coop. Unit Leader for Fisheries (2003)
Invited External Review Participant for Maine Dept. Inland Fisheries and Wildlife (2003)
Nongame/Endangered Species Advisory Council, MDIFW (1999-2002)
Chair, Search Committee for Instructor in Wildlife Ecology (2001-02)
Search Committees for Faculty Sabbatical Replacements (2) (2001-2002)
Co-author on Forestry-Wildlife Alumni Newsletter, Univ. Maine (2002)
U.S.D.A. Forest Service Expert Review Panel for Species at Risk WMNF, GMNF (2002)
Forest Biodiversity Benchmarks Working Group, Maine Forest Service (2001-02)
Advisor to Huber Corp. on forest wildlife habitat supply planning (2001-2002)
Expert Panelist, Eastern Wolf Conference (2002)
Scientific Advisor, Carnivores 2002 Conference, Monteray, California (2001-02)
Program Chair/Co-Convenor, 3rd Int. *Martes* Symp., Newfoundland, (2000)
Consulting Scientist to industry on biocontaminants issues with aquatic mammals, (2000)
Search Committee for Finance/Communications Coordinator, Maine Coop. Forest Res.Unit, (1999)
Search Comm. for Asst. Leader/Wildlife, Maine Coop. Fish and Wildlife Research Unit, (1999)
College Committee for Development of Green Endowment policies (1999)
Research and Public Service Committee, Faculty Senate, (1994-95, 1998-1999)
Forest Research Center Steering Committee, College of NFA (1998-2000)
Restructuring Committee for Maine Cooperative Forestry Research Unit (1998-1999)
Usniversity of Maine Faculty Senate (elected), (1993-1999)
Lynx Research Working Group, MDIFW & USFWS (2000-present)
Timber Wolf Advisory Committee, Maine Dept. Inland Fisheries & Wildlife (1997-2000)
Search Committee for Silvicultural Program Leader, CFRU, (1997-98)
Search Committee for Instructor, Dept. Wildlife Ecology, (1997)
Academic Affairs Committee, Faculty Senate, (1997-98)
Constitution and Bylaws Committee, Faculty Senate, (1996-97)
Search Committee for Program Scientist, CFRU (1996)
Search Committee for Assistant Professor of Wildlife Ecology (1995)
Admissions Committee, Graduate Program in Ecology and Environmental. Sciences, (1994-96)
Forest Ecosystem Research Committee, University Maine, (1993-95)
Auditing Committee, NE Section, The Wildlife Society, (1989-94)
Scholarship Committee, College Forest Resources, (1989-94)
Scholarship Committee, Department of Wildlife Ecology, (1988-96)
University Forest Advisory Committee, College of Forest Resources, (1989-94)
Predator Management Committee, Baxter State Park, (1993)
Presidential Public Service Awards Committee, University Maine, (1993-94)
Faculty Research Funds Committee, University Maine, (1988-91), Chair, (1990-91)
Evaluation Committee for Dean of Graduate School, (1991)

Executive Committee of the Graduate School, (elected), (1989-90)
Graduate Board, (elected), University Maine, (1988-91)
Northeast Fur Resource Technical Committee, (1985-1991)
Facilities and Safety Committee, College of Forest Resources, (1988-89)
Cooperative Extension-College of Forest Resources Working Group, (1988-89)
Advisor, Student Chapter of the Wildlife Society, University Maine, (1988-92)
Executive Board (elected), Maine Chapter of The Wildlife Society (1989)

Editorships

-Associate Editor for *Wildlife Biology*, September 2009 – 2012
-Senior Editor for a Contributed book: ***Ecology and management of Martes in human altered landscapes: An International Perspective***. Reviewed, edited, and revised 22 contributed chapters, wrote Preface, and coordinated publication (published by Springer, New York in 2004).
-Guest editor for Northeastern Naturalist (2005-06)
-Consulting Editor for Wildlife Monographs (2000)

Manuscript Reviews (in order of number of manuscripts reviewed: range 1-49)

Journal of Wildlife Management
Wildlife Biology
Journal of Mammalogy
Wildlife Society Bulletin
Forest Ecology and Management
Landscape Ecology
Conservation Biology
Canadian Journal of Zoology
Northeastern Naturalist
Wildlife Monographs
Bioscience
Behavioral Ecology
Ecology
Ecological Applications
Ecography
Environmental Monitoring and Assessment
Southeast Proceedings
Southwest Naturalist
Northeast Wildlife
American Midland Naturalist
Wildlife Biology
Wildlife Research
Proceedings of 5th International *Martes* Symposium
Proceedings of 2nd International *Martes* Symposium
Proceedings of 1st International *Martes* Symposium
Maine Agricultural and Forest Experiment Station Miscellaneous Reports

Other Professional Contributions

Granted > 130 media interviews; contributed to 3 film documentaries, presented legal and public testimony on numerous occasions, have provided technical advice to natural resource agencies and non-governmental organizations in Maine, Alaska, Rocky Mountain states, Ontario, New Brunswick, Nova Scotia and Newfoundland Canada, and Tanzania; hosted numerous field trips for visiting scientists, organizations, and businesses; provided technology transfer (newsletters, phone calls, presentations, field visits) for forest products businesses in Maine, handled hundreds of requests for information from public; presented >100 public talks; frequently review scientific proposals for business, federal agencies, and other universities.

Honors and Awards

2009:	Distinguished Alumnus Award, Department of Wildlife Ecology, University of Maine
2008-2009:	University Research Sabbatical, University of Maine (competitive system-wide award)
2008:	Award of Professional Excellence, Department of Wildlife Ecology, The University of Maine (awarded to alumni)
2007:	Maine Chapter of the Wildlife Society's Meritorious Service Award
2007:	Appointed Cooperating Professor, Center for Research on Sustainable Forests
2006:	G. Peirce and Florence Pitts-Webber Award to the Outstanding Researcher in Forest Resources, University of Maine
2000:	G. Peirce and Florence Pitts-Webber Award to the Outstanding Researcher in Forest Resources, University of Maine
1998:	Appointed Cooperating Scientist, Maine Cooperative Forestry Research Unit
1992:	Distinguished College of Forest Resources Professor of the Year, University of Maine
1985:	Dow-Griffee Award to Outstanding Graduate Students in Agriculture, Forestry and Wildlife at the University of Maine
1984:	New England Outdoor Writer's Scholarship to Outstanding Wildlife Student in New England (selected from regional competition among state-level awardees).
1984:	New England Outdoor Writer's Scholarship to Outstanding Wildlife Student in Maine
1979:	Phi Kappa Phi, University of Wyoming

GRADUATE ADVISING:

-Served as major advisor for 19 M.S., 3 non-thesis Masters and 7 Ph.D. students; 25 dissertations, theses, and final project reports completed to date.
-Served on 42 graduate committees where I did not serve as major advisor.
-Mentored 4 post-doctoral Research Scientists and several post-M.S. Research Associates.

TEACHING EXPERIENCE:

Taught 37 sections of 6 undergraduate semester courses (median instructor rating 1.42; 1=excellent, 5=poor); managed and taught the required 3-week, summer field session for wildlife students annually for 10 years (median instructor rating 1.50); advised 8-33 undergraduate wildlife students annually, taught 12 semesters of graduate courses in Predator Ecology and Habitat Analysis (median instructor rating 1.50), and instructed graduate thesis (54 semesters).

PUBLICATIONS (* = refereed)**:**

Books, Journal Articles, Book Chapters, and Published Conference Proceedings

*xxxx - Loman, Z. G., W. V. Deluca, D. J. Harrison, P. B. Wood, C. S. Loftin, and W. S.Schwenk. Submitted. Forest birds usefulness as representatives using fine scale proxy models. ***Diversity and Distributions***.

*xxxx – Rolek, B. W., D. J. Harrison, C. S. Loftin, and P. B. Wood. Submitted. Regenerating clearcuts and post-harvest treatments promote spruce-fir avian assemblages and richness in managed stands. ***Forest Ecology and Management***

*xxxx – Simons-Legaard, E. M., D.J. Harrison, and K. R. Legaard. Submitted. Efficacy of regulations to reduce winter habitat loss and fragmentation in deer wintering areas. ***Biological Conservation***.

*In press - Loman, Z. G., W. V. Deluca, D. J. Harrison, C. S. Loftin, B. W. Rolek, and P. B. Wood. Submitted. Landscape capability models as a tool to predict fine-scale forest bird occupancy and abundance. ***Landscape Ecology***.

*2017 - Loman, Z. G., E. J. Blomberg, W. V. Deluca, D. J. Harrison, C. S. Loftin, and P. B. Wood. Landscape capability predicts upland game bird abundance and occurrence. ***Journal of Wildlife Management*** DOI:10.1002/jwmg.21265

*2016 – Simons-Legaard, E.M., D.J. Harrison and K.R. Legaard. Habitat monitoring and projections for Canada lynx: linking the Landsat archive with carnivore occurrence and prey density. ***Journal of Applied Ecology*** 53:1260-1269.

*2013 - Fuller, A. K,. and D. J. Harrison. Modeling the influence of forest structure on microsite habitat use by snowshoe hares***.*** ***International Journal of Forestry Research***: Volume 2013, Article ID 892327, 7 pages, http://dx/doi.org/10.1155/2013/892327.

*2013 - Fuller, A. K., S. M. Spohr, D. J. Harrison, and F. A. Servello. Nest survival of wild turkeys in a mixed-use landscape: influences at nest-site and patch scales. ***Wildlife Biology*** 19:138-146.

*2013 - Simons-Legaard, E. M., D. J. Harrison, W. B. Krohn, and J. H. Vashon. Canada lynx occurrence and forest management in the Acadian forest. ***Journal of Wildlife Management*** 77:567-578.

*2012 - I. D. Thompson, J. Fryxell, and D. J. Harrison. Improved insights into use of habitat by American martens, since the 2nd International Martes Symposium in 1991. ***Pages 209 – 229 in K.B. Aubry, W.J. Zielinski, M.G. Raphael, G. Proulx, and S.W. Buskirk,*** **editors,** ***Biology and conservation of martens, sables, and fishers: a new synthesis.*** Cornell University Press, Ithaca, New York, USA.

*2010- Fuller, A. K., and D. J. Harrison. Movement paths reveal scale-dependent habitat decisions by Canada lynx. ***Journal of Mammalogy*** 91:1269-1279.

*2010- Hearn, B. J., D. J. Harrison, A. K. Fuller, C. G. Lundrigan, and W. J. Curran. Paradigm shifts in habitat ecology of threatened Newfoundland martens. ***Journal of Wildlife Management*** 74:719-728.

*2007 - Fuller, A. K., D. J. Harrison, and J. H. Vashon. Winter habitat selection by Canada lynx in Maine: prey abundance or accessibility? ***Journal of Wildlife Management*** 71:1980-1986.

2007 - Harrison, D. J., W. B. Krohn, L. Robinson, A. K. Fuller, and C. L. Hoving. Multi-scalar habitat preferences of snowshoe hares: how does a prey specialist coexist with a specialist predator? Page 175 *in* K. Sjoberg and T. Rooke, editors, ***International Union of Game Biologists Conference Proceedings***, Department of Wildlife, Fish, and Environmental Studies, Swedish University of Agricultural Sciences (SLU), Umea, Sweden.

*2007- Homyack, J. A., D. J. Harrison, and W. B. Krohn. Effects of precommercial thinning on snowshoes hares in Maine. ***Journal of Wildlife Management*** 71: 4-13.

*2006 - Homyack, J.A., D. J. Harrison, J.A. Litvaitis, and W.B. Krohn. Quantifying densities of snowshoe hares in Maine using pellet plots. ***Wildlife Society Bulletin*** 34: 74-80.

*2005 - Fuller, A. K. and D. J. Harrison. Influence of partial timber harvesting on American martens in north-central Maine. ***Journal of Wildlife Management*** 69:710-722.

*2005- Homyack, J. A., D. J. Harrison, and W. B. Krohn. Long-term effects of precommercial thinning on small mammals in northern Maine. ***Forest Ecology and Management***: 205:43-57.

*2005 - Hoving, C. L. D. J. Harrison, W. B. Krohn, R. A. Joseph, and M. O'Brien. Broad-scale predictors of Canada lynx occurrence in eastern North America. ***Journal of Wildlife Management*** 69:739-751.

*2004 - Fuller, A. K., D. J. Harrison, and H. J. Lachowski. Stand-scale effects of partial harvesting and clearcutting on small mammals and forest structure. ***Forest Ecology and Management*** 191:373-386.

*2004 - Harrison, D. J., A. K. Fuller, and G. Proulx. Martens and Fishers (Martes) in Human Altered Environments: An International Perspective***. *Springer, New York, New York (edited, peer-reviewed book).***

*2004 - Homyack, J. A., D. J. Harrison and W. B. Krohn. Structural differences between precommercially thinned and unthinned conifer stands. ***Forest Ecology and Management*** 194:131-143.

*2004 - Hoving, C. L., D. J. Harrison, W. B. Krohn, W. J. Jakubas, and M. A. McCollough. Canada lynx habitat and forest succession in northern Maine, United States. ***Wildlife Biology*** 10(4):285-294.

*2004 - Krohn, W. K., C. L. Hoving, D. J. Harrison, D. Phillips, and H. Frost. Martes foot-loading and snowfall patterns in eastern North America: Implications to broad-scale distributions and interactions of mesocarnivores. Pages 115-131 *in* D. J. Harrison, A. K. Fuller, and G. Proulx, editors, ***Martens and Fishers (Martes) in Human Altered Environments: An International Perspective***. Springer, New York, New York.

*2004 - Payer, D. C. and D. J. Harrison. Relationships between forest structure and habitat use by American martens in Maine, USA. Pages 173-186 i*n* D. J. Harrison, A. K. Fuller, and G. Proulx, editors, ***Martens and Fishers (Martes) in Human Altered Environments: An International***

Perspective. Springer, New York, New York.

*2004 -Payer, D. C., D. J. Harrison, and D. M. Phillips. Territoriality and Home-Range Fidelity of American Martens in Relation to Timber Harvesting and Trapping. Pages 99-114 i*n* D. J. Harrison, A. K. Fuller, and G. Proulx, editors, ***Martens and Fishers (Martes) in Human Altered Environments: An International Perspective***. *Springer,* New York, New York.

*2004 - Spohr, S. M., F. A. Servello, D. J. Harrison, and D. W. May. Survival and reproduction of wild turkey hens in a suburban environment. ***Northeast Naturalist*** 11*: 363-374.*

2003 - Fuller, A. K. and D. J. Harrison. Occurrence, distribution, and survey methods for native terrestrial mammals in Acadia National Park, Mount Desert Island, Maine. ***Maine Agricultural and Forest Experiment Station Miscellaneous Publication 752***, Orono, Maine, 28 pp.

*2003 -- Payer, D. C., and D. J. Harrison. Influence of forest structure on habitat use by American marten in an industrial forest. ***Forest Ecology and Management*** 179:145-156.

*2000 - Payer, D. C., and D. J. Harrison. Structural differences between forests regenerating following spruce budworm infestation and clearcut harvesting: implications for American marten. ***Canadian Journal of Forest Research*** 30:1965-1972.

1999 - Harrison, D. J. Response of wildlife to thinning in forests of the northeastern U.S. Pp. 35-40 *in* ***Proceedings of Conference on Thinning in the Maine Forest***, Cooperative Forestry Research Unit and Office of Professional Development, University of Maine, Orono.

*1998 **-** Harrison, D. J., and T. G. Chapin. Extent and connectivity of habitat for wolves in eastern North America. ***Wildlife Society Bulletin*** 26:767-775.

*1998 **-** Chapin, T. G., D. J. Harrison, and D. D. Katnik. Influence of landscape pattern on habitat use by American marten in an industrial forest. ***Conservation Biology*** 12:1327-1337.

*1998 - Long, R. A., A. F. O'Connell, Jr., and D. J. Harrison. Mortality and survival of white-tailed deer Odocoileus virginianus fawns on a north Atlantic coastal island. ***Wildlife Biology*** 4:237-247.

*1998 - Phillips, D. M., D. J. Harrison, and D. C. Payer. Seasonal changes in home-range area and fidelity of martens. ***Journal of Mammalogy*** 79:180-190.

1997 - Bissonette, J. A., D. J. Harrison, C. D. Hargis, and T. G. Chapin. The influence of spatial scale and scale-sensitive properties on habitat selection by American marten. Pages 368-385 in J.A. Bissonette (editor). ***Wildlife and Landscape Ecology: effects of pattern and scale*****.** Springer-Verlag, New York.

*1997 - Chapin. T. G., D. J. Harrison, and D. M. Phillips. Seasonal habitat selection by marten in an untrapped forest preserve. ***Journal of Wildlife Management*** 61:707-717.

*1997 - Chapin, T. G., D. M. Phillips, D. J. Harrison, and E. C. York. Seasonal selection of habitats by resting marten in Maine. Pages 166-181 *in* G. Proulx, H.N. Bryant, and P.M. Woodard (editors). ***Martes: taxonomy, ecology, techniques and management***. Provincial Museum of Alberta,

Edmonton, Alberta, Canada. 474pp.

*1997 - Hodgman, T. P., D. J. Harrison, D. M. Phillips, and K. D. Elowe. Survival of American marten in an untrapped forest preserve in Maine. Pages 86-99 *in* G. Proulx, H.N. Bryant, and P.M. Woodard (editors). ***Martes: taxonomy, ecology, techniques and management***. Provincial Museum of Alberta, Edmonton, Alberta, Canada. 474pp.

*1996 - Chilelli, M., B. Griffith, and D. J. Harrison. Interstate comparisons of river otter harvest data. ***Wildlife Society Bulletin*** 24(2):238-246.

1995 - Harrison, D. J. Foreword. Pp. 1-4 in G. Parker. ***Eastern coyote: the story of its success***. Chelsea Green Publishing Company, White River Junction, Vermont.

*1994 - Hodgman, T. P., D. J. Harrison, D. D. Katnik, and K. D. Elowe. Survival in an intensively trapped marten population in Maine. ***Journal of Wildlife Management***. 58:593-600.

*1994 - Katnik, D. D., D. J. Harrison, and T. P. Hodgman. Spatial relations in a harvested population of marten in Maine. ***Journal of Wildlife Management*** 58:600-607.

*1992 - Harrison, D. J. Dispersal characteristics of coyotes in Maine. ***Journal of Wildlife Management*** 56:128-138.

*1992 - Harrison, D. J. Social ecology of coyotes in northeastern North America: relationships to dispersal, food resources, and human exploitation. Pages 53-72 *in* A. Boer (editor) ***Ecology and Management of the Eastern Coyote***. Wildlife Research Unit, University of New Brunswick, Frederickton.

1992 - Harrison, D. J., and N. E. Famous. Effects of peat harvesting on a large mammalian carnivore: a case study with coyotes (Canis latrans). Pages 77-96 *in* D. Grubich (editor) ***Peat and Peatlands: the Resource and Its Utilization***. Proceedings International Peat Symposium, Duluth, Minnesota.

*1992 – O'Connell, A. F., Jr., D. J. Harrison, B. Connery, and K.B. Anderson. Food use by an insular population of coyotes. ***Northeast Wildlife*** 49:36-42.

*1991 - Harrison, D. J., J. A. Harrison, and M. O'Donoghue. Pre-dispersal movements of coyote (Canis latrans) pups in eastern Maine. ***Journal of Mammalogy*** **72:**756-763.

*1989 - Harrison, D. J., J. A. Bissonette, and J. A. Sherburne. Spatial relationships among coyotes and red foxes in eastern Maine. ***Journal of Wildlife Management*** 52:181-185.

*1989 - Litvaitis, J. A., and D. J. Harrison. Bobcat-coyote niche relationships during a period of coyote population increase. ***Canadian Journal of Zoology*** 67:1180-1188.

1986 - Harrison, D. J., and W. B. Krohn. Population characteristics of Maine coyotes. ***U.S. Fish and Wildlife Service Research Information Bulletin No. 86***:112.

*1986 - Harrison, D. J. Coyotes in the northeast: their history, origin, and ecology. ***Appalachia*** 46:30-39.

1986 - Major, J. T., J. A. Sherburne, J. A. Litvaitis, and D. J. Harrison. Resource use by and interspecific relations between bobcats and other large mammalian predators in Maine. Pages 291 *in* S.D. Miller and D.D. Everett, (editors) ***Cats of the World: Biology, Conservation and Management***. Natl. Wildlife Federation, Washington, D.C.

*1985 - Harrison, D. J., and J. R. Gilbert. Denning ecology and movements of coyotes in Maine during pup rearing. ***Journal of Mammalogy*** 66:712-719.

*1984 - Harrison, D. J., and J. A. Harrison. Foods of adult Maine coyotes and their known-aged pups. ***Journal of Wildlife Management*** 48:922-926.

1984 - Harrison, D. J. Use of white-tailed deer by coyotes during pup rearing in Maine. ***Transactions of the Northeast Deer Technical Committee*** 20:34-35.

Technical Reports and Miscellaneous Publications:

2017 – Dunham, S. and D. Harrison. Spruce grouse habitat in the Acadian forests of Maine: Results and recommendations for forest managers. CFRU Research Note 17-01, Maine Cooperative Forestry Research Unit. University of Maine. Orono, ME.

2016 – Harrison, D., S. Morano, and S. Olson. Relationships among forest harvesting, snowshoe hares, and Canada lynx in Maine. Pages 52-56 *in* Roth, B.E. (Ed.) Cooperative Forestry Research Unit: 2015 Annual Report. University of Maine. Orono, ME.

2016 – Tebbenkamp, J., E. Blomberg, D. Harrison, and S. Dunham. Population dynamics of spruce grouse in the managed forest landscapes of northern Maine. Pages 57-61 *in* Roth, B.E. (Ed.) Cooperative Forestry Research Unit: 2015 Annual Report. University of Maine. Orono, ME.

2016 – Rolek, B., D. Harrison, C. Loftin, and P. Wood. Bird communities of coniferous forests in the Acadian region: habitat associations and responses to forest management. Pages 57-61 *in* Roth, B.E. (Ed.) Cooperative Forestry Research Unit: 2015 Annual Report. University of Maine. Orono, ME.

2015 – Harrison, D., and S. Olson. Relationships among forest harvesting, snowshoe hares, and Canada lynx in Maine. Pages 68-74 *in* B.E. Roth, editor, Cooperative Forestry Research Unit: 2014 Annual Report, University of Maine, Orono.

2015 – Dunham, S., and D. Harrison. Patch occupancy, habitat use, and population performance of spruce grouse in commercially managed conifer stands. Pages 75-79 *in* B.E. Roth, editor, Cooperative Forestry Research Unit: 2014 Annual Report, University of Maine, Orono.

2015 - Rolek, B., D. Harrison, C. Loftin, and P. Wood. Bird communities of coniferous forests in the Acadian Region: Habitat associations and response of birds to forest management. Pages 80-88 *in* B.E. Roth, editor, Cooperative Forestry Research Unit: 2014 Annual Report, University of Maine, Orono.

2014 – Harrison, D., S. Olson, D. Mallett, A. Fuller, and J. Vashon. Relationships among forest harvesting, snowshoe hares, and Canada lynx in Maine. Pages 57-62 *in* B.E. Roth, editor, Cooperative Forestry

Research Unit: 2013 Annual Report, University of Maine, Orono.

2014 – Dunham, S., and D. Harrison. Patch occupancy, habitat use, and population performance of spruce grouse in commercially managed conifer stands. Pages 63-66 *in* B.E. Roth, editor, Cooperative Forestry Research Unit: 2013 Annual Report, University of Maine, Orono.

2014 – Rolek, B., D. Harrison, and C. Loftin. Bird communities of coniferous forests in the Acadian Region: habitat associations and response of birds to forest management. Pages 67-73 *in* B.E. Roth, editor, Cooperative Forestry Research Unit: 2013 Annual Report, University of Maine, Orono.

2013 – Harrison, D., E. Simons-Legaard, K. Legaard, and S. Sader. Effectiveness of zoning to protect deer wintering habitats in Maine: Did the designation of LURC-zoned deeryards achieve desired objectives during the period 1975-2007? Final Report to Northeastern States Research Cooperative and USDA Forest Service. http://nsrcforest.org/sites/default/files/uploads/harrison08full.pdf

2013 – Harrison, D., S. Olsen, D. Mallett, A. Fuller, and J. Vashon. Relationships among commercial forest harvesting, snowshoe hares and Canada lynx in Maine. Pages 79-84 *in* B.E. Roth, editor, Cooperative Forestry Research Unit: 2012 Annual Report, University of Maine, Orono.

2013 – Dunham, S., and D. Harrison. Patch occupancy, habitat use, and population performance of spruce grouse in commercially managed conifer stands. Pages 85-89 *in* B.E. Roth, editor, Cooperative Forestry Research Unit: 2012 Annual Report, University of Maine, Orono.

2012 - Harrison, D., S. Olson, D. Mallet, J. Vashon, and A. Fuller. Relationships among commercial forest harvesting, snowshoe hares, and Canada lynx in Maine. Pages 95-98 *in* B.E. Roth, editor, Cooperative Forestry Research Unit: 2011 Annual Report, University of Maine, Orono.

2012 - Harrison, D., and S. Dunham. Relative densities, patch occupancy, and population performance of spruce grouse in managed and unmanaged forests in northern Maine. Pages 99-104 *in* B.E. Roth, editor, Cooperative Forestry Research Unit: 2011 Annual Report, University of Maine, Orono.

2011 – Fuller, A. K. and D. J. Harrison. A landscape planning initiative for northern Maine using area-sensitive umbrella species: Evaluating baseline conditions and effects of alternative management scenarios and silvicultural portfolios on future timber harvest volumes, standing forest inventory, and marten and lynx habitat supply on The Nature Conservancy's St. John lands in northern Maine. ***Final Report to the Maine Chapter of The Nature Conservancy***. 133 pp.

2011 – Harrison, D., W. Krohn, S. Olson and D. Mallett. Snowshoe hares spatio-temporal dynamics and implications for Canada lynx in managed landscapes. Pages 43 - 48 *in* Mercier***, W. J. and A. S. Nelson (eds.) Cooperative Forestry Research Unit: 2010 Annual Report***, The University of Maine, Orono.

2011 – Simons, E. M., D. J. Harrison, K. R. Legaard, and S. A. Sader. The effectiveness of state regulation to protect deer wintering areas in Maine: Did the designation of LURC-zoned deer yards achieve desired objectives during the period 1975-2007? Pages 38-42 *in* ***Mercier, W. J. and A. S. Nelson (eds.) Cooperative Forestry Research Unit: 2010 Annual Report***, The University of Maine, Orono.

2011 – Vashon, J., D. Harrison, A. Fuller, D. Mallet, W. Jakubas, and J. Organ. Documenting the response of

Canada lynx to declining snowshoe hare populations in an intensively managed private forest landscape in northern Maine. Pages 49-51 *in* ***Mercier, W. J. and A. S. Nelson (eds.) Cooperative Forestry Research Unit: 2010 Annual Report,*** The University of Maine, Orono.

2010 – Simons, E., D. Harrison, A. Whitman, and J. Wilson. Quantifying biodiversity values across managed landscapes in northern and western Maine. ***Final Report to the Maine Cooperative Forestry Research Unit,*** University of Maine, Orono. 29 pp.

2010 - Harrison, D. J., W. B. Krohn, and S. Scott. Effects of changing hare densities on probability of lynx occurrence throughout the commercially managed landscape of northwestern Maine. Pages 61-64 *in* ***Meyer, S. R. (Ed.): Cooperative Forestry Research Unit: 2009 Annual Report.*** University of Maine, Orono.

2010 - Simons, E., D. Harrison, K. Legaard, and S. Sader. The effectiveness of zoning to protect deer wintering areas during the period 1975-2007: Does compromising forest productivity to protect deer habitat achieve desired ecological objectives? Pages 51-56 *in* ***Meyer, S. R. (Ed.): Cooperative Forestry Research Unit: 2009 Annual Report.*** University of Maine, Orono.

2010 - Simons, E., D. Harrison, A. Whitman, and J. Wilson. Quantifying biodiversity values across managed landscapes in northern and western Maine - Year # 3 Progress Report. Pages 66-75 *in* ***Meyer, S. R. (Ed.): Cooperative Forestry Research Unit: 2009 Annual Report.*** University of Maine, Orono.

2010 – Vashon, J., D. Harrison, A. Fuller, D. Mallett, S. McLellan, W. Jakubas, and J. Organ. Documenting the response of Canada lynx to declining snowshoe hare populations in an intensively managed private forest landscape in northern Maine. Pages 57-60 *in* ***Meyer, S. R. (Ed.): Cooperative Forestry Research Unit: 2009 Annual Report.*** University of Maine, Orono.

2009 - Fuller, A.K, and D. J. Harrison. Home range, habitat use, edge relationships, mortality sources, age structure,, and survival of white-tailed deer on Mount Desert Island, Maine, 1992-1994. ***Final contract report to Natural Resource Stewardship Science Office***, Northeast Region, U.S. Department of Interior, National Park Service. 69 pp.

2008 – Simons, E., D. Harrison, A. Whitman, J. Hagan and E. Wilkerson. Quantifying biodiversity values across managed landscapes in northern and western Maine. Pages 52-54 *in* Maine Cooperative Forestry Research Unit Annual Report, ***Maine Agricultural and Forest Experiment Station Miscellaneous Report 444***, Orono, Maine.

2008 – Simons, E. K. Legaard, D. Harrison, S. Sader, J. Wilson, and W. Krohn. Predicting responses of forest landscape change on wildlife umbrella species. Pages 55-59 *in* Maine Cooperative Forestry Research Unit Annual Report, ***Maine Agricultural and Forest Experiment Station Miscellaneous Report 444***, Orono, Maine.

2007 – Fuller, A.K, D. J. Harrison, B. J. Hearn. Application and testing of models to predict probability of occupancy and density of endangered Newfoundland martens. ***Final Contract Report to Natural Resources Canada, Newfoundland-Labrador Wildlife Division, and Western Newfoundland Model Forest***, Corner Brook, Newfoundland. 75 pp.

2007 - Harrison, D., W. Krohn, L. Robinson, and J. Homyack. Temporal and spatial relationships among hares, lynx and forestry. Pages 53-57 *in* CFRU Annual Report 2005-2006, ***Maine Agricultural and Forest Experiment Station Miscellaneous Report 440***, University of Maine, Orono.

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1991 - Chilelli, M., B. Griffith, and D.J. Harrison. ***Analysis of river otter harvest and reproductive data in the northeastern U.S., 1970-89.*** Final Contract Report, Northeast Region, U.S. Fish and Wildlife Service. 48pp.

1990 - Harrison, D.J., and D. Wood. ***An educational and resource management strategy for Lake Manyara National Park, Tanzania: alternative approaches for meeting park management goals***. Report submitted to Tanzania National Parks and Protected Areas. 31pp.

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Fuller, A. K., D. J. Harrison, J. A. Hepinstall-Cymerman, and B.J. Hearn. A quantitative method for detecting ecological thresholds: nonlinear responses to habitat loss by American martens. ***Ecological Applications***: (in revision).

Fuller, A. K., and D. J. Harrison. Competition and resource partitioning between island red foxes and recently colonized coyotes. ***Wildlife Biology*** (in revision).

Hepinstall, J. A., and D. J. Harrison. A method for simulating home ranges and determining habitat currencies. ***Journal of Wildlife Management*** (in prep).

Fuller, A. K., and D. J. Harrison. Effects of habitat loss versus fragmentation on habitat occupancy by endangered Newfoundland martens. ***Conservation Biology*** (in prep).

Harrison, D.J. Influence of dispersal on social ecology of coyotes: do social pressures or prey size promote pack formation? ***Animal Behaviour*** (in preparation).

Hepinstall, J. A., and D. J. Harrison. Prediction and validation of occupancy models for American martens. ***Journal of Wildlife Management*** (draft manuscript complete).

Hearn, B. J. and D. J. Harrison. Home range and body scaling in American martens in Maine and Newfoundland: why are home ranges in Newfoundland so large? ***Oikos*** (draft manuscript complete).

Hearn, B. J. and D. J. Harrison. When the sink becomes the source: survival of martens in relation to timber harvesting in Newfoundland. ***Oikos*** (manuscript in preparation)

Hepinstall, J.A. and D. J. Harrison. The relative effects of habitat loss versus fragmentation in determining habitat occupancy by American marten. ***Conservation Biology*** *(manuscript complete and undergoing pre-submission review).*

D. J. Harrison, W. B. Krohn, S. Scott, and L. D. Robinson. Effects of partial forest harvesting on habitat and densities of snowshoe hares. ***Forest Ecology and Management*** *(manuscript in prep).*

Payer, D.C., and D.J. Harrison. Influences of timber harvesting and trapping on habitat selection and home range characteristics of marten. ***Journal of Wildlife Management*** *(analyses ongoing).*

<u>GRANTS AND PROPOSALS</u>:

External (total funded >4.3 million, direct funding to University of Maine =$3,858,897 and is presented in

bold):

Responses of marten populations to 30 years of habitat change in commercially managed landscapes of northern Maine. Maine Cooperative Forestry Research Unit, 2018-2020, **$79,200**, funded.

Responses of marten populations to 30 years of habitat change in commercially managed landscapes of northern Maine. Matching funds of $67,218 requested from Maine Department of Inland Fisheries and Wildlife, 2018-2020, $67,218, not funded.

Spatio-temporal dynamics of snowshoe hares in northern Maine from 2001-2015. Post-doctoral matching support requested from Maine Department of Inland Fisheries and Wildlife, 2017-2018, $33,250, not funded.

Linking habitat associations with demographics to inform conservation of spruce grouse throughout the Northern Forest. Northeastern States Research Cooperative, Theme Four, not funded, $63,633 requested, Co-investigator with Erik Blomberg.

Studies of snowshoe hare population cycles. U.S. Fish and Wildlife Service, funded **$21,290** 1/15/2015-12/31/2017.

Demography and populations status of spruce grouse in northern Maine forests, Co-investigator with Erik Blomberg, Maine Outdoor Heritage Fund, funded **$17,835**, 2014-2015.

Population dynamics of spruce grouse in the managed forest landscapes of northern Maine. Co-investigator with Erik Blomberg, Maine Cooperative Forestry Research Unit, funded, **$89,238** 2015-2017.

Evaluation of representative bird species Landscape Capability models. Co-investigator with Cynthia Loftin, USGS Science Support Program, funded, **$276,731**, 2015-2017

Effects of forest management practices in the Acadian northern hardwood/conifer forests of Maine on forest bird communities. Co-investigator with Cynthia Loftin. U.S. Fish and Wildlife Service and USGS Science Support Partnership Program, funded, **$380,884**, 2012-2016.

Effects of forest management practices in the Acadian conifer forests of Maine on forest bird communities, with emphasis on species of federal conservation priority. Co-investigator with Cynthia Loftin, **$87,000**, Maine Cooperative Forestry Research Unit, funded 2013-2015.

Studies of snowshoe hare densities and forest succession following forest harvesting. U.S. Fish and Wildlife Service. Cooperative Agreement 2011-2015. **$15,000**, funded.

Long-term studies of snowshoe hares, Canada lynx and forest structure associated with forest succession following clearcutting and various forms of partial harvests. **$157,110**, Maine Cooperative Forestry Research Unit, funded 2012-2015.

Cost-shared funding and base support for a Cooperating Scientist in wildlife-forestry relationships. Proposal to Maine Cooperative Forestry Research Unit, The Nature Conservancy,and other forest stakeholders. $510,000 funded, 2010-2015 – but project cancelled due to candidate taking faculty

position at another university.

Relative densities, patch occupancy, and population performance of spruce grouse in clearcut, precommercially thinned, mid-late successional conifer forests, and in coniferous forested wetlands in northern Maine**. $118,007**, funded, Maine Cooperative Forestry Research Unit, funded 2010 –2013.

Genetic-based analyses of lynx diets from scats collected with aid of detection dogs. Funded $6,812, 2013. Funded by Maine Department of Inland Fisheries and Wildlife and paid directly to genetics subcontractor.

Effectiveness of zoning to protect deer wintering areas**. $17,500** funded by Northeastern States Research Cooperative, USDA Forest Service for 2008-2010.

Trends in habitat supply for wildlife species whose habitat requirements are not addressed using coarse-filter umbrella species approaches, with a focus on deer wintering areas**. $77,000** funded by Maine Cooperative Forestry Research Unit for 2009-2011.

An evaluation of course filter umbrella species for landscape planning: trends in habitat supply for wildlife species whose habitat requirements are not addressed using umbrella species approaches. Pre-proposal submitted to Northeastern States Research Cooperative, Theme 4, USDA Forest Service for 2008-2010, $45,629, not funded.

Long-term monitoring of snowshoe hare populations to inform stand and landscape-scale forest management and the recovery planning for Canada lynx in Maine, and collaboration with Maine Department of Inland Fisheries and Wildlife to address changes in lynx demography and spatial ecology associated with declining hare populations. **$97,083** funded by Maine Cooperative Forestry Research Unit for 2008-2011and **$14,637** funded by U.S. Fish and Wildlife Service.

An evaluation of coarse-filter umbrella species for landscape planning. $59,311 requested from Northeast Regional Conservation Needs Grants Program, not funded.

Long-term habitat management planning for lynx and marten across the managed landscapes of northern Maine. **$265,000** funded by U.S. Natural Resource Conservation Service, Healthy Forest Reserve Program (The Nature Conservancy and Natural Resource Conservation cooperating) for 2007-2010.

Developing a black bear model system of skeletal mechanotransduction. $2,105,885 requested from U.S. Department of Human Services (with R. Seger as lead P.I. and others), not funded.

Forecasting and assessing the future of Maine's forests using LiDAR. $2,098,924 requested from Maine Technology Institute (with B. Wiersma as lead P.I. and others), not funded.

Documenting relationships among forest management and the occurrence patterns of Northern Goshawks in Maine. Proposal to Maine Cooperative Forestry Research Unit, $64,000 for 2008-2009 (not funded).

Application and testing of models to predict probability of occupancy and density of endangered Newfoundland marten. **$26,329** funded by Canadian Forest Service and Newfoundland-Labrador Wildlife Division 2006-2007.

Integrating landscape-scale biodiversity conservation with diverse forest management goals on large ownerships in Maine. **$115,427** funded by Maine Cooperative Forestry Research Unit for 2006-2009 (with Manomet Center for Conservation Sciences).

Responses of snowshoe hares and lynx to forest harvesting across multiple spatial scales. **$96,000** funded by Maine Cooperative Forestry Research Unit, **$20,000** funded by U.S. Fish and Wildlife Service, **$15,000** by National Council for Air and Stream Improvement; 2005 - 2009 (with W. Krohn).

Trends in deer-vegetation relationships in Acadia National Park from 1980-2007: relationships of an unhunted insular deer population to forage carrying capacity. $99,830 requested from U.S. National Park Service (not funded).

Completion of deer studies in Acadia National Park. **$8,900** funded by U.S. National Park Service, 2006.

Support for lynx-hare research at The University of Maine, 2005-2007. **$20,000** in grants funded by International Paper Company through the Department of Industrial Cooperation, University of Maine (with W. Krohn).

Gift from The Nature Conservancy to support lynx-hare research projects, May 2006, **$5,000**.

Predicting responses of forest landscape change on wildlife umbrella species: Modeling future effects of alternative forest harvesting scenarios on vertebrate diversity across multiple spatial scales on commercial forestlands in Maine. **$124,00**0 funded by USDA Forest Service, Agenda 20/20 Program 2005-2007, and **$17,000** funded by Maine Cooperative Forestry Research Unit. This project is in collaboration with Drs. Steve Sader, Jeremy Wilson, and William Krohn and supports 2 graduate students.

Predicting responses of snowshoe hares and lynx to alternative forest harvesting scenarios across spatial multiple scales in northern Maine. Science Support Program, USGS/FWS, **$89,810** funded for 2004-2007 (with W.B. Krohn, MCFWRU, M. McCollough, FWS).

Predicting responses of snowshoe hares and lynx to alternative forest harvesting scenarios across multiple spatial scales. **$50,000** funded by CFRU for 2005-2006, **$10,500** funded by U. S. Fish and Wildlife Service (with W. B. Krohn).

Predicting responses of snowshoe hares and lynx to alternative forest harvesting scenarios across spatial multiple scales. **$30,000** funded by National Council for Air and Stream Improvement and Plum Creek Corporation for 2004-2006 (with W. B. Krohn).

Evaluating the umbrella species approach for biodiversity conservation on commercial forestlands in Maine. **$28,850** funded by CFRU for 2004. This project supported a collaboration with post-doctoral scientist Jeff Hepinstall at the University of Washington, Seattle.

Development of a stand-scale model for predicting snowshoe hare densities for forest measurements. **$22,000** funded by CFRU for 2004 (with W. B. Krohn). This project supported a research collaboration with Jessica Homyack, Research Associate, U.S. Fish and Wildlife Service, Cheyenne, Wyoming.

Gift from The Nature Conservancy to support lynx-hare research projects, August 2004, **$5,000**.

Support for publication of edited book titled: *Martens and Fishers (Martes) in Human-Altered environments: An International Perspective*. Gift of **$8,000** from Canadian Forest Service (2002) and **$3,000** from Newfoundland-Labrador Wildlife Division.

Influence of forest practices on stand- and sub-stand scale habitat selection of lynx in northern Maine. Maine Cooperative Forestry Research Unit, **$63,046**, (funded, 2001-2003), Fraser Paper Company **$3,000**.

Influence of forest practices on stand- and sub-stand scale habitat selection of lynx in northern Maine. U.S. Fish and Wildlife Service and Maine Department of Inland Fisheries and Wildlife, **$12,000** (funded 2001-2003).

Landscape thresholds and response to fragmentation by endangered Newfoundland marten. Canadian Wildlife Service, Canadian Forest Service, Western Newfoundland Model Forest, Parks Canada, Newfoundland Wildlife Division, **$180,600**(US$) (funded, 2002-2007).

National Commission on Science for Sustainable Forestry – authored preproposal in collaboration with Manomet scientists requesting $160,000 to support landscape planning for biodiversity in northern Maine. The preproposal was selected as one of 3 finalists (2 to be funded) nationally and we were invited to develop a full proposal. Preproposal was withdrawn because of administrative responsibilities associated with Interim Chair position.

Lynx research projects in northern Maine. The Nature Conservancy, **$7,000** (gift) in 2003.

Influence of pre-commercial thinning on wildlife habitat in northern Maine, with special emphasis on snowshoe hares. Maine Cooperative Forestry Research Unit, U.S. Fish and Wildlife Service, National Council of the Paper Industry for Air and Stream Improvement, **$177,176** (funded, 2000-2003).

A habitat supply assessment for marten: linking population management alternatives to habitat extent and distribution across northern Maine. Maine Cooperative Forestry Research Unit, **$45,000** (funded 2000-2002).

A habitat supply assessment for marten: linking population management alternatives to habitat extent and distribution across northern Maine. National Council of the Paper Industry for Air and Stream Improvement, $30,000 (not funded).

Marten as a tool for landscape-scale habitat planning in northern Maine. Maine Outdoor Heritage Fund and Maine Dept. Inland Fisheries and Wildlife, **$71,498**, (funded, 1999-2002).

Marten as a tool for landscape-scale habitat planning in northern Maine. Maine Chapter of The Nature Conservancy $15,000 requested, **$7,500** funded, 2000-2002).

A GIS-based evaluation of lynx habitat at multiple spatial scales. National Council of the Paper Industry for Air and Stream Improvement (NCASI), U.S. Fish and Wildlife Service, Maine Dept. Inland Fisheries

and Wildlife $59,503 requested, **($52,003**, funded, 1998-2001), co-investigator: W. Krohn.

Population demography of marten in Newfoundland, Canada. Natural Resources Canada, **$20,000**, (funded 1998-99).

Influence of partial harvesting on habitat selection by marten and primary prey species in northern Maine. Maine Cooperative Forestry Research Unit, **$37,151** (funded, 1997-99).

Effects of timber harvesting and trapping on marten populations in northern Maine: the industrial forest site. Maine Department of Inland Fisheries and Wildlife, **$169,259** direct funding, $60,800 *in-kind* (funded, 1993-99).

Effects of timber harvesting and trapping on marten populations in northern Maine: the forest preserve site. Maine Cooperative Forestry Research Unit, **$90,889** (funded, 1993-98), Maine Forest Service, **$71,689** (funded, 1994-98), Maine Department of Inland Fisheries and Wildlife, $25,500 *in-kind* (funded 1994-98). Influence of microhabitat characteristics on intensity of forest use and productivity of martens in Maine: implications for forest practices. National Council of the Paper Industry for Air and Stream Improvement, **$38,214** (funded, 1995-98).

Factors influencing nesting success of wild turkeys in Connecticut. National Wild Turkey Federation and Wildlife Division, Connecticut Dept. of Environmental Protection **$25,000** + *in-kind* support (funded 1996-98), co-investigator F. Servello.

Potential habitat for wolves in the northeastern U.S. and connectivity with habitat occupied by extant wolf populations in southeastern Canada. Wildlife Conservation Society, **$4,559**, (funded, 1996).

Opportunities for management of habitat of American marten on Crown lands leased and managed by Fraser, Inc., in New Brunswick. Fraser Paper, Inc., New Brunswick, $69,334, (not funded, 1996).

Effects of timber harvesting and residual stand characteristics on habitat selection by martens in northern Maine. National Council for the Paper Industry for Air and Stream Improvement. **$28,232**, (funded 1993-95).

White-tailed deer mortality, population dynamics, movements, and spatial interactions with coyotes in Acadia National Park, Maine. U.S. National Park Service. **$208,547**, (funded 1991-95, 1999-2000), co-investigator A. O'Connell, Jr.

Predation on white-tailed deer fawns by coyotes on Mount Desert Island, Maine. U.S. National Park Service. **$69,103**, (funded 1992-94), co-investigator A. O'Connell.

Influence of trapping and timber harvesting on pine martens in northern Maine. New Brunswick Executive Forest Research Committee, Inc. $248,000, (not funded).

Occurrence, distribution, and interactions among mammalian carnivores in Acadia National Park. U.S. National Park Service, **$59,000**, (funded 1988-90).

Effects of browsing by white-tailed deer and snowshoe hare on vegetation at Acadia National Park. U.S.

National Park Service, **$39,000**, (funded 1988-90).

Fecal nitrogen as an index to white-tailed deer nutritional condition in Acadia National Park. U.S. National Park Service , **$1,300**, (funded 1990).

Interactions among trapping, timber harvesting, and pine marten populations. Submitted to Maine Department of Inland Fisheries and Wildlife; $73,000 contractual requested, **$58,000** of *in kind* were provided (1988-92).

A review of methodologies and harvest data used to manage river otter populations in northeastern North America. N.E. Region, U.S. Fish & Wildlife Service, **$52,000**, (funded 1989-90), Co-investigator with B. Griffith.

Internal

Add $2k support for Zach Loman in June 2017 from CRSF and new M-Stennis project October 2015-September 2020

A very high resolution aircraft mounted digital imaging system for remotely sensing forest vegetation. University of Maine Competitive Research Funds, Co-Investigator with Stephen Sader and Robert Wagner, **$14,972**, funded, 4/2012.

Received a competitive University Sabbatical ($15,000) that funded Linda Ilse as an Adjunct Professor and provided additional funds to DWE during my sabbatical in spring 2008.

Multi-scalar effects of forestry on an early-and a late-successional forest obligate across commercially managed lands in northern Maine: How are densities of snowshoe hares and occurrence patterns of spruce grouse differentially affected by broad-scale forest harvesting. Maine Agricultural and Forest Experiment Station, McIntire-Stennis Project funded October 2010 – September 2015. Funding includes 25-50% of P.I. salary, 1 graduate research assistantship (12 months), and ca. $3,000 in annual support for research expenses.

Secured funding for 50% ($25,000 per year, plus fringe benefits for 2 years) of an Assistant Scientist salary (Erin Simons) from the Center for Research on Sustainable Forest's ForCAST initiative 2008-2009.

Landscape-Scale Effects of Forestry on Forest Carnivores and Other Vertebrates. This project forms the basis for my McIntire-Stennis (MAFES) associated research program and is approved for the period 10/2004-9/2009. Funding includes 50% of P.I. salary, 1 graduate research assistantship (12 months), and ca. $6,000 in annual support for research expenses.

Influence of partial harvesting on American marten and primary prey species. McIntire-Stennis proposal, base funded 1998-2004.

A habitat supply assessment for marten: linking population management alternatives to habitat extent and distribution across northern Maine. $22,500 requested from research and development funding, College of Natural Sciences Forestry and Agriculture, University of Maine (not funded, 2002).

A research scientist to complete analyses and report writing for long-term studies in Acadia National Park. Department of Wildlife Ecology, Office of the Dean of College of Natural Sciences, Forestry and Agriculture, and Office of the Vice Provost for Research and Graduate Studies, Univ. Maine, $15,000, funded, 1999-2000.

A GIS-based evaluation of potential habitat for lynx in eastern North America at geographic and landscape scales. $7,500, funded, 11/98. Competitive funding for research and development, College of Natural Sciences, Forestry and Agriculture, University of Maine.

Synthesis and application of data from long-term studies of mammalian carnivores and prey. $31,980, not funded, 11/98. Competitive funding for research and development, College of Natural Sciences, Forestry and Agriculture, University of Maine.

A real-time, differentially corrected, global positioning system for studying animal movements. $6,500, funded, 12/97. Faculty Research Funds - Equipment Grant Competition, Univ. Maine.

Influence of partial harvesting on American marten and primary prey species. McIntire-Stennis proposal, base funded 1998-2003, included $7,900 in annual research funding, plus a graduate assistantship.

Effects of timber harvesting on population performance and habitat selection by American martens in northern Maine. McIntire-Stennis proposal, base funded, 1993-1998.

Interaction of forest management practices and pine marten populations. McIntire-Stennis proposal, base funded 1989-1993.

Submitted proposals requesting supplemental McIntire-Stennis funding in 1988, 1989, 1990, 1991, 1992: $44,190 requested, $40,310 funded.

Effects of trapping on pine marten populations in northern Maine. $5,000, funded, 1991. Faculty *Research Funds - Summer Research Grant Competition, Univ. Maine.*

SCIENTIFIC PRESENTATIONS (abridged to include January 1988 – June 2017: presenter is listed first):

2016 – Tebbenkamp 2 posters at TWS Conference, October 2016

2017- Dunham, S. W., D. J. Harrison, and E. J. Blomberg. Spruce Grouse Habitat Ecology in Maine's Commercially Managed Acadian Forest. *Presented at the Adapt, Adopt, Advance: Resiliency in Natural Resource Management Conference,* Bangor, Maine. March 9.

2017 - Harrison, D. J., B. W. Rolek, C.S. Loftin, P.B. Wood. Effects of forest management practices in Acadian conifer forests on spruce-fir bird communities. *Presentation to Irving Corporation Wildlife Biologists and Foresters and to the New Brunswick Forest Research Advisory Committee Advisory,* Sainte Anne de Madawaska, New Brunswick, Canada, May 30.

2017 - Harrison, D. J., B. W. Rolek, C.S. Loftin, P.B. Wood. Effects of forest management practices in

Acadian conifer forests on forest bird communities, with emphasis on species of conservation priority. *Presentation to Advisory Committee of Maine Cooperative Forestry Research Unit*, Orono, Maine, April 12.

2017 - Loman, Z., D. Harrison, C. Loftin, P. B. Wood. Validation of Designing Sustainable Landscapes Models using forest game birds, passerine birds, and a representative species approach. *Workshop presented to U.S. Fish and Wildlife Service, Migratory Bird Division.* Hadley, MA, USA. 12 January.

2017 - Loman, Z., D. Harrison, C. Loftin, P. B. Wood. Designing sustainable landscapes evaluation: where we're going and where we've been. USGS Maine Coop Unit Cooperators Meeting. Orono, ME, March 22.

2017 – Loman, Z. G. Loman, .W. V. Deluca, D. J. Harrison, C. S. Loftin,, Petra B. Wood. Do representative forest songbirds effectively predict occurrences of ecologically similar species? *Paper presented at Northeast Association of Fish and Wildlife Agencies Annual Conference, Rayleigh, NC*, April 11.

2017 - Rolek, B.W., D. Harrison, C.S. Loftin, P.B. Wood. Spruce-fir birds and forest management in Northern New England. *Workshop presented to U.S. Fish and Wildlife Service, Migratory Bird Division.* Hadley, MA, USA. 12 January.

2017 - Rolek, B.W., D. Harrison, C.S. Loftin, P.B. Wood. Softwood forest birds and forestry in New England. *Presentation to Cooperating Committee Meeting for Maine Cooperative Fish and Wildlife Research Unit*, Orono, Maine, USA. 22 March.

2016 - Dunham, S.W., and D.J. Harrison. Female spruce grouse habitat selection during the brood-rearing season in managed conifer forests. *Poster. 6th North American Ornithological Conference. Joint meeting of American Ornithological Union, Cooper Ornithological Society, Wilson Ornithological Society, Association of Field Ornithologists, and Society of Canadian Ornithologists. Washington, DC.* August 17.

2016 - Harrison, D. and S. Dunham. Final project report: Relative densities, patch occupancy, and population performance of spruce grouse in managed and unmanaged forests in northern Maine. *Presentation to Advisory Committee of Maine Cooperative Forestry Research Unit*, Orono, Maine, April 20.

2016 - Loman, Z.G., E. J. Blomberg, W. D. Deluca, D. Harrison, C. Loftin, and P. B. Wood. 2016. Landscape capability as a predictor of upland game bird space use in the northeastern United States. *Presentation at The Wildlife Society Annual Conference. Raleigh, North Carolina*, October 15-19.

2016 - Rolek, B.W., D. Harrison, C.S. Loftin, P.B. Wood. Opportunities to enhance habitat for spruce-fir passerines using commercial forest management. *Paper at North American Congress for Conservation Biology, Society for Conservation Biology, Madison, Wisconsin*, July 17-20.

2016 - Rolek, B.W., D. Harrison, C.S. Loftin, P.B. Wood. Softwood forest birds and forestry in New England. *Presentation at Cooperating Committee Meeting for Maine Cooperative Fish and Wildlife Research Unit, Orono, Maine,* March 23.

2016 - N. S. Parkhill, N. S., J. Tebbenkamp, S. Dunham, D. Harrison, and E. Blomberg. Effect of forest structure on nest site selection by spruce grouse across two scales. *Poster presented at The Wildlife Society Annual Conference. Raleigh, North Carolina*, October 15-19.

2016 - Tebbenkamp, J., E.Blomberg, D. Harrison, and R. Holberton. Is autumnal display associated with territorial defense or mate prospecting? A case study with spruce grouse. *Poster presented at The Wildlife Society Annual Conference. Raleigh, North Carolina*, October 15-19.

2015 - Dunham, S. W., D. J. Harrison, and E. J. Blomberg. 2015. Spruce grouse (*Falcipennis canadensis)* patch occupancy and abundance estimates in the commercially managed forests of Maine. *Presentation at the 13th International Grouse Symposium, Reykjavik, Iceland,* September 8.

2015 - Harrison, D. J. Updates on wildlife projects funded by the Maine Cooperative Forestry Research Unit (CFRU). *Presentation at CFRU Advisory Committee Meeting, Houlton, Maine*, October 28, 2015.

2015 - Olson, S. J., D. J. Harrison, A. K. Fuller, J. H. Vashon. Canada lynx food habits responses to seasons, and to low vs. high hare density periods: Always a specialist? *Poster presentation at The Wildlife Society Annual Conference, Winnipeg, Manitoba, Canada*, October 21-22.

2015 - Rolek, B.W., D. Harrison, C.S. Loftin, P.B. Wood. *Workshop on spruce-fir birds and forest management in Northern New England at U.S. Fish and Wildlife Service Migratory Bird Division. Hadley, MA, USA*, October 8.

2015 - Rolek, B.W., C. Loftin, D. Harrison, and P. Wood. Effects of forest management on avian abundance in spruce-fir forests of New England. *Joint Meeting of the Canadian Ornithological Society, Association of Field Ornithologists, and Wilson Ornithological Society. Wolfville, NS*, Canada, July 17.

2015 - Rolek, B.W., C. Loftin, D. Harrison, and P. Wood. Softwood forest birds and silviculture in New England. *Annual Meeting of the Research Committee for Baxter State Park, Augusta, Maine*, March 27.

2014 - Dunham, S. W., and D. J. Harrison. 2014. Spruce grouse breeding season patch occupancy and female home range use across forest management treatments in Maine. *Poster presented at the Annual Conference of The Wildlife Society, Pittsburgh, Pennsylvania,* October 27-28.

2014 – Harrison, D. Origin, spatial and social ecology, and predator-prey relationships of eastern coyotes: a review. *Invited lead presentation in Symposium on Ecology and Management of Coyotes in Eastern North America: Synthesizing Information from Contemporary Studies, The Wildlife Society 21st Annual Conference, Pittsburg, Pennsylvania*, October 27.

2014 – Dunham, S. and D. Harrison. Spruce grouse breeding season patch occupancy and home range comparisons across forest management treatments in Maine. *Presentation at 70th Northeast Fish and Wildlife Conference, Portland, Maine,* April 14.

2014 - Dunham, S. and D. Harrison. Habitat selection of female spruce grouse during brood rearing in commercially managed forests. Presentation at Annual Meeting of the American Ornithologists

Union, Estes Park, Colorado. September 27.

2014 – Harrison D. and E. Blomberg. Population dynamics of spruce grouse on commercially managed forestlands in Maine: a proposal. *Presentation at winter meeting of CFRU Advisory Committee, Orono, Maine,* January 22.

2014 – Harrison, D., S. Olson, S. Dunham, B. Rolek, and C. Loftin. Updates of research findings from studies of snowshoe hares, Canada lynx, spruce grouse and forest songbirds funded by the Maine Cooperative Forestry Research Unit (CFRU). *Presentation at winter meeting of CFRU Advisory Committee, Orono, Maine,* January 22.

2014 – Olson, S. and D. Harrison. Seasonal influences of vegetation on snowshoe hare pellet densities across forest management types in Maine. *Presentation at 70th Northeast Fish and Wildlife Conference, Portland, Maine,* April 14.

2014 – Olson, S. and D. Harrison. Snowshoe hare response to seasonal changes in Acadian managed forests of northern Maine. *Presentation at American Society of Mammalogists Annual Conference, Oklahoma City, Oklahoma*, June 10.

2014 – Parkhill, N. S., D. Harrison, and S. Dunham. Effects of forest vegetation on spruce grouse nest-site selection across 2 spatial scales. *Poster at 70th Northeast Fish and Wildlife Conference, Portland, Maine,* April 14.

2014 – Rolek, B., C. Loftin, D. Harrison, and P. Bohall Wood. The influence of silviculture on New England bird communities in northern coniferous forests. *Presentation at 70th Northeast Fish and Wildlife Conference, Portland, Maine,* April 15.

2014 - Simons-Legaard, E. and D. Harrison. Trends in habitat conditions in LURC-zoned deer wintering Areas: implications for management of deer on commercially-owned forestlands. *Invited presentation and panel discussion at Maine Industrial Forest Forum, Bangor, Maine,* February 16.

2013 – Fuller, A. K. and D. J. Harrison. Trade-offs among forest management objectives, focal wildlife species, and ecological reserves: implications for future forest biodiversity and timber harvests. *Invited Seminar to Department of Wildlife Ecology, University of Maine, Orono, Maine,* October 28.

2013 – Harrison, D., D. Mallett, A. K. Fuller, and J. H. Vashon. Snowshoe hares, forests, and Canada lynx: a dynamic interaction between populations, forestry and habitat. *Presentation at Meeting of Maine Cooperative Forestry Research Unit, Orono, Maine*, April 24.

2013 – Harrison, D.J. Conserving sustainable landscapes: using Canada lynx and American martens as umbrella species to enhance landscape planning. *Invited presentation at 2013 Kennebec Land Trust Lyceum, Wayne, Maine,* March 21.

2013 - Rolek, B., C.S. Loftin, D. Harrison, and P. B. Wood. Softwood forest birds and forest management in New England, *USGS-Maine Cooperative Fish and Wildlife Research Unit Annual Coordinating Committee Meeting, Wells Conference Center, Orono, Maine,* March 21.

2012 – Harrison, D., C. Loftin, and P. Wood. Forestry and forest birds: trends in FWS priority bird species in managed forest landscapes. *Presentation to U.S. Fish and Wildlife Service Refuge Biologists, Portland, Maine*, December 18.

2012 - Harrison, D., and E. Simons-Legaard. 2012. Trends in biodiversity in Maine's northern forest. *Presentation at Annual Program and Executive Board Meeting of The Maine Chapter of The Wildlife Society, Brewer, Maine*, May 10.

2012 - Harrison, D. Effects of forest management on Maine's forest bird communities. *Presentation at Advisory Meeting of the Maine Cooperative Forestry Research Unit, Orono, Maine,* January 25.

2012 - Simons-Legaard, E. and D. Harrison. Trends in habitat conditions in LURC-zoned deer wintering areas. *Presentation at Annual Program and Executive Board Meeting of The Maine Chapter of The Wildlife Society, Brewer, Maine,* May 10.

2012 - Simons-Legaard, E. and D. Harrison. Habitat trends in Maine's LURC-zoned deer wintering areas. *Seminar, Department of Wildlife Ecology, The University of Maine,* October 15.

2011 - Fuller, A., D. Harrison, and W. Krohn. 2011. The role of ecological reserves to maintain American marten and Canada lynx in a working forest landscape. *Poster presented at The Wildlife Society, 18th Annual Conference, Waikoloa, Hawaii,* November 9.

2011 - Fuller, A. and D. Harrison Trade-offs among forest management objectives, focal wildlife species, and ecological reserves: implications for future biodiversity and timber harvests. *Poster presented at the Society of Annual Foresters Annual Conference, Honolulu, Hawaii,* November 4

2011 – Harrison, D., E. Simons, A. Fuller, and W. Krohn. Trends in habitat for forest wildlife in Maine's great north woods: the need for landscape planning. *Invited presentation at U.S. Fish and Wildlife Service Northeast Region Biologists Conference, Baltimore, Maryland*, February 14.

2011- Harrison, D., E. Simons, A. Fuller, and W. Krohn. Habitat planning and assessment for forest vertebrates in northern Maine. *Invited Presentation at Annual Coordinating Committee Meeting of the U. S. Geological Survey, Maine Cooperative Fish and Wildlife Research Unit*, *University of Maine, Orono, Maine,* April 12.

2011 – Harrison, D. J. Effects of wind power development on American martens and Canada lynx: an issue of scale. *Invited Presentation at Wind Energy and Wildlife Forum, The Maine Chapter of The Wildlife Society, Orono, Maine*, May 5.

2011 – Simons-Legaard, E. M., D. J. Harrison, K. Legaard, and S. Sader. The effectiveness of zoning to protect deer wintering areas during the period 1975-2007: Does compromising forest productivity to protect deer habitat achieve desired ecological objectives? *Invited Presentation at Advisory Committee Meeting, Maine Cooperative Forestry Research Unit, University of Maine*, Orono, January 26.

2010 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. Applications of habitat modeling for wildlife umbrella species to landscape planning on commercial forestlands. *Presentation at meeting of Maine Cooperative Forestry Research Unit, Orono, Maine*, April 14.

2010 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. A wildlife-based modeling approach to forest landscape planning. *Presentation at The Wildlife Society Annual Conference, Snowbird, Utah*, October 6.

2010 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. Required steps to develop a habitat classification and structured decision-making framework for use in planning for multiple biodiversity and forest objectives on TNC's St. John Lands. *Presentation at Workshop on Managing Working Forest Landscapes for Multiple Biodiversity and Fiber Objectives Using American Martens and Canada Lynx as Focal Species*, University of Maine, Orono, November 10.

2010 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. Results from a structured process for deciding among alternative management scenarios on TNC's St. John lands: trends in habitat supply for martens and lynx and resulting inventory and forest-related metrics. *Presentation at Workshop on Managing Working Forest Landscapes for Multiple Biodiversity and Fiber Objectives Using American Martens and Canada Lynx as Focal Species*, University of Maine, Orono, November 10.

2010 – Harrison, D., W. Krohn, and S. Scott. Spatio-temporal relationships of snowshoe hare populations to forest harvesting, succession, and natural population cycles: implications for forest managers. *Final project report presentation to Maine Cooperative Forestry Research Unit, Orono, Maine*, January 27.

2010 - Harrison, D., W. Krohn, and S. Scott. Snowshoe hares, forestry and Canada lynx: A dynamic interaction. *Invited Paper presented at Lessons From the Past- Research for the Future: A Workshop for CFRU members*, Orono, Maine, May 20.

2010 - Harrison, D. J. and W.B. Krohn. Ongoing research efforts to link landscape conservation with wildlife habitat planning on commercial forestlands in northern Maine. *Invited Presentation to Directors of Resource Conservation, Wildlife, and Planning, Maine Department of Inland Fisheries and Wildlife, Augusta, Maine,* June 15.

2010 – Harrison, D. J., E. Simons, A. Whitman, J. Wilson. Present and future status of biodiversity on managed forest landscapes in Maine, U.S.A. *Presentation at the Annual Meeting of the Society for Conservation Biology*, Edmonton, Alberta, July 7.

2010 – Harrison, D. J. Incorporating landscape planning into the conservation of sensitive forest wildlife species in the northeastern U.S. *Invited presentation at Landscape Workshop for U.S. Fish and Wildlife Service Refuge Biologists and Refuge Managers, Moosehorn National Wildlife Refuge*, Calais, Maine, August 18.

2010 – Harrison, D. J. Stand- and landscape-scale responses of forest mammals to the various forms of siliviculture applied in the Acadian forests of Maine. *Invited presentation and field tour for U.S. Forest Service biologists, foresters and managers. U.S. Forest Service Northern Forest Research Station*, Bradley, Maine, September 9.

2010 – Harrison, D. J. The need for landscape planning on commercially managed landscapes in Maine: *Presentation at Workshop on Managing Working Forest Landscapes for Multiple Biodiversity and Fiber Objectives Using American Martens and Canada Lynx as Focal Species*, University of Maine, Orono, November 10.

2010 - Mallet, D. G., D. J. Harrison, and A. K. Fuller. Variable fix success of GPS collars across habitats used by Canada lynx: influences of habitat structure, topography, and satellite configuration. *Paper presented at 66th Annual Northeast Fish and Wildlife Conference*, Newton, Massachusetts, April 27.

2010 - Simons, E., D. Harrison, A. Whitman, and J. Wilson. 2010. Quantifying biodiversity: seeing the big picture. *Invited Paper presented at Lessons From the Past- Research for the Future: A Workshop for CFRU members*, Orono, Maine, May 20.

2010 – Simons, E., D. Harrison, A. Whitman, and J. Wilson. Present and future status of biodiversity in Maine's commercial forests as indicated by a suite of condition indicators. *Seminar presented at Department of Wildlife Ecology Spring Seminar Series, University of Maine*, Orono, March 29.

2010 - Simons, E. M., W. B. Krohn, and D. J. Harrison. Influences of past and future forest management on the spatiotemporal dynamics of habitat supply for Canada lynx and American marten. *Invited Presentation at the Cooperators' Meeting, Maine Cooperative Fish and Wildlife Research Unit*, University of Maine, Orono. May 11.

2010 - Simons, E., W. Krohn, and D. Harrison. Predicting responses of forest landscape changes on wildlife umbrella species: future projections results for Canada lynx and American marten. *Poster presented at the Cooperators' Meeting, Maine Cooperative Fish and Wildlife Research Unit*, University of Maine, Orono. May 11.

2010 - Scott, S. A., W. B. Krohn, and D. J. Harrison. Influence of declining snowshoe hare densities on Canada Lynx occurrence in northern Maine. *Poster presented at the Cooperators' Meeting, Maine Cooperative Fish and Wildlife Research Unit*, University of Maine, Orono. May 11.

2009 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. Landscape planning on The Nature Conservancy lands in northern Maine. *Invited presentation to executive director and staff of The Nature Conservancy,* Brunswick, Maine. February 24.

2009 - Fuller, A. K. D. J. Harrison, B. J. Hearn, and J. A. Hepinstall. Spatial responses to habitat loss in two populations of forest martens. Paper presented at *5th International Martes Symposium – Biology and Conservation of Martens: a New Synthesis*, Seattle, Washington. September 10.

2009 – Harrison, D. J. Forests, forest mustelids, and forest fragmentation: what happens when mammals don't read? *Invited presentation at Symposium on Behavioral Ecology of Mammals, W. M. Keck Center for Behavioral Ecology, North Carolina State University*, September 4.

2009 – Harrison, D. J. and B. J. Hearn. Ecological comparisons of home-range characteristics of American martens in Newfoundland and Maine: why are home ranges of threatened Newfoundland martens so large? Paper presented at *5th International Martes Symposium – Biology and Conservation of Martens: a New Synthesis*, Seattle, Washington. September 10.

2009 – Harrison, D. J. and A. K. Fuller. Ecology of white-tailed deer in Acadia National Park: Results from Research Conducted at The University of Maine. *Presentation to Resource Management Staff, Acadia National Park, Bar Harbor, Maine*, November 6.

2009 – Harrison, D .J., E. Simons, A. Whitman, and J. Wilson. Quantifying biodiversity values across managed landscapes in northern and western Maine. *Presentation to the Maine Cooperative Forestry Research Unit, Mars Hill, Maine*, October 28.

2009 – Harrison, D. J. The growing need to fund additional scientists working on forest-wildlife interactions in Maine: a proposal. *Presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine. February 26.

2009 – Harrison, D. J. Forestry and Forest Wildlife, Chaired session at New England Society of American Foresters 89th Winter Meeting**.** Bio: Mass, Fuel, Products, Diversity - Resource Management in a Changing World. Portland, Maine. March 19**.**

2009 – Harrison, D. J., and A. K. Fuller. Relative Densities, Patch Occupancy, and Population Performance of Spruce Grouse in Regenerating Conifer, Precommercially Thinned, Mature Conifer, and Conifer Wetlands Stands: a proposal. *Presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine. April 15.

2009 – Harrison, D. J., E. M. Simons, and W. B. Krohn. Habitat changes for wildlife umbrella species: implications for landscape conservation strategies in northern Maine. *Invited presentation to northern Appalachians landscape conservation committee*, The Nature Conservancy, Brunswick, Maine. May 21.

2009 – Harrison, D. J., W. B. Krohn, and E. M. Simons. Past and future trends in habitat supply for forest carnivores in northern Maine: implications for forest policy. *Invited presentation to leadership of Maine Forest Service, Maine Department of Inalnd Fisheries and Wildlife and Maine Natural Areas Program*, Augusta, Maine. June 30.

2009 - Patterson W. and A. K. Fuller. Silvicultural prescriptions for maintaining marten and lynx habitat requirements. Field tour of the Nature Conservancy St. John ownership for staff of The Nature Conservancy, U.S. Fish and Wildlife Service, and Huber Resources Group. May 4-6.

2009 - Scott, S. A, D.J. Harrison, and W. B. Krohn. The relative effects of forest practices and natural population processes on the temporal dynamics of hare populations in northern Maine. *Invited Paper at New England Society of American Foresters 89th Winter Meeting***,** Portland, Maine. March 19**.**

2009 - Scott, S.A., D.J. Harrison, and W.B. Krohn. Spatio-temporal dynamics of snowshoe hares in northern Maine**.** *Presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine. April 15.

2009 – Scott, S. A., D. J. Harrison, and W. B. Krohn. Spatio-temporal dynamics of snowshoe hares in northern Maine. *Paper presented at Northeast Fish and Wildlife Conference*, Lancaster, Pennsylvania. April 27.

2009 - Simons, E. M., D. J. Harrison, W. B. Krohn, K. R. Legaard, J. S. Wilson, and S. A. Sader. Past and future trends in habitat supply for martens and lynx across the landscapes of northern Maine, 1973-2032. . *Invited Paper at New England Society of American Foresters 89th Winter Meeting*, Portland, Maine. March 19**.**

2009 - Simons, E. M., D. J. Harrison, W. B. Krohn, K. R. Legaard, J. S. Wilson, and S. A. Sader. Past and future trends in habitat supply for martens and lynx across the landscapes of northern Maine, 1973-2032. .

Invited presentation to executive director and staff of The Nature Conservancy, Brunswick, Maine. February 24.

2009 – Simons, E. M. Influences of past and future forest management on the spatiotemporal dynamics of habitat supply for Canada lynx and American martens in northern Maine. *Ph.D. defense seminar, The University of Maine*, Orono. March 25.

2009 - Simons, E. M., J. S. Wilson, D. J. Harrison, W. B. Krohn,. Future trends in habitat supply for martens and lynx across the landscapes of northern Maine under alternative forest management scenarios, 2007-2032. . *Presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine. April 15.

2008 - Fuller, A. K., D. J. Harrison, and B. J. Hearn. 2008. Application and testing of models to predict probability of occupancy and density of endangered Newfoundland martens. *Presentation to Newfoundland Marten Recovery Team*, Corner Brook, Newfoundland. January 4.

2008 - Fuller, A. K., D. J. Harrison, and B. J. Hearn. 2008. Spatial responses to habitat loss in two isolated populations of forest martens. *Invited talk in the Ecology, Evolution, and Behavior seminar series. Virginia Tech. University*, Blacksburg. February 1.

2008 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. Landscape planning initiative for northern Maine using area sensitive umbrella species. *Invited presentation at USDA Natural Resources Conservation Service and U.S. Fish and Wildlife Service workshop on the Healthy Forest Reserve Program in Maine*, Bangor, Maine. July 1.

2008 – Fuller, A. K., D. J. Harrison, B. K. Hearn, and J. A. Hepinstall. Spatial responses to habitat loss in 2 populations of forest martens. *Paper presented at The Wildlife Society 15th Annual Conference*, Miami, Florida. November 11.

2008 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. Applications of lynx and marten models to operational forest management. *Invited presentation at Lynx on the landscape: workshop and fall field tour*, Cooperative Forestry Research Unit, Greenville, Maine. October 28.

2008 – Harrison, D. J., W. B. Krohn, and A. K. Fuller. Long-term monitoring of snowshoe hare populations to inform stand- and landscape-scale forest management and recovery planning for Canada lynx in Maine. *Presentation to Advisory Committee, Maine Cooperative Forestry Research Unit*, Orono. April 9.

2008 – Harrison, D. J., A. K. Fuller, and E. Simons. Trends in habitat supply for wildlife species whose habitat requirements are not addressed using coarse-filter umbrella species approaches, with a focus on deer wintering areas. *Presentation to Advisory Committee, Maine Cooperative Forestry Research Unit*, Orono. April 9.

2008 – Harrison, D. J., W. B. Krohn, S. Scott, A. K. Fuller, and L. Robinson. Stand-scale management to increase hare and lynx populations. *Invited presentation at Bridging Science and Stewardship Workshop*, Maine Cooperative Forestry Research Unit, Brewer, Maine. May 14.

2008 – Harrison, D. J., A. K. Fuller, J. A. Hepinstall, and E. Simons. Forests, forest carnivores, and fragmentation: Wildlife-habitat relationships in the Acadian forests of Maine, USA. *Invited seminar, Department of Ecology and Natural Resource Management*, Norwegian University of Life Sciences, As, Norway. September 16.

2008 – Harrison, D. J., A. K. Fuller, J. A. Hepinstall, and E. Simons. Forests carnivores as a tool for landscape conservation: Case studies focusing on American martens and Canada lynx. *Seminar presented at Grimso Wildlife Research Station*, Lindesberg, Sweden. September 19.

2008 – Harrison, D. J., A. K. Fuller, J. A. Hepinstall, E. Simons, B. J. Hearn, and D. Payer. Forests, forestry, and forest martens: a landscape perspective. *Invited presentation at conference titled: Pour une sylviculture adaptee a al feret irreguliere et sa faune,* Faculty of Forestry, University of Laval, Baie Comeau, Quebec. October 8.

2008 - Krohn W. B., D. J. Harrison, S. A Scott, L. L. Robinson, C. L. Hoving, A. K. Fuller, and E. M. Simons. Variation in snowshoe hare densities as related to Canada lynx and forest management in eastern North America. *Presentation at Eastern CANUSA Forest Science Conference*, Orono, Maine. October 17.

2008 - Scott, S., D.J. Harrison, and W. B. Krohn. Partial harvests: contributing to foraging habitat?. *Presentation at Lynx on the Landscape Workshop*, Maine Cooperative Forestry Research Unit , Workshop. Greenville, ME. October 28.

2008 - Simons, E. M., D. J. Harrison, W. B. Krohn, K. R. Legaard, and S. Sader. Trends in American marten habitat on the commercial forestlands of northern Maine. *Presented at Impact of Wildlife on the Forest Industry Workshop*, New England Regional Council on Forest Engineering, University of Maine, Orono. March 10.

2008 - Simons, E. M., D. J. Harrison, W. B. Krohn, K. R. Legaard, and S. Sader. Predicting responses of forest landscape change on wildlife umbrella species. *Presentation to the Maine Cooperative Forestry Research Unit Advisory Committee*, Orono. April 7.

2008 - Simons, E. M., D. J. Harrison, W. B. Krohn, K. R. Legaard, S. Sader, and J. S. Wilson. Landscape indicators of forest biodiversity: application of American marten, Canada lynx, and snowshoe hares. *Presentation at Bridging Science and Stewardship Workshop*, Maine Cooperative Forestry Research Unit, Brewer. May 14.

2008 - Simons, E. M., D. J. Harrison, W. B. Krohn, K. R. Legaard and S. A. Sader. Ecological factors associated with landscape-scale occurrences of Canada lynx in northern Maine. *Invited Presentation at Lynx on the Landscape: What You Need to Know Workshop and Field Tour*, Maine Cooperative Forestry Research Unit, Greenville, Maine. October 29.

2008 - Simons, E. M., D. J. Harrison, W. B. Krohn, K. R. Legaard, and S. A. Sader. Retrospective changes in habitat supply for Canada lynx and snowshoe hares resulting from timber harvesting: Implications for lynx recovery? *Paper presented at The Wildlife Society 15th Annual Conference*, Miami, Florida. November 9.

2008 - Simons, E. M., K. R. Legaard (Co-Presenters), D. J. Harrison, W. B. Krohn, and S. Sader. Evaluating broad-scale changes in timber harvesting patterns, forest landscape structure, and wildlife habitat supply for umbrella species in northern Maine. *Invited presentation at Friends of ForCAST, Center for Research on Sustainable Forests*, Orono. November 20.

2007 - Fuller, A. K., and D. J. Harrison. "The relative roles of fine- and coarse-grained habitat choices by Canada lynx during winter." *Paper presented at The Wildlife Society 14th Annual Conference*, Tucson, Arizona. September 23.

2007 - Fuller, A. K., D. J. Harrison, and W. B. Krohn. 2007. Landscape planning initiative for northern Maine using area sensitive umbrella species: an overview. *Presented to Beginning with Habitat Steering Committee*, Orono, Maine. October 17.

2007 - Fuller, A. K., and D. J. Harrison. Foraging paths reveal scale-dependent habitat decisions by Canada lynx. *Paper presented at Canada Lynx on the Border, Biological and Political Realities for Conservation Planning: An International Workshop*, Grand Portage, Minnesota. October 26.

2007 - Harrison, D.J. Forest carnivores, forestry, and fragmentation: modeling landscape sustainability using marten and lynx. *Seminar presented to Division of Biological Sciences and School of Forest Resources*, University of Montana, Missoula. April 30.

2007 - Harrison, D. J. The role of predation on population dynamics of white-tailed deer. *Presentation to Commissioner's Task Force to Assess the Northern and Eastern Maine Deer Population*. June 12.

2007 - Harrison, D. J., E. Simons, and K. Legaard. Forest carnivores, forestry and fragmentation: Using American marten as the canary in the coal mine. *Department of Biological Sciences Seminar Series*, University of Maine. May 4.

2007 - Harrison, D. J. and J. McCloskey. Documenting occurrence patterns of northern goshowks in Maine. *Proposal presentation to Advisory Committee, Maine Cooperative Forestry Research Unit*, Orono, Maine. April 25.

2007 - Harrison, D. J., W. B. Krohn, L. Robinson, A. K. Fuller, and C. L. Hoving. 2007. Multi-scalar habitat preferences of snowshoe hares: how does a prey specialist coexist with a specialist predator? Paper *presented at International Union of Game Biologists XXVIII Congress*, Uppsala, Sweden. August 17.

2007 – Harrison, D. J. Effects of forest practices on habitat for wintering deer. *Workshop and Field Tour for Maine Cooperative Forestry Research Unit Advisory Committee*. October 10.

2007 - Harrison, D. J., W. B. Krohn, L. Robinson, S. Scott, A. K. Fuller, and C. L. Hoving. Temporal and spatial variation in snowshoe hare densities in eastern North America: relationships to lynx and forest management. *Invited paper presented at Canada Lynx on the Border, Biological and Political Realities for Conservation Planning: An International Workshop*, Grand Portage, Minnesota. October 26.

2007 – Harrison, D. J. The influence of predators on overwinter deer survival: interactions with habitat. *Invited presentation at Deer Wintering Area Workshop*, Orono, Maine. December 10.

2007 - Hearn, B. J., D. J. Harrison, C. Lundrigan, W. J. Curran, and A. K. Fuller. Multi-scale habitat selection by the endangered Newfoundland marten. *Paper presented at The Wildlife Society 14th Annual Conference*, Tucson, Arizona. September 23.

2007 - Simons, E. M., L. Robinson, D. J. Harrison, W. B. Krohn, and K. R. Legaard. Ecological factors associated with landscape-scale occurrences of Canada lynx in northern Maine. *Paper presented at Canada Lynx on the Border, Biological and Political Realities for Conservation Planning: An International Workshop*, Grand Portage, Minnesota. October 24.

2006 – Fuller, A. K., and D. J. Harrison. Stand-scale habitat relationships of lynx in northern Maine. *Presentation at Maine Lynx Workshop*, Bangor, Maine, December 3.

2006 – Fuller, A. K., and D. J. Harrison. Stand-scale habitat relationships of lynx in northern Maine. *Paper presented at 2006 Carnivores Conference*, St. Petersburg, Florida, November 14.

2006 – Fuller, A. K., and D. J. Harrison. Stand-scale habitat relationships of lynx in northern Maine. *Invited presentation at Forestry Noontime Seminar Series*, University of Maine, Orono, March 3.

2006 – Fuller, A. K., and D. J. Harrison. Stand-scale habitat relationships of lynx in northern Maine. *Final contract report presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine, January 25.

2006 – Harrison, D. J. Interactions among forestry and forest wildlife in the Acadian forest: the need for landscape planning. *Invited lecture in FES 508: Industrial Spruce-Fir Ecosystems*, University of Maine, Orono, December 15.

2006 – Harrison, D. J., W. B. Krohn, J. A. Homyack, L. Robinson, and A. K. Fuller. Temporal and spatial variation in hare populations in relation to forest harvesting in Maine. *Presentation at Maine Lynx Workshop*, Bangor, Maine, December 1.

2006 - Harrison, D. J., W. B. Krohn, A. K. Fuller, and L. Robinson. Hare population dynamics and lynx and hare habitat selection in Maine. *Presentation at National Interagency Lynx Biology Team Meeting, Duluth, MN*. October 20.

2006 - Harrison, D. J. and W. K. Krohn. Long-term results from research on snowshoe hares and lynx in relation to forest management activities in Maine. *Presentation to Advisory Committee, Maine Cooperative Forestry Research Unit*, University of Maine. October 4.

2006 – Harrison, D. J., W. K. Krohn, L. Robinson, J. A. Homyack, and A. K. Fuller. Temporal and spatial variation in hare densities within the geographic range of lynx in Maine. *Invited paper presented at Symposium on Lynx Conservation in the lower 48 states, The Wildlife Society Annual Conference*, Anchorage, Alaska, September 27.

2006 – Harrison, D. J. Managing forest stands and landscapes to maintain wildlife biodiversity. *Invited presentation at Research, Results and the Resource Workshop*, sponsored by Maine Cooperative Forestry Research Unit, Orono, Maine, May 25.

2006 – Harrison, D. J. Research results and applications for management: stand and landscape management for marten and lynx on commercial forestlands in Maine. *Invited presentations and field tour, Annual meeting of Foresters, Wagner Land Management Corp*., Bethel, Maine, May 3.

2006 – Harrison, D. J. Quantifying biodiversity values across managed landscapes in northern and western Maine. *Presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine, April 26.

2006 – Harrison, D. J. Wildlife, forest succession, vegetation management, and biodiversity. *Invited lecture in FES 435/535: Managing Forest Succession*, University of Maine, Orono, April 13.

2006 – Krohn, W. B., D. J. Harrison, C. Hoving and L. Robinson. Factors influencing patterns of lynx occurrence across multiple spatial scales in eastern North America. *Presentation at Maine Lynx Workshop*, Bangor, Maine, December 1.

2006 - Krohn, W. B., D. J. Harrison L. Robinson, and C. Hoving. Results for species occurrence modeling with lynx across 3 spatial scales in Maine. *Presentation at National Interagency Lynx Biology Team Meeting*, Duluth, MN. October 20.

2006 – Robinson, L., D. J. Harrison, W. B. Krohn, J. Vashon, and M. McCollough. Modeling habitat occupancy of lynx in northern Maine. *Paper presented at Carnivores 2006 Conference*, St. Petersburg, Florida, November 14.

2006 – Robinson, L., D. J. Harrison, W. B. Krohn. Ecological relationships between partial harvesting, snowshoe hares, and lynx in Maine. *Presentation and Wiscussion for Forestry and Wildlife Professionals in Maine*, University of Maine, Orono, August 24.

2006 – Simons, E., K. Legaard, D. J. Harrison, S. Sader, and W. B. Krohn. Forest harvesting trends affecting lynx and marten habitat in Maine as revealed by change detection of multiple LANDSAT TM images, 1988-2004. *Presentation at Maine Lynx Workshop*, Bangor, Maine, December 1.

2006 – Simons, E., K. Legaard, D. J. Harrison, S. Sader, and W. B. Krohn. Trends in forest harvesting in Maine as revealed by change detection of multiple LANDSAT TM images. *Poster presented at 2006 CANUSA Conference*, Quebec City, Canada, October.

2005 - Fuller, A. K., D. J. Harrison, and B. J. Hearn. Modeling habitat occupancy of marten in western Newfoundland: management and planning applications. *Invited presentation to the Newfoundland Marten Recovery Team*, Corner Brook, Newfoundland, November 2.

2005 – Fuller, A. K., D. J. Harrison, and B. J. Hearn. Modeling habitat occupancy of marten in western Newfoundland: management and planning applications. *Final contract report presentation to Canadian Forest Service, Western Newfoundland Model Forest, and other project cooperators*, Corner Brook, Newfoundland, November 1.

2005 - Fuller, A. K., D. J. Harrison, and J. Vashon. Stand-scale habitat selection by lynx on commercial forestlands in northern Maine. *New England Chapter of Society of American Foresters Conference*, Portland, ME. March 17.

2005 - Fuller, A. K., D. J. Harrison, and J. H. Vashon. Effects of forest practices on habitat selection by Canada lynx during winter. *Lynx Research Working Group Meeting*, Orono, ME. April 14.

2005 - Harrison, D. J. An overview of the research program in the Department of Wildlife Ecology. Presentation to the *Office of the Vice President for Research*, University of Maine, Orono, ME. February 1.

2005 - Harrison, D. J. Predators, prey, and forestry in northern and eastern Maine: a historical perspective. *University of Maine at Machias Science Club and Downeast Salmon Federation*, Machias, ME. March 2, 2005.

2005 - Harrison, D. J. Overview of research conducted by The University of Maine during 1980-1994 regarding the population status and relationships of deer and vegetation in Acadia National Park. *Acadia National Park Resource Management Staff*, Bar Harbor, ME. July 26.

2005 - Harrison, D. J. and J. A. Hepinstall. Evaluating the utility of forest carnivores as umbrella species to promote biodiversity conservation. Final contract report presentation, *Maine Cooperative Forestry*

Research Unit, University of Maine, Orono, ME. January 26.

2005 - Harrison, D. J., and W. B. Krohn. Relationships among partial harvesting, snowshoe hares, Canada lynx and forest harvesting: a survey of research activities at the University of Maine and Maine Cooperative Fish and Wildlife Research Unit. *National Lynx Biology Team Meeting*, Minneapolis, MN. August 17.

2005 – Harrison, D. J., W. B. Krohn, and J. A. Hepinstall. A landscape planning framework for northern Maine: an overview of recent research results for marten, lynx and other forest vertebrates. *Maine Department of Inland Fisheries and Wildlife*, Augusta, December 21.

2005 - Harrison, D. J. and W. B. Krohn. A summary of preliminary research findings from studies of snowshoe hares and lynx conducted by the University of Maine and the Maine Cooperative Fish and Wildlife Research Unit. *Eastern Science Team, National Council for Air and Stream Improvement*, Sugarloaf, U.S.A. August 24.

2005 - Hearn, B. J., D. J. Harrison, and A.K. Fuller. Landscape-scale habitat selection by Newfoundland marten & an update on efforts to model habitat for Newfoundland marten. *Newfoundland Marten Recovery Team*, Corner Brook, NL. May 17, 2005.

2005 - Homyack, J. A., D. J. Harrison, and W. B. Krohn. Effects of precommercial thinning on snowshoe hares, small mammals, and forest structure in northern Maine. *Department of Fisheries and Wildlife Sciences, Virginia Polytechnic Institute and State University*, Frostburg, VA. April 26.

2004 - Fuller, A. K. and D. J. Harrison. Preliminary results of studies of substand-scale habitat selection by lynx in northern Maine. *Invited presentation at Wildlife Management Institute's Eastern Lynx Workshop*, North Conway, New Hampshire, January 6.

2004 - Fuller, A. K. and D. J. Harrison. Preliminary results of studies of substand-scale habitat selection by lynx in northern Maine. *Presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine, January 21.

2004 – Fuller A. K. and D. J. Harrison. Influence of forest practices on stand-scale habitat selection of lynx in northern Maine. *Paper presented at Eastern CANUSA Forest Science Conference*, Frederickton, New Brunswick, October 15.

2004 - Fuller, A. K. and D. J. Harrison. Stand-scale habitat selection by lynx in northern Maine: preliminary results. *Invited presentation at Fourth Northeastern Mesocarnivore Workshop: Lynx and marten in the northern Appalachians*, Portland, Maine, December 9.

2004 - Harrison, D. J., J. A. Homyack, A. K. Fuller, and W. B. Krohn. Effects of precommercial thinning and partial harvesting on snowshoe hares in Maine. *Invited presentation at Wildlife Management Institute's Eastern Lynx Workshop*, North Conway, New Hampshire, January 6.

2004 - Harrison, D. J., J. A. Homyack, J. A. Litvaitis, and W. B. Krohn. Quantifying densities of snowshoe hare in Maine using pellet plots. *Invited presentation at Wildlife Management Institute's Eastern Lynx Workshop*, North Conway, New Hampshire, January 6.

2004 - Harrison, D. J., C. L. Hoving, and W. B. Krohn. Distribution and extent of lynx habitat in eastern North America and Maine from GIS modeling. *Presentation at Wildlife Management Institute's Eastern Lynx Workshop*, North Conway, New Hampshire, January 7.

2004 - Harrison, D. J. Status of lynx litigation, critical habitat designations, and recovery planning in the U.S. *Presentation to Maine Cooperative Forestry Research Unit*, Orono, Maine, January 21.

2004 - Harrison, D. J. Effects of clearcutting, precommercial thinning, and partial harvesting on forest dependent wildlife species. Invited presentation at workshop on *Managing for Fiber Production, Wildlife Habitat, and Biodiversity: Latest Results from CFRU Research,* Ashland Maine, May 12.

2004 – Harrison, D. J. and J. A. Hepinstall. Predicting marten and lynx occurrences across the landscape: Evaluating the utility of forest carnivores as umbrella species to promote biodiversity conservation. *Wildlife Ecology Seminar Series, University of Maine*, Orono, 6 December.

2004 – Harrison, D. J., W. B. Krohn, L. Robinson, and A. K. Fuller. Lynx and hare research sponsored by the Maine Cooperative Forestry Research Unit. *Field tour at sites in northern Maine for forest industry representatives.* October 28.

2004 – Harrison, D. J. and J. A. Hepinstall. Broad-scale viability habitat modeling, habitat supply trends, and umbrella species applications for marten and lynx in Maine. *Invited presentation at Fourth Northeastern Mesocarnivore Workshop: Lynx and marten in the northern Appalacians, Wildlife Conservation Society*, Portland, Maine, December 9.

2004 – Harrison, D. J., A. K. Fuller, and B. Hearn. Updates of results on habitat selection and fragmentation studies on Newfoundland marten. *Presentation to Newfoundland marten recovery team*, Corner Brook, Newfoundland, December 15.

2004 – Hepinstall, J. A. and D. J. Harrison. Utility of forest carnivores (American marten and Canada lynx) as umbrella species for biodiversity conservation. *Carnivores 2004 Conference*, Sante Fe, New Mexico, November 15.

2004 – Homyack, J. A., D. J. Harrison, W. B. Krohn, A. K. Fuller, and C. L. Hoving. *Comparing conservation issues affecting Canada lynx within the northeastern U.S. and the Rocky mountains*. *Presentation to Wyoming Chapter of The Wildlife Society*, Laramie, November 11.

2004 - Krohn, W. B., D. J. Harrison, and M. A.,McCollough. An overview of the lynx-hare landscape modeling project in northern Maine. *Invited presentation at Wildlife Management Institute's Eastern Lynx Workshop*, North Conway, New Hampshire, January 6.

2003 - Harrison, D.J., and J.A. Hepinstall. Marten as a tool for landscape-scale habitat planning in northern Maine. *Final contract report presentation to Maine Cooperative Forestry Research Unit, Orono, Maine.* January 29.

2003 - Harrison, D.J. Ecological aspects of coyote predation and the potential for effective control of predation via snaring. *Invited presentation and panel discussion at winter meeting of Maine Chapter of The Wildlife Society, Augusta, Maine.* January 30.

2003 - Harrison, D.J. and J.A. Hepinstall. Using marten as a landscape-scale conservation tool for maintaining diversity of forest-dependent vertebrates. *Presentation and workshop conducted for Maine Department of Inland Fisheries and Wildlife Habitat Planning Committee, Bangor, Maine.* March 10.

2003 - Harrison, D.J., and J.A. Hepinstall. Marten as a tool for landscape-scale habitat planning and biodiversity conservation. *Presentation to Recovery Team for the Endangered Newfoundland Marten, Deer Lake, Newfoundland.* April 1.

2003 - Harrison, D.J. Predicting responses of snowshoe hares and lynx to alternative forest harvesting scenarios. *Presentation to Maine Cooperative Forestry Research Unit, Orono, Maine.* April 17.

2003 - Harrison, D.J. Relative densities, habitat selection, and population performance of spruce grouse in clearcut, intensively managed, and "classic" habitat in northern Maine. *Presentation to Maine Cooperative Forestry Research Unit, Orono, Maine.* April 17.

2003 - Harrison, D.J. Evaluating the umbrella species approach for biodiversity conservation on commercial forestlands in Maine. *Presentation to Maine Cooperative Forestry Research Unit, Orono, Maine.* April 17.

2003 - Harrison, D. J. Effects of coyotes on Maine's deer herd: Is there a need for a snaring program. *Talk presented to Student Chapter of The Wildlife Society*, University of Maine, Orono, December 6.

2003 - Harrison, D. J. A. K. Fuller, J. A. Homyack, and W. B. Krohn. How do clearcutting, pre-commercial thinning, and partial harvesting influence wildlife habitat? Invited presentation at workshop on *Managing for Fiber Production, Wildlife Habitat, and Biodiversity: Latest Results from CFRU Research*. Plum Creek Timber Company, Fairfield, Maine, December 16.

2003 - Harrison, D. J. and J. A. Hepinstall. Landscape planning for wildlife. Invited presentation at workshop on *Managing for Fiber Production, Wildlife Habitat, and Biodiversity: Latest Results from CFRU Research*. Plum Creek Timber Company, Fairfield, Maine, December 16.

2003 - Harrison, D. J., D. C. Payer, and A. K. Fuller. Maintaining structural requirements of wildlife within forest stands. Invited presentation at workshop on *Managing for Fiber Production, Wildlife Habitat, and Biodiversity: Latest Results from CFRU Research*. Plum Creek Timber Company, Fairfield, Maine, December 16.

2003 - Hepinstall, J.A., and D. J. Harrison. Predicting habitat supply for American marten using measures of landscape composition and configuration. *Paper presented at Resource Selection Conference, Laramie, Wyoming.* January 5-8.

2003 - Hepinstall, J.A., and D.J. Harrison. Does the umbrella leak?: Biodiversity conservation based on marten habitat. *Paper presented at the 10th Annual Conference of The Wildlife Society, Burlington, VT*. September 9.

2003 - Homyack, J.A. Effects of precommercial thinning on snowshoe hares, small mammals, and forest structure in northern Maine. *Seminar presented to Department of Wildlfe Ecology, University of Maine.* February

27.

2003 - Homyack, J.A., D.J. Harrison, and W.B. Krohn. Effects of precommercial thinning on snowshoe hares, small mammals, and forest structure in northern Maine. *Final contract report presentation to Maine Cooperative Forestry Research Unit, Orono, Maine.* April 17.

2003 - Krohn, W.B., J.A. Homyack,and D.J. Harrison. "Changes in the Acadian Forest: Implications for Wildlife." *Invited paper presented in Special Wildlife Session on Early Successional Habitats: A Critical Problem, 59th Northeast Fish and Wildlife Conference, Newport, Rhode Island*. April 15.

2002 - Fuller, A. K. and D. J. Harrison. "Resource partitioning and interspecific competition between coyotes and red foxes on an island during recent colonization by coyotes." *Paper presented at the Northeast Fish and Wildlife Conference*, Portland, ME. April 23.

2002 - Fuller, A. K., and D.J. Harrison. Resource partitioning and interspecific competition between coyotes and red foxes on an island during recent colonization by coyotes. *Paper presented at Carnivores 2002 Conference, Monteray, California.* November 18.

2002 - Harrison, D.J., and J. A. Hepinstall. "A workshop on approaches to evaluate habitat requirements and to inventory habitat supply for endangered marten in Newfoundland." *Workshop presented to Canadian Forest Service Scientists, Newfoundland Government Scientists, and Western Newfoundland Model Forest Scientists*, Cornerbrook, Newfoundland, January 9.

2002 - Harrison, D.J. "Forestry and forest carnivores: conflict or opportunity." *Talk presented to Student Chapter of The Wildlife Society*, Orono, Maine, February 7.

2002 - Harrison, D.J. "Forestry and forest carnivores: conflict or opportunity." *Department of Biology Seminar Series, Colby College*, Waterville, Maine, March 8.

2002 - Harrison, D.J., C. L. Hoving, A. K. Fuller, and W.B. Krohn. "A summary of research needs for lynx in eastern North America: what do we know, what are we researching, and what is left?" *Presentation at Northern Appalachians Lynx Science Workshop*, Portland, Maine, April 24.

2002 - Harrison, D.J. "Landscape considerations for conserving habitat for wolves, American marten, and lynx in the White and Green Mountain National Forests." *Presentation at Species Viability Workshop, U.S. Forest Service*, Manchester, New Hampshire, May 22.

2002 - Harrison, D. J. and A.K. Fuller. Effects of partial harvesting on forest mammals. *Presentation and field tour for Cooperative Forestry Research Unit, Northern Maine.* October 9.

2002 - Harrison, D.J., and J.A. Hepinstall. Landscape management for fragmentation-sensitive species. *Presentation and field tour for Cooperative Forestry Research Unit, Northern Maine.* October 9.

2002 - Harrison, D.J. and A.K. Fuller. Substand-scale responses of Canada lynx to habitat and prey: an ongoing study. . *Invited presentation at Interagency Lynx Biology Team Meeting, Orono, Maine*. October 22.

2002 - Harrison, D.J., W.B. Krohn, and C. Hoving, Broad-scale habitat ecology of Canada lynx in eastern North

America. *Invited presentation at Interagency Lynx Biology Team Meeting, Orono, Maine*. October 22.

2002 - Harrison, D.J., and J.A. Hepinstall. Modeling habitat supply as a tool for marten conservation. *Invited presentation at Newfoundland Marten Habitat Supply Workshop, Grand Falls, Newfoundland.* December 3.

2002 - Harrison, D.J., and J.A. Hepinstall. Predictive modeling and trends in marten occurrence across the landscape of Northern Maine: marten as a tool for conserving forest biodiversity. *Invited presentation at Wildlife Division Meeting, Maine Department of Inland Fisheries and Wildlife, Bangor, Maine.* December 17.

2002 - Hearn, B., and D.J. Harrison. Home range characteristics of Newfoundland marten. *Invited presentation at Newfoundland Marten Habitat Supply Workshop, Grand Falls, Newfoundland.* December 3.

2002 - Hepinstall, J. A. and D. J. Harrison, and W. B. Krohn. "Spatially explicit wildlife habitat modeling; case studies from Maine." Seminar presented at the *Department of Wildlife Ecology Seminar Series*, Orono, ME. April 8.

2002 - Hepinstall, J. A., D. J. Harrison, D. C. Payer and A. K. Fuller. "Habitat supply modeling for American marten in the managed forests of northern Maine." *Poster presented at the Northeast Fish and Wildlife Conference, Portland, ME*. April 21- 24.

2002 - Hepinstall, J. A., D. J. Harrison, D.C. Payer, and A. K. Fuller. "Can marten serve as an umbrella species for forest management in northern Maine?" *Paper presented at the 17th annual symposium of the International Association for Landscape Ecology – United States Regional Association (US-IALE)*, Lincoln, NE. April 23-27.

2002 - Hepinstall, J. A. and D. J. Harrison. "Applications of Field Research to Forest Landscape Planning: A Case Study Using American Marten in Maine." Paper presented at *Beyond the Data: Integrating Research Findings into Forest Management Planning and Operations,* Moncton, New Brunswick, Canada. May 3-4.

2002 - Hepinstall, J.A., D.J. Harrison, D.C. Payer, and A.K. Fuller. Predicting habitat supply for American marten using measures of landscape composition and configuration. *Poster presented at Eastern Canada-USA (CANUSA) Forest Science Conference, Orono, Maine.* October 20.

2002 - Hepinstall, J.A., D.J. Harrison, D.C. Payer, and A.K. Fuller. Predicting habitat supply for American marten using measures of landscape composition and configuration. *Paper presented at Carnivores 2002 Conference, Monteray, California.* November 19.

2002 - Homyack, J. A., D. J. Harrison, and W. B. Krohn. "Effects of intensive forest management on small mammals and snowshoe hare in northern Maine." *Presentation at the Spring 2002 Evening Seminar Series of the University of Maine Student Chapter of the Wildlife Society, Orono, ME*. April 14.

2002 - Homyack, J. A., D. J. Harrison, and W. B. Krohn. "Effects of precommercial thinning on small mammals in northern Maine." *Paper presented at the Northeast Fish and Wildlife Conference, Portland, ME.* April 23.

2002 - Homyack, J. A., D. J. Harrison, and W. B. Krohn. "Preliminary results of the effects of precommercial thinning on snowshoe hare." *Poster presented at the Northeast Fish and Wildlife Conference, Portland, ME*. April 21- 24.

2002 - Homyack, J. A., D. J. Harrison, and W. B. Krohn. "Effects of precommercial thinning on snowshoe hare in northern Maine." *Paper presented at The Annual Meeting of The Wildlife Society, Bismarck, ND*. September 27.

2002 - Homyack, J. A., D. J. Harrison, and W. B. Krohn. Precommercial thinning effects on hare habitat. *Presentation and field tour for Cooperative Forestry Research Unit, Northern Maine.* October 9.

2002 - Homyack, J.A., D.J. Harrison, and W.B. Krohn. Effects of precommercial thinning on abundance of snowshoe hare in northern Maine. *Paper presented at Eastern Canada-USA (CANUSA) Forest Science Conference, Orono, Maine.* October 20.

2002 - Homyack, J.A., D.J. Harrison, and W.B. Krohn. Effects of precommercial thinning on small mammals in northern Maine. *Paper presented at Eastern Canada-USA (CANUSA) Forest Science Conference, Orono, Maine.* October 20.

2002- Homyack, J.A., D.J. Harrison, and W.B. Krohn. Effects of precommercial thinning on snowshoe hares in northern Maine: implications for Canada lynx. *Invited presentation at Interagency Lynx Biology Team Meeting, Orono, Maine*. October 22.

2002- Homyack, J.A., D.J. Harrison, and W.B. Krohn. Effects of precommercial thinning on snowshoe hare: implications for Canada lynx. *Paper presented at Carnivores 2002 Conference, Monteray, California.* November 19.

2002 - Hoving, C. L., D. J. Harrison, W. B. Krohn, and W. J. Jakubas. "Canada lynx habitat, forest harvest strategies and regeneration in northern Maine." *Paper presented at the Northeast Fish and Wildlife Conference, Portland, ME*. April 24.

2002 – Hoving, C., D.J. Harrison, W.B. Krohn, and W. Jakubas. Canada lynx habitat, forest harvest strategies and regeneration in northern Maine. *Paper presented at Carnivores 2002 Conference, Monteray, California.* November 19.

2002 – Hoving, C., D.J. Harrison, W.B. Krohn, R.A. Joseph, and M. O'Brien. Climate change and lynx: spatial occurrence models for eastern North America. *Poster presented at Carnivores 2002 Conference, Monteray, California.* November 17-20.

2002 - Spohr, S., D.J. Harrison, and F.A. Servello. "Effects of landscape and cover characteristics on nest success of eastern wild turkeys in southeastern Connecticut." *Paper presented at the Northeast Fish and Wildlife Conference*, Portland, Maine, April 23.

2001 - Fuller, A.K., and D.J. Harrison. "Partial harvest guidelines for maintenance of marten in Maine." *Invited lecture presented at the "Newfoundland Marten Endangered Species Recovery Team Meeting*", St. John's, Newfoundland, January 12.

2001 - Harrison, D.J. Landscape scale habitat requirements and fragmentation thresholds of marten. *Lecture at workshop attended by Canada Parks scientists and invited advisors to address habitat needs of endangered marten in western Newfoundland*. Gros Morne National Park Newfoundland, January 9.

2001 – Harrison, D.J., and D.C. Payer "Influences of trapping mortality on current distribution and population dynamics of marten: a biogeographical and empirical perspective." *Invited paper presented at "Newfoundland Marten Accidental Trapping and Snaring Workshop*", St. John's, Newfoundland, January 12.

2001 - Harrison, D.J. An update of lynx and marten issues related to forest management. *Presentation to Advisory Committee, Maine Cooperative Forestry Research Unit,* Orono, January 25.

2001 – Harrison, D. J. "Marten and Forestry: Conflict or Opportunity." *Invited paper presented at J. D. Irving, Limited's 2001 Science Forum*, Frederickton, NB, April 3, 2001.

2001 - Harrison, D.J. "Forestry and Forest Carnivores: Conflict or Opportunity." *Presented at the University of Maine, Forestry Noontime Seminar Series*, April 6.

2001 - Harrison, D.J. Potential forest management issues and research opportunities with federally threatened lynx in Maine. *Presentation to to Advisory Committee, Maine Cooperative Forestry Research Unit*, Orono, Maine, May 3.

2001 – Harrison, D.J. "Extent and distribution of wolf habitat in eastern North America and niche characteristics of wolves versus eastern coyotes." Served as *invited panelist and presenter at Wolf Symposium for invited government agencies, university personnel and non-governmental organizations*, Burlington, VT, May 16.

2001 - Harrison, D. J., D.C. Payer, J. A. Hepinstall, A. K. Fuller and D. J. Katnik. "Landscape thresholds and nonlinear responses to fragmentation by American marten." *Paper presented at 15th Annual Meeting of the Society for Conservation Biology*, Hilo, Hawaii, July 31.

2001 - Harrison, D. J., and J. A. Hepinstall. "Habitat supply planning for American marten in Maine and Newfoundland." *Seminar presented to Canadian Forest Service and Newfoundland Provincial Scientists*, Cornerbrook, Newfoundland, August 26.

2001 - Harrison, D. J. "Marten habitat supply assessment." *Presentation at meeting of Maine Cooperative Forestry Research Unit Advisory Committee*, Millinocket, Maine, October 17.

2001 - Harrison, D.J. "Habitat potential for wolves and niche overlap with eastern coyotes in eastern North America." *Paper presented at Eastern Wolf Workshop*, Dixville Notch, New Hampshire, October 19.

2001 – Hepinstall, J. A., D. J. Harrison, D. C. Payer, A. K. Fuller, and D. D. Katnik. "Using marten as an umbrella species for forest management." *Invited paper presented at the 37th Annual North American Moose Conference and Workshop*, Sugarloaf, ME, May 14, 2001.

2001 - Hepinstall, J.A., D.J. Harrison, D.C. Payer, and A.K. Fuller. Predicting the occurrences of American

marten in harvested landscapes. *Paper presented at the 8th Annual Conference of The Wildlife Society, Reno, Nevada*, September 25-29.

2001 - Homyack, J. A., D. J. Harrison, and W. B. Krohn. "Update on the effects of precommercial thinning on snowshoe hare and small mammals in northern Maine." *Field tour and presention to Advisory Committee, Maine Cooperative Forestry Research Unit*, Millinocket, Maine, October 17.

2001 - Hoving, C. L. "Historical occurrence and habitat ecology of Canada lynx in eastern North America." *Talk presented at the Maine Audubon's Wildlife Conference, Maine Audubon Society*, Falmouth, ME, April 7.

2001 - Hoving, C.L, D. J. Harrison, and W.B. Krohn. Historical occurrence and habitat ecology of Canada lynx in eastern North America. *Final contract seminar to Maine Department of Inland Fisheries and Wildlife*, Bangor, ME, March 22.

2001 - Hoving, C.L. Historical occurrence and habitat ecology of Canada lynx in eastern North America. *Final thesis seminar presented to Department of Wildlife Ecology, University of Maine*, April, 12.

2001 – Hoving, C. L., R. A. Joseph, and W. B. Krohn. "Historical and current distributions of lynx in Maine, 1833-1999." *Paper presented at the 57th Northeast Fish and Wildlife Conference*, Saratoga Springs, NY, April 22-26.

2001 – Hoving, C. L., D. J. Harrison, W. K. Krohn, W. J. Jakubas, R. A. Joseph, R. Lafond, and M. O'Brien. "A probability model of Canada lynx occurrence in eastern North America." *Poster presented at the 57th Northeast Fish and Wildlife Conference*, Saratoga Springs, NY, April 22-26.

2001 - Hoving, C.L., D. J. Harrison and W. B. Krohn. " Habitat ecology of Canada lynx in eastern North America." *Poster presented at the U. S. Fish and Wildlife Service regional office, Hadley, MA*, April 26.

2001 - Hoving, C. L., D. J. Harrison, and W. K. Krohn. " Multi-scale habitat relations of Canada lynx in eastern North America." *Paper presented at the 2001 Meeting of the Northeast Fur Technical Committee*, Providence, Rhode Island, September 13.

2001 - Hoving, C. L., D. J. Harrison, W. K. Krohn, W. J. Jakubas, R. A. Joseph, R. Lafond, and M. O'Brien. "Canada lynx habitat associations in eastern North America." *Paper presented at The Wildlife Society 8th Annual Conference*, Reno, Nevada, September 27.

2001 - Hoving, C. L., D. J. Harrison, and W. B. Krohn. "Canada lynx habitat in eastern North America." *Presented at the Alice Steward Lecture Series, Maine Center for the Arts*, Orono, ME. October 31.

2000 - Fuller, A.K., H. J. Lachowski, and D. J. Harrison. Responses of mammals at two trophic levels to partial harvesting. *Paper presented at 80th Annual Meeting of the American Society of Mammalogists*, University of New Hampshire, Durham, June 19.

2000 - Fuller, A.K. and D.J. Harrison. Influence of partial harvesting on habitat selection by American marten in an industrially forest landscape. . *Paper presented at 3rd International Martes Symposium*, Corner Brook, Newfoundland, August 14.

2000 - Fuller, A., H.J. Lachowski, and D. Harrison. 2000. Stand-level responses of American marten and prey to forest management: do marten respond to distribution of prey? *Paper presented at 3rd International Martes Symposium, Corner Brook*, Newfoundland, August 15.

2000 - Fuller, A.K., and D.J. Harrison. Fuller, A.K. and D.J. Harrison. Influence of partial harvests on American marten habitat selection in Maine. *Final contract seminar presented to Advisory Committee, Maine Cooperative Forestry Research Unit*, Sugarloaf Mountain, Maine, October 3.

2000 - Harrison, D.J. Presented a seminar of final results of 10 year study on effects of forest harvesting and trapping on American martens to Advisory Committee, *Cooperative Forestry Research Unit*, University of Maine, Orono, February 2.

2000 - Harrison, D.J. Extent and distribution of potential wolf habitat in eastern North America; an international issue. *Presentation at "Northeast Wolf Forum: a discussion of issues and concerns"*, Rumford, Maine, July 12.

2000 - Harrison, D.J. Served as Program Chair and provided opening comments for *3rd International Martes Symposium*, Corner Brook, Newfoundland, August 14.

2000 - Harrison, D., D. Payer, A. Fuller, J.Hepinstall, D. Katnik. Landscape thresholds and response to fragmentation by American marten. Paper presented at *3rd International Martes Symposium*, Corner Brook, Newfoundland, August 14.

2000 - Harrison, D. Served as chairperson for session titled: Planning and Managing Landscapes for *Martes*, *3rd International Martes Symposium*, Corner Brook, Newfoundland, August 14.

2000 - Harrison, D. Served as an invited panelist for discussion of : What is suitable habitat for North American *Martes*? *3rd International Martes Symposium*, Corner Brook, Newfoundland, August 15.

2000 - Harrison, D. Chaired plenary session titled: Status of *Martes* and their habitats from a global perspective. *3rd International Martes Symposium*, Corner Brook, Newfoundland, August 15.

2000 - Harrison, D.J. Fragmentation thresholds for American marten: preliminary results. *Presentation to Advisory Committee, Maine Cooperative Forestry Research Unit*, Sugarloaf Mountain, Maine, October 3.

2000 - Harrison, D.J., J.Homyack, and A.K. Fuller. Led a field trip and presented preliminary data on effects of forest harvesting on snowshoe hares and small mammals at field tour for Maine forest industry representatives, *Maine Cooperative Forestry Research Unit Fall Field Tour*, October 4.

2000 - Harrison, D. J. Presentation on wolf ecology , habitat potential in Maine, and behavior of wolf-hybrids. *7th grade science and literature classes at the Reeds Brook Middle School*, Hampden, November 8.

2000 – Harrison, D.J. T.G. Chapin, and C.L. Hoving. Distribution, extent, and connectivity of potential habitat for wolves in Maine and eastern Canada. *Poster presented at Carnivores 2000 Conference*, Denver, Colorado, November 13-15.

2000 - Harrison, D.J. Influence of dispersal on social ecology of coyotes: do social pressures or prey size promote pack formation? *Invited paper at Carnivores 2000 Conference*, Denver, Colorado, November 14.

2000 - Krohn, W.B., C.L. Hoving, D.J. Harrison, D.M. Phillips, and H.C. Frost. Martes foot-loading and snowfall distribution in eastern North America: implications to broad-scale distributions and mesocarnivore interactions. *Paper presented at 3rd International Martes Symposium*, Corner Brook, Newfoundland, August 14.

2000 - Payer, D.C., and D.J. Harrison. Influence of forest structure on habitat use by American marten. *Paper presented at 10th Northern Furbearer Conference*, Fairbanks, Alaska, April 17.

2000 - Payer, D.C., and D.J. Harrison. 2000. Effects of timber harvesting and trapping on demographic characteristics of marten. *10th Northern Furbearer Conference*, Fairbanks, Alaska, April 18.

2000 - Payer, D.C., and D.J. Harrison. Demographic characteristics of American marten in relation to clearcutting and trapping. . *Paper presented at 3rd International Martes Symposium*, Corner Brook, Newfoundland, August 14.

2000 - Payer, D.C., and D.J. Harrison. Effects of timber harvesting and trapping on habitat selection by American marten. *Paper presented at 3rd International Martes Symposium*, Corner Brook, Newfoundland, August 15.

2000 - Payer, D.C., and D.J. Harrison. Territoriality and home-range fidelity of American marten in relation to timber harvesting and trapping. *Paper presented at 3rd International Martes Symposium*, Corner Brook, Newfoundland, August 16.

1999 - Harrison, D.J. Response of wildlife to thinning in forests of the *northeastern U.S. Invited* presentation at *Conference on Thinning in the Maine Forest*, Augusta, Maine. November 15.

1999 - Harrison, D. J. Influence of dispersal on social ecology of coyotes: Comparison of a mainland and island population. *The Wildlife Society 6th Annual Conference*, Austin, Texas. September 11.

1999 - Harrison, D. J. Responses of wide ranging carnivores to forest characteristics at multiple spatial scales. *North American Forest Ecology Workshop*, University of Maine, Orono. June 28.

1999 - Harrison, D. J. Session summary: stand- and landscape-scale responses of wildlife to forest practices. *North American Forest Ecology Workshop*, University of Maine, Orono. June 30.

1999 - Harrison, D. J. Habitat associations of marten in Maine: responses to forestry and trapping. Invited presentation at *Pine Marten Symposium*, Corner Brook, Newfoundland. January 27.

1999 - Fuller, A.K. and D.J. Harrison. Influence of partial harvests on American marten habitat selection in Maine. *The Wildlife Society 6th Annual Conference*, Austin, Texas. September 11.

1999 - Fuller, A.K., H. J. Lachowski, and D. J. Harrison. Responses of mammals at two trophic levels to stand-

scale forest harvesting in Maine. *North American Forest Ecology Workshop*, University of Maine, Orono. June 28.

1998 - Harrison, D. J. Using carnivores as a model for landscape-scale forest planning. Invited paper at *Maine Forest Biodiversity Conference*, Orono, Maine. November 19.

1998 - Harrison, D. J. Wolves, science, and the future of Maine=s forests. Lecture to *Forum for Undergraduate Science Majors*, University of Maine. December 10.

1998 - Harrison, D. J. A summary from 10 years of marten research with a look to the future. Invited seminar presented to *Resource Assessment Staff, Maine Department of Inland Fisheries and Wildlife.* November 19.

1998 - Fuller, A.K., and D.J. Harrison. Use of partially harvested stands by American marten: a preliminary analysis. Poster presented at *Euro-American Mammal Congress*, Santiago de Compostela, Spain. July 23.

1998 - Harrison, D.J. Habitat ecology of American marten: specialist or generalist? Invited Paper presented in symposium: *Mustelids in a Modern World*, Euro-American Mammal Congress, Santiago de Compostela, Spain. July 23.

1998 - Harrison, D.J. A summary of results from ongoing studies of American marten in Maine. Invited presentation at *Newfoundland Marten Recovery Team Meeting*, Grand Falls-Windsor, Newfoundland. May 13.

1998 - Harrison, D.J. Potential habitat for eastern timber wolves in Maine. Invited presentation at *Eastern Wolf Recovery Meeting*, Pinkham Notch, NH. September 29.

1998 - Harrison, D.J. and D.C. Payer. Substand-level habitat use by American marten: recommendations for foresters. Presentation to Advisory Committee, *Maine Cooperative Forestry Research Unit*, Orono, Maine. April 29.

1997 - Harrison, D.J. An assessment of potential habitat for eastern timber wolves in the northeastern United States. Invited presentation at *meeting of eastern wolf experts*, Sherbrook, Quebec. October 23.

1997 - Harrison. D.J. Habitat selection by American marten at multiple spatial scales. Invited seminar presented to *Wildlife Division, Department of Natural Resources, St. Johns, Newfoundland*, Canada, March 3.

1997 - Harrison, D.J. "Results from coyote-deer studies in Acadia National Park: insights into predator social ecology and prey demography." Seminar presented to *Dept. of Wildlife Ecology, Univ. Maine*, Orono, April 7.

1997 - Harrison, D.J. Influence of forest harvesting and trapping on populations of American marten. Invited seminar presented to forest industry personnel*, Corner Brook, Newfoundland*, Canada, March 4.

1997 - Harrison, D.J. Influence of forest harvesting and fur trapping on populations of American marten.

Invited paper presented at *Marten Biology and Habitat Guidelines Workshop*, Sault Ste. Marie, Ontario, Canada, May 28.

1997 - Harrison D.J. Influence of landscape composition and configuration on habitat occupance by American marten. Invited paper presented at *Marten Biology and Habitat Guidelines Workshop*, Sault Ste. Marie, Ontario, Canada, May 28.

1997 - Harrison, D.J. Integrating marten and forest management: the Maine experience. Invited paper presented at *Marten Biology and Habitat Guidelines Workshop*, Sault Ste. Marie, Ontario, Canada, May 28.

1997 - Harrison, D.J. Microhabitat-, stand-, and landscape-scale habitat selection by marten in Maine. Invited paper presented at *Workshop on Lynx and Marten Management in Eastern Boreal Forests*, White Mountain National Forest, Gilead, ME, August 26.

1997 - Harrison, D.J. Results from ongoing studies of American marten on industrial forestland in Maine. Seminar presented to *Advisory Committee, Maine Cooperative Forestry Research Unit*, Orono, ME, January 21.

1997 - Harrison, D.J. Ecology and habitat relationships of American martens in Maine. *Penobscot Valley Chapter, Maine Audubon Society*, February 7.

1997 - Harrison, D.J. "The influence of partial harvesting on American marten: a proposal." Presentation to *Advisory Committee, Cooperative Forestry Research Unit*, Univ. Maine, Orono, April 29, 1997.

1997 - Harrison, D.J., and W.B. Krohn. What do, and don=t, we know about lynx and marten in Maine? Invited paper presented at *Workshop on Lynx and Marten Management in Eastern Boreal Forests*, White Mountain National Forest, Gilead, ME, August 25.

1997 - Payer, D.C., and D.J. Harrison. Influence of site-level habitat characteristics on spatial patterns of habitat use by American marten in an industrial forest and a forest preserve in Maine. *The Wildlife Society National Conference*, Snowmass, Colorado, September 25.

1997 - Payer, D.C. and D.J. Harrison. Influence of microsite characteristics on patterns of habitat occupancy by American marten. Presentation at seminar series sponsored by the *Department of Wildlife Ecology, University of Maine*. November 3.

1997 - Payer, D.C., and D.J. Harrison. Structural differences between forests regenerating following spruce-budworm infestations and clearcutting, with implications for merican marten. Presentation at seminar series sponsored by the *Department of Wildlife Ecology, University of Maine*. November 3.

1996 - Chapin, T. G. and D. J. Harrison. Seasonal Selection of Habitats by Resting Marten in Maine. Paper presented at *52nd Northeast Fish and Wildlife Conference*, Farmington, CT. April 2.

1996 - Chapin, T. G. and D. J. Harrison. Seasonal habitat selection by marten in an untrapped forest preserve. Paper presented at *Ecological Society of America and Society for Conservation Biology*

Meeting, Providence, RI. August 14.

1996 - Harrison, D. J. Habitat requirements of American marten in northeastern forests. Seminar presented to *Fraser Paper, Inc. and J. D. Irving Corporation's foresters*. Edmundston, New Brunswick. February 27.

1996 - Harrison, D. J. Marten, forests, and biodiversity: a model for conservation. Invited presentation at *Maine Forest Biodiversity Conference*, Ellsworth, Maine. March 12.

1996 - Harrison, D. J. Funding, infrastructure, and partnerships for wildlife conservation in the U.S. Invited seminar presented to *Department of Ecosystem Planning*, *Tokyo Noko University*, Japan. March 20.

1996 - Harrison, D. J. Habitat relationships of American marten: specialist or generalist. Seminar presented to *U. S. Forest Service Redwood Sciences Laboratory and College of Natural Resources, Humboldt University*, Arcata, CA. March 28.

1996 - Harrison, D. J. Influence of spatial and body scaling on habitat selection by mammalian carnivores. Seminar presented to *Utah Cooperative Fish and Wildlife Research Unit and Dept. of Fisheries and Wildlife, Utah State University*, Logan. April 5.

1996 - Harrison, D. J. Influence of spatial and body scaling on habitat selection by mammalian carnivores. Seminar presented to *Dept. of Zoology and Physiology, University of Wyoming, Laramie*. April 11.

1996 - Harrison, D. J. Marten as a barometer of forest health in Maine. Seminar presented at *Annual Meeting, Maine Chapter of The Wildlife Society*, Brewer, ME. April 25.

1996 - Harrison, D.J. A conservation model for habitat of American martens in Maine. Seminar presented to *Executive Council, Maine Audubon Society*, Ellsworth, ME, November 11.

1996 - Harrison, D. J., D. Payer, and H. J. Lachowski. Influence of forest harvesting and forest structure on habitat selection by American marten Presentation and field tour to *National Council of the Paper Industry (NCASI)* scientists and other forest industry representatives, Millinocket, ME. August 22.

1996 - Harrison, D. J., and S. L. Glass. Comparative social ecology of coyotes: does large prey cause pack formation? Paper presented at *Ecological Society of America and Society for Conservation Biology Meeting*, Providence, RI. August 13.

1996 - Long, R .A., D. J. Harrison, and A. F. O'Connell, Jr. Survival and cause-specific mortality of white-tailed deer fawns on Mount Desert Island, Maine. Paper presented at *Ecological Society of America and Society for Conservation Biology Meeting*, Providence, RI. August 14.

1995 - Chapin, T.G., and D.J. Harrison. Marten use of residual stands in an industrial forest landscape in Maine. Presented at the *51st Annual Northeast Fish and Wildlife Conference*, Ocean City, MD. April 8-12.

1995 - Chapin, T.G., and D.J. Harrison. Marten use of residual stands in an industrial forest landscape in Maine. Paper presented at the *Second International Martes Symposium,* Edmonton, Alberta. August

12-16.

1995 - Chapin, T.G and D.J. Harrison. Influence of landscape pattern and forest type on use of habitat by marten in Maine. Seminar presented to *Department of Wildlife Ecology, University of Maine*, Orono. June 15.

1995 - Chapin, T. G. and D. J. Harrison. Influence of landscape pattern on spatial us of habitat by marten in an industrial forest. Paper presented at *National Conference of the Society of American Foresters*, Portland, ME, November 1.

1995 - Harrison, D. J. Influence of Forest Harvesting on Marten Populations in Northern Maine. Invited paper presented at *Society of American Foresters National Convention*, Portland, ME. October 28-29.

1995 - Harrison, D. J. Ecology and life history of the northeastern coyote. Invited seminar presented to *Illinois Natural History Museum*, University of Illinois, Urbana. November 14.

1995 - Harrison, D. J. Social ecology and prey relationships of the eastern coyote: the influence of prey size on pack formation. Invited seminar presented to *Dept. of Ecology, Ethology, and Evolution*, University of Illinois, Urbana. November 15.

1995 - Harrison, D. J. Habitat Requirements of American Marten: Reassessing Paradigms. Seminar presented to *Department of Wildlife Ecology, Univ. Maine*, November 28.

1995 - Harrison, D.J. Relative influences of timber harvesting and trapping on marten populations in Maine. Presentation at the *Spring Meeting of Forest Resources Research Advisory Committee*, University of Maine, Orono. April 11.

1995 - Harrison, D.J. Incorporating marten habitat requirements into forest management activities. Presentation and field tour, *Cooperative Forestry Research Unit Annual Conference*, Millinocket, ME. September 20-21.

1995 - Harrison, D.J., D.M. Phillips, T.G. Chapin, D.P. Katnik, and T.P. Hodgman.. Population performance and habitat selection by American marten: a need to reassess accepted paradigms and conservation practices. Invited paper presented at the *Second International Martes Symposium*, Edmonton, Alberta. August 12-16.

1995 - Hodgman, T.P., and D. J. Harrison. 1995. Survival in a heavily harvested marten population: a preliminary assessment. Poster presented at *Annual Conference of the Maine Cooperative Forestry Research Unit*, Millinocket, ME. September 20.

1995 - Hodgman, T.P., D.J. Harrison, D.M. Phillips, and K.D. Elowe. Survival of marten in an untrapped forest preserve in Maine. Paper presented at the *Second International Martes Symposium*, Edmonton, Alberta. August 12-16.

1995 - Long, R.A., S.L. Glass, D.J. Harrison, and A.F. O'Connell. Cause-specific mortality of white-tailed

deer fawns on Mount Desert Island, Maine. Presented at the *51st Annual Conference of the Northeast Fish and Wildlife Conference*, Ocean City, MD. April 9-12.

1995 - Long, R.A., D.J. Harrison, S.L. Glass, and A.F. O'Connell. Annual survival and cause-specific mortality of white-tailed deer fawns on Mount Desert Island, Maine. Paper presented at the *21st Maine Biological and Medical Sciences Symposium*, Bar Harbor, ME. June 8-9.

1995 - Long, R.A., D.J. Harrison, and A.F. O'Connell, Jr. Annual survival and cause-specific mortality of white-tailed deer fawns, and relative abundance of snowshoe hare on Mount Desert Island, Maine. Seminar presented to *Department of Wildlife Ecology, University of Maine, Orono*. June 16.

1995 - Long, R, D.J. Harrison, S. L. Glass, and A. F. O'Connell. Mortality of white-tailed deer fawns in Acadia National Park. Seminar presented to research and management staff, *Acadia National Park*, Bar Harbor, ME. August 30.

1995 - Phillips, D.M., and D.J. Harrison. Seasonal changes in density, range area, and range fidelity of American marten in a forest preserve. Paper presented at *Second International Martes Symposium*, Edmonton, Alberta. August 12-16.

1994 - Chilelli, M., B. Griffith, and D.J. Harrison. Utility of regional furbearer data: the river otter example." Paper presented at *First Annual Conference of The Wildlife Society*, Albuquerque, New Mexico, September 21.

1994 - Harrison, D.J. "A proposal to study the relationships among trapping, forest harvesting, and marten populations in northern Maine." Presentation to *Maine Cooperative Forestry Research Unit Advisory Committee*, University of Maine, January 25.

1994 - Harrison, D.J. "Preliminary results from ongoing research to assess influences of forest harvesting and trapping on marten populations in northern Maine." Invited presentation at *Wildlife Division Meeting, Maine Department of Inland Fisheries and Wildlife*, Rockland, ME, April 14.

1994 - Harrison, D.J. The effects of scale on habitat selection. Guest presentation in graduate course in *Evaluation of Wildlife Habitats*, University of Maine, Orono. October 7.

1994 - Harrison, D.J. Evidence for external regulation in an unmanaged deer population. Paper presented at the *Conference on Science of Overabundance*, Front Royal, VA. November 10-11.

1994 - Harrison, D.J., and T.D. Chapin. "Effects of forest fragmentation on martens in northern Maine: preliminary results from ongoing studies." Presentation to *National Council of the Paper Industry for Air and Stream Improvement*, Albuquerque, NM, September 23.

1994 - Phillips, D.M., and D.J. Harrison. "Density, home-range, and spatial overlap of marten in an industrial forest and forest preserve." Paper presented at *Northeast Fish and Wildlife Conference*, Burlington, VT, May 3.

1993 - Harrison, D.J. "Potential forest management issues associated with habitat requirements of the marten." Presentation to *Maine Chapter, Association of Consulting Foresters*, Bangor, ME,

October 12.

1993 - Harrison, D.J. "Objectives and preliminary results of a study to assess the influence of trapping and forest harvesting on marten populations in northern Maine." Presentation to foresters of *Scott Paper, Inc., Rockwood, Maine*, December 14.

1993 - Harrison, D.J. "Habitat associations of the marten: does the species deserve spotted owl status?" Invited paper presented at *Conserving Species Dependent on Older Forests: a Population Viability Workshop*. Fundy National Park, Alma, New Brunswick, October 27.

1993 - Harrison, D.J. The role and effectiveness of predator control to enhance game populations. Presentation to *Maine Chapter of The Wildlife Society*, April 5.

1993 - Harrison, D.J. Feasibility and issues associated with restoring wolves to Maine. Presentation to *Maine Chapter of The Wildlife Society*, April 5.

1992 - Saeki, M., and D.J. Harrison. Influence of food availability and fire history on dietary quality of white-tailed deer (Odocoileus virginianus). Paper presented at Seventy-second annual meeting of *American Society of Mammalogists*, Salt Lake City, Utah.

1992 - Harrison, D.J. Significance of pine martens to future forest practices in Maine. Presentation to *Woodlands staff, Great Northern Corp*., Millinocket, Maine.

1992 - Harrison, D.J. Pine marten habitat requirements: will the Forest Practices Act safeguard marten habitat? Presentation to *Maine Chapter of The Wildlife Society*, Orono, Maine.

1991 - Harrison, D. J. Chaired session and provided summative comments for session titled: "Habitat management of martens and fishers," *International Symposium on the Biology and Management of Martens and Fishers*, Laramie, Wyoming.

1991 - Harrison, D. J. Coyote social organization and relationships to dispersal and food resources: predictions with an unpredictable animal. Invited paper presented at *Eastern Coyote Symposium*, Fredericton, New Brunswick.

1991 - Harrison, D.J., A.F. O'Connell, and J.A. Subijanto. Seasonal food habits of a recently established insular population of coyotes. Poster presented at *Northeast Fish and Wildlife Conference*, Portland, Maine.

1991 - Harrison, D.J., A.F. O'Connell, Jr., and J. A. Subijanto. Seasonal food habits of a recently established insular coyote population. Invited paper presented at *Second National Park Service Conference on Science and Natural Resource Management in the North Atlantic Region*, Newport, RI.

1991 - Harrison, D.J., and N.E. Famous. Effects of peat harvesting on a large mammalian carnivore: a case study with coyotes (*Canis latrans*). Paper presented at *International Peat Symposium*, Duluth, Minnesota.

1991 - Harrison, D.J., T.P. Hodgman, and D.D. Katnik. Survival in a heavily harvested marten population, a preliminary assessment. Paper presented at *International Symposium on the Biology and Management of Martens and Fishers*, University of Wyoming, Laramie.

1991 - Giuliano, W., and D.J. Harrison. A preliminary assessment of spatial-temporal relationships in an unexploited pine marten population. Poster presented at *International Symposium on the Biology and Management of Martens and Fishers*, University of Wyoming, Laramie.

1991 - Saeki, M. and D. J. Harrison. Trends in browse use and preference in an unhunted deer and hare population. Paper presented at *Second National Park Service Conference on Science and Natural Resource Management in the North Atlantic Region*, Newport, Rhode Island.

1990 - Harrison, D.J. Status of ongoing mammal research. Seminar presented to regional management staff, *Maine Department of Inland Fisheries and Wildlife*, Bar Harbor.

1990 - Harrison, D.J. Status, ecology, and inter-specific relationships of mammalian predators in Acadia National Park. Seminar presented to *North Atlantic Region, science staff, U.S. National Park Service*, Bar Harbor, Maine.

1990 - Harrison, D.J. An abstract of results from ongoing research involving coyote-fox spatial interactions, deer-hare browsing relationships, and marten population characteristics in Maine. Seminar presented at annual Wildlife Division meeting, *Maine Department of Inland Fisheries and Wildlife*, Rockland, Maine.

1990 - Harrison, D.J. Ecology and interspecific relationships among Maine's predators. Seminar presented to faculty and staff, *Suffolk University*, Edmunds, ME.

1990 - Harrison, D.J. Pre-dispersal movements of coyote pups in eastern Maine. Paper presented at *70th annual meeting of the American Society of Mammalogists*, Frostburg, Maryland.

1989 - Harrison, D.J. Dispersal characteristics of juvenile coyotes: implications for social organization. Paper presented at *69th Annual Meeting of the American Society of Mammalogists*, Fairbanks, Alaska.

1989 - Harrison, D.J. Distribution, productivity, and food habits of a recently established coyote population in Connecticut. Paper presented at *Northeast Fish and Wildlife Conference*, Ellenville, NY.

1989 - Harrison, D.J. Spatial dynamics and inter-specific relationships among Maine predators. Seminar presented at *Unity College*, Unity, Maine.

1989 - Harrison, D.J. Ecology and management of coyotes in Maine. Seminar presented to *Department of Animal Science*, University of Maine.

1988 - Harrison, D.J. A proposal to assess the utility and interstate comparability of river otter sex, age, and reproductive data. Invited presentation at *Northeast Furbearer Resources Technical Committee Meeting*, Quebec City.

1988 - Harrison, D.J. Interaction of forest management practices and pine marten populations. Invited presentation at *Northeast Furbearer Resources Technical Committee Meeting*, Quebec City.

1988 - Harrison, D.J. A proposal to reintroduce fishers to northwest Connecticut. Paper presented at *Second Natural Diversity Conference*, Rocky Hill, Connecticut.

1988 - May, D,W., D.J. Harrison, and P. Rego. Characteristics and diet of colonizing coyote populations in Connecticut. Paper presented at *Second Natural Diversity Conference*, Rocky Hill, Connecticut.

Public Talks and Workshops (abridged to include since 2007 only):

2015 - Rolek, B.W., C. Loftin, D. Harrison, and P. Wood. Habitat associations, forestry, and coniferous forest birds. *Downeast Birding Festival. Machias, Maine*, May 2015.

2015- Harrison, D. Eastern coyotes and wolves: their history, origin, and ecology in the northeastern U.S. *Invited presentation at the Maine State Museum, Augusta*, April 8.

2013 – Dunham, S., and D. Harrison. Habitat ecology of the spruce grouse in Maine's northern forests. *Presentation sponsored by the Bangor Nature Club, Bangor, Maine*. May 15.

2013 – Olson, S., and D. Harrison. Seasons of the snowshoe hare. *Presentation at Sunkhaze Café, hosted by Friends of Sunkhaze National Wildlife Refuge, Old Town, Maine*. April 20.

2011 - Harrison, D. J. Lynx, forests, and forestry in northern Maine. *Presentation at SummerMeeting of The Forest Society of Maine*, Greenville, ME. August 15.

2008 – Harrison, D. J. "Wildlife in Winter". *Presentation at Maine Audubon's Fields Pond Nature Center*. January 8.

2007 - Harrison, D. J. "Applying umbrella species as tools for land conservation: case examples using martens and lynx in Maine." Presentation to the Board of Directors, Forest Society of Maine, Falmouth, Maine. September 11.

2007 - Harrison, D. J. "What is a predator ecologist and what does it do?" Presentation to first year students in WLE 100. October 12.

2007 - Harrison, D. J. Co-led a field tour for professional foresters highlighting the management of deer wintering habitat in northern Maine. October 10.

2007 - Harrison, D. J. Presented invited guest lecture in WLE 100. October 12.

2007 – Harrison, D. J., W. B. Krohn, E. Simons and A. K. Fuller. Co-led a northern Maine landscape planning workshop for NGO's and state agency personnel. October 17.

2007- Harrison, D. J., W. B. Krohn, and M. McCollough. Contributed to an article titled "Cats in a Quandry" that highlighted finding from our lynx research and appeared in National Wildlife Magazine December-January 2008 issue.

From: Grizzle, Betty
To: Shoemaker, Justin
Subject: Excerpts from USFS Northern Rocky Mtns climate assessment
Date: Friday, January 19, 2018 2:41:33 PM
Attachments: From 2016 USFS climate report.docx

See attached.

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Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

From 2016 USFS climate report (still draft; emphasis added):

The range of potential changes to climate looks complex, particularly for such a varied landscape as the Northern Rockies. **Perhaps the most important point to summarize from the above is that the current climatological settings vary over the landscape at both macroscales and fine scales**. There are broad east west changes in precipitation seasonality and amount, and local differences between nearby mountain and valley weather stations echo that pattern. Trends and drivers for climate variations will differ greatly from east to west. **Fundamentally, topography is an important factor affecting seasonality, precipitation amount, and potential trends.**

Historical trends in snowpack accumulation have been negative across much of the region (Mote et al. 2005; Regonda et al. 2005). Although earlier work has ascribed the changes primarily to warming temperatures, the interior parts of the Northern Rockies are cold enough to be relatively insensitive to warming and strongly sensitive to precipitation variation (Luce et al. 2014; Mote 2006). Consequently, interior snowpacks have likely responded primarily to reduced precipitation (Luce et al. 2013).

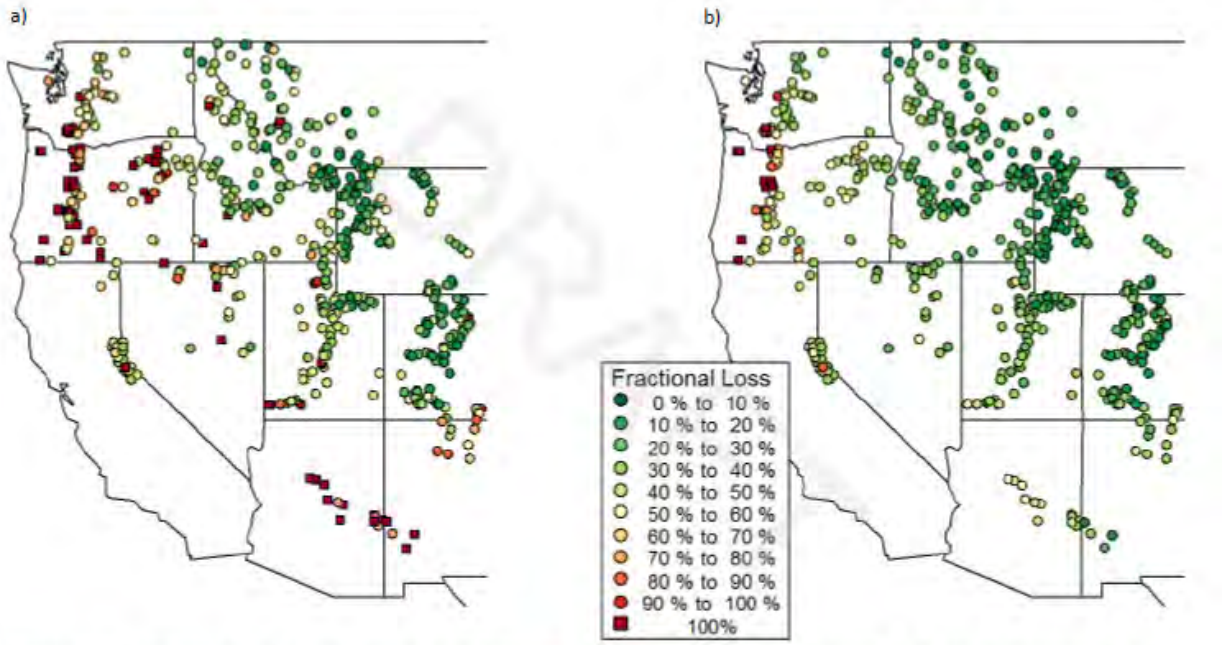

Figure 4.5—Estimated loss of a) April 1 snow water equivalent and b) mean snow residence time as related to warming of 5.4 °F (from Luce et al. 2014).

From:	Grizzle, Betty
To:	John Guinotte
Subject:	Fwd: Excerpts from USFS Northern Rocky Mtns climate assessment
Date:	Tuesday, January 30, 2018 12:56:20 PM
Attachments:	From 2016 USFS climate report.docx

Here is another section related to snowpack modeling that I sent earlier to Justin. The second paragraph could be included with what I sent you yesterday.

---------- Forwarded message ----------
From: **Grizzle, Betty** <betty_grizzle@fws.gov>
Date: Fri, Jan 19, 2018 at 1:41 PM
Subject: Excerpts from USFS Northern Rocky Mtns climate assessment
To: "Shoemaker, Justin" <justin_shoemaker@fws.gov>

See attached.

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Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

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Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

From 2016 USFS climate report (still draft; emphasis added):

The range of potential changes to climate looks complex, particularly for such a varied landscape as the Northern Rockies. **Perhaps the most important point to summarize from the above is that the current climatological settings vary over the landscape at both macroscales and fine scales**. There are broad east west changes in precipitation seasonality and amount, and local differences between nearby mountain and valley weather stations echo that pattern. Trends and drivers for climate variations will differ greatly from east to west. **Fundamentally, topography is an important factor affecting seasonality, precipitation amount, and potential trends.**

Historical trends in snowpack accumulation have been negative across much of the region (Mote et al. 2005; Regonda et al. 2005). Although earlier work has ascribed the changes primarily to warming temperatures, the interior parts of the Northern Rockies are cold enough to be relatively insensitive to warming and strongly sensitive to precipitation variation (Luce et al. 2014; Mote 2006). Consequently, interior snowpacks have likely responded primarily to reduced precipitation (Luce et al. 2013).

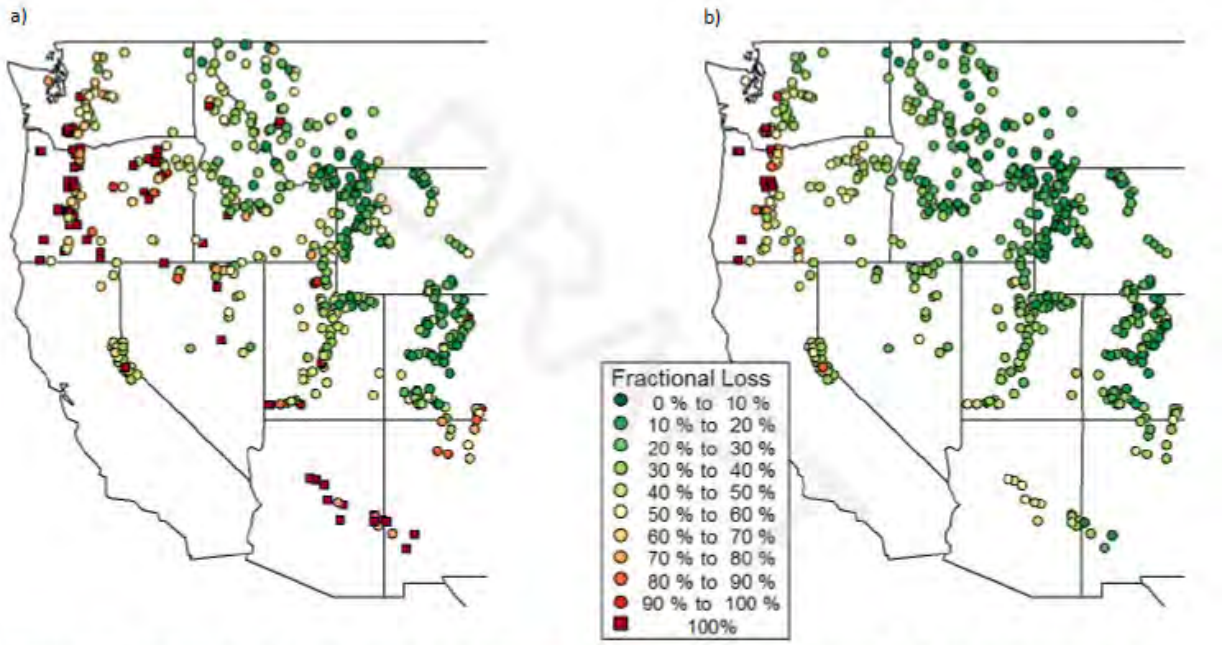

Figure 4.5—Estimated loss of a) April 1 snow water equivalent and b) mean snow residence time as related to warming of 5.4 °F (from Luce et al. 2014).

From:	Nelson, Marjorie
To:	Guinotte, John
Cc:	Shoemaker, Justin; Grizzle, Betty; Stephen Torbit; Jodi Bush; Michael Thabault
Subject:	Re: Wolverine call on Wednesday
Date:	Monday, February 26, 2018 2:05:40 PM
Attachments:	20180221_Final_Revised Briefing for Deputy Director_Wolverine 12mo finding_JS (2).pptx

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Marj

Marjorie Nelson
Chief, Division of Ecological Services
Mountain-Prairie Region
U.S. Fish and Wildlife Service
303-236-4258 direct
720-582-3524 cell

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Stephanie Potter

Executive Assistant

Office of the Regional Director

Mountain-Prairie Region

U.S. Fish and Wildlife Service

303-236-7920

North American Wolverine (*Gulo gulo luscus*): SSA Summary/Listing Determination

Photo credit: Mark Packila; used with permission.

Briefing to Deputy Director
Mountain Prairie Regional Office
February 28, 2018

Wolverine Listing Decision Recommendation

Not T or E, not a valid DPS

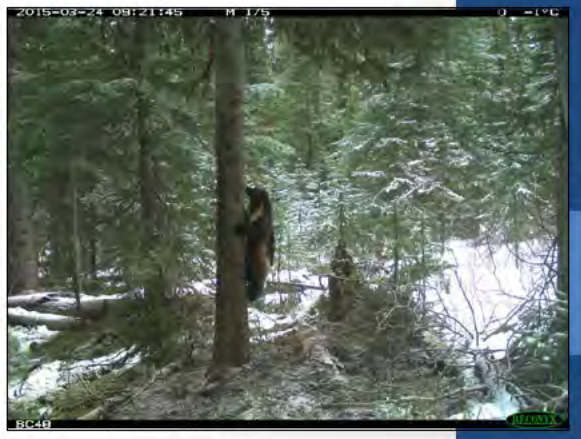
- No stressors currently having population level impacts – not Endangered
- No future stressors expected to result in population level impacts – not Threatened
- Not a DPS – wolverines in lower 48 not discrete or significant to North American wolverine taxon.

Listing History

- **2010: 12-month Finding (DPS in lower 48)**
- **2013: Proposed Rule, with (2010) DPS**
  - Primary threat: synergistic effects of climate change
- **2014: Withdrawal**
  - Challenged
- **Court decision 2016 (D. Mont.)**
  - Withdrawal vacated; remanded to Service
    - Re-examine threats from effects of CC, population size, genetic diversity
- **Current Action: Finalize Propose Rule or Withdrawal**
  - Status review – a "fresh" look at science
  - Recommendation informed by SSA Report

SSA Report –New information and analyses

- Contacted many wolverine experts (both within and outside U.S.), State agencies, and other scientists
  - Updated species' life history & ecology (e.g., physiology)
- New range maps created
- New insights from Scandinavian and Canadian studies
  - Wolverines and den sites detected outside previous snow model (i.e., Copeland et al. 2010)
  - New Canadian Wolverine Status Review
- New snow persistence/snow cover analysis
- New genetic analysis



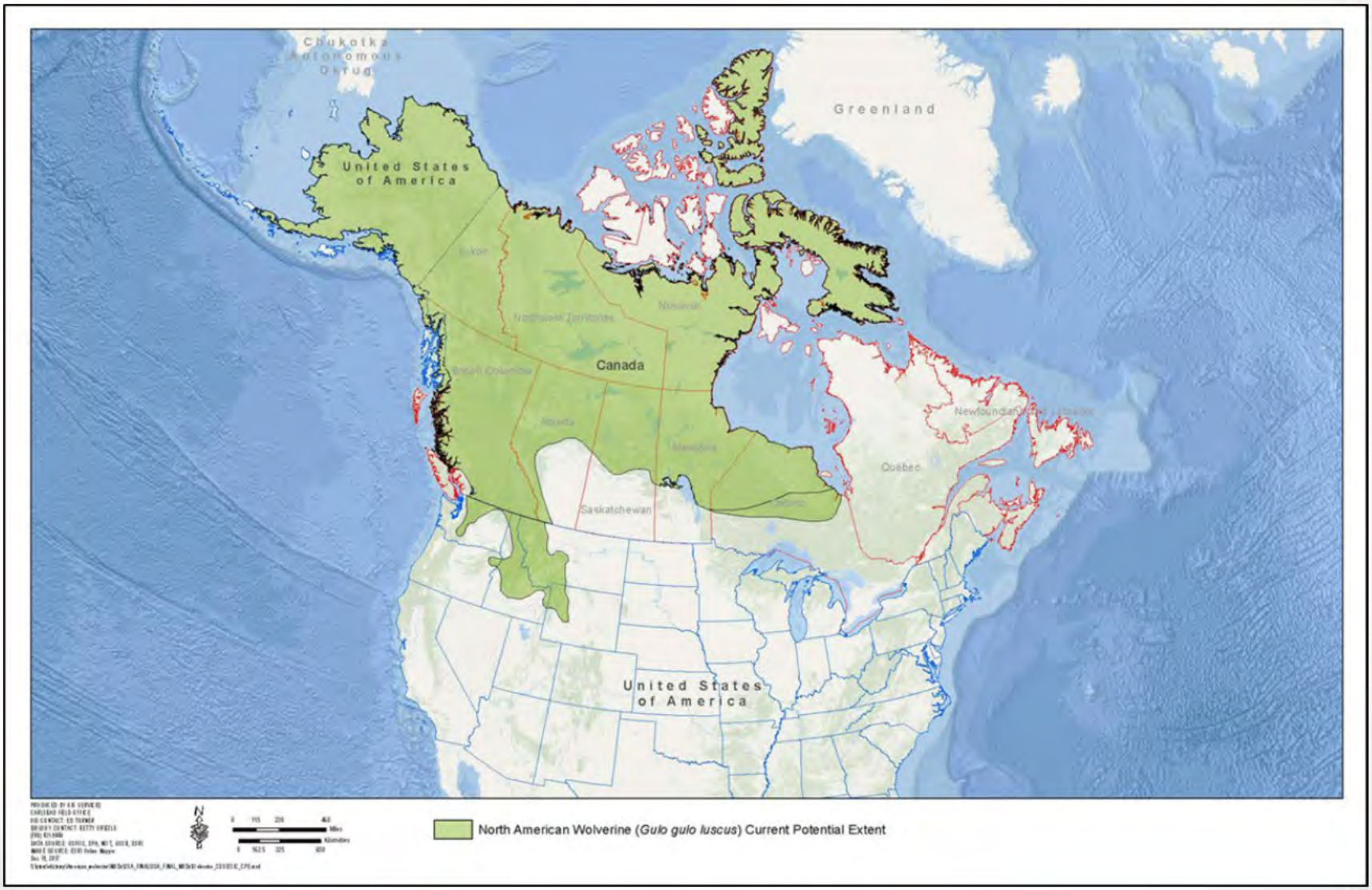
Clevenger et al. 2017

North American Wolverine Range Maps

- Maximum Extent of Occurrences (North America) (“historic range”)

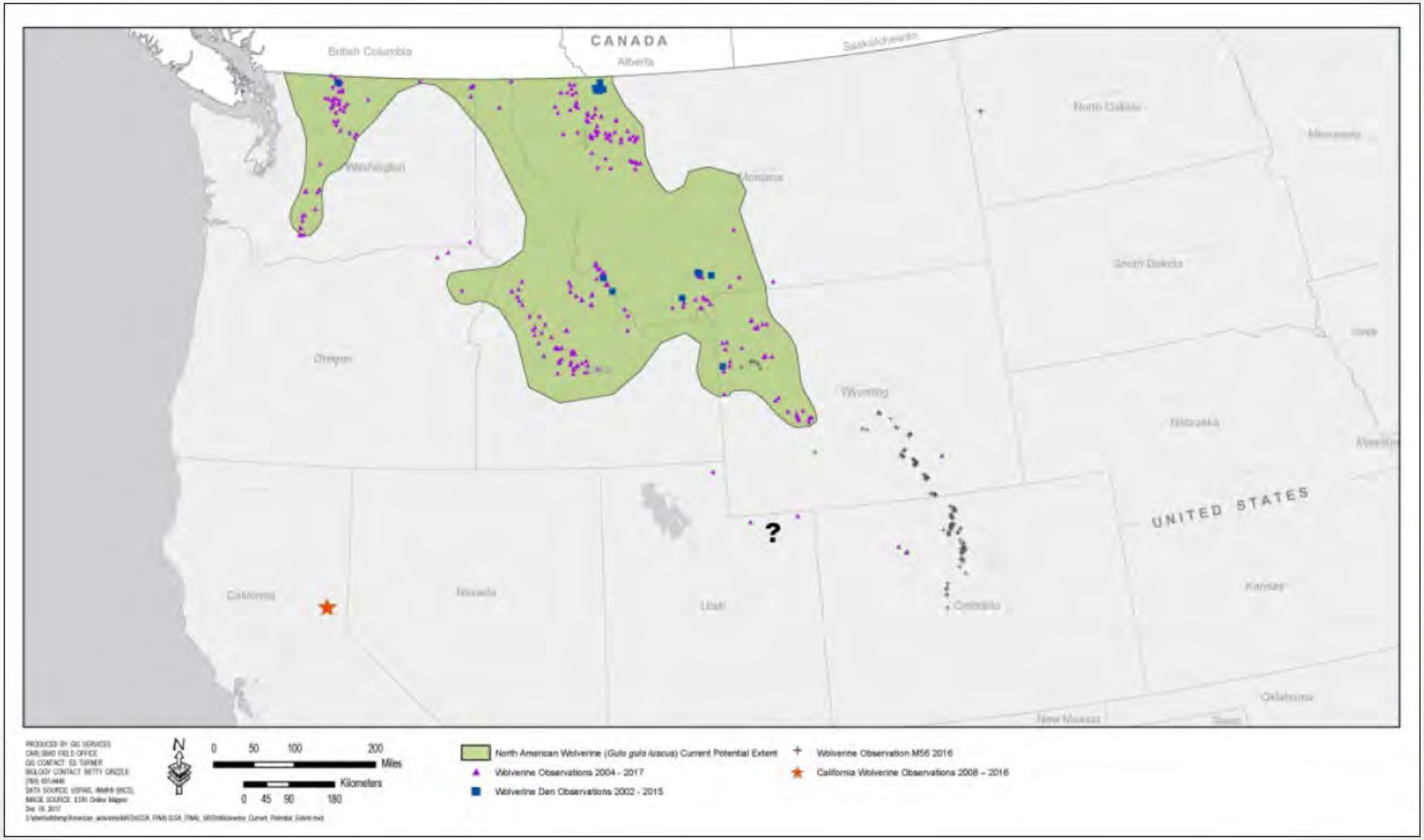
North American Wolverine Range Maps

- Current Extent of Occurrences (North America) (“current range”)



North American Wolverine Range Maps

- Current Potential Extent of Occurrences (Lower 48 only)



Species Description & Needs

- Extensive movement and dispersal capabilities
  - Colorado, Utah, California, Michigan (all in 2000s)
  - Large territories, remote areas, high elevations
- Key physical/ecological needs
  - Access to variety of food, seasonal variability
  - Physical/Structural habitat features (e.g., talus slopes)
  - Snow adapted vs. snow obligate?

"Buddy" in California, May 2016;
Photo credit: Chris Stermer, CDFW

Suspected wolverine M56 in Colorado;
Photo credit: Ray Rafiti from Packila et al. 2017

Biological Status (current conditions)

- In North America: uncommon and at naturally low densities
  - Wolverines still recovering from decades of previously unregulated persecution
  - Wolverines now observed in areas previously extirpated (US & Canada)
- No population trend information for contiguous U.S.
  - 2013 modeled estimate = 318 individuals (range 249-626)
- Canada – over 10,000 adults
  - Stable or increasing in this northern part of No Am range
- AK population considered stable
- Multi-State Wolverine Occupancy Survey (2016, 2017)
  - Genetic analysis
    - 43 unique individuals
    - mtDNA: no unique haplotypes found

Potential Stressors Evaluated

- Effects from roads
- Effects from wildland fire
- Disturbance – winter recreational activity, other infrastructure
- Disease and Predation
- Overutilization
  - Research activities
  - Harvesting and incidental trapping
- For Future Conditions
  - Effects of Climate Change
  - Cumulative Effects

Assessment of Stressors

- Known or likely potential stressors represent low risk to the species
- Legal trapping currently prohibited in contiguous U.S.
  - Trapping in Canada & Alaska appears to be sustainable
- Western US climate trends
  - Increased temperatures
  - Precipitation trends less clear (and varies regionally)

Evaluation of key assumptions

- Took a detailed look at assumptions regarding:
  - Snow obligate relationship
  - Snow persistence related to CC effects
- Two key publications:
  - Copeland et al. 2010 – correlation of where wolverines occur and where they den based on snow cover
  - McKelvey et al. 2011 – future CC projections indicate reduced snow cover, using Copeland model

Heinemeyer et al. 2017

Our understanding of wolverine distribution and denning habitat

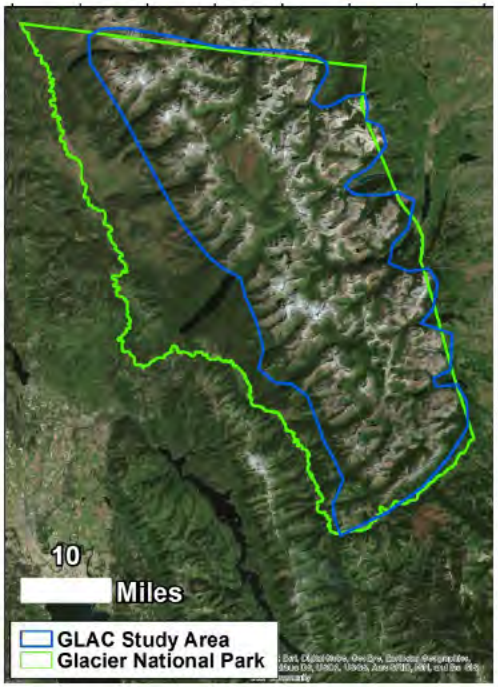
- **Many factors** influence wolverine distribution, den locations, and shifts in den locations
- Denning habitat varies across range
- Limited information on how denning habitat affects reproductive success
- Re-evaluated assumptions on timing of natal den use
- New studies – wolverines will den **outside** snow model projections

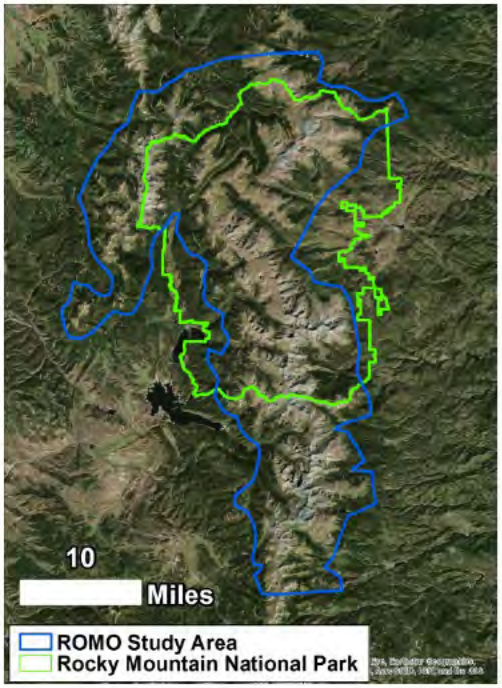
Denning "habitat" in Glacier NP; from Copeland and Yates 2008

March 2, 2017 den in Sweden (lower left, under boulder)

Our understanding of future snow cover and persistence

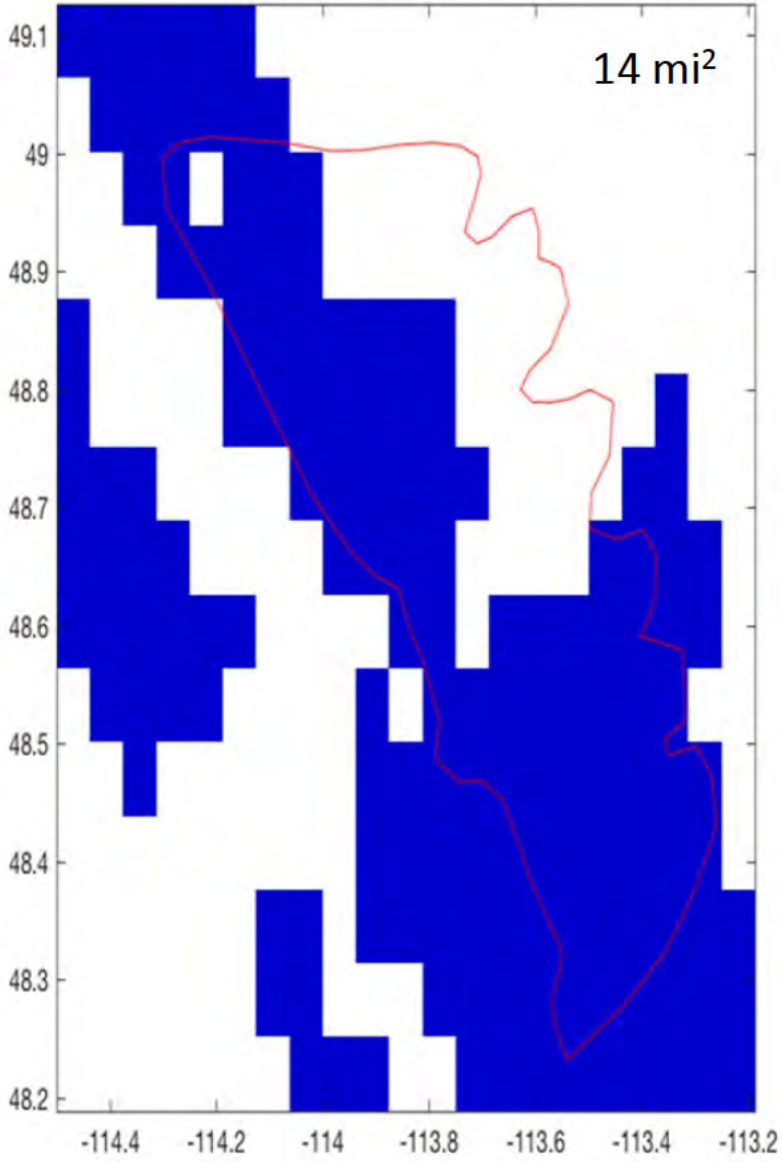
- Court identified concerns with how we considered McKelvey et al. 2011 in our 2014 withdrawal
- We identified concerns with the methods (e.g., coarse scale) used by McKelvey et al.
- Contracted with NOAA/CU to conduct a more detailed look at snow persistence – Glacier and Rocky Mountain National Parks



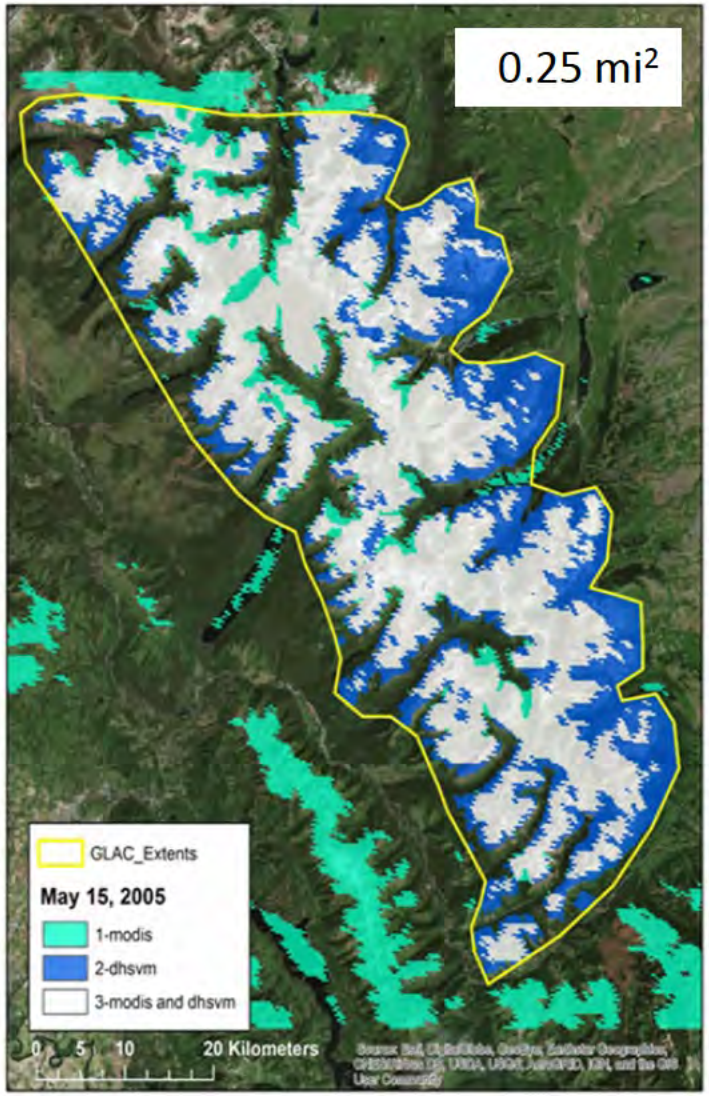


Future Projections of Snow Cover

McKelvey et al 2011

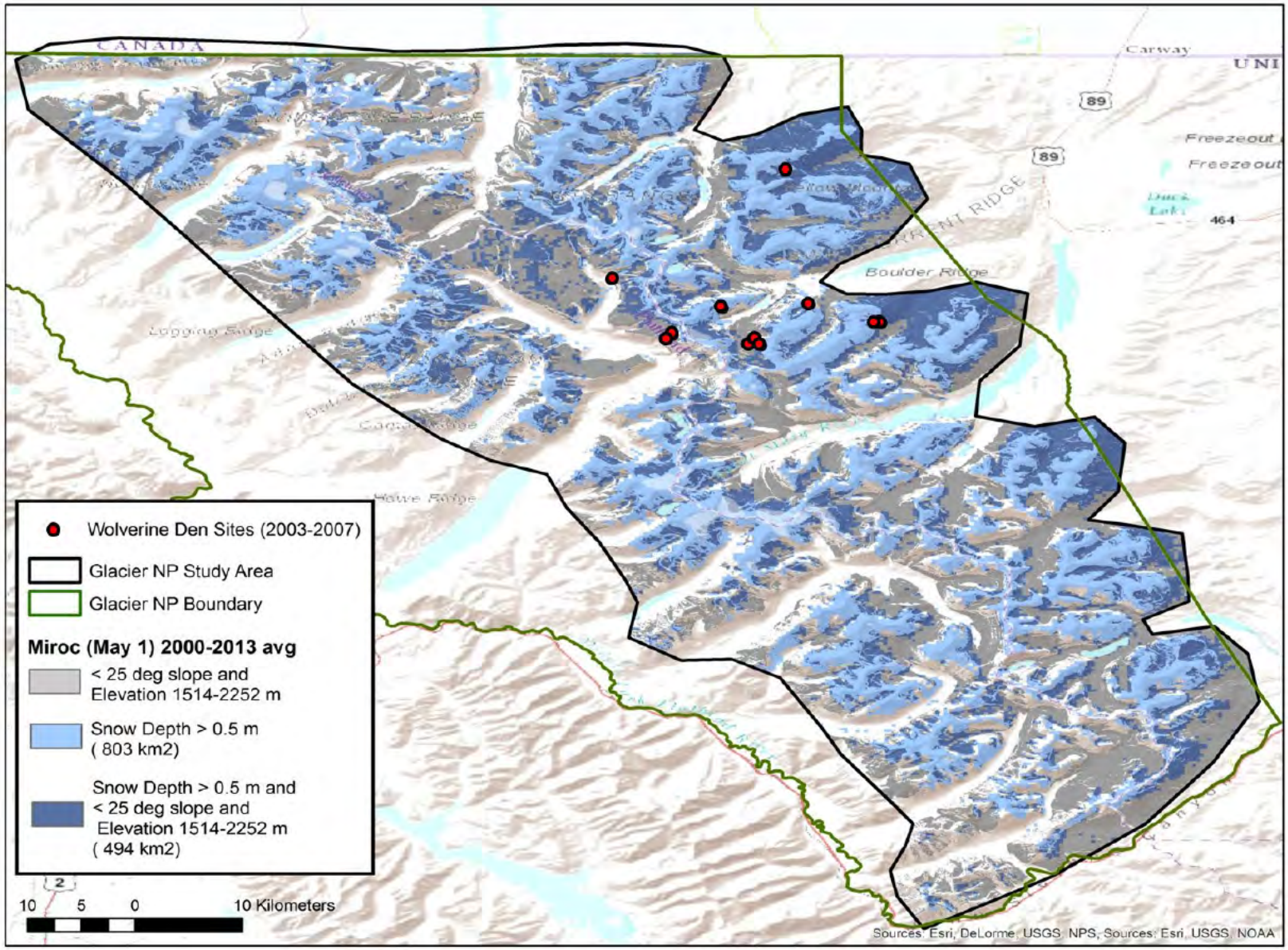


NOAA / CU 2017



(John Guinotte, FWS)

Future Projections for Snow Cover



Summary of Future Conditions

- Climate change model projections for the range of the wolverine within the contiguous United States indicate:
  - Increases in temperature by the mid-21st century
  - But future precipitation patterns less clear
- Snow cover projected to decline in response to warming temperatures and changing precipitation patterns
  - But, varies by elevation, topography, and by region
- Higher elevations will retain more snow cover than lower elevations, particularly in early spring (April 30/May1)
- Results from NOAA/CU analysis (Glacier and Rocky Mountain National Parks)
  - *Several hundred square miles projected to have deep snow (greater than 20 inches in depth) on May 1 at elevations currently used by wolverines for denning*
  - This holds across the range of climate models to Year 2055

Conservation Mechanisms

- Legal protections (T, E, or Candidate) in several western States and Canadian provinces
- "Current range" in lower 48:
  - 72 % on Federal lands
  - 18 % of this area is within designated wilderness areas
- Management actions identified in State Wildlife Action Plans, the Idaho Wolverine Conservation Plan, and USFS Mgt Plans
  - Winter road closures, fire management, land acquisition or conservation easements.
- Western States Wolverine Working Group
- WAFWA Wildlife Chiefs Wolverine Subcommittee
  - To date, approximately $1.5 million applied towards conservation and management actions for the wolverine

Comments Received

Response to Oct 2016 NOI (proposed rule/status review)

- Over 200 comments posted (from several States, Canada, U.K.)
- Most, but not all, general public comments favored listing

SSA Report Review

- 11 States and Agency (Technical) Comments submitted
- No Tribal comments submitted
- Peer Reviewers – generally positive
- Comments received reflected on-going debate on snow obligate characterization

DPS Determination

- 2013 identifies a DPS in lower 48
  - States and industry disputed validity
  - Discreteness was based on "conservation status" across the international border
    - Effective population size, connectivity
  - Significance was based on a gap in range
- 2018, lower 48 not a valid DPS
  - Discreteness determination
    - No difference in conservation status that is significant in light of Factor D
    - Looked at trapping along border, not a significant barrier
  - Significance determination
    - Spatial evaluation of range to determine lower 48 extent, using detections, not estimates of range

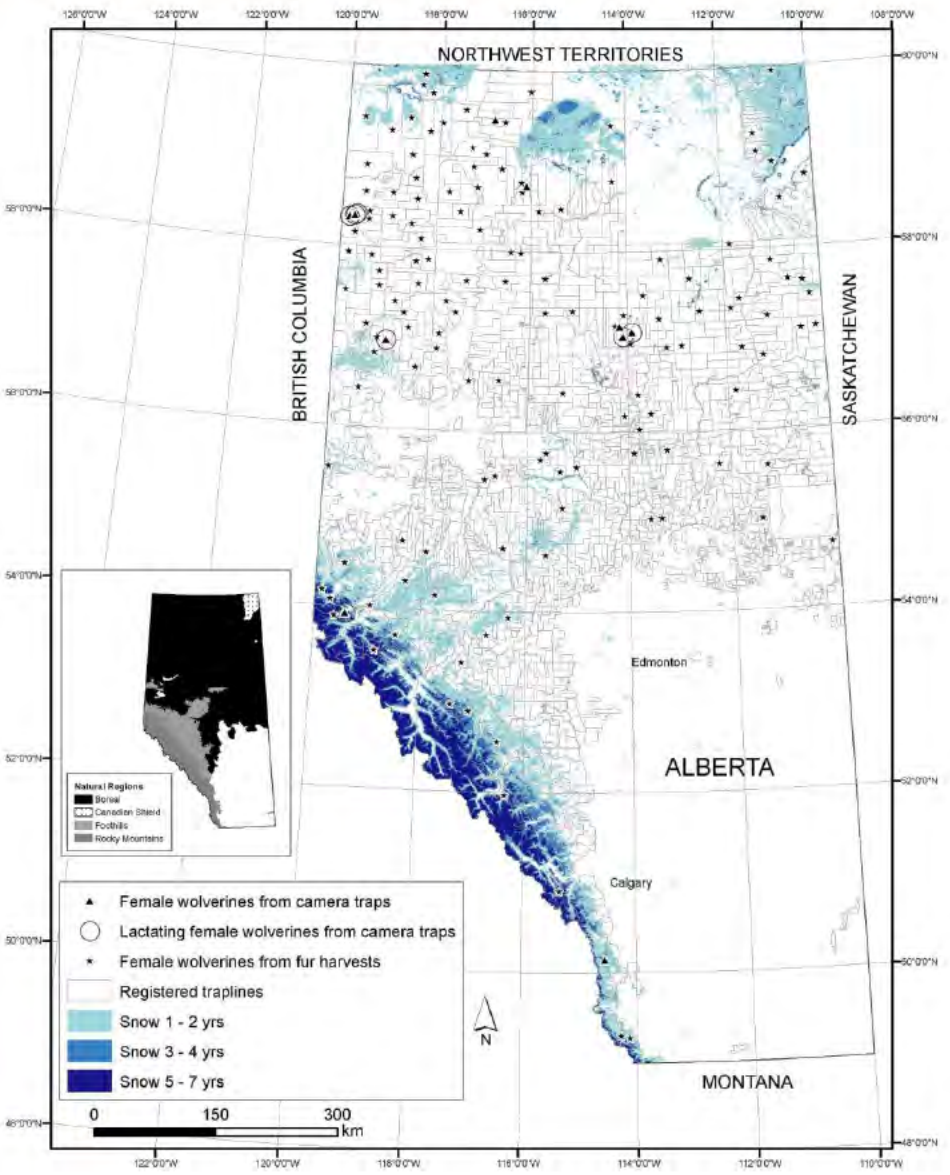
Next Steps

- Proposed approach
  - Withdrawal of previous (2013) proposed rule
  - Recommend using Sonoran bald eagle approach (vetted through RSOL)
    - Address both prongs of the DPS policy – why not discrete or significant *and*
    - Full status review as if lower 48 qualified as a DPS
- Listing determination identified in the FY 2018 workplan

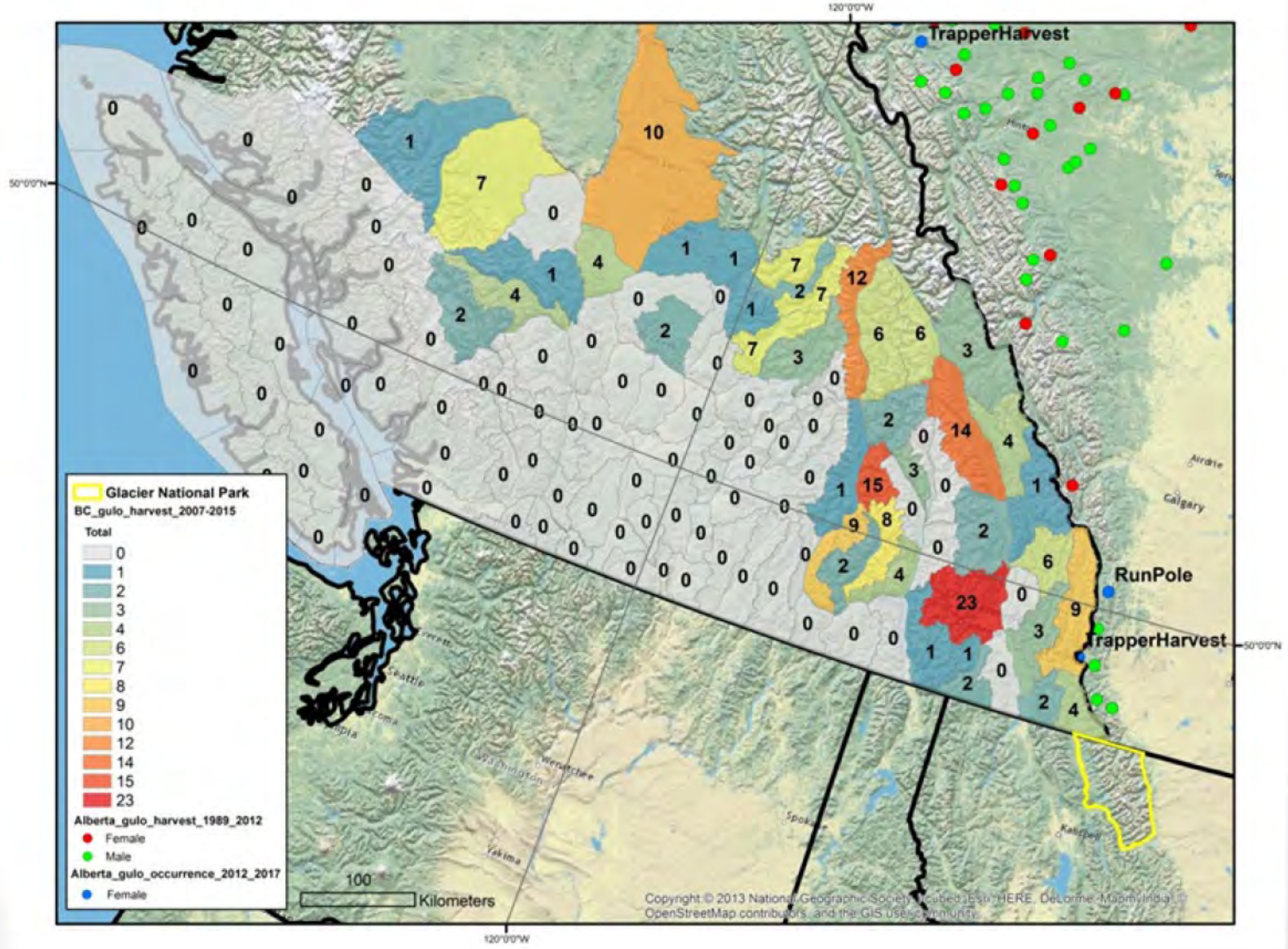
wolverinepedia.zaxtor.net

Additional informational slides

Locations of lactating females/dens, Alberta, Canada

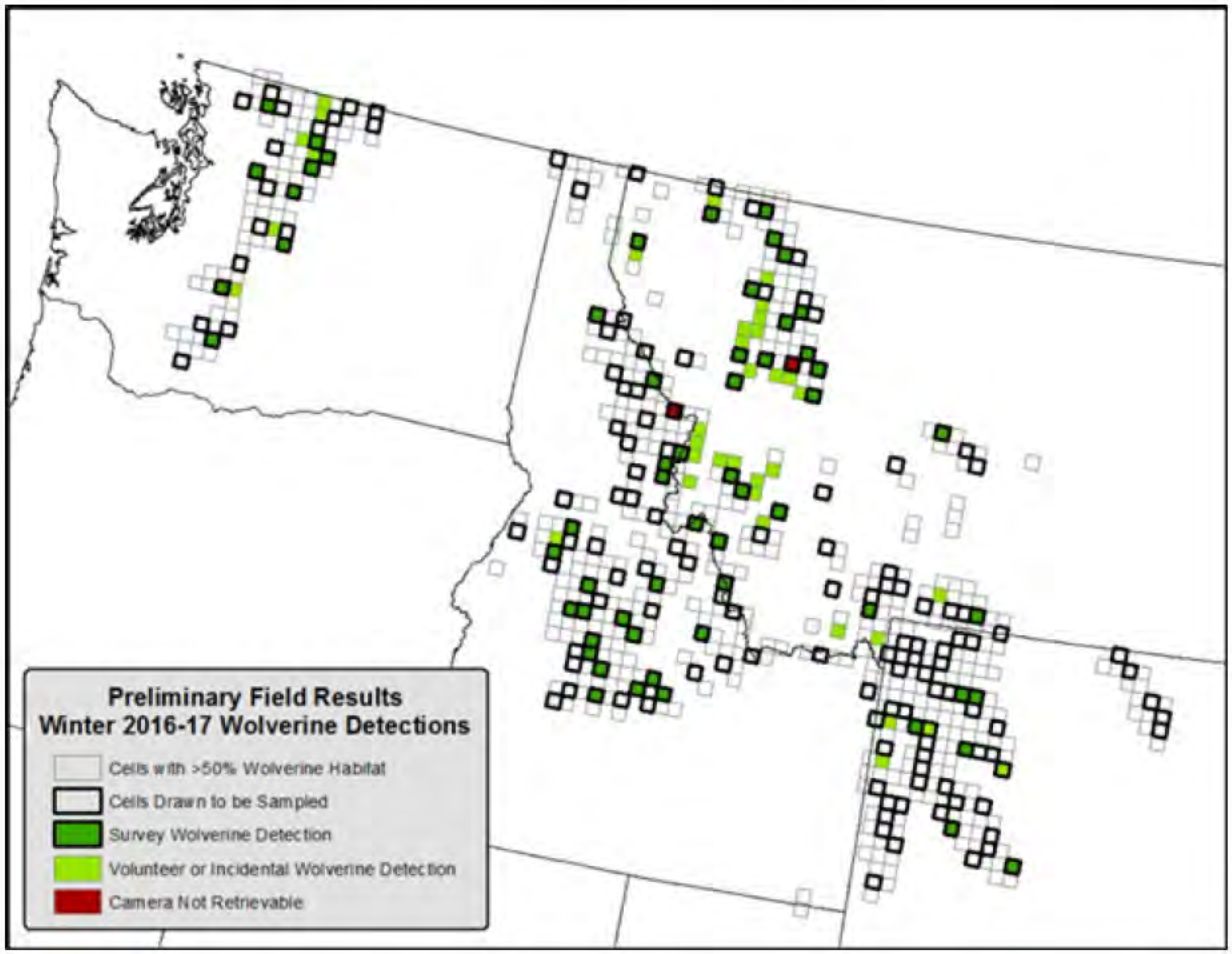


U.S.-Canada Border Trapping

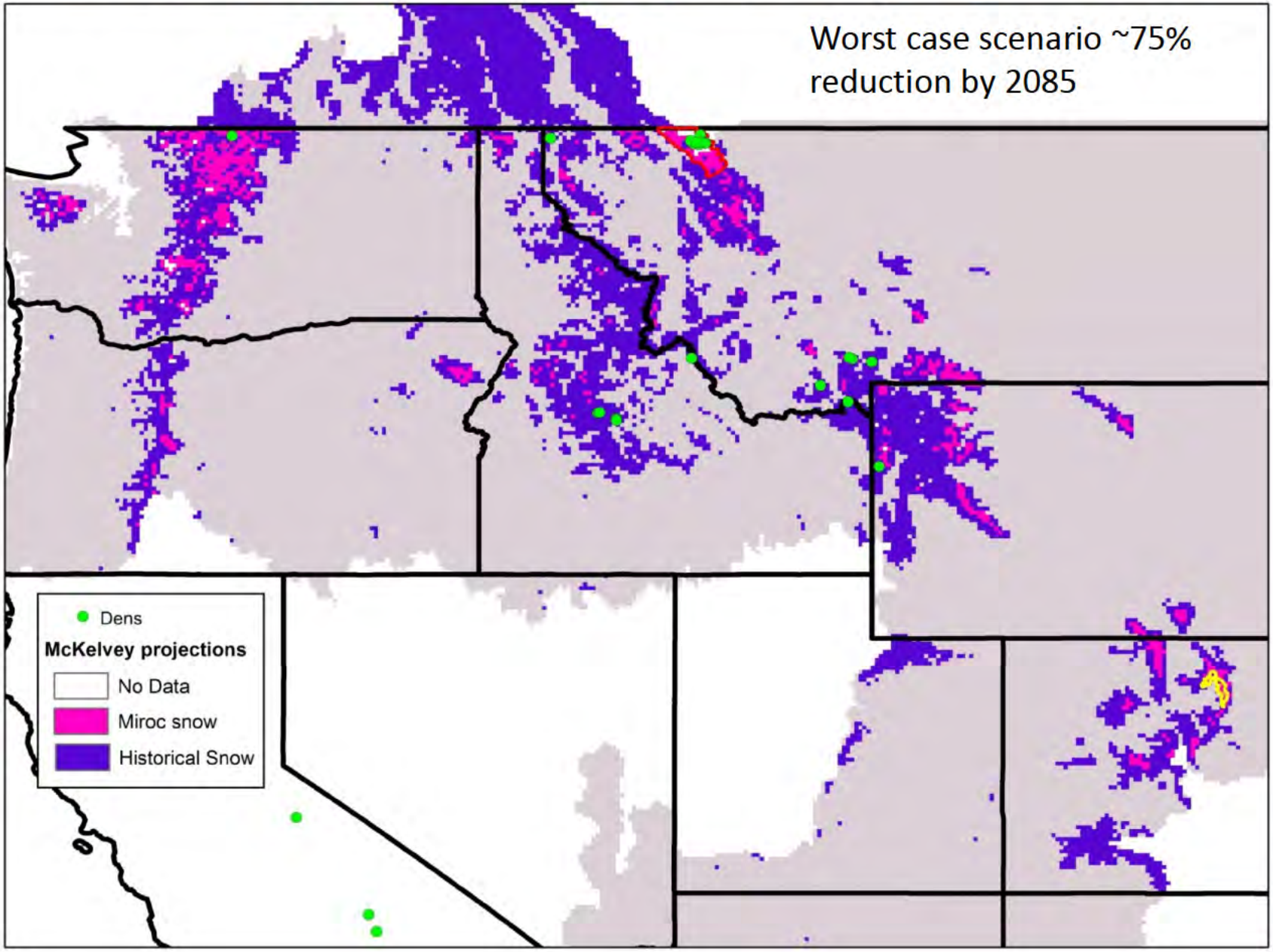


Occupancy Survey Results

- 4 Western States (2016-2017); WY only (2015-2016)



McKelvey et al (2011) snow projections



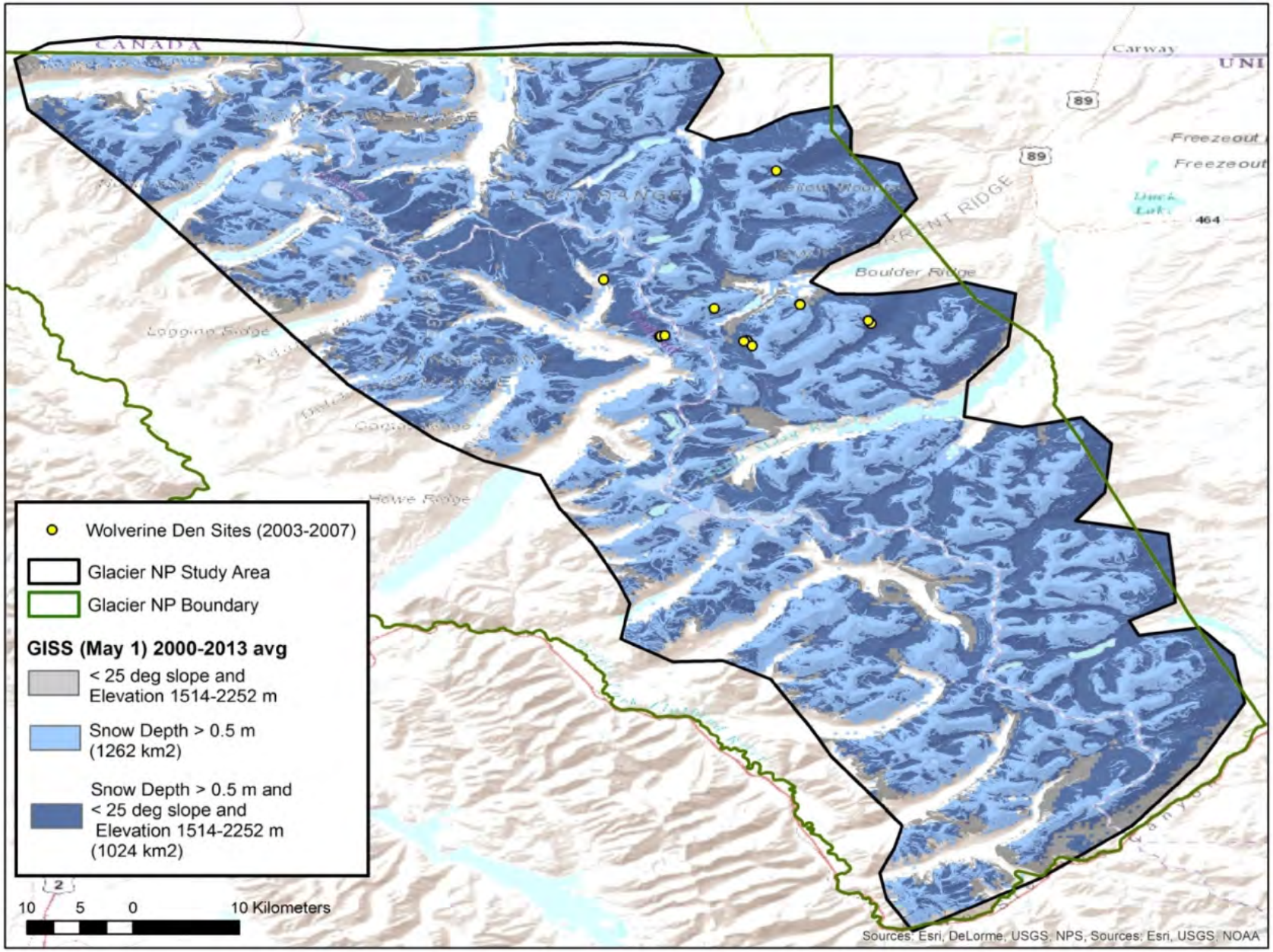
Comparison of Methods

Ray et al. (2017)	Copeland et al. (2010); McKelvey et al. (2011)

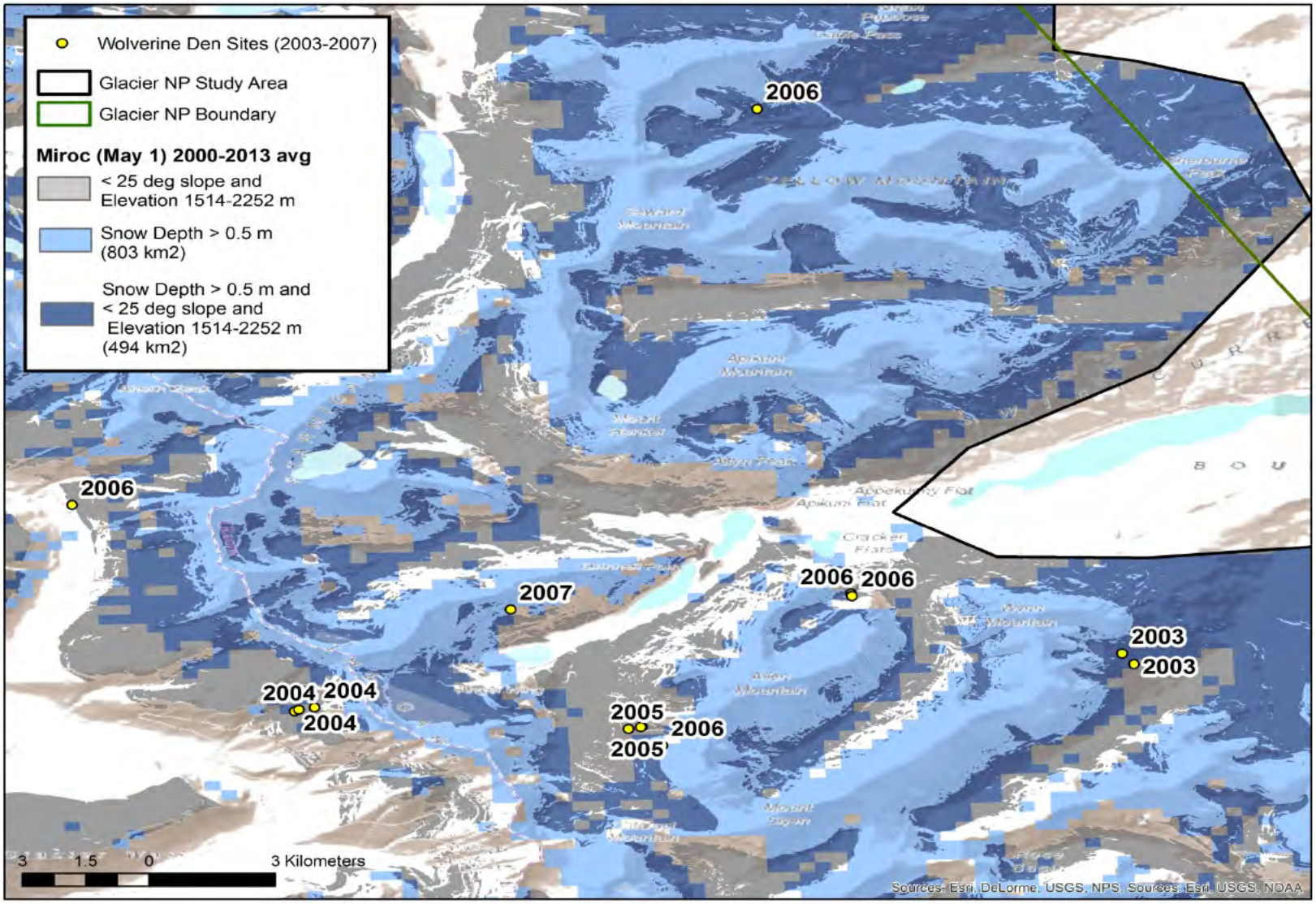
• 0.24 mi^2 spatial resolution
  • Glacier and Rocky Mtn NP
	• 14.29 mi^2 spatial resolution
	  • Western U.S. (except CA, GB)

• Topographic features used (slope, aspect, shading)	• No topo features used
• Validated with SNOTEL and MODIS	• No validation for snow
• 17 years of MODIS data	• 7 years of MODIS data
• Snow cover dates include April 15, May 1, May 15 (better aligns w/ life history)	• Snow cover dates include May 15 and May 29 (both derived)
• Snow presence defined: 1.25 cm (0.5 in) snow depth on May 15	• Snow presence defined: 13 cm (5.12 in) snow depth on May 1

Glacier NP Future Snow Projections (~2055)



Glacier Dens and Future Snow Projections



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Corrected version.

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Chief, Division of Ecological Services
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> Michael Thabault
> Assistant Regional Director
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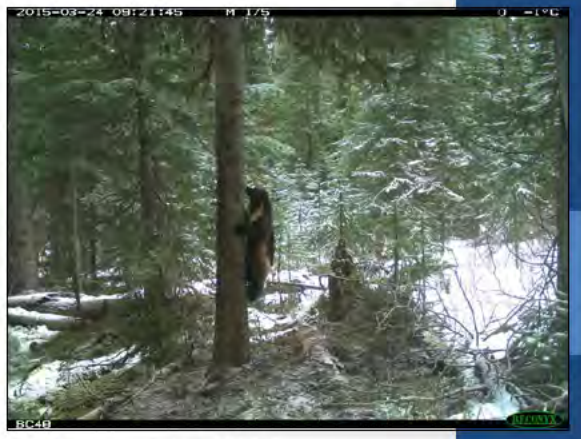

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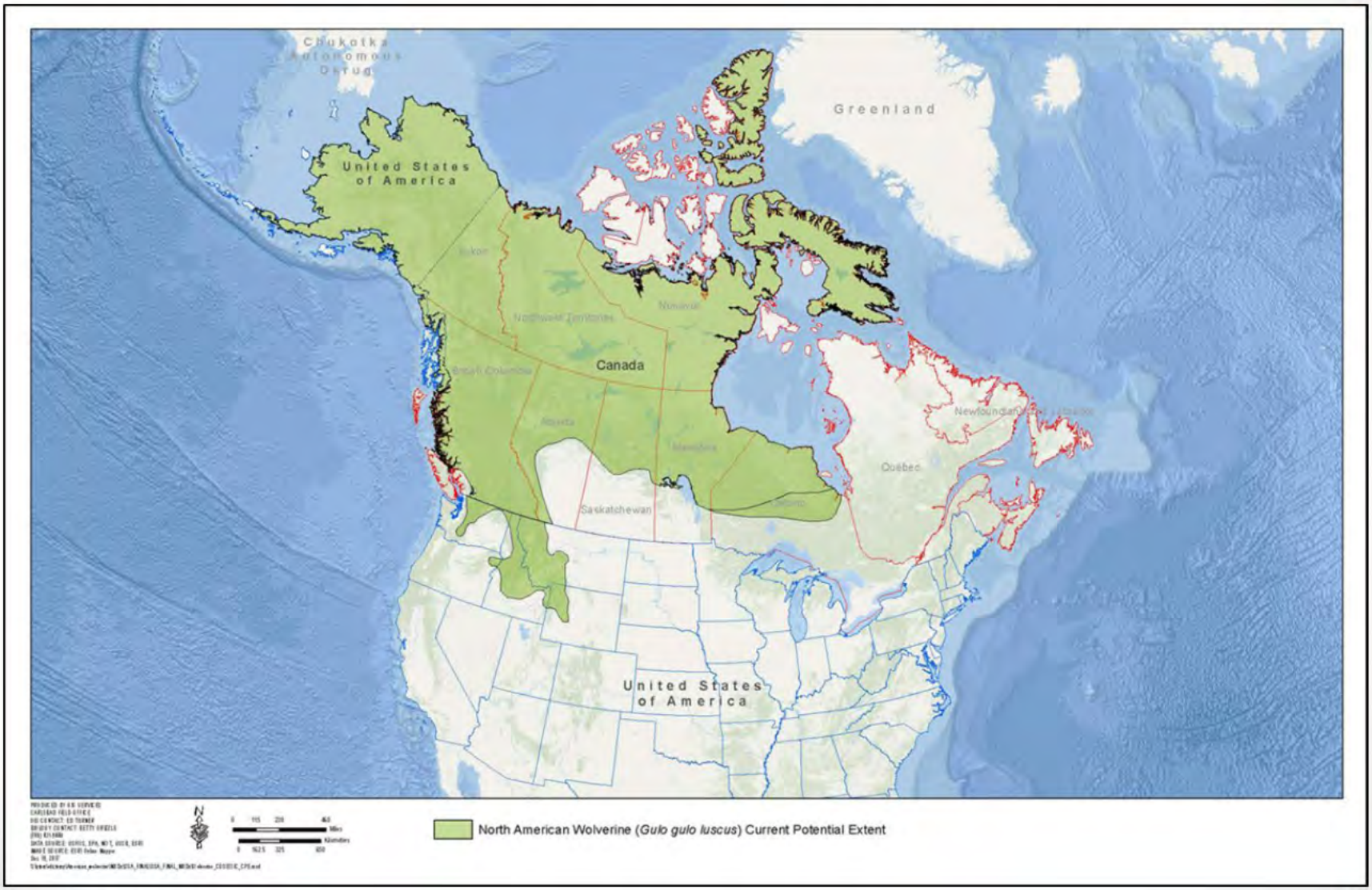

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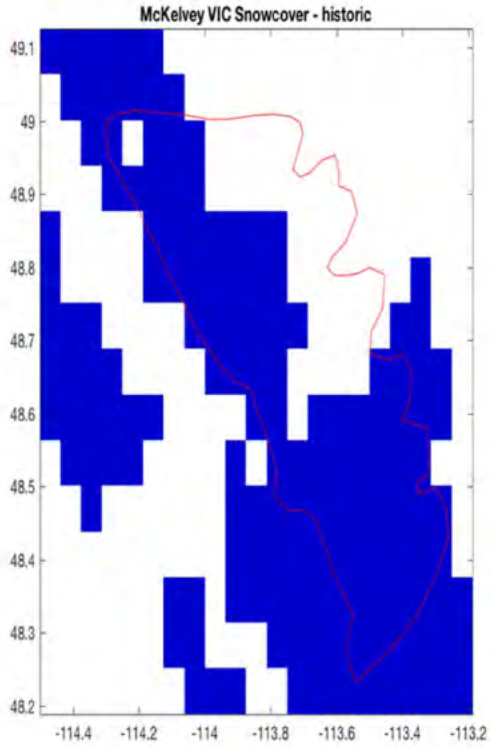
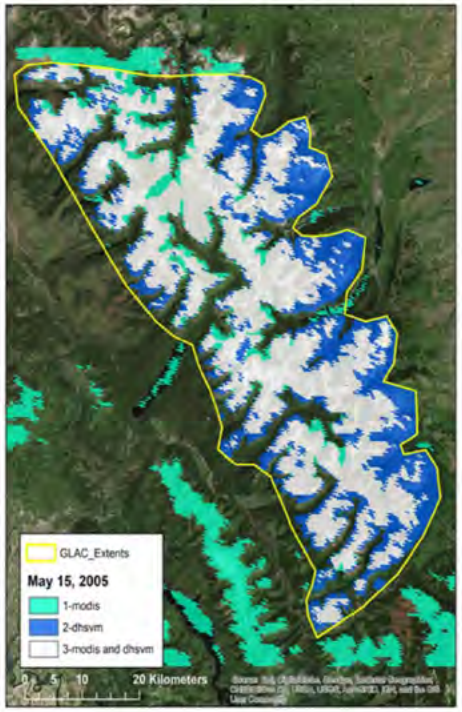


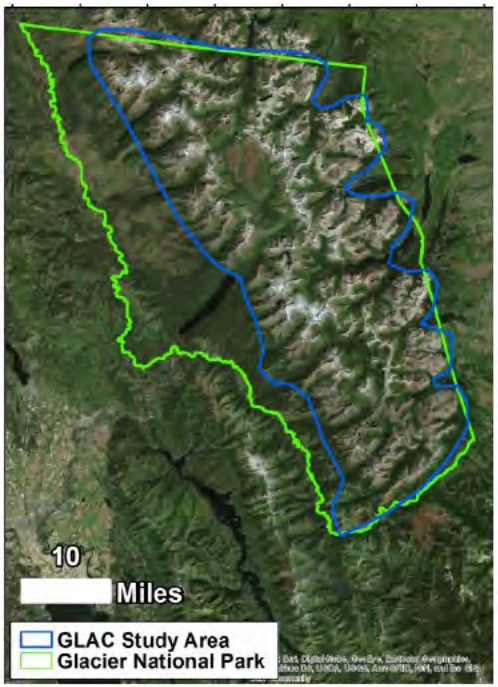
NOAA / CU 2017

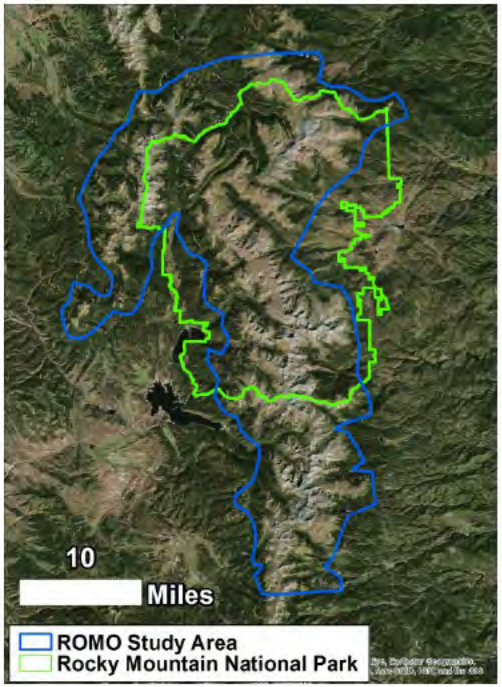


(John Guinotte, FWS)

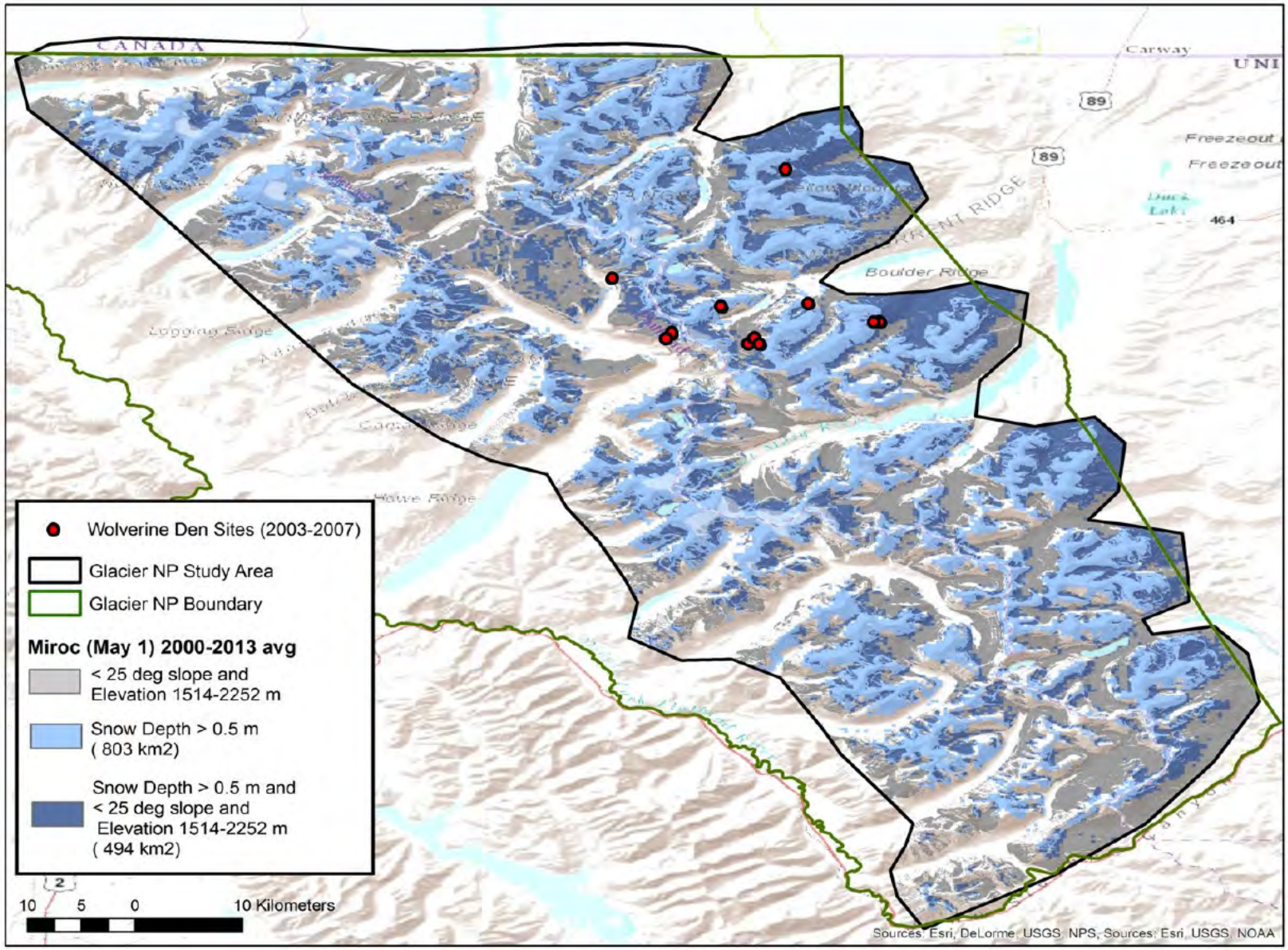
Snow Persistence Related to Climate Change Effects

- Contracted with NOAA/CU to conduct a more detailed look at snow persistence – Glacier and Rocky Mountain National Parks





Future Projections for Snow Cover



Summary of Future Conditions

- Climate change model projections for the range of the wolverine within the contiguous United States indicate:
  - Increases in temperature by the mid-21st century
  - But future precipitation patterns less clear
- Snow cover projected to decline in response to warming temperatures and changing precipitation patterns
  - But, varies by elevation, topography, and by region
- Higher elevations will retain more snow cover than lower elevations, particularly in early spring (April 30/May1)
- Results from NOAA/CU analysis (Glacier and Rocky Mountain National Parks)
  - *Several hundred square miles projected to have deep snow (greater than 20 inches in depth) on May 1 at elevations currently used by wolverines for denning*
  - This holds across the range of climate models to Year 2055

Conservation Mechanisms

- Legal protections (T, E, or Candidate) in several western States and Canadian provinces
- "Current range" in lower 48:
  - 72 % on Federal lands
  - 18 % of this area is within designated wilderness areas
- Management actions identified in State Wildlife Action Plans, the Idaho Wolverine Conservation Plan, and USFS Mgt Plans
  - Winter road closures, fire management, land acquisition or conservation easements.
- Western States Wolverine Working Group
- WAFWA Wildlife Chiefs Wolverine Subcommittee
  - To date, approximately $1.5 million applied towards conservation and management actions for the wolverine

Comments Received

Response to Oct 2016 NOI (proposed rule/status review)

- Over 200 comments posted (from several States, Canada, U.K.)
- Most, but not all, general public comments favored listing

SSA Report Review

- 11 States and Agency (Technical) Comments submitted
- No Tribal comments submitted
- Peer Reviewers – generally positive
- Comments received reflected on-going debate on snow obligate characterization

DPS Determination

- 2013 identifies a DPS in lower 48
  - States and industry disputed validity
  - Discreteness was based on "conservation status" across the international border
    - Effective population size, connectivity
  - Significance was based on a gap in range
- 2018, lower 48 not a valid DPS
  - Discreteness determination
    - No difference in conservation status that is significant in light of Factor D
    - Looked at trapping along border, not a significant barrier
  - Significance determination
    - Spatial evaluation of range to determine lower 48 extent, using detections, not estimates of range

Next Steps

- Proposed approach
  - Withdrawal of previous (2013) proposed rule
  - Recommend using Sonoran bald eagle approach (vetted through RSOL)
    - Address both prongs of the DPS policy – why not discrete or significant *and*
    - Full status review as if lower 48 qualified as a DPS
- Listing determination identified in the FY 2018 workplan

wolverinepedia.zaxtor.net

From: Grizzle_Betty
To: Shoemaker_Justin
Subject: Fwd: FW: Incidental wolverine trapping - PNF - Wildlife Control Services
Date: Thursday, December 15, 2016 2:19:46 PM
Attachments: image007.png
image009.png
image010.png
image008.png

FYI

---------- Forwarded message ----------
From: **Galloway, June -FS** <jgalloway02@fs.fed.us>
Date: Thu, Dec 15, 2016 at 11:57 AM
Subject: FW: Incidental wolverine trapping - PNF - Wildlife Control Services
To: "betty_grizzle@fws.gov" <betty_grizzle@fws.gov>

Hi Betty,

Here is the information that we discussed earlier regarding incidental trapping of wolverine on the Payette NF, since 2004, provided by IDFG. I was told that there were at 2 more recent trappings but have not been able to verify that. My assumption with the (2) males that were trapped and released is that they were probably injured (lethal wolf traps) so it could very well be three mortalities. No way to know for sure though.

Please let me know if you have any questions.

Thanks,

June

Species	Date	UTM_E	UTN_N	Gender	General_Location	Comments
Gulo	7/21/2004	0570207	5000777	Male	Fisher Creek Saddle	trapped & released by Wildlife Services
Gulo	8/19/2005	0568980	5005858	Male	Lava Ridge Saddle	trapped & released by Wildlife Services
Gulo	9/14/2010	0569184	6012216	Female	Lave Ridge	trap mortality, Wildlife Services

June M. Galloway
Forest Wildlife Biologist
Forest Service

Payette National Forest

p: 208-634-0791
f: 208-634-0744
jgalloway02@fs.fed.us

500 Mission Street, Bldg. 2
McCall, ID 83638-3805
www.fs.fed.us

Caring for the land and serving people

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Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

From: Grizzle, Betty
To: Guinotte, John
Cc: Shoemaker, Justin; Stephen Torbit
Subject: Re: Adaptation Partnership assessments
Date: Friday, January 27, 2017 11:02:09 AM
Attachments: NRAPFinalDraft_2016.07.25.pdf
IAPVulnerabilityAssessmentSummariesDraft.pdf

I am attaching two of the three references cited in the comment letter. I haven't been able to find (yet) a 2017 draft document being prepared as a chapter for a GTR from Rocky Mtn Research Station.

Regarding your preliminary analysis, how did you determine the melt out date? Also, it will be important to also look at southern den sites. Thanks for sharing this.

On Fri, Jan 27, 2017 at 9:53 AM, Guinotte, John <john_guinotte@fws.gov> wrote:

> Hi Betty,
> No I haven't seen the site. Can you share the two documents? I just had a closer look at the 13 den sites in Glacier where I have historic Modis snow cover data. Spreadsheet is attached. Looks like melt out date was well after the dates Copeland recorded for all sites.
> Best, John
>
> John Guinotte
> Fish and Wildlife Biologist
> Ecological Services
> U.S. Fish and Wildlife Service
> Mountain Prairie Region 6
> 134 Union Blvd., Lakewood, CO 80228
> 303-236-4264
> john_guinotte@fws.gov
>
> On Fri, Jan 27, 2017 at 10:42 AM, Grizzle, Betty <betty_grizzle@fws.gov> wrote:
>
> > John - Have you seen the following website?
> > http://adaptationpartners.org/nrap/
> >
> > I received a comment letter today referencing 3 documents produced by this collaborative partnership (identified as drafts). I am reviewing these now, but it looks like two of them are vulnerability assessments related to climate change effects - essentially generated scenarios - and wolverine is one of 20 species considered.
> >
> > --
> >
> > Betty J. Grizzle, D.Env.
> > Fish and Wildlife Biologist
> > U.S. Fish and Wildlife Service
> > Carlsbad Fish and Wildlife Office
> > 2177 Salk Ave, Suite 250
> > Carlsbad, CA 92008
> > 760-431-9440, ext. 215
> > 760-431-5901 fax

--

Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

Climate Change Vulnerability and Adaptation in the Northern Rocky Mountains

Jessica E. Halofsky

David L. Peterson

S. Karen Dante-Wood

Linh Hoang

Joanne J. Ho

Linda A. Joyce

Editors

Halofsky, Jessica E.; Peterson, David L.; Dante-Wood, S. Karen; Hoang, Linh; Ho, Joanne J.; Joyce, Linda A., editors. 2017. Climate change vulnerability and adaptation in the Northern Rocky Mountains. Gen. Tech. Rep. RMRS-GTR-xxx. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. xxx p.

Abstract

The Northern Adaptation Partnership (NRAP) identified climate change issues relevant to resource management in the Northern Rockies (USA) region, and developed solutions that minimize negative effects of climate change and facilitate transition of diverse ecosystems to a warmer climate. The NRAP region covers 183 million acres, spanning northern Idaho, Montana, northwest Wyoming, North Dakota, and northern South Dakota, and includes 15 national forests and 3 national parks across the U.S. Forest Service Northern Region and adjacent Greater Yellowstone Area. U.S. Forest Service scientists, resource managers, and stakeholders worked together over a two-year period to conduct a state-of-science climate change vulnerability assessment and develop adaptation options for national forests and national parks in the Northern Rockies region. The vulnerability assessment emphasized key resource areas—water, fisheries, wildlife, forest and rangeland vegetation and disturbance, recreation, cultural heritage, and ecosystem services—regarded as the most important for local ecosystems and communities. Resource managers used the assessment to develop a detailed list of ways to address climate change vulnerabilities through management actions. The large number of adaptation strategies and tactics, many of which are a component of current management practice, provide a pathway for slowing the rate of deleterious change in resource conditions.

Keywords: adaptation, climate change, ecological disturbance, climate-smart resource management, Northern Rocky Mountains, vulnerability assessment

Jessica E. Halofsky is a Research Ecologist with the University of Washington, College of the Environment, School of Environmental and Forest Sciences in Seattle, Washington.

David L. Peterson is a Research Biological Scientist with the U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station in Seattle, Washington.

S. Karen Dante-Wood is a Natural Resource Specialist, U.S. Department of Agriculture, Forest Service, Office of Sustainability and Climate Change in Washington, DC.

Linh Hoang is the Regional Inventory, Monitoring, Assessment and Climate Change Coordinator, U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

Joanne J. Ho is a Research Environmental Economist with the University of Washington, College of the Environment, School of Environmental and Forest Sciences in Seattle, Washington.

Linda A. Joyce is a Research Ecologist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Human Dimensions Research Program in Fort Collins, Colorado.

Summary

The Northern Rockies Adaptation Partnership (NRAP) is a science-management partnership consisting of 15 national forests in the Northern Region of the U.S. Forest Service, three national parks, the U.S. Forest Service Pacific Northwest and Rocky Mountain Research Stations, the University of Washington, and numerous other organizations and stakeholders. These organizations worked together over a period of two years to identify climate change issues relevant to resource management in the Northern Rocky Mountains (USA) and to find solutions that can minimize negative effects of climate change and facilitate transition of diverse ecosystems to a warmer climate. The NRAP provided education, conducted a climate change vulnerability assessment, and developed adaptation options for national forests and national parks that manage more than 28 million acres in northern Idaho, Montana, northwestern Wyoming, North Dakota, and northern South Dakota.

Global climate models project that the Earth's current warming trend will continue throughout the 21st century in the Northern Rockies. Compared to observed historical temperature, average warming across the five NRAP subregions is projected to be about 4 to 5 °F by 2050, depending on greenhouse gas emissions. Precipitation may increase slightly in the winter, although the magnitude is uncertain.

Climatic extremes are difficult to project, but they will probably be more common, driving biophysical changes in terrestrial and aquatic ecosystems. Droughts of increasing frequency and magnitude are expected in the future, promoting an increase in wildfire, insect outbreaks, and non-native species. These periodic disturbances, will rapidly alter productivity and structure of vegetation, potentially altering the distribution and abundance of dominant plant species and animal habitat.

Highlights of the vulnerability assessment and adaptation options for the Northern Rockies include the following:

Water resources and infrastructure

- Effects: Decreasing snowpack and declining summer flows will alter timing and availability of water supply, affecting agricultural, municipal, and public uses in and downstream from national forests, and affecting other forest uses including livestock, wildlife, recreation, firefighting, road maintenance, and instream fishery flows. Declining summer low flows will affect water availability during late summer, the period of peak demand (e.g., for irrigation and power supply). Increased magnitude of peak streamflows will damage roads near perennial streams, ranging from minor erosion to extensive damage, thus affecting public safety, access for resource management, water quality, and aquatic habitat. Bridges, campgrounds, and national forest facilities near streams and floodplains will be especially vulnerable, reducing access by the public.
- Adaptation options: Primary adaptation strategies to address changing hydrology in the Northern Rockies include restoring the function of watersheds, connecting floodplains, reducing drainage efficiency, maximizing valley storage, and reducing hazardous fuels. Tactics include adding wood to streams, restoring beaver populations, modifying livestock management, and reducing surface fuels and forest stand densities. Primary strategies for infrastructure include increasing the resilience of stream crossings, culverts, and bridges to higher peak flows and facilitating response to higher peak flows by reducing the road system and disconnecting roads from streams. Tactics include completing geospatial databases of infrastructure (and drainage) components, installing higher capacity culverts, and decommissioning roads or converting them to alternative uses. It will be important to map aquifers and alluvial deposits, improve monitoring to provide feedback on water dynamics, and understand the physical and legal availability of water for aquifer recharge. Erosion potential to protect water quality can be addressed by reducing hazardous fuels in dry forests, reducing non-fire disturbances, and using road management practices that prevent erosion.

Fisheries

- Effects: Decreased snowpack will shift the timing of peak flows, decrease summer low flows, and in combination with higher air temperature, increase stream temperatures, all of which will reduce the vigor of cold-water fish species. Abundance and distribution of cutthroat trout and especially bull trout will be greatly reduced, although effects will differ by location as a function of both stream temperature and competition from non-native fish species. Increased wildfire will add sediment to streams, increase peak flows and channel scouring, and raise stream temperature by removing vegetation.
- Adaptation options: Primary strategies to address climate change threats to cold-water fish species include maintaining or restoring functionality of channels and floodplains to retain (cool) water and buffer against future changes, decreasing fragmentation of stream networks so aquatic organisms can access similar habitats, and developing wildfire use plans that address sediment inputs and road failures. Adaptation tactics include using watershed analysis to develop integrated actions for vegetation and hydrology, protecting groundwater and springs, restoring riparian areas and beaver populations to maintain summer baseflows, reconnecting and increasing off-channel habitat and refugia, identifying and improving stream crossings that impede fish movement, decreasing road connectivity, and revegetating burned areas to store sediment and maintain channel geomorphology. Removing non-native fish species and reducing their access to cold-water habitat reduces competition with native fish species.

Forest vegetation

- Effects: Increasing air temperature, through its influence on soil moisture, is expected to cause gradual changes in the abundance and distribution of tree, shrub, and grass species throughout the Northern Rockies, with more drought tolerant species becoming more competitive. The earliest changes will be at ecotones between lifeforms (e.g., upper and lower treelines). Ecological disturbance, including wildfire and insect outbreaks, will be the primary facilitator of vegetation change, and future forest landscapes may be dominated by younger age classes and smaller trees.

High-elevation forests will be especially vulnerable if disturbance frequency increases significantly. Increased abundance and distribution of non-native plant species, as well as the legacy of past land uses, create additional stress for regeneration of native forest species.

- Adaptation options: Most strategies for conserving native tree, shrub, and grassland systems focus on increasing resilience to chronic low soil moisture (especially extreme drought and low snowpack), and to more frequent and extensive ecological disturbance (wildfire, insects, non-native species). These strategies generally include managing landscapes to reduce the severity and patch size of disturbances, encouraging fire to play a more natural role, and protecting refugia where fire-sensitive species can persist. Increasing species, genetic, and landscape diversity (spatial pattern, structure) is an important "hedge your bets" strategy that will reduce the risk of major forest loss. Adaptation tactics include using silvicultural prescriptions (especially stand density management) and fuel treatments to reduce fuel continuity, reducing populations of non-native species, potentially using multiple genotypes in reforestation, and revising grazing policies and practices. Rare and disjunct species and communities (e.g., whitebark pine, quaking aspen) require adaptation strategies and tactics focused on encouraging regeneration, preventing damage from disturbance, and establishing refugia.

Rangeland vegetation

- Effects: A longer growing season is expected to increase net primary productivity of many rangeland types, especially those dominated by grasses, although responses will depend on local climate and soil conditions. Elevated atmospheric carbon dioxide may increase water use efficiency and productivity of some species. In many cases, increasing wildfire frequency and extent will be particularly damaging for big sagebrush and other shrub species that are readily killed by fire. The widespread occurrence of cheatgrass and other non-natives facilitates frequent fire through annual fuel accumulation. In montane grasslands, wildfire may kill Douglas-fir and other species that have recently established in rangelands through fire exclusion. Shrub species

that sprout following fire may be quite resilient to increased disturbance, but may be outcompeted by more drought tolerant species over time.

- Adaptation options: Adaptation strategies for rangeland vegetation focus on increasing resilience of rangeland ecosystems, primarily through non-native species control and prevention. Using ecologically based non-native plant management focuses on strategies to repair damaged ecological processes that facilitate invasion, and seeding of desired natives can be done where seed availability and dispersal of natives are low. Proactive management to prevent establishment of non-native species is also critical (early detection-rapid response), including tactics such as weed-free policies, education of employees and the public, and collaboration among multiple agencies to control weeds. Livestock grazing can also be managed through the development of site-specific indicators that inform livestock movement guides and allow for maintenance and enhancement of plant health.

Wildlife

- Effects: Few data exist on the direct effects of climatic variability and change on most animal species. Therefore, projected climate change effects must be inferred from what is known about habitat characteristics and the autecology of each species. Habitat for mammals that depend on high-elevation, snowy environments for both predators (Canada lynx, fisher, wolverine) and prey (snowshoe hare) is expected to deteriorate relatively soon if snowpack continues to decrease. Species that are highly dependent on a narrow range of habitat (pygmy rabbit, Brewer's sparrow, greater sage-grouse,) will be especially vulnerable if that habitat decreases from increased disturbance (e.g., sagebrush mortality from wildfire). Species that are mobile or respond well to increased disturbance and habitat patchiness (deer, elk) will probably be resilient to a warmer climate in most locations. Some amphibian species (Columbia spotted frog, western toad) may be affected by pathogens (e.g., amphibian chytrid fungus) that are favored by a warmer climate.

- Adaptation options: Adaptation for wildlife is focused on maintaining adequate habitat and healthy wildlife populations, and increasing knowledge of species' needs and climate sensitivities. Connectivity is an important conservation strategy for most species in the Northern Rockies. Maintaining healthy American beaver populations will provide riparian habitat structure and foraging opportunities for multiple species. Quaking aspen habitat, which is also important for several species, can be enhanced by allowing wildfire, protecting aspen from grazing, and reducing conifer encroachment. Restoration of more open stands of ponderosa pine and mixed conifer forest through reduction of stand densities will benefit species such as fisher and flammulated owl. Excluding fire and reducing non-native species will maintain sagebrush habitats that are required by several bird and mammal species.

Recreation

- Effects: Recreation has a significant economic impact throughout the Northern Rockies. A warmer climate will generally improve opportunities for warm-weather activities (hiking, camping, sightseeing) because it will create a longer time during which these activities are possible, especially in the spring and autumn "shoulder seasons." However, it will reduce opportunities for snow-based, winter activities (downhill skiing, cross-country skiing, snowmobiling) because snowpack is expected to decline significantly in the future. Recreationists will probably seek more water-based activities in lakes and rivers in order to seek refuge from hotter summer weather. Higher temperatures may have both positive and negative effects on wildlife-based activities (hunting, fishing, birding) and gathering of forest products (e.g., berries, mushrooms), depending on how target habitats and species are affected.
- Adaptation options: Recreationists are expected to be highly adaptable to a warmer climate by shifting to different activities and different locations, behavior that is already observed from year to year. For example, downhill skiers may switch to ski areas that have more reliable snow, cross-country skiers will travel to higher elevations, and larger ski areas on federal lands may expand to

multi-season operation. Water-based recreationists may adapt to climate change by choosing different sites that are less susceptible to changes in water levels. Hunters may need to adapt by altering the timing and location of hunts. Federal management of recreation is currently not very flexible with respect to altered temporal and spatial patterns of recreation. This can be at least partially resolved by assessing expected use patterns in a warmer climate, modifying opening times of facilities, and deploying seasonal employees responsible for recreational facilities earlier in the year.

Ecosystem services

Ecosystem services are increasingly valued on federal lands, beyond just their economic value. Climate change effects will vary greatly within different subregions of the Northern Rockies, with some ecosystem services being affected in the short term and others in the long term. Of the many ecosystem services provided in the Northern Rockies, eight are considered here, most of which are relevant to other resource categories included in the assessment.

- While annual *water yield* is not expected to change significantly, timing of water availability will likely shift, and summer flows may decline. These changes may result in some communities experiencing summer water shortages, although reservoir storage can provide some capacity. Rural agricultural communities will be disproportionately affected by climate change if water does become limiting.
- *Water quality* will decrease in some locations if wildfires and floods increase, adding sediment to rivers and reservoirs. Agriculture is currently the major source of impairment, affecting riparian systems, aquatic habitat, water temperatures, and fecal coliform. Climate change is expected to amplify these effects. Hazardous fuel treatments, riparian restoration, and upgrading of hydrologic infrastructure can build resilience to disturbances that damage water quality.
- *Wood products* are a relatively small component of the Northern Rockies economy, and effects from economic forces will probably have the biggest impacts in the future. As wildfires and

insect outbreaks become more common, wood supply could become less reliable, but overall effects will generally be small except in small towns that depend on steady timber supply.

- *Minerals* and mineral extraction are important economic drivers in eastern Montana and western North Dakota. The biggest effects on this industry will be economic factors, as well as how it connects to other ecosystem services, particularly water quality. Wildfires and floods can put mineral extraction infrastructure at risk in some watersheds.
- *Forage for livestock* is expected to increase in productive grasslands as a result of a longer growing season and in some cases elevated carbon dioxide. Therefore, ranching and grazing may benefit from climate change. Primary effects on grazing include loss of rural population, spread of non-native grasses, and fragmentation of rangelands.
- *Viewsheds and air quality* will be negatively affected by increasing wildfires and longer pollen seasons. A growing percentage of the Northern Rockies population will be in demographic groups at risk for respiratory and other medical problems on days with poor air quality. Hazardous fuel treatments can help build resilience to disturbances that degrade air quality.
- *Regulation of soil erosion* will be decreased by agricultural expansion, spread of non-native plants, and increased frequency of wildfire and floods. Increased capital investments may be needed for water treatment plants if water quality degrades significantly. Climate-smart practices in agriculture and road construction can reduce some negative effects.
- *Carbon sequestration* will be increasingly difficult if wildfires, insect outbreaks, and perhaps plant disease increase as expected, especially in the western part of the Northern Rockies. At the same time, managing forests for carbon sequestration is likely to become more important in response to national policies on carbon emissions. Hazardous fuel treatments can help build resilience to disturbances that rapidly oxidize carbon and emit it to the atmosphere.

Cultural resources

Disturbances such as wildfires, floods, and soil erosion place cultural and heritage values at risk. Damage to cultural and historic sites are irreversible, making protection a key management focus. Climate-induced changes in terrestrial and aquatic habitats affect abundance of culturally-valued plants and animals (especially fish), affecting the ability of Native American tribes to exercise their treaty rights. Effects on cultural resources are amplified by external social forces that include a growing regional population, vandalism, and loss of traditional practices in a globalizing culture.

The NRAP facilitated the largest climate change adaptation effort on public lands to date, including participants from federal agencies and stakeholder organizations interested in a broad range of resource issues. It achieved specific goals of national climate change strategies for the U.S. Forest Service and National Park Service, providing a scientific foundation for resource management and planning in the Northern Rockies. The large number of adaptation strategies and tactics, many of which are a component of current management practice, provide a pathway for slowing the rate of deleterious change in resource conditions. Rapid implementation of adaptation—in land management plans, National Environmental Policy Act documents, project plans, and restoration—will help maintain functionality of terrestrial and aquatic ecosystems in the Northern Rockies, as well as build the organizational capacity of federal agencies to incorporate climate change in their mission of sustainable resource management. Long-term monitoring will help detect potential climate change effects on natural resources, and evaluate the effectiveness of adaptation options that have been implemented.

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Chapter 1: Introduction

S. Karen Dante-Wood

The Northern Rockies Adaptation Partnership (NRAP) is a science-management partnership among the Forest Service, U.S. Department of Agriculture regional offices and national forests (mostly in the Northern Region, and small portions of the Intermountain and Rocky Mountain Regions); U.S. Forest Service Pacific Northwest and Rocky Mountain Research Stations; Glacier, Yellowstone and Grand Teton National Parks; Great Northern and Plains and Prairie Potholes Landscape Conservation Cooperatives; Department of Interior North Central Climate Science Center; Greater Yellowstone Coordinating Committee; Oregon State University; and EcoAdapt.

Initiated in 2013, the NRAP is a collaborative project with the goals of increasing climate change awareness, assessing vulnerability, and developing science-based adaptation strategies to reduce adverse effects of climate change and ease the transition to new climate states and conditions (see http://adaptationpartners.org/nrap). Developed in response to proactive climate change strategies of the Forest Service (USDA FS 2008, 2010a,c), and building on previous efforts in national forests (Halofsky et al. 2011; Littell et al. 2012; Raymond et al. 2013, 2014; Rice et al. 2012; Swanston and Janowiak 2012; Swanston et al. 2011), the partnership brings together resource managers and research scientists to plan for climate change in the Northern Rockies.

CLIMATE CHANGE RESPONSE IN THE FOREST SERVICE AND NATIONAL PARK SERVICE

Climate change is an agency-wide priority for the U.S. Forest Service (USFS), which has issued direction to administrative units for responding to climate change (USDA FS 2008) (table 1.1). In 2010, the USFS provided specific direction to the National Forest System in the form of the National Roadmap for Responding to Climate Change (USDA FS 2010a) and the Performance Scorecard for Implementing the Forest Service Climate Change Strategy (USDA FS 2010a). The goal of the USFS climate change

420 strategy is to "ensure our national forests and private working lands are conserved, restored, and made
421 more resilient to climate change, while enhancing our water resources" (USDA FS 2010a). To achieve
422 this goal, starting in 2011, each national forest and grassland began using a 10-point scorecard system to
423 report accomplishments on ten elements in four dimensions: (1) increasing organizational capacity; (2)
424 partnerships, engagement, and education; (3) adaptation; and (4) mitigation and sustainable consumption.
425 Progress towards accomplishing elements of the scorecard must be reported annually by each national
426 forest and national grassland; all units are expected to accomplish 7 of 10 criteria by 2015, with at least
427 one "yes" in each dimension.

428 Similarly, the National Park Service (NPS) Climate Change Response Strategy provides direction for
429 addressing the impacts of climate change on the National Park System lands (NPS 2010) (table 1.2). The
430 strategy has four components to guide NPS actions: science, adaptation, mitigation and communication.
431 The science component involves conducting and synthesizing research at various scales, monitoring
432 trends and conditions, and delivering information to resource managers and partners. It also provides the
433 scientific basis for adaptation, mitigation, and communication. Adaptation involves developing capacity
434 within the agency to assess climate change scenarios and risks and implementing actions to better manage
435 natural and cultural resources and infrastructure for a changing climate. Mitigation efforts focus on
436 reducing the agency carbon footprint and enhancing carbon sequestration. Finally, the strategy requires
437 the NPS to take advantage of agency capacity for education and interpretation to communicate the effects
438 of climate change to NPS employees and to the public. Park rangers and other employees are encouraged
439 to engage visitors about climate change, because national parks are visible examples of how climate
440 change can affect natural and cultural resources. The similarity of USFS and NPS climate response
441 strategies facilitated coordination between the two agencies.

442 The NRAP built on existing efforts in ecosystem-based management and ecological restoration to
443 address climate change and put these efforts in a broader regional context in the Northern Rockies.
444 Restoration is a priority in most national forests in this region, particularly related to hazardous fuel
445 reduction in dry forests (stand density reduction plus surface fuel removal, often with prescribed burning),

and restoration of riparian areas to improve hydrologic and biological function. The NRAP works in conjunction with these management priorities to access the best available science on climate change effects and implement climate change adaptation plans.

In 2010, a climate change report was developed for the Kootenai and Idaho Panhandle National Forests planning effort (USDA FS 2010b). At the time, this was the most comprehensive climate change vulnerability assessment and adaption document compiled for the Northern Region. Although this report addressed many issues, it did not include non-forested vegetation, cultural resources, recreation resources, or ecosystem services. The Northern Region also partially funded the University of Washington Climate Impacts Group to provide datasets of historical (1916-2006) and future (2040s, 2080s) downscaled climate and hydrologic data for the Upper Missouri River and Columbia River basins (Littell et al. 2011).

Building on these downscaled data, the Northern Region developed climate change "primers" to help assess and evaluate regionally specific climate-related trends. Primers for wildland fire, watershed ecology, forest regeneration, and forest landscapes were in progress when the NRAP was initiated and have been incorporated into this publication. In addition to these primers, the Northern Region is currently developing a watershed-based climate change vulnerability assessment, downscaling regional water and stream temperature data for the Lolo National Forest, focused on bull trout (*Salvelinus confluentus*) and a preliminary discussion of the western pearlshell mussel (*Margaritifera falcata*), water supply, and forest infrastructure (USDA FS 2015).

The NRAP also incorporates existing USFS Northern Region efforts to consider and address climate change effects in management operations. In 2011, the Northern Region developed an Integrated Restoration & Protection Strategy that provided a framework for climate change adaptation (Bollenbacher et al. 2014, USDA FS 2011). In addition, periodic Northern Region restoration and resiliency reports provide baseline information on vegetative characteristics to better understand the effects of adaptive management (USDA FS 2014).

Most previous efforts to consider climate change effects and adaption strategies in the Northern Rockies have focused on vegetation and aquatic resources. The NRAP broadens these efforts to develop a

synthesis for a more comprehensive list of resource values, and to develop adaptation strategies for resources that have not been emphasized in management operations.

SCIENCE-MANAGEMENT PARTNERSHIPS

Previous efforts in the Pacific Northwest and beyond have demonstrated the success of science-management partnerships for increasing climate change awareness among resource managers and adaptation planning on federal lands. Olympic National Forest and Tahoe National Forest initiated the first science-management partnerships for developing adaptation options for individual national forests (Littell et al. 2012). The Olympic climate change study assessed resource vulnerabilities and developed adaptation options for Olympic National Forest and Olympic National Park on the Olympic Peninsula in Washington (Halofsky et al. 2011). Similar to efforts in the Olympics, the North Cascadia Adaptation Partnership assessed vulnerabilities and formulated adaptation options for two national forests and two national parks in Washington (Raymond et al. 2014).

In collaboration with three management units in California—Tahoe National Forest, Inyo National Forest, and Devils Postpile National Monument—the USFS Pacific Southwest Research Station held climate change education workshops and developed the Climate Project Screening Tool in order to incorporate adaptation into project planning (Morelli et al. 2012). In response to requests from the Shoshone National Forest in northern Wyoming, the Forest Service Rocky Mountain Research Station synthesized information on past climate, future climate projections, and potential effects of climate change on the multiple ecosystems within the forest (Rice et al. 2012).

In the largest effort to date in the eastern United States, the USFS Northern Research Station, in collaboration with the Chequamegon-Nicolet National Forest in northern Wisconsin and numerous other partners, conducted a vulnerability assessment for natural resources (Swanston et al. 2011) and developed adaptation options (Swanston and Janowiak 2012). Another joint national forest and Forest Service research vulnerability assessment effort focused on the vulnerability of watersheds to climate change (Furniss et al. 2013). Watershed vulnerability assessments, conducted on 11 national forests throughout the United States, were locally focused (at a national forest scale) and included water resource values,

hydrologic reaction to climate change, watershed condition and landscape sensitivity. The assessments were intended to help national forest managers identify where limited resources could be best invested to increase watershed resilience to climate change.

The processes, products, and techniques used for several studies and other climate change efforts on national forests have been compiled in a guidebook for developing adaptation options for national forests (Peterson et al. 2011). The guidebook outlines four key steps to facilitate adaption in national forests: (1) become aware of basic climate change science and integrate that understanding with knowledge of local conditions and issues (review), (2) evaluate sensitivity of natural resources to climate change (rank), (3) develop and implement options for adapting resources to climate change (resolve), and (4) monitor the effectiveness of on-the-ground management (observe) and adjust as needed. The NRAP is focused on implementation of the principles and practices in the guidebook.

THE NORTHERN ROCKIES ADAPTATION PARTNERSHIP PROCESS

The NRAP includes 15 national forests, 7.8 million acres of wilderness, and 3 national parks across the U.S. Forest Service Northern Region and the adjacent Greater Yellowstone Area. The NRAP region covers 183 million acres (fig.1.1), spanning northern Idaho, Montana, northwest Wyoming, North Dakota, and northern South Dakota. In order to facilitate analyses and interpretations, the NRAP assessment is divided into the following 5 subregions:

- **Western Rockies:** Idaho Panhandle National Forest, Kootenai National Forest, Nez Perce-Clearwater National Forest, Glacier National Park
- **Eastern Rockies:** Beaverhead-Deerlodge National Forest (eastern portion), Custer National Forest (eastern portion), Gallatin National Forest (northern portion), Helena National Forest, Lewis and Clark National Forest
- **Central Montana:** Bitterroot National Forest, Flathead National Forest, Lolo National Forest
- **Grassland:** Custer National Forest (part), Dakota Prairie National Grassland
- **Greater Yellowstone Area:** Bridger-Teton National Forest, Caribou-Targhee National Forest, Shoshone National Forest, Gallatin National Forest (southern portion), Custer National Forest

(western portion), Beaverhead-Deerlodge National Forest (western portion), Grand Teton National Park, Yellowstone National Park

The NRAP process includes: (1) a vulnerability assessment of the effects of climate change on hydrology and roads, fisheries, wildlife, forested and non-forested vegetation and disturbance, recreation, and cultural, ecosystem services, (2) development of adaptation options that will help reduce negative effects of climate change and assist the transition of biological systems and management to a warmer and a changing climate, and (3) development of an enduring science-management partnership to facilitate ongoing dialogue and activities related to climate change in the Northern Rockies region. These resource sectors were selected based on their importance in the region and current management concerns and challenges.

Vulnerability assessments typically involve exposure, sensitivity, and adaptive capacity (Parry et al. 2007), where exposure is the degree to which the system is exposed to changes in climate, sensitivity is an inherent quality of the system that indicates the degree to which it could be affected by climate change, and adaptive capacity is the ability of a system to respond and adjust to the exogenous influence of climate. Vulnerability assessments can be both qualitative and quantitative and focus on whole systems or individual species or resources (Glick et al. 2011). Several tools and databases are available for systematically assessing sensitivity (e.g., Lawler and Case 2010, Luce et al. 2014) and vulnerability of species (e.g., Potter and Crane 2010).

For the NRAP, we used scientific literature and expert knowledge to assess exposure, sensitivity and adaptive capacity to identify key vulnerabilities for the identified resource areas. The assessment process took place over 16 months, and involved monthly phone meetings for each of the resource-specific assessment teams (see appendix 1A for assessment team members). Each assessment team refined key questions that the assessment needed to address, selected values to assess, and determined which climate change impact models best informed the assessment. In some cases, assessment teams conducted spatial analyses and/or ran and interpreted models, selected criteria in which to evaluate model outputs, and developed maps of model output and resource sensitivities. To the greatest extent possible, teams focused

on effects and projections specific to the NRAP region and used the finest scale projections that are scientifically valid (Littell et al. 2011).

By working collaboratively with scientists and resource managers and focusing on a specific region, the goal of NRAP was to provide the scientific foundation for operationalizing climate change in planning, ecological restoration, and project management (Peterson et al. 2011; Raymond et al. 2013, 2014; Swanston and Janowiak 2012). After identifying key vulnerabilities for each resource sector, five workshops were convened in October and November 2014 in Bismarck (North Dakota), Bozeman (Montana), Coeur d'Alene (Idaho), Helena (Montana), and Missoula (Montana) to present and discuss the vulnerability assessment, and to elicit adaptation options from resource managers (see appendix 1A for workshop participants).

During these workshops, scientists and resource specialists presented information on climate change effects and current management practices for each of the resources. Facilitated dialogue was used to identify key sensitivities and adaption options. Participants identified strategies (general approaches) and tactics (on-the-ground actions) for adapting resources and management practices to climate change, as well as opportunities and barriers for implementing these adaptation actions into projects, management plans, partnerships and policies. Participants generally focused on adaptation options that can be implemented given our current scientific understanding of climate change effects, but they also identified research and monitoring that would benefit future efforts to assess vulnerability and guide management practices. Information from the region-wide assessment was also downscaled to identify the most significant vulnerabilities to climate change for priority resources in each subregion. Facilitators captured information generated during the workshops with a set of spreadsheets adapted from Swanston and Janowiak (2012). Initial results from the workshops were augmented with continued dialogue with federal agency resource specialists.

This publication contains a chapter on expected climatological changes in the Northern Rockies, and one chapter for each of the resource sectors covered in the vulnerability assessment (water resources, fisheries, forested and rangeland vegetation, disturbance, wildlife, recreation, ecosystem services, and

cultural heritage) (see appendix 1B for author affiliations). Each of the resource chapters includes a review of climate change effects, sensitivities, current management practices, and results of the adaptation strategies and tactics discussions.

Resource managers and other decision makers can use this publication in several ways. First, the vulnerability assessment will provide information on climate change effects needed for national forest and national park plans, project plans, conservation strategies, restoration, and environmental effects analysis. The assessment will be particularly useful for national forest and national park planning and management. Second, climate change sensitivities and adaptation options developed at the regional scale will provide the scientific foundation for subregional and national forest and national park vulnerability assessments, adaptation planning, and resource monitoring. We expect that over time, and as needs and funding align, appropriate adaptation options will be incorporated into plans and programs of federal management units. Third, we anticipate that resource specialists will apply this assessment in land management throughout the region, thus operationalizing climate-smart resource management and planning.

Adaptation planning is an ongoing and iterative process. Implementation may occur at critical times in the planning process, such as when managers revise USFS land management plans and other planning documents, or after the occurrence of extreme events and ecological disturbances (e.g., wildfire). We focus on adaptation options for the USFS and NPS, but this publication provides information that can be used by other land management agencies as well. Furthermore, the NRAP process can be emulated by national forests, national parks, and other organizations outside the Northern Rockies, thus propagating climate-smart management across larger landscapes (e.g., the Intermountain Adaptation Partnership in Utah, Nevada, and southern Idaho; http://adaptationparnters.org/iap).

ALL-LANDS APPROACH TO CLIMATE CHANGE ADAPTATION

The USFS and NPS climate change strategies identify the need to build partnerships and work across jurisdictional boundaries when planning for adaptation. This concept of responding to the challenge of climate change with an “all-lands” approach is frequently mentioned, but a process for doing so is rarely defined. Unique in its effort to implement an all-lands approach to adaptation for a specific region, NRAP

602 is an inclusive partnership of multiple agencies and organizations with an interest in managing natural
603 resources in a changing climate. In addition to representatives from the national forests, grasslands, and
604 parks, several other agencies and organizations participated in the resource sector workshops (see
605 appendix 1A). This type of partnership enables a coordinated and complementary approach to adaptation
606 that crosses jurisdictional boundaries. NRAP also provides a venue for agencies to learn from the
607 practices of others so that the most effective adaptation strategies can be identified.

608 Risks and vulnerabilities resulting from climate change and gaps in scientific knowledge and policy
609 need to be assessed. Adaptation is a prominent focus of the NRAP, with emphasis on creating resilience
610 in human and natural systems. Communicating climate change information and engaging employees,
611 partners, and the general public in productive discussions is also an integral part of successfully
612 responding to climate change. The need for partnerships and collaborations on climate change issues was
613 also identified in the NRAP. Sharing climate change information, vulnerability assessments, and
614 adaptation strategies across administrative boundaries will contribute to the success of climate change
615 responses in the Northern Rockies.

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Chapter 2: Biogeographic, Cultural, And Historical Setting Of The Northern Rocky Mountains

S. Karen Dante-Wood

The Northern Rocky Mountains Adaptation Partnership (NRAP) includes diverse landscapes, ranging from high mountains to grasslands, from alpine glaciers to broad rivers (fig. 1.1). This region, once inhabited solely by Native Americans, has been altered by two centuries of settlement by Euro-Americans, including extractive activities such as timber harvest, grazing, mining, and water diversions. Although urbanization is relatively small in this region, paved and unpaved roads and electrical transmission wires permeate much of the landscape. A significant portion of the Northern Rockies is owned and managed by federal agencies, including 15 national forests and 3 national parks.

Resource conditions, resource management issues, effects of climatic variability and change, and climate change adaptation options differ greatly from Idaho to North Dakota and from the Canadian border to Wyoming. In order to capture these differences, the NRAP climate change vulnerability assessment and adaptation strategy were conducted for five subregions: Western Rockies, Central Rockies, Eastern Rockies, Greater Yellowstone Area, and Grassland. These subregions are briefly described below.

WESTERN ROCKIES SUBREGION

The Western Rockies subregion occupies approximately 17 million acres across portions of Idaho and Montana, including the Idaho Panhandle, Kootenai, and Nez Perce-Clearwater National Forests and several Native American reservations (e.g., Nez Perce Indian Reservation, Coeur d'Alene Indian Reservation). Most of this subregion is extremely mountainous and heavily forested, the mountains broken by river and stream valleys and two large grassland ecosystems, Big Camas Prairie and Palouse country. The subregion also includes 1.7 million acres of wilderness lands.

781 The Rocky Mountains encompass a large area of Idaho and extend from the Idaho panhandle along
782 the Wyoming border. To the west of the Rockies lie the prairie lands of Washington and Oregon, while
783 the east is home to mountainous western Montana. A distinguishing feature of this region is the rugged
784 mountains that extend lengthwise along the panhandle. The Bitterroot Mountains border the Idaho
785 Panhandle along the Montana/Idaho border; the Coeur d'Alene Mountains lie in the northern portion of
786 the panhandle from Lake Pend Oreille in the north to Lake Coeur d'Alene in the south; and south of the
787 Coeur d'Alene Mountains are the Clearwater and Salmon River Mountains.
788 Continental glaciers shaped the topography of this panhandle region by excavating lake basins and
789 depositing glacial till and outwash. The bedrock found here is composed of sedimentary rocks of the Belt
790 Supergroup, deposited 1470-1400 million years B.P. Deposition took place in a large basin where space
791 was not a limiting factor and the sediment was able to build up vertically (ISU 2014a). Due to this
792 deposition, the Coeur d'Alene area contains large silver, lead, and zinc deposits.
793 The Western Rockies subregion contains numerous large rivers. Commonly referred to as the "River
794 of No Return," the Salmon River winds 425 miles through central Idaho and divides the northern and
795 southern part of the state. The canyon gorge is deeper than the Grand Canyon of Colorado. It is one of the
796 longest rivers in the state and renowned for its spawning beds for Pacific salmon species. The Clearwater
797 River, also in Idaho, was fed by the Bitterroot Mountains and was preferred by explorers, trappers,
798 miners, and loggers because it was easier to navigate than the turbulent Salmon River (ISU 2014b). Other
799 rivers include the Kootenai and Pend Oreille, which flow into the Columbia River. The Clark Fork of the
800 Columbia River feeds into Lake Pend Oreille and the Saint Maries, Saint Joe, and Coeur d'Alene Rivers
801 flow into Lake Coeur d'Alene. Priest Lake and Hayden Lake near Pend Oreille are heavily used for
802 recreation because of their scenic setting among forested mountains (ISU 2014b).
803 Since Idaho is only 300 miles east from the Pacific Ocean, its climate is affected by a maritime
804 atmospheric pattern, bringing more precipitation to northern Idaho than southern Idaho. Summers are
805 typically hot and dry, and winters are relatively cold due to the high amount of moisture carried through
806 the Columbia River Gorge.

The most actively managed forests in the Western Rockies are found in northern Idaho, which is characterized as a steppe-coniferous forest alpine meadow province (Schnepf and Davis 2013). A 2012 Forest Service, U.S. Department of Agriculture report used Forest Inventory and Analysis data to describe various forest cover types in the subregion. The six most common forest groups include Douglas-fir (*Pseudotsuga menziesii*), subalpine fir (*Abies lasiocarpa*)/Engelmann spruce (*Picea engelmannii*)/mountain hemlock (*Tsuga mertensiana*), lodgepole pine (*Pinus contorta* var. *latifolia*), ponderosa pine (*Pinus ponderosa*), western hemlock (*Tsuga heterophylla*)/Sitka spruce (Picea sitchensis), and quaking aspen (*Populus tremuloides*)/paper birch (*Betula papyrifera*) (Sullivan et al. 1986). Commercially harvested coniferous species in this area include Douglas-fir, Engelmann spruce, grand fir (*Abies grandis*), lodgepole pine, ponderosa pine, subalpine fir, western hemlock, western larch (*Larix occidentalis*), western redcedar (*Thuja plicata*), and western white pine (*Pinus monticola*). Other species not used for wood products include whitebark pine (*Pinus albicaulis*), limber pine (*Pinus flexilis*), alpine larch (*Larix lyallii*), mountain hemlock, and western juniper (*Juniperus occidentalis*). Quaking aspen, black cottonwood (*Populus nigra*) and paper birch are also commonly found.

The western white pine is an important tree species to this region. It grows on a variety of soil types and slopes and can regenerate across a broad range of environments. Western white pine forests usually originate from wildfires and when the species matures, it can survive fire better than nearly all of its shade-tolerant competitors. While the species can survive to 300 to 400 years old, it unfortunately is declining due to white pine blister rust.

Common shrub species in the subregion include serviceberry (*Amelanchier alnifolia*), Redosier dogwood (*Cornus sericea*), oceanspray (*Holodiscus discolor*), Lewis mockorange (*Philadelphus lewisii*), huckleberries (*Vaccinium membranaceum*) and smooth sumac (*Rhus glabra*). Evergreen shrubs include Oregon-grape (*Berberis aquifolium*), snowbrush ceanothus (*Ceanothus velutinus*), and mountain lover (*Paxistima myrsinites*), and evergreen groundcovers include kinnikinnick (*Arctostaphylos uva-ursi*), and twinflower (*Linnaea borealis*) (Sullivan et al. 1986).

832 The ecologically diverse habitats in the Western Rockies subregion also support a large number of
833 rare plant species. The warm, dry grassland areas in the western part of the subregion harbor populations
834 of Spalding's catchfly (*Silene spaldingii*), a federally threatened species, and Palouse goldenweed
835 (*Pyrrocoma liatriformis*). In contrast, the much wetter forests in the Clearwater River drainage contain
836 several narrowly endemic plants such as Constance's bittercress (*Cardamine constancei*), as well as a
837 number of disjunct species that are geographically isolated from their main ranges in the Cascade
838 Mountains, such as Pacific dogwood (*Cornus nuttallii*). In the northern part of the subregion, fens
839 (groundwater-dependent wetlands where peat has accumulated) are uncommon habitats that support
840 peripheral populations of more northern plant species such as spoon-leaved sundew (*Drosera intermedia*)
841 and small cranberry (*Vaccinium oxycoccos*).
842 The Western Rockies provide habitat for over 300 animal species. Large mammal species include
843 woodland caribou (*Rangifer tarandus caribou*), black bear (*Ursus americanus*), grizzly bear (*U. arctos*),
844 whitetail deer (*Odocoileus virginianus*), mule deer (*O. hemionus hemionus*), elk (*Cervus elaphus*), moose
845 (*Alces alces*), coyote (*Canis latrans*), gray wolf (*Canis lupus*), bobcat (*Lynx rufus*), cougar (*Puma*
846 *concolor*), and wolverine (*Gulo gulo*). Smaller vertebrates include Coeur d'Alene salamander (*Plethodon*
847 *idahoensis*) and pygmy shrew (*Sorex hoyi*).
848 A broad range of avian taxa include bald eagle (*Haliaeetus leucocephalus*), golden eagle (*Aquila*
849 *chrysaetos*), osprey (*Pandion haliaetus*), many species of owls, wild turkey (*Meleagris gallopavo*),
850 California quail (*Callipepla californica*), greater sage grouse (*Centrocercus urophasianus*), blue jay
851 (*Cyanocitta cristata*), and calliope hummingbird (*Stellula calliope*).
852 Both native and nonnative fish are found in many of Western Rockies rivers and lakes, making it a
853 popular area for angling and spawning. Fish species include native cutthroat trout (*Oncorhynchus clarkii*),
854 rainbow trout (*O. mykiss*), and bull trout (*Salvelinus confluentus*), which is federally listed, and nonnative
855 brook trout (*Salvelinus fontinalis*). The Kootenai River is home to the endangered white sturgeon
856 (*Acipenser transmontanus*) and threatened burbot (*Lota lota*).

857 Wildfire is a dominant influence on the structure, function, and productivity of forest ecosystems in
858 the Western Rockies. Fire frequency varies greatly depending on biogeographic conditions, with stand
859 replacement fires occurring at 50-500 year intervals, and surface fires occurring in dry forests at 2-50 year
860 intervals. Frequent fires keep many forests in the early stages of succession as indicated by high numbers
861 of western larch and pine (Schnepf and Davis 2013), although fire exclusion during the past 80 years or
862 so has reduced fire frequency in lower-elevation dry forests, resulting in dense stands and elevated
863 accumulation of surface fuels.

864 Mountain pine beetles (*Dendroctonus ponderosae*) kill large numbers of lodgepole pine, often in
865 outbreaks of thousands of acres, and they increasingly kill whitebark pine and limber pine (*Pinus flexilis*)
866 at high elevation as the climate continues to warm. Western spruce budworm (*Choristoneura*
867 *occidentalis*) causes sporadic outbreaks in Douglas-fir and true firs (*Abies*), and Douglas-fir tussock moth
868 (*Orygia pseudotsugata*) is a prominent defoliator of Douglas-fir.

869 White pine blister rust (*Cronartium ribicola*), a nonnative fungus, causes mortality in five-needle
870 pines (western white pine, whitebark pine, limber pine), and has greatly reduced the dominance of
871 western white pine (Schwandt et al. 2013). Forests dominated by Douglas-fir and grand fir have increased
872 as a result, accelerating forest succession toward shade tolerant, late-successional true firs, western
873 hemlock and western redcedar (Bollenbacher et al. 2014). Attempts to control the spread of blister rust
874 through removal of currant (*Ribes*), its alternate host, were mostly unsuccessful (Russell and Jain 2007).

875 Various root diseases kill and reduce the vigor of Douglas-fir and grand fir (*Abies grandis*), especially
876 north of the Salmon River. Parasitic dwarf mistletoes (*Arceuthobium* spp.) reduce the vigor of and
877 sometimes kill several species of conifers, including western larch, Douglas-fir, ponderosa pine, and
878 lodgepole pine (Idaho Forest Products Commission 2011).

879 Several silvicultural treatments are used to reduce the effects of these disturbances and stressors,
880 including thinning, mechanically mixing the soil, and prescribed burning to favor the regeneration of
881 different species and reduce surface fuels (Graham and Jain 2005). Treatments can be targeted to modify
882 different portions of forest stands, from the soil to the upper canopy. Harvesting larger trees can result in

883 the redistribution of fewer stems, create canopy openings, and encourage regeneration. Thinning to
884 remove the mid-story of forests can result in a various species combinations. Ground-level vegetation
885 treatments can increase the density of small trees and, creating a continuous distribution of low-stature
886 fuels.

887 The economic structure of the Western Rockies integrates northern Idaho, northeastern Washington,
888 and western Montana as "the inland empire." In the early 1950s, the timber industry was the second
889 largest after agriculture. Large-scale lumbering operations did not occur until after Weyerhauser
890 Corporation opened up plants near Sandpoint and Moscow in northern Idaho. Before 1900, timber was
891 used locally for lumber and fuel wood for homes, railroads, and fence posts. After outside markets
892 developed, operating sawmills produced various products such as 2x4 studs, plywood, wafterboard,
893 particleboard, house logs, posts, poles, pulp and paper, wood beams, mobile homes, roof supports and
894 much more. Although forest industry maintains a significant presence in the Western Rockies, it has
895 declined in the past 20 years because of changing economic conditions, competition with other markets,
896 and greatly reduced harvest on federal lands.

897 Agriculture is a dominant industry on private lands, and continuous cultivation and livestock grazing
898 has occurred on fertile prairie lands since the 1860s. Mining, which began in the 1880s, is another
899 important industry in some areas, especially the Coeur d'Alene region, which leads the nation in silver
900 production and produces other nonferrous metals such as lead and zinc. Water that originates in high
901 mountains of the Western Rockies is an extremely important resource because of its value for agriculture,
902 hydroelectric power, industry, and municipal consumption. Forests are increasingly recognized and
903 managed for their capacity to produce large amounts of clean water and to reduce erosion that would
904 degrade water quality.

905 As extractive industries have declined in the past 30 years and affluence of human populations has
906 increased, recreation and aesthetically based activities have increased in popularity and economic
907 importance. Rugged topography, forests, lakes, and streams are a major attraction for primary residences,
908 seasonal residences, and recreational travel (fig. 2.1). Hunting, fishing, hiking, mountain biking, off-road

vehicle use, and snow skiing are popular activities for local residents and visitors from throughout North America. Federal management increasingly focuses on providing opportunities for a broad range of recreational activities.

The Western Rockies has large populations of the Nez Perce, Kalispel, Kootenai, and Coeur d'Alene tribes who have lived for thousands of years in the terrestrial and aquatic ecosystems, and more recently urban areas, of this subregion. Most tribes in this area had many villages and camps. They lived in teepees during the warmer months, and in large camps, mainly underground houses, during the winter. Hunting, fishing (especially for salmon), and gathering of wild foods occurred year round, and men and women typically had separate duties. Men hunted and fished, and women gathered vegetables and fruits such as chokecherry (*Prunus virginiana*), huckleberry (*Vaccinium* spp.), wild strawberry (*Fragaria virginiana*), and common camas (*Camassia quamash*). Native people in this subregion excelled at basketry, which was used for collecting nuts, storing fruits and roots, and cooking food. Federal agencies increasingly collaborate with tribal partners to ensure that tribal values (including cultural) and access to resources are considered in land management planning.

CENTRAL ROCKIES SUBREGION

The Central Rockies subregion occupies approximately 12 million acres across portions of western Montana and Idaho and includes the Bitterroot, Flathead, and Lolo National Forests; Glacier National Park, and Flathead Indian Reservation (fig. 1.1). The subregion contains steep mountains, rolling meadows, large rivers and lakes (fig. 2.2), and alpine ecosystems that span the Sapphire Mountains, Bitterroot Mountains, Mission Mountains, and many other ranges. It also contains the largest contiguous area of designated wilderness in the United States outside of Alaska. The northern portion of the Central Rockies is referred to as the Crown of the Continent, which includes Glacier National Park and the Flathead National Forest.

The Bitterroot and Missoula Valleys located in west-central Montana experience an inland mountain climate. Air masses that develop over the Pacific Ocean release moisture in the Cascade Range and over the mountains of northern Idaho. West-central Montana occupies the rain-shadow area receiving dried-out

Pacific air and little moisture in the valley bottoms, approximately 13 inches annually (Lackschewitz 1991). Humidity is high is this region, except during the summer months, and winters are cold and moist. The climate in the Flathead and Glacier region is very similar, influenced by the Pacific Maritime atmospheric pattern with warm, dry summers and wet, cold winters.

Alluvial sediments filled the Bitterroot River valley during the Tertiary period, and glacial Lake Missoula drained and refilled several times as a section of a continental glacier repeatedly washed out and redeveloped. Glacial lake sediments of various depths and qualities cover the slopes, bottomlands and terraces in west-central Montana today (Lackschewitz 1991). During the Pleistocene era, low-elevation valleys were scoured by continental glaciers, while the mountains were shaped by alpine glaciers in the Flathead and Glacier region (Newlon and Burns 2009).

In the Central Rockies, microclimate has a big effect on the distribution, abundance, and productivity of vegetation. For example, steep south-facing slopes with low retention of snow and soil moisture in summer are generally less productive and have different species composition than north-facing slopes. The bottoms of mountain canyons support lush vegetation due to the high level of moisture, whereas ridge tops support vegetation that requires little moisture for growth and survival.

Due to the Pacific-influenced climate, forests found in the west-central region (Bitterroot and Missoula valleys) are drier than those in Idaho and northwestern Montana. Only a few species typical of the Pacific Coast are found here, such as western redcedar, western white pine, Pacific yew (*Taxus brevifolia*), bride's bonnet (*Clintonia uniflora*), American trail plant (*Adenocaulon bicolor*), and threeleaf foamflower (*Tiarella trifoliata*). Intermountain forest species dominate the west-central Montana landscape, including western larch, subalpine larch (*Larix lyallii*), ponderosa pine, mock azalea (*Menziesia ferruginea*), Hitchcock's smooth woodrush (*Luzula hitchcockii*), common beargrass (*Xerophyllum tenax*). Bottomland ponderosa pine and hardwood species are commonly found in moist sites, whereas different types of bunchgrass species (*Agropyron, Festuca*) and a mixture of ponderosa pine and bunchgrasses are found in dry sites. Douglas-fir, grand fir, and subalpine fir dominate at higher elevation (Lackschewitz 1991). Extensive stands of lodgepole pine are present at mid to upper elevations.

961 Much of the native vegetation in the lower Bitterroot and Missoula valleys have either been lost to pasture
962 or urban development.

963 In the Flathead Valley and Glacier National Park, lower elevations are dominated by Douglas-fir,
964 ponderosa pine, grand fir, Engelmann spruce, and western redcedar. Douglas-fir, western larch and
965 subalpine fir are common at mid elevation, and whitebark pine is found at high elevation (Newlon and
966 Burns 2009). Black cottonwood (*Populus trichocarpa*) and quaking aspen are common deciduous trees
967 found at lower elevations near Glacier National Park, often along lakes.

968 Wildfire is a major disturbance in the Central Rockies. Fires were fairly regular at lower and middle
969 elevations in the Bitterroot and Missoula valleys prior to 1900. Seral western larch and lodgepole pine
970 previously dominated north-facing slopes, but fire exclusion has led to increased dominance of shade
971 tolerant species. As a result, silvicultural and prescribed burning treatments are being used to increase the
972 distribution and abundance of seral tree and shrub species (Lackschewitz 1991).

973 The Central Rockies contain over 60 species of mammals, with wilderness locations having relatively
974 intact populations. Species include gray wolf (*Canis lupus*), Canada lynx (*Lynx canadensis*), cougar, elk,
975 mountain goat (*Oreamnos americanus*), bighorn sheep (*Ovis canadensis*), northern bog lemming
976 (*Synaptomys borealis*), grizzly bear, golden-mantled ground squirrel (*Callospermophilus lateralis*), and
977 pygmy shrew. Canada lynx and grizzly bear are on the threatened species list, and gray wolf, bald eagle,
978 and peregrine falcon (*Falco peregrinus*) have been removed from the federally threatened and endangered
979 species list.

980 Hundreds of bird species are found in the Central Rockies, including killdeer (*Charadrius vociferus*)
981 and spotted sandpiper (*Actitis macularius*) in riparian areas, song sparrows (*Melospiza melodia*) in
982 grassland, willow flycatcher (*Empidonax traillii*) and MacGillivray's warbler (*Geothlypis tolmiei*) in
983 shrubby habitat, and bald eagle and Bullock's oriole (*Icterus bullockii*) in mature forest canopy.

984 Diverse native cold-water fish and nonnative fish are abundant in Central Rockies rivers. For
985 example, Flathead National Forest is well known for its populations of native bull trout and westslope
986 cutthroat trout (*Oncorhynchus clarki lewisi*), which are found in Flathead Lake and the Flathead River.

The Bitterroot River is home to many native fish species including bull trout, westslope cutthroat trout, northern pike minnow (*Ptychocheilus oregonensis*), and largescale sucker (*Catostomus macrocheilus*). As a result of the diversity and abundance of fish species, angling is a popular recreational activity in this area.

Wildfires and insect outbreaks are disrupting ecosystems in the Central Rockies. Although wildfires play an important ecological role, with warmer spring and summer temperatures, there have been more occurrences of larger wildfires and longer wildfire seasons. These fires are becoming increasingly expensive to control as they make their way around the forested landscape but also as they enter the wildland-urban interface, the zone where housing borders forests and woodlands. Insect invasions in this subregion have also been known to damage and kill trees.

Mountain pine beetle is one of the most destructive bark beetles in North America and has caused serious damage and mortality to whitebark pine in this subregion. Lodgepole pine were affected by the beetle between 1911 and 1942 in the forests of Idaho and Montana. These outbreaks originally occurred at lower elevations and moved upwards into whitebark pine habitat. This occurred in the Flathead National Forest in the 1970s, where the mountain pine beetle invaded lodgepole pine forests first and then moved upward into whitebark pine (Bartos and Gibson 1990). White pine blister rust has caused extensive mortality in whitebark pine in the Central Rockies, especially in Glacier National Park and adjacent areas, where over 70 percent of the trees are infected and 30 percent have died.

Many of the aforementioned flora and fauna were documented by Meriwether Lewis and William Clark during their expedition in the early 1800s. The explorers travelled across the Bitterroot River and Lolo Creek valley twice and never passed through the Flathead valley. Other early explorers to the region included fur companies and independent trappers. Fur companies obtained fur during by trading goods for furs with Native Americans, employing hunters and trappers, and trading furs with hunters and trappers at trading posts (McKay 1994). Hudson's Bay Company, had a good rapport with the Flathead, Pend d'Oreille, and Kootenai tribes, trading products for bison provided by Native Americans.

In 1855, the Hellgate Treaty established the Flathead Indian Reservation for the Flathead, Pend d'Oreille, and Kootenai tribes. As the tribes began to live on the reservation, Euro-American settlement accelerated. Initially inhabited by quartz miners, fur trappers, and French Canadians, the upper Flathead valley was more heavily settled after the Northern Pacific Railroad connected with Missoula in 1883.

Timber harvest was a primary extractive activity in the Central Rockies in the late 1800s. With the passage of the 1891 Forest Reserve Act, the President had authority to create forest reserves to revise public land laws (McKay 1994), and various protections gradually spread across federal lands. Yellowstone was the first forest reserve established by President Harrison. In 1897, the Flathead, Bitterroot, Lewis and Clark, and Priest River became the first four reserves in the Northern Region established by President Cleveland. Much of the lower elevation land in the Central Rockies today has been converted to agriculture and urban and suburban development. The major industries are agriculture, ranching, forestry, and recreation/tourism.

EASTERN ROCKIES SUBREGION

The Eastern Rockies subregion occupies approximately 12 million acres in central, west-central, north-central, and southwest Montana (fig. 1.1). Included in this area are the Beaverhead-Deerlodge (eastern portion), Helena, and Lewis and Clark National Forests. These forests are mostly found on the eastern side of the Continental Divide. The subregion extends from high mountains (often exceeding 11,000 ft) in the west to broad plains in the east, including several large wilderness areas. It contains numerous mountain ranges—the Beaverhead, Bitterroot, Pioneer, Centennial, Bridger, Madison, Absaroka, Beartooth, Crazy, Gallatin, Elkhorn, and Big Belt Mountains—most of which have reasonably intact ecosystems at higher elevation.

Climate in the Eastern Rockies varies considerably, based on location relative to the Continental Divide. The western side receives more precipitation as air masses from the west cool and release moisture over the mountain ranges, whereas on the eastern side, the air becomes warmer and drier, often accompanied by downslope air movement known as Chinook winds that create a more moderate than that

of the Great Plains (Phillips 1999). In general, the eastern portion of the subregion experiences a drier continental climate.

The Rocky Mountains were developed from intense plate tectonic movement during the Jurassic, Cenozoic, and Laramide orogeny periods. The Laramide orogeny, which took place approximately 70-40 million years B.P., is responsible for elevating the Rocky Mountains. California, Oregon, and Washington were added to North America during the Mesozoic Era, whereas the Rockies were added to the continent much later (70 million years B.P.). Although mountain building usually occurs 200-400 miles inland from the boundary of a tectonic plate (the subduction zone), the Rocky Mountains are several hundred miles inland. In the Rockies, the oceanic plate sank beneath the continental plate at a flat angle that led to mountain building farther inland than might be expected (USGS 2014).

Numerous rivers flow through the Eastern Rockies, including the Missouri, Blackfoot, and Smith Rivers. The longest river in North America, the Missouri begins at the confluence of the Jefferson and Madison Rivers near Three Forks, Montana and includes three reservoirs (Canyon Ferry, Hauser, and Upper Holter). The Smith River is a tributary of the Missouri River and flows between the Little Belt and Big Belt Mountains. The Blackfoot River, a snow and spring fed river, begins at the Continental Divide in Lewis and Clark County, and is the river featured in the book *A River Runs Through It* by Norman Maclean. These rivers are known for their blue-ribbon trout fishery status, scenic floats, and other water-based recreational activities.

Vegetation in the Eastern Rockies varies primarily as a function of elevation and aspect. Lower elevations are dominated by grassland and sagebrush steppe that include needle-and-thread grass (*Hesperostipa comata*), Idaho fescue (*Festuca idahoensis*), sagebrush (*Artemisia* spp.), rabbitbrush (*Chrysothamnus* spp.), milkvetch (*Astragalus* spp.) and wildflowers such as lupine (*Lupinus*) and balsamroot (*Balsamorhiza* spp.). Fremont's cottonwood (*Populus fremontii*), yellow willow (*Salix lutea*), coyote willow (*S. exigua*), woods rose (*Rosa woodsii*), and golden currant (*Ribes aureum*) are commonly found along rivers and streams. Dominant species in foothills and woodlands include limber pine (*Pinus flexilis*), Rocky Mountain juniper (*Juniperus scopulorum*), Douglas-fir, and ponderosa pine trees.

Understory species include antelope bitterbrush (*Purshia tridentata*), mountain-mahogany (*Cercocarpus*), and skunkbrush sumac (*Rhus aromatica* var. *simplicifolia*). Douglas-fir and ponderosa pine dominate upper montane slopes, and lodgepole pine and Engelmann spruce common at high elevation (Phillips 1999).

Common wildlife species in the eastern Rockies include mountain goat, bighorn sheep, elk, cougar, Canada lynx, wolverine and black bear. Hunters from around the world have and continue to purchase tags to hunt in this subregion for many of the aforementioned big game species. Also common are bald eagle, greater sage grouse, peregrine falcon, and red-tailed hawk (*Buteo jamaicensis*). Fly fishing opportunities are plentiful due to abundant populations of westslope cutthroat trout, rainbow trout, brook trout, and northern pike (*Esox lucius*). There are a few populations of grizzly bear and gray wolf in the region, but these species are concentrated in the western section of the eastern Rockies, particularly in wilderness areas.

Forests in the Eastern Rockies have been subject to widespread drought, wildfire, and insect outbreaks over the past 20 years (Montana DEQ 2013). Several large wildfires have burned with uncharacteristic intensity because the absence of fire for several decades has resulted in elevated accumulation of fuels. Mountain pine beetle has caused extensive mortality of lodgepole pine and some ponderosa pine, the concurrence of older, non-vigorous stands being susceptible to elevated beetle populations caused by warmer temperature. Western spruce budworm has caused mortality and stunted growth in Engelmann spruce and Douglas-fir in some areas.

The travels of Meriwether Lewis and William Clark through the Eastern Rockies have created a prominent historical legacy (fig. 2.3). Their expedition began in 1804 near St. Louis, and in the spring of 1805, they traveled to Three Forks, Montana via the Jefferson River. On this route, the explorers interacted with Shoshone Indians, and after passing over the Bitterroot Mountains, they made their way down to Fort Clatsop on the Oregon side of the Columbia River (Perry 2010). The Lewis and Clark National Forest and other place names commemorate the expedition.

1088 Thousands of years before Euro-Americans arrived, the Blackfoot, Sioux, Cheyenne, Flathead and
1089 Crow Indians used the area as hunting grounds and a place to winter. Prior to 1806, the Blackfoot had
1090 exchanged wolf and beaver pelts with Canadian and English settlers for guns and ammunition. The
1091 livelihoods and cultures of these tribes were highly dependent on hunting the American bison (*Bison*
1092 *bison*), which provided food, shelter, and clothing. After horses were introduced to the region in the mid
1093 1700s, hunters had much greater mobility to pursue bison, and horses themselves became part of
1094 livelihood, commerce, and culture. The decimation of bison herds by Euro-Americans in the mid 1800s
1095 contributed to a rapid decline in Native American populations.
1096 In the mid 1800s, mining for gold and other precious minerals was a common activity along the
1097 Continental Divide, particularly near the town of Helena, which was founded in 1864 and had the second
1098 largest placer gold deposit in Montana. Within four years, Last Chance Gulch (the original name for
1099 Helena) produced $19 million of gold. Since the city was adjacent to major transportation routes, the
1100 mining town was able to persist through the gold rush (History 2009).
1101 Agriculture is the largest industry in Montana, and Beaverhead County is the leading cattle and calves
1102 producer in the state, followed by Gallatin County, Jefferson County and Madison County (Ranch and
1103 Recreational Group 2011). In the past several years, ranchland has been increasingly at risk to subdivision
1104 development. The wave of development in this region has transformed the forests and grasslands
1105 landscape into one of towns, farms, and increasingly fragmented forested areas. Several organizations
1106 such as The Nature Conservancy are working with private landowners to add conservation easements on
1107 their lands to limit subdivisions from fragmenting wildlife landscapes and affecting ranching operations.
1108 The Forest Service often coordinates with the Bureau of Land Management and Montana Department of
1109 Fish, Wildlife and Parks on natural resource issues related to landscape connectivity and restoration.

1110 **GREATER YELLOWSTONE AREA SUBREGION**

1111 The Greater Yellowstone Area (GYA) subregion occupies approximately 23 million acres, extending
1112 across portions of Wyoming, Montana and Idaho. It includes both the country's first national park
1113 (Yellowstone) and first national forest (Shoshone), in addition to Grand Teton National Park and portions

of Bridger-Teton, Caribou-Targhee, Gallatin, Custer and Beverhead-Deerlodge National Forests. One of the defining features of the subregion is a group of 24 conterminous mountain ranges that wrap around the Yellowstone Plateau (Morgan 2007).

The Yellowstone "hotspot" and associated geological activity have shaped the geography, topography, climate, soils, and biota of the GYA. The hotspot is a thermal disturbance fixed in the Earth's mantle below the North American continental plate, moving to the northeast at the rate of one inch per year (Morgan 2007). This volcanic hotspot is responsible for eruptions that have left calderas in Oregon, Nevada, and Idaho and for creating the eastern Snake River plain. Volcanism formed the Yellowstone rhyolite plateau, and faulting formed sediment-filled basins and steep mountains such as the Teton Range/Jackson Hole and Madison Range/Madison Valley. Uplift contributed to the high altitude of the GYA and associated deep valleys (Morgan 2007). The heat of eruptions that created calderas originated in the Earth's mantle, providing the source of heat for hot springs and geysers, one of the primary reasons that Yellowstone National Park was established; more geysers are found here than anywhere else in the world (USDI NPS 2015).

The GYA is the source of three major river systems—the Missouri/Mississippi, Snake/Columbia, and Green/Colorado. The Missouri River begins in the northwest corner of the GYA and merges into the Mississippi River, the Snake River begins in the southeast corner of the GYA and merges into the Columbia River, and the Green River is the main tributary of the Colorado River. Anglers are drawn to these river systems for their blue-ribbon fishing streams.

The GYA is one of the largest relatively intact and functional natural ecosystems in the temperate zone (Keiter and Boyce 1991). Abiotic factors such as topography and soils strongly influence vegetation composition and structure of the area. Differences in elevation strongly influence local climate, with valley bottoms experiencing substantially higher annual temperatures than higher elevations. Soils are deeper in valley bottoms than on the Yellowstone Plateau, which is more affected by nutrient-poor soils derived from the Yellowstone Caldera (Hansen et al. 1999). Valley bottoms are generally occupied by lodgepole pine (USDI NPS 2013), lower slopes and richer soils (on basaltic or andesitic volcanic rocks,

sedimentary rocks, and Precambrian crystalline rocks) support Engelmann spruce, subalpine fir, and Douglas-fir (Morgan 2007), and the highest elevations are dominated by whitebark pine (USDI NPS 2012). Quaking aspen, willows, and cottonwoods are also found on richer soils, such as valley toe slopes and bottoms.

In lodgepole pine forests, elk sedge (*Carex geyeri*) and grouse whortleberry (*Vaccinium scoparium*) are dominant understory plants, whereas understories of Douglas-fir forests are dominated by pinegrass (*Calamagrostis rubescens*). Utah honeysuckle (*Lonicera utahensis*), snowberry (*Symphoricarpos albus*), and buffaloberry (*Shepherdia canadensis*) are dominant understory species around the edge of the northern range of the GYA. Mountain big sagebrush (*Artemisia tridentata* var. *vaseyana*) and Idaho fescue dominate lower elevation grassland and meadows (NPS 2012).

The GYA appears to have retained most of its historical complement of vertebrate wildlife species (NPS 2013). The largest elk (*Cervus elaphus*) and bison (*Bison bison*) herds in North America and the United States, respectively, are found in the area. The northern range—the grassland in the northern part of Yellowstone National Park—sustains large populations of these animals. This ecosystem supports other charismatic megafauna such as grizzly bear (fig. 2.4), moose, white-tailed deer (*Odocoileus virginianus*), gray wolf, and coyote; distinctive avifauna such as trumpeter swan (*Cygnus columbianus*) and bald eagle; several hundred species of other small mammals and birds; and thousands of species of insects and other invertebrates (Keiter and Boyce 1991). This rich diversity of fauna allows for intact predator-prey interactions and other aspects of trophic dynamics.

Of the many fish species found in the GYA, westslope cutthroat trout and Yellowstone cutthroat trout (*Oncorhynchus clarkii bouvieri*) are keystone species preyed upon by many wildlife species, including grizzly bears (*Ursus arctos*). Cutthroat trout are currently at risk from hybridization and competition with nonnative lake trout (*Salvelinus namaycush*) (USDI NPS 2012). Apart from fishing pressure, water resources will become increasingly important if the population of the 21 counties in the GYA continues increase.

Climate, soil and plant productivity are some of the many factors that influence where organisms are found. For example, many bird species are predominantly found at lower elevations, because primary productivity is highest there and climate is moderate (Hansen et al. 1999). In the GYA, plant assemblages dominated by lodgepole pine, cottonwood, quaking aspen, and willow have high bird abundance and diversity.

The topography of the GYA has influenced human use of the region for more than 10,000 years. Native Americans entered the Greater Yellowstone region soon after they entered North America 13,500-12,800 years B.P. For their survival, hunter-gatherer groups would forage for seeds, fruit, and animals at lower elevations and follow the maturation of plants and migration of animals into mountainous areas. Around 1872, Native Americans were moved to a reservation in central Wyoming. Soon after, roads were developed for gold camps in Montana. During the development of roads, Native Americans tried to protect their hunting grounds by constructing forts. Pioneering ranchers eventually settled into the lower valleys of the region. It was the construction of the railroad from Livingston, Montana to Yellowstone National Park that brought increasing numbers of tourists to the area (Morgan 2007).

Current land allocations and land use in the GYA indicate that human activities are prevalent at low elevations, similar to the abundance of native species. From the Yellowstone Plateau to the Gallatin Valley, land use transitions from timber management, grazing, and agriculture to rural and urban residences. Development in urban areas such as Bozeman has increased in the past several years where the majority of the population is concentrated along the foothills, near streams or transportation routes (Hansen et al. 1999).

The GYA has faced many land-use changes and disturbances, both natural and human caused. Wildfire has had an enormous impact, especially the fires of 1988, which burned over 1.2 million acres. These fires helped change how scientists, resource managers, and the general public think about the role of large fires in the fire ecology of Western forests. Mountain pine beetles have killed thousands of acres of lodgepole pine in the GYA, although the outbreaks have not been as extensive as in other areas of North America.

One of the most controversial issues in the region to date involves the restoration of wolves to the area. Many scientists consider the reintroduction of wolves to be successful in restoring ecological completeness in the GYA (USDI NPS 2013). However, others consider it to be a disruption to existing conditions and local resources, including big game species such as elk, and livestock in adjacent private and public lands. As of September 2014, the western gray wolves have been removed from the endangered species list and listed as a nonessential experimental population for the state of Wyoming.

The Yellowstone grizzly bear population is also of importance to this subregion (fig. 2.4). The U.S. Fish and Wildlife Service listed the grizzly bears as a threatened species in 1975 as the species range was reduced to two percent of its former range. To help the population recover, federal and state agencies implemented many actions such as placing a stop on grizzly hunting seasons, and establishing a Yellowstone grizzly bear recovery area, and two interagency teams – Interagency Grizzly bear Study Team and Interagency Grizzly Bear Committee – to coordinate management and increase communication. While the population has recovered to some extent, the species is back on the threatened species list today. Managers and scientists continue to monitor the population and strive to maintain a viable population (USDI NPS 2015).

The GYA attracts visitors from all over the world to tour the national parks and participate in recreational activities such as fishing, hunting, skiing, and hiking. The economy of the area is therefore driven by the character and quality of the natural and social environment, which draws visitors and permanent residents to the area. Communities such as Gardiner and West Yellowstone depend on Yellowstone National Park for economic activity, whereas communities such as Bozeman, Livingston, and Cody are less dependent on the park and have more diverse economies (Graff 2005).

GRASSLAND SUBREGION

The Grassland subregion occupies 119 million acres, extending across portions of Montana, Wyoming, North Dakota and South Dakota. The area includes portions of Custer National Forest, all of the Dakota Prairie National Grassland and several Indian reservations including the Crown Indian, Fort Peck, Standing Rock, Blackfoot, Cheyenne River and Spirit Lake.

The Wisconsinan glacier shaped the rolling and flat plains of North Dakota at the end of the last glacial period, approximately 12,000 years B.P. The southwestern corner of North Dakota was untouched by the glacier, which in turn led to the formation of the Little Missouri Badlands. Although this Ice Age glacier did not help shape the badlands, a previous glacier did. The Little Missouri River flowed northward up until 600,000 years B.P. until a glacier blocked its path and diverted its flow east (Herman and Johnson 2008a), creating a cycle of erosion and downcutting which led to the development of badlands.

Sedimentary layers found here are mainly continental sediments deposited by rivers and streams. Siltstone, claystone, sandstone, and lignite coal are common sediments in this environment (Bluemle 1996). Clinkers (or scoria), rocks produced by burning coal beds, are also commonly found in the badlands. They are mostly reddish in color but also include shades of pink to black. The landforms found in the Badlands—hills, valleys, cliffs, buttes—are a result of the differential hardness of minerals and their resistance to erosion (Bluemle 1996). As Theodore Roosevelt remarked, "The Badlands grade all the way from those that are almost rolling in character to those that are so fantastically broken in form and so bizarre in color as to seem hardly properly to belong to this earth."

The rugged badlands were carved from rocks from the Late Cretaceous through the Eocene period. Cretaceous and Tertiary sedimentary formations mark the period when dinosaurs became extinct. The Hell Creek formation, located in the southern portion of the Little Missouri Badlands, has remnants of the last species of dinosaurs that existed on Earth, the most common of which was *Triceratops* spp. (Bluemle 1996). Along with dinosaur remains, other common fossils found in the area include those of fish, turtles, alligators, birds, and small mammals. Fossils of broad-leafed trees, cycads, palms, and ground ferns are also present, indicating the presence of a subtropical coastal plain environment during the Cretaceous period. Petrified wood is commonly found in the Badlands and is thought to be the remains mostly of dawn redwood (*Metasequoia glyptostroboides*) (Bluemle 1996).

The Missouri, Red, and Souris (or Mouse) Rivers are the three major river systems in the Dakota Prairie portion of the Grassland subregion. The Missouri River is the largest and longest in the state of

North Dakota. The Red River borders North Dakota and Minnesota, and the Souris River begins in eastern Saskatchewan, Canada and flows into North Dakota, after which it loops back into Canada. The Tongue and Powder Rivers are the major river systems that flow into the Yellowstone River in the southern portion of the Grassland subregion.

The subregion is characterized by three very different ecosystem types, badlands, prairie, and ponderosa pine forest. The pine forests are found in "islands of green in a sea or rolling prairie." Most of the ponderosa pine forest in the Custer and Sioux National Forest burned in the last decade. Located mostly along the Little Missouri River, the badlands are a collection of rugged landscapes as described above. Sioux Indians, a group that lived in the region before Euro-American settlement, called the badlands "makosika" (land bad), and the French explorers called it "les mauvais terrers a traverser" which means bad lands to travel across (Bluemle 1996).

Most of the vegetation found in the badlands is native and consists of grasses, forbs, trees and shrubs. Shortgrasses are dominant because average precipitation is only 10-12 inches annually. Common bunchgrasses include little bluestem *(Schizachyrium scoparium*), blue grama (*Bouteloua gracilis*), and needle and thread (*Hesperostipa comata*). In areas where precipitation reaches close to 15 inches, western wheatgrass (*Pascopyrum smithii*) is fairly common. Open areas that can retain moisture throughout the year can support trees and shrubs. Deciduous trees include eastern cottonwood (*Populus deltoides*), green ash (*Fraxinus pennsylvanica*), boxelder (*Acer negundo*) and American elm (*Ulmus americana*), and ponderosa pine and Rocky Mountain juniper (*Juniperus scopulorum*) are common in some locations. Drainages dominated by trees also provide habitat for shrubs such as western serviceberry (*Amelanchier alnifolia*), chokecherry (*Prunus virginiana*), currant species, and American plum (*P. americana*). Shrubs found in drier locations include sagebrush, winterfat (*Krascheninnikovia lanata*), rabbitbrush, and buckbrush (*Ceanothus cuneatus*). Prairie wildflowers include gumbo lily (*Mentzelia decapetala*), scarlet globemallow (*Sphaeralcea coccinea*), soapweed yucca (*Yucca glauca*), and brittle pricklypear cactus (*Opuntia fragilis*) (Herman and Johnson 2008a).

1268 The badlands landscape provides wildlife habitat in native prairie, sagebrush, woody draws, shrubby
1269 areas, and buttes. Large animals include bighorn sheep, pronghorn (*Antilocapra americana*), elk, white-
1270 tailed deer, and mule deer. When Lewis and Clark passed through North Dakota in 1804, the most
1271 abundant animal they encountered was bison followed by pronghorn. Populations of wildlife considered
1272 food and game species were greatly reduced after Euro-American settlement. Other mammals found in
1273 the Grassland include black-tailed prairie dog (*Cynomys ludovicianus*), cougar, porcupine (*Erethizon*
1274 *dorsatum*), cottontail rabbit (*Lepus sylvaticus*), and bobcat. Common reptiles include prairie rattlesnake
1275 (*Crotalus viridis*), bullsnake (*Pituophis catenifer*), and sagebrush lizard (*Sceloporus graciosus*), and
1276 common amphibians include Woodhouse's toad (*Anaxyrus woodhousii*), Great Plains toad (*A. cognatus*),
1277 and plains spadefoot toad (*Spea bombifrons*) (Herman and Johnson 2008).
1278 The badlands support a diversity of bird species such as long-billed curlew (*Numenius americanus*),
1279 yellow-breasted chat (*Icteria virens*), mountain bluebird (*Sialia currucoides*), rock wren (*Salpinctes*
1280 *cabanis*), western kingbird (*Tyrannus verticalis*), eastern kingbird (*T. tyrannus*), black-billed magpie
1281 (*Pica hudsonia*), prairie falcon (*Falco mexicanus*), and burrowing owl (*Athene cunicularia*). Greater sage
1282 grouse are found in southwestern North Dakota and depend on declining sagebrush habitat, and sharp-
1283 tailed grouse (*Tympanuchus phasianellus*) are found in similar sagebrush and prairie habitat (Herman and
1284 Johnson 2008a).
1285 The native prairie component of the Grassland subregion is dominated by grasses and forbs (fig. 2.5)
1286 that tolerate low precipitation, strong winds, cold winters and hot summers, frequent fire, and herbivory.
1287 Native grasses have deep and extensive connected root systems that allow them to persist under stressful
1288 conditions (Herman and Johnson 2008b). Native prairie is divided into three tallgrass, mixed grass, and
1289 shortgrass. Tallgrass prairie, which dominates eastern North Dakota, requires the most moisture, and
1290 shortgrass prairie requires the least.
1291 The largest remaining tallgrass prairie is in the Red River Valley, dominated by big bluestem
1292 (*Andropogon gerardii*), switchgrass (*Panicum virgatum*), Indian grass (*Sorghastrum*), and prairie
1293 dropseed (*Sporobolus heterolepis*) (NDGF 2012). Humus, which develops as grasses and forbs

decompose, helps retain soil moisture. This fertile soil led to the near extinction of the tallgrass prairie as farmers cultivated the land for wheat and other crops. The Sheyenne National Grassland contains most of the remaining tallgrass prairie in North Dakota today. Cedar River National Grassland, which connects with Grand River National Grassland in South Dakota, contains both tallgrass and shortgrass species. Warm and cool season grasses dominate this area, such as prairie junegrass (*Koeleria macrantha*), crested wheatgrass (*Agropyron cristatum*), green needlegrass (*Nassella viridula*), needle and thread, blue grama, little bluestem, and needleaf sedge (*Carex duriuscula*). Dominant forbs include eastern pasque flower (*Anemone patens*), western wall-flower (*Erysimum asperum*), prairie smoke (*Geum triflorum*), blacksamson (*Echinacea angustifolia*) and common yarrow (*Achillea millefolium*) (Herman and Johnson 2008b).

Shortgrass prairie, found in the higher elevation region of the Missouri slope of North Dakota, is dominated by warm season species that require little rainfall, including spikemoss (*Selaginella*), blue grama, needleaf sedge, threadleaf sedge (*Carex filifolia*), buffalo grass (*Urochloa mutica*), and needle and thread. These grasses are 3-7 inches tall. The Little Missouri National Grassland contains both mixed and shortgrass prairie. Common prairie forbs include wild prairie rose (*Rosa arkansana*), blacksamson, showy milkweed (*Asclepias speciosa*), soapweed yucca, gumbo lily, and tenpetal blazingstar (*Mentzelia decapetala*) (Herman and Johnson 2008b).

American bison was formerly the iconic “ruler of the prairies,” and Native Americans depended on bison for their livelihood. However, Euro-American settlement and hunting nearly drove the bison to extinction. Other mammals found in prairie habitat of the Grassland subregion include elk, red fox (*Vulpes vulpes*), coyote, American badger (*Taxidea taxus*), several species of ground squirrel (*Spermophilus* spp.) and pocket gopher (*Thomomys* spp.), white-tailed jackrabbit (*Lepus townsendii*), eastern cottontail (*Sylvilagus floridanus*), and meadow vole (*Microtus pennsylvanicus*) (Herman and Johnson 2008b).

Reptiles found in the prairie include garter snakes (*Thamnophis* spp.), smooth green snake (*Opheodrys vernalis*), and western hognose snake (*Heterodon nasicus*). Bird species include greater

prairie chicken (*Tympanuchus cupido*) in the tallgrass prairie, sharp-tailed grouse, greater sage grouse, upland sandpiper (*Bartramia longicauda*), nonnative ring-necked pheasant (*Phasianus colchicus*), and many songbird species (Herman and Johnson 2008b).

The Grassland subregion is home to over 100 species of fish, including northern pike, walleye (*Sander vitreus*), and sauger (*Sander canadensis*). Walleye inhabit large reservoirs such as Lake Sakakawea and Lake Oahe, while sauger are mostly found in the Missouri River (Herman and Johnson 2008c). In addition, this subregion contains a variety of endemic prairie fish assemblages, including sensitive species like northern redbelly dace (*Phoxinus eos*), a sensitive species, and associated native macroinvertebrates like fatmucket mussels (*Lampsilis siliquoidea*).

The Sioux, Assiniboine, Cheyenne, Mandan, Hidatsa, and Arikara were the first inhabitants of the land. In 1910, approximately 6,000 Native Americans lived in North Dakota. That number increased to over 25,000 in 1970 and over 30,000 today. Today, there are five federally recognized tribes in North Dakota: Fort Berthold, Lake Traverse Indian Reservation, Standing Rock Indian Reservation, Spirit Lake Reservation, and Turtle Mountain Reservation.

With the majority of the Grassland subregion located on fertile soil, agriculture drives the economy. Wheat, flaxseed, canola, peas, lentils, and oats are some of the many products grown here, especially in the Red River Valley (also known as “Breadbasket of the World”). Livestock production occurs on the less suitable lands and includes beef, dairy cattle, and hogs. North Dakota is currently in a boom phase of oil production, focused on the Bakken and Three Forks formations, making it the second largest oil-producing state. Petroleum refining and food processing are also major industries.

The declining sage-grouse population is of extreme concern to western states and is now a candidate species for listing under the Endangered Species Act. Over half of the greater sage-grouse habitat has been lost resulting in sage-grouse population numbers of 200,000 to 500,000. The Bureau of Land Management, U.S. Forest Service, U.S. Fish and Wildlife Service and the Natural Resources Conservation Service are working together to conserve the western sagebrush habitat. Several Environmental Impact Statements have been developed by these agencies to incorporate sage-grouse

conservation measures into land use plans (USDI BLM 2015). While agencies continue to monitor and evaluate the western landscape, a final decision on the species listing is forthcoming.

Many organizations such as the U.S. Forest Service, U.S. Fish and Wildlife Service, The Nature Conservancy, North Dakota Game and Fish Department, and Ducks Unlimited are working to protect existing grasslands and aquatic habitat. Although most of the land is under private ownership, many land owners have converted cropland to grassland under the Conservation Reserve Program, in which the federal government pays farmers to plant grass on less fertile lands. In many cases, reserve lands produce higher populations of white-tailed deer, ducks, ring-necked pheasant, and many non-game species. Unfortunately West Nile virus, oil and gas development, and conversion of sagebrush land to cropland have reduced greater sage-grouse range habitat and populations (USFWS 2014).

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Chapter 3: Historical and Projected Climate in ihe Northern Rockies Adaptation Partnership Region

Linda A. Joyce, Marian Talbert, Darrin Sharp, Jeffrey Morisette, and John Stevenson

INTRODUCTION

Climate influences the ecosystem services we obtain from forest and rangelands. Climate is described by the long-term characteristics of precipitation, temperature, wind, snowfall, and other measures of weather that occur over a long period in a particular place. Day to day implementation of resource management practices are made in response to weather conditions; resource management strategies and plans are developed using our understanding of climate, the long-term average conditions. With the need to consider climate change in planning and management, an understanding of how climate may change in the future in a resource management planning area is valuable. In this chapter, we present the current understanding of the future changes in climate for the Northern Rockies Adaptation Partnership Region (NRAP).

CLIMATE MODEL PROJECTIONS: CMIP3 AND CMIP5

Global climate models have been used to understand the nature of global climate, how the atmosphere interacts with the ocean and the land surface. Scientist can use these models to pose questions about how changes in the atmospheric chemistry would affect global temperature and precipitation patterns. Given a set of plausible greenhouse gas scenarios, these models can be used to project potential future climate. These projections can be helpful in understanding how the environmental conditions of plants and animals might change in the future; how runoff and seasonal flows might vary with precipitation and timing of snowmelt, how wildfire, insects and disease outbreaks might be affected by changes in climate, and how humans might respond in their use of the outdoors and natural resources.

The Coupled Model Intercomparison Project (CMIP) began in 1995 to coordinate a common set of experiments for evaluating changes to past and future global climate (Meehl et al. 2007). This approach

allows comparison of results from different global climate models around the world and improves our understanding of the "range" of possible climate change. The third CMIP modeling experiments, or CMIP3, were used in the International Panel on Climate Change (IPCC) Fourth Assessment Report (Solomon et al. 2007), whereas CMIP5, the latest experiments, were used in the IPCC Fifth Assessment Report (Stocker et al. 2013).

A key difference between CMIP3 and CMIP5 is the set of emissions scenarios that drive, or force, the simulations of future climate (fig. 3.1, taken from Walsh et al. 2014). The CMIP3 simulations of the 21st century were forced with emission scenarios from the Special Report on Emissions Scenarios (SRES) (Nakićenović et al. 2000). The CMIP3 scenarios represent futures with different combinations of global population growth and policies related to alternative energy and conventional fossil fuel sources (Solomon et al. 2007). The CMIP5 simulations of the 21st century are driven by representative concentration pathways (RCP) scenarios (van Vuuren et al. 2011). The RCPs do not define emissions, but instead define concentrations of greenhouse gases and other agents influencing the climate system. RCPs present the range of current estimates regarding the evolution of radiative forcing, the total amount of extra energy entering the climate system throughout the 21st century and beyond. Projections made with RCP 2.6 show a total radiative forcing increase of 2.2 Wyd^{-2} (Watts per square yard) by 2100; projected increased radiative forcing through the scenarios of RCP 4.5, RCP 6.0 and RCP 8.5 indicate increases of 4.5, 6.0, and 8.5 Watts per square meter, respectively (3.75, 5.0, and 7.1 Wyd^{-2}, respectively). Unlike the SRES scenarios used in CMIP3, the RCPs in CMIP5 do not assume any particular climate policy actions. Rather, policy analysts and social scientists are free to develop mitigation scenarios that lead to one of the RCPs. Comparisons between CMIP3 and CMIP5 model results for the states of Oregon and Washington are described in box 3.1.

CLIMATE OF THE NORTHERN ROCKIES ADAPTATION PARTNERSHIP REGION

Historical Climate

For historical data, we drew from and contrasted three common gridded historic datasets; Parameter-elevation Regressions on Independent Slopes Model (PRISM) (PRISM 2014), Maurer (Maurer et al.

2002), and TopoWx (Oyler et al. 2014). These three gridded historic products are knowledge-based systems that use point measurements of precipitation, temperature, and other climatic factors to produce continuous, digital grid estimates of monthly, yearly, and event-based climatic parameters. Due to differences in the station data used by these gridded products as well as the models and assumptions used to interpolate to a grid, these climate models do not always agree on the historic climate or trend for a region. This is especially true in the western mountains where PRISM has been shown to have an artificial amplification in warming trend (Oyler et al. 2015). For this reason we chose to contrast all models rather than the trend and values produced by a single model.

Projected Climate

For an overview of projected climate in the NRAP region, we use downscaled CMIP5 projections based on RCP 4.5 and RCP 8.5 scenarios (fig. 3.2). Output from global climate models is at a scale too coarse to represent climate dynamics in subregions and management areas relevant for the NRAP. Many methods have been developed to bring climate projection information down to a scale that can be helpful to resource managers. We drew on climate projections that had been downscaled using the bias-correction and spatial disaggregation (BCSD) method (Maurer et al. 2007). We obtained the downscaled projection data from the Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections archive at: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections. We use projections from 36 climate models for RCP 4.5 and 34 climate models for RCP 8.5 (table 3.1). The variables available for each BCSD climate projection include monthly precipitation and monthly surface air temperature for the 1950-2099 period. Spatial resolution of the data is 1/8-degree latitude-longitude (~7.5 mi by 7.5 mi) and covers the entire NRAP region. We use a base period of 1970-2009 for the historical climate, and compare projections for two periods (2030-2059, 2070-2099) with this historical climate. These time periods were selected in an attempt to summarize climate that has influenced the current conditions (base period) and two future periods that will be relevant to long-term management action (such as road construction, hydrological infrastructure, or vegetation planting).

The currently cooler climates associated with the Rocky Mountains are evident as are the warmer parts of eastern Montana and South Dakota (fig. 3.2). All areas warmed under both projections, with a greater warming in RCP 8.5. Average annual precipitation ranges from less than 6 inches to just over 85 inches with the wetter areas occurring in the northern parts of the mountains in Montana (fig. 3.3). See box 3.2 for key messages associated with these NRAP region maps.

COMPARISONS OF CMIP5 PROJECTIONS WITH THE CMIP3 PROJECTIONS USED IN THE RESOURCE CHAPTERS

The CMIP3 projections have been widely used in assessments, such as the National Climate Assessment (Walsh et al. 2014), and the Forest Service, U.S. Department of Agriculture Resource Planning Act Assessment (USDA Forest Service 2012). Since many of the resource chapters in this report use published literature using the CMIP3 projections developed by Littell et al. (2011), figure 3.4 compares the CMIP5 results used in this overview with CMIP3 projections of Littell et al. (2011) for use in natural resource assessments. There are many ways to compare projections; one such comparison involves comparing the change in temperature with the change in precipitation over a common period. The downscaled projections from Littell et al. (2011) did not cover the entire NRAP region (they cover the western area but stop at the continential divide). However, because we are interested in comparing the differences in temperature and precipitation between the CMIP3 and CMIP5 models for the entire region, we estimated the change in temperature and precipitation using global results for the models Littell et al. (2011) used - 10 CMIP3 model projections using the A1B scenario. We obtained these 1-degree global model projections for the entire NRAP region (Littell, written communication). Using these data we estimate the change in temperature and percent change in precipitation between a future period (2040-2060) and a historical period (1979-2009) for the models that Littell et al. (2011) used and the CMIP5 models that we are using in this study. In fig 3.4, the projected change in mean annual temperature is shown on the horizontal axis, and the percent change in precipitation is shown on the vertical axis. Change is described as the difference in temperature (future mean annual value minus historical mean

annual value) and percent change in precipitation (100*[future mean annual value minus historical mean annual value]/historical mean annual value).

Across all models, projected change in temperature by the 2040-2060 period ranges from just under 2 ºF to nearly 8 ºF (fig. 3.4). Generally, the projected change for models using the RCP 8.5 scenario (shown in red) is greater than the change projected for RCP 4.5 scenario (shown in yellow). Change in precipitation ranges across these CMIP5 models from a decrease of approximately 5 percent to an increase of 25 percent with a mean projected change of around 6 and 8 percent for RCP 4.5 and RCP 8.5 respectively. Change in the CMIP3 projections developed by Littell et al. (2011) is shown on this graph as pcm1, Ensemble (average of 10 model projections), and miroc_3.2 (where pcm1 and miroc_3.2 are individual climate models). We conclude that when this set of CMIP3 results (Littell et al. 2011) are compared with CMIP5 results for the NRAP region, the CMIP3 results are in the same temperature range for 2040-2060, although CMIP5 precipitation projections are slightly wetter in the future (fig. 3.4).

CLIMATIC VARIABILITY AND CHANGE IN NRAP SUBREGIONS

The following five sections summarize historical and projected climate for the five subregions in the Northern Rockies Adaptation Partnership: Western, Central, Eastern, Greater Yellowstone, and Grassland (see figure of subregions in chapter 2). Each section contains a set of figures based on a common template that we describe here. Key messages for each region are given in a series of boxes.

The first figure in each section shows the annual mean daily maximum temperature (ºF), the annual mean daily minimum temperature (ºF), and the total annual precipitation (inches) for 1949 to 2010. For this historical data, we drew from and contrasted three common gridded historic datasets; PRISM, Maurer, and TopoWx. In both temperature and precipitation there is variability, so we show the 10-year rolling average to highlight any short-term trends (bold lines).

The second figure in each section shows the historical modeled and projected annual mean of the daily maximum and minimum temperatures (ºF), and total annual precipitation (inches) for the RCP 4.5 and the RCP 8.5 scenarios based on the CMIP5 1/8th degree BCSD data available on the Green Data Oasis (https://computing.llnl.gov/resources/gdo/). Typically, the higher emission scenario (RCP 8.5) will

show a higher temperature by 2100. In these figures, each model was backcast and we display the modeled historic data, which include all CMIP5 models that are bias corrected and downscaled in the same manner as the model projections. We overlay the 1/8-degree spatial resolution (about 7.5 mi) gridded historical observation dataset (blue line) (Maurer et al. 2002), which was used in the bias correction of the modeled data. The projections are shown in the colors used in figure 3.6, red for RCP 8.5 and yellow for RCP 4.5. The ensemble median from all models for each scenario is shown in the heavy line; the 5th and 95th percent quantiles for all models are shown by the shaded area. The precipitation projections have a greater variability than either temperature projection, and there is less confidence in any one particular model's projection for precipitation.

The third figure in each section shows the seasonal means of the daily maximum temperature (°F) for the historical and projected period. We use box plots here, where each box is an aggregation of 20 years of modeled historical or projected seasonal data. For example, the box labeled as 1960 represents the seasonal average of 1950 to 1969. The modeled historical boxes are grey, and boxes for projections use the same colors as in other figures: yellow for RCP 4.5 and red for RCP 8.5. The central line in each box is the median, indicating the same number of modeled historical or projections lie above and below this line. The hinges or edges of the boxes are the first and third quartiles. Whiskers extend past the first and third quartile by 1.5 times the interquartile range.

The fourth figure in each section shows the seasonal means of the daily minimum temperature (°F) for the historical and projected period 1950 to 2100. The figure is set up as the third figure description above. We do not show the seasonal mean precipitation values as there is large variability and no discernible trend and hence, less confidence overall in the finer scale precipitation projections.

Western Subregion

The primary results of analysis of historical and projected climate in the Western subregion are summarized in box 3.3, with specific detail in figs. 3.5, 3.6, 3.7, and 3.8.

Central Subregion

The primary results of analysis of historical and projected climate in the Central subregion are summarized in box 3.4, with specific detail in figs. 3.9, 3.10, 3.11, and 3.12.

Eastern Subregion

The primary results of analysis of historical and projected climate in the Eastern subregion are summarized in box 3.5, with specific detail in figs. 3.13, 3.14, 3.15, and 3.16.

Greater Yellowstone Subregion

The primary results of analysis of historical and projected climate in the Greater Yellowstone subregion are summarized in box 3.6, with specific detail in figs. 3.17, 3.18, 3.19, and 3.20.

Grassland Subregion

The primary results of analysis of historical and projected climate in the Grassland subregion are summarized in box 3.7, with specific detail in figs. 3.21, 3.22, 3.23, and 3.24.

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Chapter 4: Effects of Climate Change on Snowpack, Glaciers, and Water Resources in the Northern Rockies Region

Charles H. Luce

INTRODUCTION

Water is critical to life, and the effects of climate change on ecosystems are mediated through changes to hydrology. Changes in how snow accumulates and melts are one of the more consistently noted climate-induced changes to water in the western U.S. (Barnett et al. 2005; Service 2004), and these changes affect when water will be available for forests and fish alike. Changes in summer atmospheric circulation patterns may alter the ability of summer precipitation to allow midsummer respite from seasonal drought and dampening of wildfire spread (IPCC 2013; see chapter 8). Fish will be affected by both lower low flows with earlier snowmelt and higher midwinter floods caused by rain-on-snow events. Declining summer water supplies will likewise challenge municipal and agricultural water supplies. All of these meaningful effects can be traced to interactions between temperature and precipitation changes projected for the future and described in chapter 3. In this chapter, we describe mechanisms of hydrologic change, provide maps illustrating variations in effects across the region, and discuss some uncertainties relevant to effects. Effects of climate change on stream temperature are discussed in chapter 5.

Warming temperatures are the most certain consequence of increased CO_2 in the atmosphere. The hydrological consequences of warmer temperatures include less snowpack and greater evaporative demand from the atmosphere. Snowpack depth, extent, and duration are expected to decrease due to a combination of 1) less precipitation falling as snow (Pierce et al. 2008), and 2) slightly earlier melt (Luce et al. 2014). The degree of change expected as a result of warming varies dramatically over the landscape as a function of temperature (Luce et al. 2014). Places that are warm (near the melting point of snow) are expected to be more sensitive than places where temperatures remain subfreezing throughout much of the

1742 winter despite warming (Woods 2009). In the coldest locations, snowpack may increase with increasing
1743 winter precipitation under changing climate (Hamlet et al. 2013).

1744 The relationship of evapotranspiration to a warming climate is more complicated (Roderick et al.
1745 2014). Warmer air can hold more water, which means that even if the relative humidity stays constant, the
1746 vapor pressure deficit, the difference between the actual water content of the air and the water content at
1747 saturation, increases. That difference between actual and saturation drives a water vapor gradient between
1748 leaves and the atmosphere that can draw more moisture out of the leaves. This has led many to expect
1749 greater evaporation during climate change (e.g., Cook et al. 2014; Dai 2013) using potential
1750 evapotranspiration formulations dependent on temperature, reflecting the increased "demand."

1751 Evaporation, however, is an energy intensive process, and there is only so much additional energy
1752 that will be available for evaporation. In addition, one needs to consider both the water balance and the
1753 energy balance when considering future warming (Roderick et al. 2015). The observation that
1754 temperatures are warmer during drought are more generally related to the lack of water to evaporate
1755 leading to warmer temperatures than to warmer temperatures causing faster evaporation (Yin et al. 2014).
1756 Unfortunately when potential evapotranspiration models based on air temperature (including Penman-
1757 Monteith) are applied as post-processing to general circulation model (GCM) calculations, an
1758 overestimate of increased evapotranspiration is likely, because the energy balance is no longer tracked
1759 (Milly 1992; Milly and Dunne 2011). The reality is that most of the increased energy from increased
1760 longwave radiation will result in warming rather than increased evaporation (Roderick et al. 2015).

1761 Changing precipitation is more rarely discussed in climate change projections because it is more
1762 uncertain (Blöschl and Montanari 2010; IPCC 2013). Nevertheless, it has a much more direct impact on
1763 hydrologic process than temperature and cannot be ignored. On average, across many GCMs,
1764 precipitation is expected to increase very slightly in the Northern Rockies. The bounds are quite large,
1765 however, ranging from on the order of +30% to -20% (see chapter 3). Unfortunately, because many
1766 hydrologic processes are sensitive to precipitation (e.g., floods, hydrologic drought, snow accumulation),
1767 this represents a profoundly large uncertainty. As a consequence, the general approach in this and other

analyses is to use an ensemble average (i.e., average across many GCMs) precipitation outcome. In this report, we discuss some of the uncertainty surrounding that mean estimate to illustrate which processes or hydrologic outcomes are most uncertain and where. Not all processes are sensitive to precipitation, and uncertainty in outcomes caused by uncertainty in precipitation is not the same everywhere for a given process. Acknowledging the substantial quantitative disagreement among models in projected precipitation behavior, we now turn to discussion of the general physical mechanisms behind precipitation change, on which there is some agreement.

Two primary concepts are applied for precipitation change: 1) dynamic and 2) thermodynamic (Seager et al. 2010). Dynamic drivers of precipitation change include changes in global circulation patterns (e.g., the Hadley cell extent) and changes in mid-latitude eddies. Changes in teleconnection patterns, for example the North American Monsoon System (NAMS), would also fall into this category. Thermodynamic changes refer to the fact that the atmosphere can hold more water (Held and Soden 2006) according to a non-linear Clausius-Clapeyron relationship (saturation vapor pressure versus temperature), leading to a rough expectation on the order of seven percent increase in precipitation per 1.8 °F of temperature change. There are, however, other physical limits on the disposition of energy driving the cycling of water in the atmosphere, leading to lesser estimates on the order of 1.6 percent per 1.8 °F at the global scale, with individual grid cells being less or potentially negative, particularly over land (Roderick et al. 2014). Different approaches to scaling the thermodynamic contribution is one of the reasons for differences among models, although the dynamic process modeling differences can be great as well.

When considering the impacts of precipitation change on streamflow, the seasonality of precipitation is important. One key outcome of the thermodynamically driven changes is that when precipitation happens, it is expected to fall with greater intensity. In turn, this is expected to result in greater dry spell duration between events. This process can be important in determining drought duration (and consequently severity) in locations where summer precipitation is an important component of the summer water budget (Luce et al. 2016), such as much of eastern Montana, and low elevation stations in western Montana (fig. 4.1). Locations with more exposure to westerlies (e.g., Idaho stations and the Yellowstone

area), and high elevations in northern Montana, show a more pronounced winter-wet pattern, which is broadly more representative of high elevation stations than low elevation stations (figs. 4.1 and 4.2). It is specifically worthwhile noticing that much of the region has a substantially wetter May and June than July and August, and in some cases, the May through June precipitation is on a par with or exceeds the winter snowpack contribution to the annual water budget (fig. 4.2). In these locations, the snowpack changes may have less consequence than any circulation changes driving summer precipitation, such as expected shifts in NAMS (IPCC 2013). The May through June precipitation contributions, for example, can be an important determination of the severity of summer drought and the fire season (Abatzoglou and Kolden 2013). Pairing longer periods of precipitation deficit in summer with decreasing snowpack may be particularly challenging for vegetation and fishes.

Changes in orographic enhancement of precipitation over mountain areas in the Pacific Northwest is another effect within the class of dynamic effects. Historical changes in westerly windflows have led to a decrease in the enhancement of winter precipitation by orographic lifting over mountain ranges (Luce et al. 2013), raising the important question of whether such a pattern may continue into the future. Westerly winds across the Pacific Northwest are strongly correlated with precipitation in mountainous areas (fig. 4.3), but valley precipitation is not, nor is precipitation in much of eastern Montana. The historical trend in westerlies was driven by pressure and temperature changes spatially consistent with those expected under a changing climate, but were a consequence in part (~50%) of normal climate variability. Dynamic downscaling using a regional climate model (RCM) with small (~12.5 mi) cells provides a means to estimate orographically-induced precipitation (fig. 4.4b), which cannot be simulated with the large cell size of GCMs (fig. 4.4a). While the GCM shows general moistening over most of the area, the RCM shows a pattern of drying or no change on the upwind side of major mountain ranges, with moistening limited to valleys in the lee. Since precipitation falls mostly in mountain areas where streamflows originate, this is a potentially important aspect of future changes to consider. The variable infiltration capacity (VIC) model simulations detailed later in this chapter do not include this effect, so for purposes of general discussion, it can be lumped as an additional source of uncertainty for precipitation.

The range of potential changes to climate looks complex, particularly for such a varied landscape as the Northern Rockies. Perhaps the most important point to summarize from the above is that the current climatological settings vary over the landscape at both macroscales and fine scales. There are broad east-west changes in precipitation seasonality and amount, and local differences between nearby mountain and valley weather stations echo that pattern. Trends and drivers for climate variations will differ greatly from east to west. Fundamentally, topography is an important factor affecting seasonality, precipitation amount, and potential trends. Given that forests and much of the water supply generation are generally in mountain areas, it is important to recognize the role of topography in affecting the climate. Specific hydrologic outcomes of interest are changes to snowpacks and glaciers, streamflow, and drought.

SNOWPACK AND GLACIERS

Snowpack

Snowpack declines are among the most widely cited changes occurring with climate change, as warmer temperatures will reduce the fraction of precipitation falling as snow (Klos et al. 2014; Pierce et al. 2008). On the order of 70 percent of the water supply in the western U.S. is tied to mountain snowpacks (Service 2004), and thus changes in snowpack are particularly relevant to municipal and agricultural water timing (Stewart et al. 2005).

Historical trends in snowpack accumulation have been negative across much of the region (Mote et al. 2005; Regonda et al. 2005). Although earlier work has ascribed the changes primarily to warming temperatures, the interior parts of the Northern Rockies are cold enough to be relatively insensitive to warming and strongly sensitive to precipitation variation (Luce et al. 2014; Mote 2006). Consequently, interior snowpacks have likely responded primarily to reduced precipitation (Luce et al. 2013). In contrast, the low elevation mountains of northern Idaho, the western-most mountains in the region, are heavily influenced by a maritime snow climate (Armstrong and Armstrong 1987; Mock and Birkeland 2000; Roch 1949), and are still sensitive to temperature variability, particularly with respect to snow durability (Luce et al. 2014) (fig. 4.5).

Precipitation uncertainty can be substantial, but it does not translate into uncertainty in snowpack changes everywhere (fig. 4.6). An index of uncertainty can be calculated as a ratio of the effects of the likely range of precipitation values (about +/-7.5% for one standard deviation across models) to the relatively certain temperature change (the timing is uncertain, but a change in temperature is certain as long as CO_2 concentrations continue to increase):

$$R_u = \frac{\Delta\ (\pm 7.5\%)}{\Delta}$$

Figure 4.6 shows strong certainty of large changes in April 1 snow water equivalent (SWE) for the Cascades but substantial uncertainty in outcomes for the Greater Yellowstone Area, where cold temperatures leave the snowpack more sensitive to precipitation than temperature changes. The uncertainty ratio in these areas suggests that relatively large increases in precipitation could counter the effects of warming on snowpack loss.

Glaciers

Glaciers are well known features in the Northern Rockies, with a large number located in and near Glacier National Park, on the northern edge of the region, and in the Wind River, Absaroka, and Beartooth ranges in and near Yellowstone National Park, at the southern edge. They are also found in several other mountain ranges in Montana and Wyoming (see http://glaciers.research.pdx.edu/states-glaciers for maps). Significant changes have been noted in the glaciers of Glacier National Park over the course of the 20th century (Fagre 2005), with the Grinnell Glacier having on the order of 10 percent of the ice that it had at its peak in 1850 (fig. 4.7). Declines have also been seen in the Wind River Range over the 20th century (Marston et al. 1991).

Estimating future changes in glaciers is complex (Hall and Fagre 2003), but empirical relationships derived for the glaciers indicate a brief future for them, with many glaciers becoming fragmented or disappearing by the 2030s. Increasing temperatures yield a rising equilibrium line altitude (ELA), decreasing the effective contributing area for each glacier as warming progresses. A 5.4 °F warming can translate into between 500 and 300 m of elevation rise in snow-rain partitioning and summer

temperatures. Unfortunately, for simplicity's sake, those changes do not directly equate to shift in ELA, which depends on the geometry and topography of the contributing cirque. Temperate alpine glaciers are well known for being as, or more, sensitive to precipitation variations as they are to temperature changes (McCabe and Fountain 1995), which has likely contributed to changes in glaciers across the Pacific Northwest. Westerlies and their contribution to winter precipitation have changed over the Glacier National Park region since the 1940s (fig. 4.3) and April 1 SWE at these elevations and latitudes is relatively insensitive to temperature. However, it is important to note that this area receives significant spring and summer precipitation (fig. 4.1), and changing summer temperatures affect both the melt rate and additional summertime mass contributions (new snow) in these glaciers. Thus, summer temperature is a strong predictor of their behavior, and regardless of changes in precipitation, significant reduction in area of glaciers is expected by the end of the 21st century (Hall and Fagre 2003).

STREAMFLOW

Streamflow changes of significance for aquatic species, water supply, and infrastructure include:

- Annual yield
- Summer low flows – average and extreme
- Peakflows – scouring floods
- Peakflow seasonality
- Center of runoff timing

Annual yield, summer low flows, and center of runoff timing are all important metrics with respect to water supply. Irrigation water for crops and urban landscapes is typically needed in summer months, and these metrics are most relevant to surface water supplies rather than groundwater supplies, although changes in long-term annual means could be informative for the latter. For summer low flows, two metrics are used, the mean summer yield (June through September), and the minimum weekly flow with a 10-year recurrence probability (7Q10). Center of runoff timing refers to the timing of water supply, and shifts in runoff earlier in the winter or spring disconnect streamflow timing from water supply needs. Center of timing can be redundant with other metrics that measure impact more directly, but with care in

interpretation, it can help clarify different potential causal mechanisms, changing precipitation versus changing temperature.

Peakflows are important to fishes and infrastructure. Scouring flows can damage eggs in fish redds if they occur while the eggs are in the gravel or alevin are emerging (DeVries 1997; Goode et al. 2013; Montgomery et al. 1996; Tonina et al. 2008;). Winter peakflows can affect fall spawning fish (chinook, bull trout, brook trout) while spring peakflows affect spring spawning cutthroat trout, steelhead, and resident rainbow trout (Wenger et al. 2011a,b). Spring peakflows associated with the annual snowmelt pulse are typically muted in magnitude in comparison to winter rain-on-snow events, because the rain-on-snow events tend to affect much larger fractions of a basin at a time, so scouring is less of a risk to spring spawning fishes. Consequently, a shift to more mid-winter events can yield greater peakflow magnitudes, which can threaten infrastructure such as roads, recreation sites, or water management facilities (diversions, dams).

Historical changes in some of these streamflow metrics have been examined in some of the western and southern basins in the Northern Rockies. For instance earlier runoff timing was noted by Cayan et al. (2001) and Stewart et al. (2005), and declining annual streamflows were noted by Luce and Holden (2009) and Clark (2010). Declining low flows (7Q10) have also been seen in the western half of the Northern Rockies (Kormos et al. in review) associated more with declining precipitation than warming temperature effects for the historical period. Low flow changes and timing changes in projections are generally associated with the expected changes in snowpack related to temperature (e.g., more melt or precipitation as rain in winter yielding a longer summer dry period).

Streamflow Projections

Streamflow projections were produced from the VIC model (Liang et al. 1994) for the western U.S. (available online, Western U.S. Hydroclimate Scenarios Project, https://cig.uw.edu/datasets/wus/). Climate projections are based on Coupled Model Intercomparison Project Phase 3 (CMIP3) GCM runs, the full details of which are discussed in Littell et al. (2011). Differences between the climate described by CMIP3 and CMIP5 are provided in chapter 3. The gridded data were used to estimate streamflow by

using area-weighted averages of runoff from each VIC grid cell within a given basin, following the methods of Wenger et al. (2010), to accumulate flow and validate. Streamflow metrics were calculated for stream segments in the NHD+ V2 stream segments (http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml).

Uncertainty in climate model inputs can be a significant factor in uncertainty for outcomes for natural resources (e.g., Wenger et al. 2013). Besides showing the projected change from the ensemble average, metrics were calculated for two additional climate scenarios; MIROC 3.2 and PCM GCMs were chosen to show warmer-drier and cooler-wetter summers than the ensemble mean, respectively (Littell et al. 2011). The difference between these o run is shown in the second panel of the figures for each metric to give a sense of the certainty w th which the hange is projected in a given basin. Downscaling for these runs was done statistically, so GCM pectati ns for precipitation are implicit. No effects of change in orographic enhancement (e.g., fig. 4) are i heren in these images, so readers may wish to consider an additional degree of uncertainty (in a drier rection) on the windward side of mountain ranges.

Although calculations were made for all 6 -Digi Hy rologic Units in the Northern Rockies, only the western half of the region is shown in figures 4.8-4.14 Trimm ng the d main allows easier comparison of the uncertainty map to the ensemble mean projection, at the loss of display fo eastern Montana and western North Dakota. Fortunately, the easternmost part of the maps that a shown show little change going east.

Mean annual flow (fig. 4.9) shows minor increases in the western and southern portions of the domain, with lesser changes across eastern Montana. Higher mountains in northern Idaho and northwestern Montana show substantial uncertainty in the annual scale water yield compared to the size of the change. Over much of the rest of the domain, the range of uncertainty is on par with the magnitude of the expected change in runoff. Changes in the ensemble mean are comparable to ensemble changes in precipitation.

Despite projections of increased annual flow, low flows are expected to decline (figs. 4.10 and 4.11). Uncertainty is low compared to the magnitude of changes, particularly in mountain areas. Patterns are

nominally similar, with relatively uniform changes, though with somewhat more pronounced changes in mountain areas, particularly in wetter ranges. By and large, those areas showing more pronounced change in low flows show a large shift in timing (on the order of two months; fig. 4.12), again with uncertainty generally lower than change magnitudes in mountain areas, and stronger changes in mountains with greater precipitation. The primary mechanism expected to drive lower low flows is reduced snowpack in winter, leading to less stored water.

Summer wet portions of the region are more likely to see low flows affected by summer precipitation patterns. Shifts in circulation that affect how moisture flows from the Gulf of Mexico during summer months are expected to negati ely aff ct precipitation, on the net, and there will also likely be increased spacing between precipi tion events (I CC 2013; Luce et al. 2016). These summer wet areas are also more likely to see greater loss i precip ation ith increased evaporation, but it is critically important to recognize the energy balance con traints hen timating the degree of loss (Roderick et al. 2014). This is not done in the VIC modeling, whic uses only th t mperature outputs from GCMs without reevaluating the change in energy balance from a diff ren hydrological formulation, which is known to potentially lead to overestimation of loss (Milly and D nne 20 1).

Changes to flood magnitude across the region are substantially more uncertain and spatially heterogeneous at fine scales (fig. 4.13). The second metric on flood timing shows changes in the number of days in winter that are in the top five percent of flows for the year (a maximum of 18.25 days on average; fig. 4.14). Bull trout are sensitive to this metric and tend be rare when values exceed five percent (Wenger et al. 2011a,b). The shift to more midwinter rain and more rain-on-snow flooding depends strongly on the elevation range of each given basin. Generally, the maps reflect strong declines in flood magnitude in higher elevation basins near the crest of major mountain ranges, with strong increases at middle elevations and little change below that. This matches well with the information on number of midwinter events, which shows the greatest increases at middle elevations and less pronounced changes at both higher and lower elevations. While there is less snow and more rain at higher elevations, it is probably more a process of shifting shoulder seasons (Woods 2009) than more midwinter flood events,

thus producing more rain or rain-on-spring snowmelt floods, which tend to be less severe (MacDonald and Hoffman 1995). With less snow accumulating, the annual snowmelt and rain events during snowmelt are likely to be smaller, because less area will be snow-covered. At mid-elevations, temperatures will increase enough that rain is likely on snowpacks, even in midwinter. Uncertainty in peakflow magnitudes are generally as large as or larger than the expected magnitude of the change. Uncertainty in the amount of flooding occurring in mid-winter is less uncertain.

ADAPTING WATER RESOURCES TO CLIMATIC VARIABILITY AND CHANGE IN THE NORTHERN ROCKIES

With many potential chan es in water resources, there are naturally questions about what we might be able to do to shift water nd land mana ement practices to reduce the impacts or consequences of a changing climate on water re s. Since the NRAP region includes a broad diversity of topography, geology, watershed configurations, and ecosystems, adaptation responses to climatic variability and change vary considerably across the region. However, s e al themes prevail across most of the region in response to dominant sensitivities to climate change tabl 4.1). Many of these strategies and tactics may do little to alleviate some of the more direct consequen es of shifting precipitation, snowpack timing, and temperature changes to forests during drought conditions (e.g.,Vose et al. 2016); they are largely directed toward affecting downstream water availability and consequences of hydrologic drought.

Of greatest concern is reducing the vulnerability of roads and infrastructure to flooding, a phenomenon that is expected to increase considerably as snowpack declines and snow:rain ratios increase. National forests in particular contain thousands of miles of roads, mostly unpaved. Damage to those roads and associated drainage systems reduce access by users and is extremely expensive to repair. Road damage often has direct and deleterious effects on aquatic habitats as well, particularly when roads are adjacent to streams. Resilience to higher peakflows and frequency of flooding can be increased by (1) maintaining the capability of floodplains and riparian areas to retain water, (2) conducting a risk assessment of vulnerable roads and infrastructure, and (3) modifying infrastructure where possible (e.g., increasing culvert size, improving road drainage, relocating vulnerable campgrounds or road segments).

Climate-induced occurrence of disturbances such as drought and flooding are expected to increase, thus reducing water quality. Building an information base on potential locations of and responses to disturbances will help ensure informed and timely decision making when disturbances occur. Within this overall strategy, tactics include (1) prioritizing data collection based on projections of future drought, (2) collecting pre-disturbance data on water resources, and (3) developing a clearinghouse for programs related to fire and other disturbance. All tactics are focused on federal lands (table 4.1).

In contrast to the effects of winter peakflows, reduced overall base flows (especially in summer) are expected to reduce riparian habitat, water storage, and shallow aquifers. The primary adaptation strategies in this case are to increase natu al sto age and build storage where appropriate, as well as increase knowledge about ground ater. Specifi tactics focus on (1) increasing storage with constructed wetlands, beavers, and obliterated roads, (2) considering small-scale storage in dams, retention ponds, and swales, where appropriate. In addition, it will be important to map aquifers and alluvial deposits, improve monitoring to provide feedback on water dynamics, and nderstand the physical and legal availability of water for aquifer recharge.

Public lands are a critical source of municipal wat supplies, for which both quantity and quality are expected to decrease as snowpack declines. A critical adaptation strategy is to reduce erosion potential to protect water quality, as well as prioritize municipal water supplies. Water quality can be addressed by: (1) reducing hazardous fuels in dry forests to reduce the risk of crown fires, (2) reducing other types of disturbances (e.g., off-road vehicles, livestock grazing), and (3) using road management practices that reduce erosion. These tactics should be implemented primarily in high-value locations (near communities and reservoirs) on public and private lands.

Harvesting trees to increase water yield has been a practice of interest for some time (e.g., Bates and Henry 1928). Trees use water, so it is not surprising that water yields generally increase after canopy loss (Brown et al. 2005; Jones and Post 2004; Troendle and King 1987; Troendle et al. 2010). There are, however, certain caveats to be considered. For example, increases in water yield are generally greater in moister environments or years, with less increase in drier locations or years (e.g., Brown et al. 2005), and

in some circumstances in drier climates, decreased yields may be seen (Adams et al. 2011; Guardiola-Claramonte et al. 2011). In broad terms, the general places and times one would want to see increases in water yield are the places and times when forest harvest is least effective (Troendle et al. 2010; Vose et al. 2012). Furthermore, thinning has proven to be ineffective in increasing water yield (Lesch and Scott 1997; Wilm and Dunford 1948). However, it can be useful in augmenting snow accumulation depths, for example for wildlife or recreation benefit (Sankey et al. 2015; Wilm 1944).

Canopy removal for streamflow augmentation is likewise not all positive. A negative effect of canopy reduction treatments is that they advance the timing of runoff (Luce et al. 2012). An example of large scale canopy loss in an area w h sim lar vegetation and climate is the Boise River Basin, where about 45 percent of one basin bur ed while the o her was left relatively unchanged after 46 years of calibration. This allowed for detection of fi percent increase in water yield from the 494,211-acre basin, providing an average of an additional 50,000 acre-feet each year. However, the average timing of release advanced by two weeks because the exposed snowpack melted faster, and most of the additional runoff was available prior to April, when it would be of little use in bolstering low flows. In warmer regions of the Northern Rockies, such large scale canopy removal could increase the magnitude of mid-winter rain-on-snow floods (Marks et al. 1998; Tonina et al. 2008). There are also water quality consequences to large scale canopy treatments, such as warming stream temperatures (Isaak et al. 2010) or sediment from increased road construction and use (Black et al. 2012; Luce and Black 1999).

Conceptually, replacing snowpack storage with storage in constructed reservoirs to carry over water from the winter wet season into the summer could be beneficial to irrigators in regions with significant irrigated agriculture. The degree of potential benefit, however, varies substantially with context of existing water right regulations, reservoir operating rules, snowpack sensitivity to temperature and precipitation, expectations for future precipitation, and the role and future of summer precipitation. The benefits of replacing snowpack storage with reservoir storage are somewhat built around the notion that the only thing changing is timing and that total volumes are unchanged. If, for instance, precipitation rises, temperature induced changes could be compensated for in relatively cold regions (Luce et al. 2014),

such as those found across most of the Northern Rockies. If, on the other hand, precipitation declines, total flow volume will be reduced, and it will be harder to fill reservoir storage because of other rights for water further downstream that might not be fulfilled. Ironically, this would be most difficult in dry years when the timing would be most strongly shifted because of the effect of snow water equivalence on duration of the melt period (Luce and Holden 2009). Given the large expenses, both financial and ecological, of dam construction, and that the precipitation uncertainties are considerable, it is likely worthwhile to perform a detailed economic and ecologic analysis before dam construction is seriously considered.

Shifting dam operation is nother possibility, which would cost significantly less, but still require some infrastructure inve ment in upst am snowpack, soil, and weather monitoring. Streamflow forecasting allows more infor d management of the tension between water storage for irrigation and maintaining empty reservoirs to buffer potential flooding (e.g., Wood and Lettenmaier 2006). Information on current state of the snowpack is a great boon to runoff forecasting in basins with substantial snowmelt contributions (Wood et al. 2015), even more so than climate and weather forecasting. Under such circumstances, it is reasonable to taper reservoir filling in such a way as to bring the reservoir to operational levels without undue flood risks, because later in the season, snowpack area is substantially reduced and rain-on-snow during the spring is generally less severe (or variable) than midwinter events when snowpack coverage over the basin is greater (MacDonald and Hoffman 1995). Predictability is declining in some regions as we lose snowpack, but the Northern Rockies region will still retain significant snowpack, making improved forecasting through investment in instrumentation a viable alternative. Note that besides informing reservoir operation, improved forecasting can also be used to better determine downstream financial investments in crops and community choices in how to invest water (Broad et al. 2007).

A final strategy for addressing water availability is to reduce water use by increasing efficiency, an important connection between the source of water on public lands and use of water downstream on public and private lands. First, it will be helpful to identify effective water-saving tactics and where they can be

successfully implemented. Second, low water-use appliances can be installed at administrative sites (e.g., restrooms), and drought tolerant plants can be used for landscaping (e.g., adjacent to management unit buildings). Third, the benefit of water conservation can be communicated to users of public lands (e.g., in campgrounds). These tactics demonstrate leadership in water conservation as an agency, providing outreach and public relations that extend to local communities.

More specific details on adaptation strategies and tactics for each NRAP subregion are in Appendix 4A.

CONCLUSIONS

Changes in climate over th Nort ern Rockies are likely to have substantial impacts on hydrology. A primary change will be ifts in snowp ck storage, though other changes in precipitation and atmospheric circulation could have signifi onsequences for forests, grasslands, streams, fishes, and agriculture in the region. Information is still the best tool for adaptation to a changing climate, and summaries provided here give a sense of both the general expectation for change as well as uncertainties that need to be considered in adaptation planning.

A range of adaptation options exist for the future of water resources, and while there is a bias in human nature toward taking action, information may yet be one of our better choices for future adaptation to an uncertain and varying climate. If we continue to invest in monitoring to track changing climate and outcomes, we can be better prepared, as what are now challenges of the future become current challenges. Armed with a better knowledge of how shifting temperatures and circulation have played out on our landscapes, snowpacks, and streams, we can make better decisions.

This effort illustrated that adapting to climate change does not necessarily entail drastically different management actions than those that are currently implemented. Many of the current federal agency management actions to improve and restore watersheds and riparian areas are consistent with the adaptation strategies and tactics identified here, as fully functional watersheds and riparian areas are more resilient to change. Thus, in many cases, adaptation to climate change involves increasing restoration

activities and re-prioritizing actions, and agencies are well-prepared for these types of shifts in management.

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Chapter 5: Climate Vulnerability of Native Cold-Water Salmonids in the Northern Rockies

Michael K. Young, Daniel J. Isaak, Scott Spaulding, Cameron A. Thomas, Scott A. Barndt, Matthew C. Groce, Dona Horan, David E. Nagel

INTRODUCTION

During the 21st century, climate change is expected to alter aquatic habitats throughout the Northern Rocky Mountains, intermountain basins, and western Great Plains. Particularly in montane watersheds, direct changes are likely to include warmer water temperatures, earlier snowmelt-driven runoff, earlier declines to summer baseflow, downhill movement of perennial channel initiation, and more intermittent flows (see chapter 4), as well as indirect changes attributable to altered and perhaps novel disturbance regimes. For animals restricted to freshwater aquatic environments for most or all of their lives—fishes, amphibians, crayfish, mussels, and aquatic macroinvertebrates—changes in habitat and in hydrologic regimes are likely to lead to marked shifts in their abundance and distribution. This is primarily because many of these species are ectothermic (cold blooded), thus environmental conditions dictate their metabolic rates and nearly every aspect of their life stages, including growth rate, migration patterns, reproduction, and mortality (Magnuson et al. 1979).

A vast and growing literature describes the myriad interactions between climate change, aquatic environments, and biotic communities. Rather than revisit this topic, we refer the reader to syntheses of the nexus between climate change and aquatic species in the northwestern United States (especially Rieman and Isaak 2010, but also Isaak et al. 2012a,b; ISAB 2007; Mantua et al. 2010; Mantua and Raymond 2014; Mote et al. 2003) and beyond (Ficke et al. 2007; Furniss et al. 2010, 2013; Luce et al. 2012; Poff et al. 2002; Schindler et al. 2008). However, assessments rarely provide

empirically based, spatially explicit, and precise climate change projections for species across broad geographic regions.

To address this gap, we developed high-resolution stream temperature and flow scenarios that translate outputs from global climate models (GCMs) into reach-scale habitat factors relevant to aquatic biota (Isaak et al. 2015). Those scenarios were coupled with species distribution datasets crowdsourced from the peer-reviewed literature and state and federal agency reports to develop accurate species distribution models for contemporary relationships between climate and biology. These models were used to project the probability of species habitat occupancy in streams throughout the inland northwestern United States, facilitating the identification of streams that are most likely to be occupied in the future and serve as invasion-resistant climate refugia.

We focused on climate vulnerabilities and current and projected distribution of two native salmonid fishes—bull trout (*Salvelinus confluentus*) and cutthroat trout (*Oncorhynchus clarkii*)—because of their importance to society, the large amount of data on their distribution and abundance, and their sensitivity to warm stream temperature (Eby et al. 2014; USDA FS 2013). We confined our inferences to suitable habitat for juveniles of each native species, because they are more thermally constrained than are adults. We directly addressed how the presence of nonnative species, such as brook trout (*S. fontinalis*), brown trout (*Salmo trutta*), and rainbow trout (*Oncorhynchus mykiss*) (the latter native to a portion of the analysis area) further restricts climate-suitable habitats for native species now and in the future. A full explanation of our rationale, approach, and results are in Isaak et al. (2015). The associated Climate Shield website (http://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield.html) provides access to a comprehensive archive of user-friendly digital maps and ArcGIS databases showing stream-specific model projections for multiple climate and brook trout invasion scenarios across most of the northwestern and interior western United States.

In this assessment, we summarize information for stream populations of bull trout and cutthroat trout in the Northern Rockies and briefly discuss adaptation measures and future research directions

(see Rieman and Isaak 2010 for a more comprehensive discussion). We regard our inferences as robust, but foresee the arrival of improved models fostered by ongoing improvements in measuring and modeling the attributes of populations and streams. Databases describing the distributions of many aquatic species via rapid, cost-effective environmental DNA surveys (McKelvey et al. 2016a; Wilcox et al. 2016) are rapidly proliferating and can be used with new geostatistical stream models (Isaak et al. 2014; Ver Hoef et al. 2006) to develop more precise information for many aquatic taxa. This combination of advanced survey methods and more sophisticated stream network models has already been adopted for assessing the validity and refining the predictions of the Climate Shield model for bull trout (M. Young, K. McKelvey, and D. Isaak, unpublished data).

ANALYSIS AREA AND METHODOLOGY

This assessment encompasses all streams in national forests and national parks encompassed by the Forest Service, U.S. Department of Agriculture Northern Region (fig. 5.1). To delineate a stream network for this area, geospatial data for the 1:100,000-scale National Hydrography Dataset (NHD)-Plus were downloaded from the Horizons Systems website (http://www.horizon-systems.com/NHDPlus/index.php; Cooter et al. 2010) and filtered by minimum flow and maximum stream slope criteria. Summer flow values predicted by the Variable Infiltration Capacity hydrologic model (VIC; Wenger et al. 2010) were obtained from the Western United States Flow Metrics website (http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml) and linked to individual stream reaches through the COMID field.

Stream reaches with summer flows less than 0.2 $ft^3 s^{-1}$), approximating a wetted width of 3.3 ft (based on an empirical relationship developed in Peterson et al. 2013b), or with slopes greater than 15 percent were trimmed from the network because they tend to be unoccupied or support very low numbers of fish (Isaak et al. 2015). In the case of the stream slope criterion, reaches steeper than 15 percent occur at the top of drainage networks where slopes become progressively steeper, and populations are more vulnerable to disturbances (e.g., post-wildfire debris torrents) that result in periodic extirpations (Bozek and Young 1994; Miller et al. 2003). The slope and flow criteria were

set liberally to minimize the exclusion of fish-bearing reaches from the analysis, but doing so results in the inclusion of many reaches with intermittent flows or migration barriers that prevent fish access. Thus, the network extent of 113,733 mi used as baseline habitat in this assessment probably overestimates potential habitat, but the current resolution of the NHDPlus hydrology layer and VIC flow model prevent further refinement.

Climate Scenarios

Average summer flow values for three 30-year climate periods were available from the flow metrics website: a baseline period (1970–1999, hereafter 1980s) and two future periods (2030–2059, hereafter 2040s; 2070–2099, hereafter 2080s) associated with the A1B (moderate) emission scenario. An ensemble of 10 global climate models (GCMs) that best represented historical trends in air temperatures and precipitation for the northwestern United States during the 20th century was used for future projections (table 5.1). Due to the significant uncertainties concerning the timing of change in the future, we deemphasize the dates associated with scenarios and refer to them instead as baseline (1980s), moderate change (2040s), and extreme change scenarios (2080s). With respect to scenarios used in other chapters of the NRAP assessment, the A1B scenario is similar to the RCP 6.0 scenario associated with Coupled Model Intercomparison Project 5 (CMIP5) simulations (see chapter 3).

To complement the streamflow information, geospatial data for August mean stream temperatures were downloaded for the same A1B trajectory and climate periods from the NorWeST website and linked to the stream hydrology layer (www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html). Within the study area, the NorWeST scenarios were developed using spatial statistical network models (Isaak et al. 2010; Ver Hoef et al. 2006) applied to 11,703 summers of monitoring data at 5,461 unique stream sites monitored with digital sensors from 1993 to 2011. The density and spatial extent of the temperature dataset, combined with the predictive accuracy (r^2 = 0.91; RMSE = 1.8 °F) and resolution (~0.62 mi) of the NorWeST model across those sites, was deemed sufficient for this assessment. Details about the

rationales associated with climate scenarios and the stream temperature model are discussed in Isaak et al. (2015).

Focal Species

Bull trout in the Northern Rockies are largely from an inland lineage (Ardren et al. 2011) primarily west of the Continental Divide (USFWS 2014). Bull trout may exhibit migratory or resident life histories. Migratory fish travel long distances as subadults to more productive habitats and achieve larger sizes and greater fecundity as adults before returning to natal habitats to spawn. Resident fish remain in natal habitats and mature at smaller sizes, although often at the same age as migratory adults. Adults spawn and juveniles rear almost exclusively in streams with average summer water temperatures less than 54 °F and flows greater than 1.2 $ft^3 s^{-1}$ (Isaak et al. 2010; Rieman et al. 2007). Relative to its historical distribution, this species has undergone substantial declines because of water development and habitat degradation (particularly activities leading to water temperature increases, but also cumulative losses of in-channel habitat complexity), elimination of migratory life histories by human-created barriers, harvest by anglers, and interactions with introduced nonnative fishes (Rieman et al. 1997). Nonnative species such as brook trout, brown trout, and lake trout (*Salvelinus namaycush*) may compete with or prey on bull trout (Al-Chokhachy et al. 2016; Martinez et al. 2009), or lead to wasted reproductive opportunities (Kanda et al. 2002). As a consequence, bull trout were listed as threatened under the U.S. Endangered Species Act (ESA) by the U.S. Fish and Wildlife Service in 1998 (USFWS 2015).

Cutthroat trout are represented by two subspecies. Westslope cutthroat trout (*Oncorhynchus clarki lewisi*) has a complicated lineage structure that can be roughly broken into a single lineage in the north and east that occupied and colonized river basins directly influenced by glaciation or glacial dams, and a southern and western group of several presumably older lineages in basins never directly influenced by glaciation (M. Young, unpublished data). These fish also exhibit resident and migratory life history strategies. Spawning and juvenile rearing can occur in streams smaller (<2 ft wide) and warmer (up to 57 °F) than those used by bull trout (Isaak et al. 2015; Peterson et al.

2013a,b; M. Young, unpublished data). Yellowstone cutthroat trout (*O. c. bouvieri*) has an unresolved distribution because certain lineages are found in portions of the Bonneville basin (Campbell et al. 2011; Loxterman and Keeley 2012), probably because of periodic hydrologic connectivity between the Bonneville and upper Snake River basins associated with passage of the North American plate across the Yellowstone mantle plume, Basin and Range faulting, and stream drainage reversals (Smith et al. 2002). Undisputed members of this taxon are represented by a single mtDNA clade found throughout the analysis area in the Yellowstone River basin (Campbell et al. 2011). For this analysis, we assume that life histories and presumably spawning and juvenile habitats are the same as for westslope cutthroat trout.

The distributions of both subspecies have declined substantially (>50 percent) in response to the same stressors affecting bull trout (Gresswell 2011; Shepard et al. 2005), although each subspecies appears to occupy a larger proportion of its historical habitat and is often found in larger populations at higher densities than are bull trout. Both subspecies of cutthroat trout have been petitioned under the ESA, but found not warranted for listing. Brook trout have replaced cutthroat trout in many waters in the region, disproportionately so in the upper Missouri River basin (Shepard et al. 1997). These invasions in part seem influenced by the distribution of low-gradient alluvial valleys that may serve as nurseries for brook trout (Benjamin et al. 2007; Wenger et al. 2011a). Where rainbow trout have been introduced outside their native range, introgressive hybridization occurs with both taxa of cutthroat trout at lower elevations and in warmer waters (Rasmussen et al. 2012), similar to patterns where westslope cutthroat trout occurred historically with native rainbow trout (the Clearwater River basin in Idaho and the Kootenai River basin in Idaho-Montana; McKelvey et al. 2016b). Yellowstone cutthroat trout have also been widely stocked throughout the historical range of westslope cutthroat trout (Gresswell and Varley 1988) and these two taxa readily hybridize to form hybrid swarms (Forbes and Allendorf 1991; McKelvey et al. 2016b). Lake trout predation decimated adfluvial populations of Yellowstone cutthroat trout in Yellowstone Lake at the beginning of the 21st

century, but predator control efforts are enabling cutthroat trout populations to rebound (Syslo et al. 2011).

Trout Distribution Models

Species distribution models were developed that predicted the occurrence probabilities of juvenile bull trout and cutthroat trout. We focused on juveniles as indicators of important natal habitats and the presence of locally reproducing populations (Dunham et al. 2002; Rieman and McIntyre 1995). This approach provides more precision than also considering distributions of subadults and adults, which migrate widely, occupy an array of habitats, and occur with many other fish species (Behnke 2010). Juvenile distributions, by contrast, are restricted in ecological scope and geographic extent, especially with respect to temperature (Elliott 1994). For example, juvenile bull trout are rarely found where mean summer temperatures exceed 54 °F (Dunham et al. 2003; Isaak et al. 2010), whereas adult bull trout sometimes occupy habitats as much as 9–18 °F warmer (Howell et al. 2010). Similar patterns are evident with cutthroat trout (Peterson et al. 2013a; Schrank et al. 2003), so we used a thermal criterion to delimit potentially suitable habitats for juvenile native trout.

Temperature Criterion for Juvenile Trout Habitats

A mean August stream temperature of 52 °F was selected as the temperature criterion from a set of standardized thermal niches that were developed by cross-referencing thousands of species occurrence locations in Montana, Idaho, and Wyoming with the NorWeST baseline scenario (fig. 5.2). Fish data were contributed by national forest monitoring programs; Idaho Department of Fish and Game; Montana Fish, Wildlife and Parks; and Wyoming Game and Fish Department (Isaak et al. 2015). These niches revealed that most juvenile native trout (90 percent of bull trout observations and 75 percent of cutthroat trout observations) occurred at sites less than 52 °F, whereas nonnative species like brown trout and rainbow trout were rare at those sites. The thermal niche of brook trout overlapped that of the native species, but its occurrence peaked at a slightly warmer temperature and declined thereafter. Since especially cold temperatures limit rainbow trout incursions, colder temperatures also restrict introgression with rainbow trout, such that stream reaches with

temperatures less than 48 °F usually support only genetically pure cutthroat trout (McKelvey et al. 2016b; Rasmussen et al. 2012; Yau and Taylor 2013; M. Young unpublished data).

Habitat Attributes and Logistic Regression Models

Spatially contiguous 0.6-mile (1-km) reaches of stream with temperatures less than 52 °F were aggregated into discrete cold-water habitats (CWHs), and occupancy status (present or absent) of native trout juveniles and brook trout within a subset of those CWHs (bull trout, $n = 512$; cutthroat trout, $n = 566$) was determined using the fish survey database described above. Logistic regressions were used to model the probability of native trout occupancy as a function of CWH size, stream slope, brook trout prevalence, and stream temperature. Habitat size was represented as the channel length of each CWH, stream slope as the average value across all the reaches within a CWH, and brook trout prevalence as the percentage of sample sites within a CWH where they occurred. Temperature was represented as mean August temperature averaged across all 0.6-mi sections constituting a CWH or the lowest mean temperature of any 0.6-mi section within a CWH.

The four variables were good predictors of juvenile trout occurrence within the training dataset; classification accuracy of the models at a 50 percent occupancy threshold was 78.1 percent for bull trout and 84.6 percent for cutthroat trout. The final logistic regression models included the four main predictor variables and some interactions among those variables. Plots of species response curves from the final models matched expectations based on the ecology of bull trout and cutthroat trout, but also revealed important differences between the species (fig. 5.3). Habitat occupancy for both native trout was positively related to CWH size, but bull trout required habitats five times larger than cutthroat trout to achieve comparable probabilities of occupancy. Bull trout occupancy declined as minimum temperature warmed, whereas cutthroat trout occupancy was positively related to mean temperature. Stream slope negatively affected both species, as did their co-occurrence with brook trout, especially in small streams. The presence of brook trout masked the apparent preference of cutthroat trout for habitats with low slopes. Additional details on modeling procedures and variable selection are summarized in Isaak et al. (2015).

Application of Models for Status and Vulnerability Assessment

The logistic regression models were applied to the full set of CWHs within the historical range of each native species across the Northern Rockies to project probabilities of native trout occupancy. Projections were made for the baseline and future climate periods. To account for uncertainties in brook trout distributions, occupancy probabilities were calculated and mapped for a pristine scenario (no brook trout) and a broad invasion scenario that assumed brook trout would be present at half the sites within each CWH (50 percent brook trout). For this exercise, we did not map a scenario in which brook trout were present at all sites, because their prevalence rarely exceeded 50 percent in the large CWH (i.e., greater than 25 mi) that were most likely to serve as strongholds for native trout (Isaak et al. [2015] show brook trout prevalence in over 500 streams), and because not all locations appear suitable for brook trout (Wenger et al. 2011a). In some small streams with native trout brook trout prevalence occasionally reaches 100 percent, so probabilities for a full range of invasion scenarios were integrated into the ArcGIS databases at the Climate Shield website (http://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield.html) and can be used for stream-specific assessments of brook trout invasions.

After species probability maps were developed for all streams, the information was cross-referenced with land administrative status using geospatial data from the U.S. Geological Survey Gap Analysis Program (Gergely and McKerrow 2013). The total length and percentage of CWHs and stream temperatures were summarized by jurisdiction for different climate periods. Also noted were the proportions of CWHs that were administratively protected within national parks and wilderness areas. Finally, we denoted those CWHs with probabilities of occupancy exceeding 90 percent as climate refugia.

NATIVE TROUT VULNERABILITY TO CLIMATE CHANGE

Stream Temperature Status and Projected Trends

Considerable thermal heterogeneity exists across Northern Rockies streams because of the complex topography and range of elevations in this region (fig. 5.4). Of the 114,000 miles of stream

habitat within the analysis area, 43,000 mi (38 percent) had mean temperatures less than 52 °F (table 5.2). Most of those cold-water habitats (86 percent) were in publically administered lands, primarily (69 percent) in national forests. Areas with concentrations of cold streams were generally associated with high-elevation, high-relief mountain ranges in Montana (e.g., Whitefish Range, Mission Mountains, Swan Range, Flathead Range, Lewis and Clark Range, Sawtooth Range, Anaconda Range, Flint Creek Range, Big and Little Belt Mountains, Crazy Mountains, and ranges associated with the topographic rise produced by the Yellowstone mantle plume). In contrast, comparable mountain ranges and clusters of cold-water habitats are absent in most of northern Idaho.

Mean August stream temperatures were projected to increase across the Northern Rockies by an average of 2.2 °F in the 2040s and 3.6 °F in the 2080s (table 5.1, fig. 5.4). Larger than average increases are expected in the warmest streams at low elevations, and smaller than average increases are expected for the coldest streams. Differential warming occurs because cold streams tend to be buffered by local influxes of groundwater (Luce et al. 2014), a trend represented in the NorWeST scenarios we used. Averaged across all streams, future projections imply faster rates of warming (0.4–0.5 °F per decade) than were observed in recent decades (0.2–0.3 °F per decade; Isaak et al. 2012a). If future projections are accurate, the length of streams with temperature less than 52 °f will decrease to 27,000 mi in the 2040s and 17,000 mi in the 2080s (table 5.3). In both scenarios, over 75 percent of these cold streams are in national forests. Groups of exceptionally cold streams still likely to host bull trout or cutthroat trout would originate from the Sawtooth and Lewis and Clark Ranges along the Continental Divide in northern Montana, several smaller mountain ranges scattered throughout central Montana, and along the northern flank of the Yellowstone topographic high (fig. 5.4). Persistent CWHs are more isolated elsewhere.

Cutthroat Trout Status and Projected Trends

The historical range of cutthroat trout extends through most of the Northern Rockies. The number of discrete CWHs for cutthroat trout during the baseline climate period was estimated to exceed 5,000 and encompass over 28,000 mi of streams (table 5.4, fig. 5.5). Over 90 percent of the

CWHs were predicted to have probabilities of occupancy exceeding 50 percent (table 5.4), largely because of the relatively small stream networks (6 mi is associated with a 90 percent probability of occupancy) that cutthroat trout populations require for persistence (Peterson et al. 2013a) (fig. 5.3). Nonetheless, the largest CWHs accounted for a disproportionate amount of the habitat most likely to be occupied; 32.6 percent of CWHs were climate refugia, but these accounted for 70.7 percent of the length of CWHs. As expected, the number and extent of CWHs decreased 20–60 percent in future periods, but nearly 3,500 potential habitats encompassing over 12,000 mi were projected to remain under the extreme scenario.

Since some streams are currently too cold for cutthroat trout, future warming will increase the probability of occupancy in some basins (e.g., the Teton River basin along the Rocky Mountain Front and streams in the northern portion of Yellowstone National Park). Assuming that brook trout were present within half of each CWH did not affect the number or amount of CWHs, because the habitats remained potentially suitable for cutthroat trout, but occupancy probabilities declined (table 5.4). Reductions were particularly severe in categories with the highest probabilities of occupancy (greater than 75 percent). The sensitivity of streams to brook trout invasions varied with local conditions, but reductions were most pronounced in small streams with relatively low slopes.

Bull Trout Status and Projected Trends

The historical range of bull trout occupies a smaller portion of the Northern Rockies than cutthroat trout, but the number of discrete CWHs for bull trout during the baseline climate period was still estimated to exceed 1,800 and encompass over 14,000 mi (table 5.5, fig. 5.6). Probabilities of occupancy for most bull trout CWHs were less than 50 percent because of the relatively large stream networks that bull trout require for persistence (30 mi is associated with a 90 percent probability of occupancy; fig 5.3). Although fewer than six percent of CWHs constituted climate refugia, they provided 30 percent of the total length of CWH, emphasizing the contribution of large CWH to the amount of habitat projected to be occupied. The requirement for larger CWHs caused projected decreases in the number and network extent of bull trout CWHs to be more substantial (38-

71 percent) than those for cutthroat trout, particularly for the CWHs with the highest probabilities of occupancy. More than 800 CWHs representing over 4,200 mi were projected to remain, even in the extreme scenario.

Brook trout invasions reduced bull trout occupancy rates. These declines were more pronounced for bull trout than cutthroat trout, especially in the CWHs most likely to be occupied (those with greater than 50 percent probability of occupancy); fewer than 10 climate refugia for juvenile bull trout are projected to remain under any warming scenario if brook trout occupy half of each CWH. However, many of the large habitats bull trout require appear less susceptible to broad-scale brook trout invasions (Isaak et al. 2015). As expected, CWHs with the highest bull trout occupancy probabilities during all climate periods and brook trout invasion scenarios coincided with river networks with the largest number of cold streams: headwater portions of the North and Middle Forks of the Flathead River, the Whitefish River, and the North Fork Blackfoot River (figs. 5.4, 5.6). Due to the lower elevations and warmer streams in northern Idaho, few or no climate refugia were projected to remain under either warming scenario.

Additional Fish Species

See boxes 5.1 and 5.2 for narratives on additional fish species in the Northern Rockies that are at risk from climate change and are candidates for the habitat occupancy-climate vulnerability approach described here.

INTERPRETING AND APPLYING THE ASSESSMENT

The assessment described above provides accurate, spatially explicit projections of habitat occupancy in the Northern Rockies by combining (1) ecological understanding of cutthroat trout and bull trout, (2) distribution data from public data sources, and (3) broad-scale, high-resolution stream temperature and flow projections. Assuming that species responses are related to the effects of climate on stream ecosystems—and the accuracy of the models supports this contention—the models also provide reasonably robust projections of habitat occupancy in light of anticipated climate change. These projections have several implications for the future viability of native fish populations

in the Northern Rockies and for developing management strategies targeted at conservation of these species.

Although both native trout species require cold-water habitat, their response to a changing climate is expected to differ. Bull trout, and most members of the genus *Salvelinus*, are adapted to some of the coldest freshwater environments in the Northern Hemisphere (Klemetsen et al. 2003). These species also tend to inhabit variable environments, often with strong gradients in productivity that appear to favor migration as a life history tactic (Klemetsen 2010). It is unsurprising that a species near the southern end of its distribution that relies on large amounts of cold-water habitats and is often found at low density (High et al. 2008) would be susceptible to range contraction as temperatures warm. In the Northern Rockies, we anticipate large declines in their distribution because relatively few areas have the capability to serve as climate refugia. Nevertheless, retention of at least some climate refugia implies that bull trout will not be extirpated from the region. However, the conditions favoring migratory or resident life histories may change, although how to accommodate or exploit this is uncertain. As we learn more about the extent and prevalence of populations occupying cold-water habitats with varying probabilities of occupancy, a better understanding of environmental drivers of bull trout life history may emerge.

By contrast, cutthroat trout can accommodate a wider range of thermal environments, commensurate with its broad latitudinal distribution and an evolutionary history (since the late Miocene or early Pliocene) that exposed them to fluctuation in warm/arid and cold/moist periods in western North America (McPhail and Lindsey 1986; Minckley et al. 1986). They are relatively flexible with respect to life history strategies, ranging from highly migratory populations dependent on large rivers or lakes for growth and fecundity, to resident populations that move little and have been isolated for many decades, (Northcote 1992; Peterson et al. 2013a). Although we anticipate net losses in their distribution within the Northern Rockies, they are not expected to be as severe as for bull trout, and some basins that are currently too cold to support cutthroat trout will become high-quality climate refugia (Coleman and Fausch 2007; Cooney et al. 2005). Of greater importance may

be how nonnative salmonids, which often displace or replace cutthroat trout, respond to warming conditions (Wenger et al. 2011a).

The presence of brook trout is problematic for both native species. Brook trout's tolerance of cold temperature is nearly equivalent to that of cutthroat trout, and they favor the low-gradient environments preferred by cutthroat trout and bull trout (Wenger et al. 2011a). Nonetheless, larger habitats (e.g., those > 40 mi long) appear less susceptible to invasion by this species, which may be attributed to their preference for small streams but also to the likelihood that large systems will contain other salmonid species, such as rainbow trout or brown trout, that constrain brook trout distributions in their native range in eastern North America (Fausch et al. 2009). Rainbow trout and brown trout are expected to shift their distribution upstream as temperature isotherms optimal for these species move in that direction (Isaak and Rieman 2013; Wenger et al. 2011b). Both species appear to have negative effects on cutthroat trout, but cold headwaters that resist their invasions are expected to remain widespread.

Most cold-water habitats in the Northern Rockies are in national forests (tables 5.2, 5.3). This emphasizes the critical role that the U.S. Forest Service will play in the conservation of populations of native fish. Active management that conserves native fish will be possible, because most of the cold-water habitats are outside designated wilderness areas and national parks that limit many management activities. Conservation options will vary by location. For example, even under extreme warming, some cold-water habitats are expected to persist in some river basins in Montana. Maintaining those conditions may be all that is necessary to ensure the persistence of native fish populations. By contrast, very few habitats regarded as climate refugia are anticipated to remain in the Clearwater, Spokane, and Kootenai River basins in Idaho. Those circumstances favor more active yet strategic management to promote population persistence through manipulation of habitat, fish populations, or both. Many cold-water habitats in Montana and Idaho are situated in landscapes where multiple resource values and ecosystem services are important (see chapter 11), so fish conservation strategies that are compatible with other resource objectives will be an important issue

in public land management (Rieman et al. 2010). Retaining native trout populations in some areas may require conservation investments that are unacceptably high or could prove ineffective as climate warms. In these circumstances, reallocating those investments to areas where native populations are more likely to persist may be preferable.

The model projections described above contain uncertainties associated with emission scenarios and unanticipated characteristics of future climate (Hallegatte et al. 2012). The future scenarios we considered reflect qualitatively similar trends to those that have been occurring in the Northern Rocky Mountains during the last 50 years: summer streamflow decreases, air temperature increases, and stream temperature increases (Isaak et al. 2010, 2012a,b; Leppi et al. 2012; Luce and Holden 2009). Consequently, these estimates of occupancy probabilities should be a biologically robust and spatially explicit ranking of habitats critical to the persistence of native trout. The Climate Shield fish distribution maps (fig. 5.7) and databases developed in association with this project were designed for ease of use, allowing users to gauge the amount, distribution, and persistence of native trout habitats. In addition, this information can be summarized for multiple spatial scales and biogeographic entities (e.g., stream, river network, national forest, species or subspecies, state, region).

As with all models, current predictions and future projections of occupancy by juvenile native trout are estimates. These projections could be improved by including more local information on habitat conditions (Peterson et al. 2013a), the presence of barriers that influence habitat size and connectivity among populations (Eros et al. 2012), and the application of spatial statistical network models (Isaak et al. 2014). The potential for improvement notwithstanding, the accuracy of these simple models suggests that environmental gradients are the primary drivers of habitat occupancy by juvenile native trout.

The next step in an ongoing assessment process is to continue to reduce uncertainties associated with the distribution of aquatic species and their responses to a changing climate. Although we used data from thousands of sites to develop occupancy models, data on thousands of additional sites

would improve existing models and help build new ones for additional species. Compiling a comprehensive aquatic species database from all national forests has the potential to provide information on the recent presence of species in locations from which they may have disappeared, or from which they may have been absent but now exist. These data, and outputs from occupancy models, form the basis for projecting and detecting trends in aquatic species distributions, especially if coupled with new surveys, such as those based on rapid and reliable environmental DNA surveys (McKelvey et al. 2016a). Although DNA surveys are often conducted with one or a few species in mind, the samples constitute a snapshot of the entire aquatic community and can be archived to support future analyses of multiple species. Finally, better distribution data, an understanding of changes in occupancy, and geospatial analysis will improve the accuracy of existing species occupancy models and facilitate the development of new ones, ranging from an individual reach to an entire species range.

ADAPTING FISHERIES TO CLIMATIC VARIABILITY AND CHANGE

Adaptation Strategies and Tactics

Many options are available to facilitate climate change adaptation and improve the resilience of fish populations, perhaps more options than for any other resource assessed in the Northern Rockies Adaptation Partnership. Adaptation for fish conservation has been the subject of comprehensive reviews, including for the Northern Rockies (Rieman and Isaak 2010, especially table 2) and other parts of the Northwest (Beechie et al. 2013; Isaak et al. 2012a; ISAB 2007; Luce et al. 2013; Williams et al. 2015). Having a relatively well-known set of climate sensitivities and adaptation options (Isaak et al. 2015; Mantua and Raymond 2014; Rieman et al. 2007) provides for credibility and consistency in sustainable management of fisheries in the Northern Rockies and beyond.

The Western, Central, Eastern, and Greater Yellowstone subregions within NRAP all have steep mountain topography, complex stream systems, and cold-water fish populations. Therefore, climate change sensitivities and adaptation options across this broad area tend to be similar (table 5.6), although the effects of livestock grazing as a stressor are more important in the Eastern subregion.

The Grassland subregion has no cold-water fish species and is dominated by warm-water species many of which are nonnatives. Although some concern exists about aquatic systems in this subregion, no adaptation options were developed for fisheries at the Grassland workshop (but see box 5.2).

Reduced snowpack is one of the best-documented effects of warmer temperatures in mountainous regions (see chapter 4), resulting in lower summer streamflows and warmer stream temperatures. Adaptation strategies can attempt to either maintain higher summer flows or mitigate the effects of lower flows (table 5.6). Specific adaptation tactics include pulsing flows from regulated streams when temperature is high, reducing water withdrawals for various human uses, and securing water rights for instream flows to maintain more control of overall water supply.

Another strategy is to increase cold-water habitat resilience by maintaining and restoring the structure and function of streams. Specific tactics include restoring the functionality of channels and floodplains to retain (cool) water and riparian vegetation, and ensuring that passages for aquatic organisms are effective. These tactics could be particularly appropriate in areas where restoration activities are already underway and where habitat is limiting or declining, especially near roads and where high peakflows are frequent. In addition, accelerating riparian restoration may be a particularly effective and long-lasting way to improve hydrologic function and water retention. Maintaining or restoring American beaver populations provides a “natural” engineering alternative for cool water retention. In conjunction with restoration, road removal and relocation from sensitive locations near stream channels and floodplains can significantly improve local hydrologic function.

Interactions with nonnative fish species and other aquatic organisms are a significant stress for native cold-water fish species in the Northern Rockies. One adaptation strategy is to facilitate movement of native fish to locations with suitable stream temperatures. Adaptation tactics include increasing the patch size of suitable habitat, modifying or removing barriers to fish passage, and documenting where groundwater inputs provide cold water. All of these tactics will be more effective if native fish populations are healthy and nonnatives are not already dominant. Another

adaptation strategy is to focus management on reduction of nonnative fish species. Adaptation tactics include increased harvest of nonnative fish (e.g., sport fishing), manual or chemical removal of nonnatives, and excluding nonnatives with physical or electrical barriers where feasible. These tactics will generally be more effective if nonnatives are not already well established.

In stream systems adjacent to grasslands and shrublands, livestock grazing can damage aquatic habitat, causing stress that may be compounded by warmer stream temperatures. An important adaptation strategy is to manage grazing to restore as much ecological and hydrologic function of riparian systems as possible. Specific adaptation tactics include ensuring that standards and guidelines for water quality are adhered to and monitored, making improvements that benefit water quality (e.g., fencing), and reducing the presence of cattle through the retirement of vacant grazing allotments. It will make sense to prioritize these actions for locations that have high ecological value.

In a warmer climate, it is almost certain that increased wildfire occurrence will contribute to erosion and sediment delivery to streams, thus reducing water quality for fisheries. Increasing resilience of vegetation to wildfire may reduce the frequency and severity of fires when they occur. Hazardous fuel treatments that reduce forest stand densities and surface fuels are an adaptation tactic that is already widely used in dry forest ecosystems. Disconnecting roads from stream networks, another tactic already in practice, is especially important, because most sediment delivery following wildfire is derived from roads. Finally, erosion control structures can reduce postfire sediment delivery and are often a component of Burned Area Emergency Rehabilitation on federal lands.

More specific details on adaptation strategies and tactics for the subregions are in appendix 5A. The process used to elicit adaptation options differed among subregions, with some information being general and some being geographically specific.

Toward Climate-Smart Management

The broad range of adaptation options summarized in table 5.6 and appendix 5A provide a diverse toolkit for fisheries managers. In addition to specific strategies and tactics, several overarching issues help guide applications in federal lands.

Be Strategic

Prioritizing watershed restoration such that the most important work is done in the most important places is critical, because funds, labor, and time for management of native fish populations are limited (Peterson et al. 2013b). For example, climate refugia for native trout in wilderness areas may not require or be amenable to habitat modification to ensure the persistence of those populations. Similar refugia outside wilderness might be targeted to improve habitat conditions or reduce nonnative species, particularly if doing so increases the probability of occupancy of such habitats. Regardless of such efforts, some basins are unlikely to provide suitable habitat for native trout in the future, so directing conservation investments elsewhere, or for other species, may be prudent.

Implement Monitoring Programs

Being strategic means reducing current and future uncertainties for decision-making. In the case of fisheries, more data are needed for streamflow (more sites), stream temperature (annual data from sensors maintained over many years), and fish distributions. These data can be used for better status-and-trend descriptions, and to develop robust (more accurate and precise) models for species to understand the interaction of climate change, natural variation, and land management. The feasibility of monitoring at small to broad scales is increasing with the advent of rapid, reliable eDNA inventories of aquatic organisms (Thomsen et al. 2012) and the availability of inexpensive, reliable temperature and flow sensors (USEPA 2014).

Restore and Maintain Cold Stream Temperature in Summer

Persistence of native trout species will depend on a variety of management techniques to restore and maintain stream shade and narrow unnaturally widened channels. Actions may include relocating roads away from streams, limiting seasonal grazing in some areas, and managing streamside riparian forest buffer zones to maintain effective shade and cool, moist riparian microclimates. Tactics described above have implications and consequences far beyond enhancing

the persistence of native fish populations, but being open to opportunities to do so are part of strategic thinking.

Manage Connectivity

Beyond climate change concerns, obstacles to fish migration are often removed in hopes of enhancing the success of migratory life history forms, or permitting native species to reoccupy former habitat or supplement existing populations. However, this presents a dilemma: accessible waters can be invaded by nonnative fish species that can replace natives (Fausch et al. 2009). In some cases, barriers can be installed to prevent these invasions. Native populations above barriers may be secure if they can adopt resident life histories, but could be susceptible to loss from extreme disturbance events in small habitats, requiring human intervention re-establish or supplement populations. Barriers are usually temporary, and may require reconstruction if nonnative species still remain downstream.

Remove Nonnative Species

Removal of nonnative fish species, although challenging in some locations, may be the best option for maintaining or restoring some native fish populations. These efforts typically consist of chemical treatments or electrofishing, and both tend to be feasible only in smaller, simpler habitats. Both are also costly, in part because they need to be conducted on multiple occasions to be effective. Chemical treatment can be controversial because of its perceived effects on water quality. Furthermore, any method of removal is successful only if the source of nonnative species is removed, often by installation of a migration barrier (see above). Public resistance to removal of nonnative fishes may also be an obstacle, particularly if sport fish are involved. Unauthorized introductions are also common, and can undermine conservation efforts. Finally, using control measures to manage the abundance of nonnative species rather than removing all of them has been helpful in some areas (e.g., removal of lake trout to promote bull trout persistence, electrofishing to depress brook trout and favor cutthroat trout). Such activities will be successful only if conducted at

2852 regular intervals for the foreseeable future, which assumes social acceptance and that project funding
2853 will be available indefinitely.

2854 *Implement Assisted Migration?*

2855 Moving native fish species from one location to another, a historically common activity in fish
2856 management, has typically been used to found populations in previously fishless waters. This
2857 practice, alternately termed assisted migration or managed relocation, has become controversial for
2858 some taxa in recent years. However, assisted migration may be useful in the Northern Rockies where
2859 basins are currently fishless (or host only nonnative species in limited numbers) because of natural
2860 barriers such as waterfalls, and may constitute high-quality climate refugia in the future. Moving
2861 native fish to such areas is feasible, but potential effects on other native taxa (e.g., amphibians or
2862 invertebrates) must be considered. Reintroductions of native species may also be warranted when
2863 natural refounding is not an option, such as when populations in a specific location are isolated and
2864 periodically fail or suffer population bottlenecks (Dunham et al. 2011). This degree of management
2865 intervention requires a thorough understanding of genetic principles and broodstock establishment.

2866 In conclusion, fisheries managers responding to the environmental trends associated with climate
2867 change will require a diverse portfolio comprised of many of the actions described in this chapter.
2868 Equally important is adapting our mindsets—and our administrative processes—to a new paradigm
2869 of dynamic disequilibrium for the 21st century. Under this paradigm, stream habitats will become
2870 more variable, undergo gradual shifts through time, and sometimes decline. Many populations will
2871 retain enough flexibility to adapt and track their habitats, but others could be overwhelmed by future
2872 changes. It is unlikely that we will be able to preserve all populations of all fish species as they
2873 currently exist. However, as better information continues to be developed in the future, managers
2874 will have increasingly precise tools at their disposal to know when and where resource commitments
2875 are best made to enhance the resilience of existing fish populations or to benefit other species for
2876 which management was previously not a priority. There is much to do as climate change adaptation

continues in future years, and federal lands will play a critical role in providing important refuge habitats for aquatic resources.

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Chapter 6: Climate Change Effects on Forest Vegetation in the Northern Rocky Mountains

Robert E. Keane, Mary Frances Mahalovich, Barry L. Bollenbacher, Mary E. Manning, Rachel A. Loehman, Terrie B. Jain, Lisa M. Holsinger, Andrew J. Larson, and Meredith M. Webster

INTRODUCTION

The projected rapid changes in climate will impact the unique vegetation assemblages of the Northern Rockies in myriad ways, both directly through shifts in vegetation growth, mortality, and regeneration, and indirectly through changes in disturbance regimes and interactions with changes in other ecosystem processes, such as hydrology, snow dynamics, and exotic invasions (Bonan 2008; Hansen and Phillips 2015; Hansen et al. 2001; Notaro et al. 2007). These impacts, taken collectively, could change the way vegetation is managed by public land agencies in this area. Some species may be in danger of rapid decreases in abundance, while other may experience range expansion (Landhäusser et al. 2010). New vegetation communities might form, while historical vegetation complexes may simply shift to other areas of the landscape or become rare. Juxtaposed with climate change concerns are the consequences of other land management policies and past activities, such as fire exclusion, fuel treatments, and grazing. A thorough assessment of the responses of vegetation to projected climate change is needed, along with an evaluation of the vulnerability of important species, communities, and vegetation-related resources that may be impacted by the effects, both direct and indirect, of climate change. This assessment must also account for past management actions and current vegetation conditions and their interactions with future climates.

This chapter addresses the potential impacts of climate change on forest vegetation in the Forest Service, U.S. Department of Agriculture (USFS) Northern Region and the Greater Yellowstone Area (GYA), hereafter called the Northern Rockies (NR) assessment area (fig. 6.1). Then, based on the climate impacts assessment, we present an evaluation of the vulnerability of important tree species, vegetation

types, and resources of concern to projected climate change effects. And last, we present various adaptation actions to address climate change vulnerabilities.

This chapter includes six major sections. In the introductory section, we define terminology used throughout the chapter and provide background material on the details of the assessment including the scales, geographic areas, and pertinent information used to make our assessments. We also included discussion on how to evaluate uncertainty in climate change projections and vegetation response. We also summarize the methods used to make projections of vegetation response to changing climate. The second section contains important ecological background information that was used to assess climate change impacts and projected climate change responses for 17 tree species, five forest vegetation types, and three resources of concern. The third section is comprised on information on the tree species, types, or resources of concern that are important when evaluating climate change responses. In the fourth section, we then rate the vulnerability of the species, vegetation types, and resources of concern to climate change using information presented in section three. In the fifth section, we discuss adaptation strategies and management actions that can be used to address likely impacts of climate change. The final section is a concluding discussion.

This chapter utilizes the best-available information of climate change impacts on vegetation in the NR assessment area. We have integrated broad scale modeling results with a detailed synthesis of climate change literature for the NR area. This chapter was written to aid land managers in addressing climate change impacts on forest vegetation in land management planning and development of management strategies. This chapter does *not* include the detail needed to address climate change impacts at the project level, but it does include valuable information and syntheses that can be used in project planning and in addressing broad concerns at a landscape and project scale.

Terminology

Climate

Evaluations of climatic trends can be quite confusing, mostly because weather and climate vary at different spatial and temporal scales. To reduce this confusion, it is often helpful to clearly define the

terms and explain the scales that distinguish weather, climate variability, and climate change. *Weather* is the hourly, daily, weekly or monthly summaries in temperature, precipitation, wind, humidity, and other atmospheric conditions observed at a given place or across a large region. Weather changes at relatively small temporal scales (quickly) and it can change significantly as one moves north or south, east or west, or up and down in elevation. Weather is difficult to predict more than a few days in advance. *Climate* is a statistical characterization of the weather, averaged over many years. The World Meteorological Association defines it as the average 30-year weather patterns of a region. *Climate variability* is the variation in weather statistics over relatively broad regions and long time periods. Climate variability can be caused by underlying climatic processes, such as changes in patterns of ocean temperatures. The El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO), for example, are two sources of climate variability in western North America (Newman et al. 2003). ENSO oscillations occur over two to seven year periods (Gershunov and Barnett 1998), while PDO oscillations occur on a longer cycle (20 – 50 years) (Heyerdahl et al. 2002). External forcings, such as changes in solar radiation, large volcanic eruptions, and increasing concentrations of greenhouse gases in the atmosphere, also influence climate variability. *Climate change* is a non-random change in climate that is measured over several decades or longer. It is technically defined as a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (decades or longer). Like climate variability, climate change may be due to natural internal processes or to external forcings. A *climate scenario* is a plausible and often simplified representation of one possible future climate, based on a consistent set of known principles about the climate system used as input to climate models.

Vegetation

There are several general terms that are used in vegetation ecology to describe how ecosystems respond to climate change (IPCC 2007). *Adaptive capacity* is the ability of a plant, species, or system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences. *Exposure* is the nature and degree to which a system is exposed to significant climate variations (Glick and Stein 2010). *Sensitivity* is the

degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct, such as crop yield decreases in response to a higher temperature, or indirect, such as damages caused by an increase in the frequency of coastal flooding due to sea-level rise. *Resilience* is the degree to which ecosystems can recover from one or more disturbances without a major shift in composition or function, while *resistance* is the ability of an organism, population, community, or ecosystem to withstand perturbations without significant loss of structure or function (i.e., remain unchanged) (Holling 1973; Seidl et al. 2016). From a management perspective, resistance includes both (1) the degree to which communities are able to resist change, such as that from warming climates, and (2) the manipulation of the physical environment to counteract and resist physical and biological change (i.e., cutting, burning, harvest treatments). *Vulnerability* is the degree to which a system is susceptible to, and unable to cope with, the adverse effects of climate change, including associated climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

Other terms describe how ecosystem processes that are impacted by climate change will affect vegetation. In general, *stressors* are any physical, chemical, or biological entity that can induce an adverse ecosystem response. Stressors can arise from physical and biological alterations of natural disturbances, increased unmanaged demand for ecosystem services (such as recreation), alterations of the surrounding landscape, chemical alterations in regional air quality, or from a legacy of past management actions (Joyce et al. 2008).

Management

Climate change *adaptation* is an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which hopefully moderates harm or exploits beneficial opportunities (Spittlehouse and Stewart 2004). Adaptation is often referred to as preparedness, and is based on scientifically supported strategic and tactical activities that support sustainable resource management. Adaptation addresses specific aspects of the sensitivity of resources to an altered climate. An *adaption tactic* is a specific action described in management and planning documents that supports

adaptation strategies and is implemented on the ground (e.g., reducing stem density and surface fuels in a dry mixed conifer forest, or increasing culvert size on roads along a stream that is expected to have higher flood volumes) approaches (Joyce et al. 2008; Millar et al. 2007a; West et al. 2009). *Assisted migration* is deliberately helping plant species colonize new habitats when driven out of their historical habitats due to rapid environmental change, especially climate change.

In an ideal sense, *ecological restoration* is defined as the practice of reestablishing historical plant and animal communities in a given area and the renewal of ecosystem and cultural functions necessary to maintain these communities now and into the future (Egan and Howell 2001). However, this ideal may be impossible to manage because: (1) little is known about historic conditions; (2) many key species may already be lost; (3) some efforts may be prohibitively expensive; and most importantly, (4) future climates will create novel ecosystems. As a result, The Society for Ecological Restoration has opted for a definition that states that ecological restoration is "the process of renewing and maintaining ecosystem health".

The U.S. Forest Service manual (FSM) direction contained in FSM 2020 includes objectives and a policy for restoration. The objectives of the Forest Service ecosystem restoration policy are to:

1. *Restore and maintain ecosystems* that have been damaged, degraded, or destroyed by reestablishing the composition, structure, pattern, and ecological processes.
2. *Manage for resilient ecosystems* that have a greater capacity to withstand stressors, absorb and recover from disturbances, and reorganize and renew themselves, especially under changing and uncertain environmental conditions.
3. *Achieve long-term ecological sustainability* and provide a broad range of ecosystem services to society.

The Forest Service emphasizes ecosystem restoration across all National Forest System lands with the goal of attaining resilient ecosystems. All strategic plans, including the Forest Service Strategic Plan, land and resource management plans, and area plans, must include goals and objectives to sustain the resilience and adaptive capacity of aquatic and terrestrial ecosystems by reestablishing, maintaining, or

modifying their composition, structure, function, and connectivity. The goals and objectives must be established within this framework as defined by laws, Indian treaties and Tribal values and desires, and regulations. The goals and objectives also must consider public values and desires, social concerns, economic sustainability, the historical range of variability, ecological integrity, current and likely future ecological capabilities, a range of climate and other environmental change projections, the best available scientific information, and technical and economic feasibility to achieve desired conditions for National Forest System lands. A primary element of an integrated approach is to identify and eliminate or reduce stressors that degrade or impair the ecosystem. Restoration activities should also take into account social and ecological influences at multiple scales and incorporate the concept of a dynamic system and ecological trajectory. Some ecosystems may have been altered to such an extent that reestablishing components of the historical range of variability may not be ecologically or economically possible. Therefore, goals and activities should focus on restoring the underlying processes that create functioning ecosystems.

Functional restoration, an alternative concept used in the Forest Service, is defined as the "restoration of abiotic and biotic processes in degraded ecosystems". Functional restoration focuses on the underlying processes that may be degraded, regardless of the structural condition of the ecosystem. As contrasted with ecological restoration, that tends to seek a historical reference condition, functional restoration focuses on the dynamic processes that drive structural and compositional patterns. Functional restoration aims to restore functions and improve structures with a long-term goal of restoring interactions between function and structure. It may be, however, that a functionally-restored system will look quite different than the historical reference condition in terms of structure and composition, and these disparities cannot be easily corrected because some threshold of degradation has been crossed or the environmental drivers, such as climate, that influenced structural and (especially) compositional development have changed.

Scales of Assessment

This chapter uses three scales to assess the impacts of climate change on forest vegetation: species, vegetation types, and resource concerns. We selected these scales and their elements to ensure flexibility

when considering the complex ecological concerns across the NR study area. Not only did this structure facilitate consistent and comprehensive assessments for the major management concerns identified in this chapter, but it also allows for the addition of new elements that may be identified in the future.

Species

At the finest level of assessment, we address climate change effects at the species or species group level. We allowed for the use of species groups by aggregating species by genera, guilds, plant functional types, or lifeforms. In this chapter we had only one species group – all cottonwood species (*Populus tricarpa*, P. *angustifolia,* P. *deltoides*). We selected the species scale to allow new species or species groups easily at later dates. This scale was meant to address regional concerns about important individual species or species groups that might be adversely impacted by climate change. Obviously, all tree species cannot be addressed, and so the list of species and species groups included here represent only those species that are identified by the government agencies in the NR as critical for addressing both management and climate change concerns.

Vegetation types

The vegetation type assessment scale addresses climate change concerns at a coarse vegetation community type level so that future evaulations can be spatially described using a map or geographic information system layer. Five forest vegetation types were assessed in this report to summarize potential climate change impacts, including dry ponderosa pine (*Pinus ponderosa*)/Douglas-fir (*Pseudotsuga menziesii*) forests, western larch (*Larix occidentalis*) mixed mesic forests, mixed mesic western white pine (*Pinus monticola*), western redcedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), grand fir (*Abies grandis*) forests, lodgepole pine (*Pinus contorta*) mixed subalpine forests, and whitebark pine (*Pinus albicaulis*) mixed upper subalpine forests. These types are shown in both an existing vegetation map (fig. 6.1) and a potential vegetation map (fig. 6.2). Both maps and resultant categories were derived from LANDFIRE data (Rollins 2009), which covered the entire NR study area. Many of the estimated effects of climate change were based on evaluations of MC2 model simulations (see MC2 section), and figure 6.3 portrays the MC2 vegetation types used to generate the model results in appendix 6A of this

report. The potential vegetation type map and MC2 map can be used to estimate species assemblages in the absence of disturbance.

Resource Concerns

There are a number of resource concerns related to forest vegetation that were also addressed in this report. First, we addressed the impact of climate change and vegetation response on *landscape heterogeneity*, defined as the diversity in landscape structure or patch characteristics. We assumed that landscapes with high heterogeneity are more resilient to disturbance (Ahlqvist and Shortridge 2010; Oliver et al. 2010; Turner 1987). The second resource concern is *timber production,* as represented by timber volume. We attempted to address impacts of climate change on timber production solely via vegetation response, not from disturbance. Lastly, we describe climate impacts on *carbon reserves* across the NR area. NR resource specialists selected these resource concerns.

Geographic Stratification

The NR assessment area was stratified into five geographic sub-areas (fig. 6.1). The *west side* area includes northwestern Montana and northern and central Idaho. The *central area* includes west-central Montana and all lands west of the continental divide to the west side and north to Canada. The *east side* area includes the Rocky Mountain Front and southwestern Montana. The *grasslands* area includes all lands east of the *east side* boundary to the eastern border of the Northern Region. Lastly, the GYA includes all lands that have been officially designated as part of this high profile area, including Yellowstone National Park, Grand Teton National Park, the southern end of the Gallatin National Forest and the Beaverhead Deerlodge National Forest, the western side of the Custer National Forest and parts of the Shoshone, Bridger-Teton, Caribou, and Targee National Forests.

The main purpose of dividing the assessment area into five geographic sub-areas was to refine climate change projections, impacts, and adaptation options to a specific part of the NR study area. The five sub-areas shown in figure 6.1 were included for all authors to standardize the spatial scales of their sections, but some authors of this chapter chose to evaluate climate change impacts at the national forest or finer

scale. As a result, this chapter does not include formal sections for each geographical area. Instead, the authors tuned their material to the sub-areas if the data and information allowed.

Uncertainty

Uncertainty is an expression of the degree to which something is unknown. Uncertainty can result from a lack of information or from a disagreement about what is known or even knowable. Uncertainty can also result from known and unknown errors. It may have many types of sources, from quantifiable errors in data to ambiguously-defined concepts or terminology, or uncertain projections of human behavior. Uncertainty can therefore be represented by quantitative measures, such as a range of values, or by qualitative statements, such as ass ssment of the judgment of a team of experts. Uncertainty is quite different from variability variability is he actual range of a value or ecosystem variable.

All the climate models (Gl b Circulation Models or GCMs) that predict rapidly warming climates have a high degree of uncertainty (I CC 20 7) W ile there is little debate that atmospheric CO_2 is increasing and that this increase will cause major chang i climate (IPCC 2007), there is a great deal of uncertainty about the magnitude and rate of climate han e (Roe and Baker 2007; Stainforth et al. 2005). This uncertainty will almost undoubtedly increase as c mate p ojection are made at finer resolutions, for different geographical areas, and for longer time periods (Knutti an Sedlacek 2013). The range of possible projections of future climate from GCMs (anywhere from a 2.88 14.4 °F increase in global average annual temperature) is much greater than the variability of climate over the past two or three centuries (Stainforth et al. 2005), and the variability across GCMs is greater than the variability in each model's climate projections. Since it is impossible to know whether society will respond to climate change by employing technological innovations to minimize CO_2 emissions or to mitigate its effects, most GCMs also simulate a suite of scenarios that capture a range of possible strategies to deal with climate change, introducing yet another source of uncertainty. Moreover, it is the high variability of climate extremes, not the gradual change of average climate, that will drive most ecosystem responses to the climate-mitigated disturbance and plant dynamics, and these rare, extreme events are the most difficult to predict (Easterling et al. 2000).

Yet another source of uncertainty in attempting to predict ecosystem change is introduced when we try to predict how the Earth's vegetation and ecosystems will respond to highly uncertain climate change (Araujo et al. 2005). Mechanistic ecological simulation of climate, vegetation, and disturbance dynamics across landscapes is still in its infancy (Keane and Finney 2003; Sklar and Costanza 1991; Walker 1994). Many current ecosystem simulation models are missing the important direct interactions of disturbance, hydrology, and land use with climate that will surely dictate effects on plant distributions (Notaro et al. 2007). Little is known about the interactions among climate, vegetation, and disturbance, and interactions among different disturbance regimes (fire and beetles, for example) could create novel landscape behaviors. It is also difficult to determine how the critical plant and animal life cycle processes of reproduction, growth, an mortality wi respond to changing climate (Gworek et al. 2007; Ibanez et al. 2007; Keane et al. 2001; Lam ht et al 2007). These modeling uncertainties greatly increase as projections are made further into th future d at ner spatial scales (Xu et al. 2009).

Managers must account for these uncer ainties when us ng the information in this report in any land management plan or analysis. Sometimes there is les un ertainty in implementing conventional restoration designs than in designing restoration or trea ment plans that attempt to account for climate change impacts. For some areas or resources, such as the restoration of western larch ecosystems, addressing climate change in management plans may require only minor changes to current management practices, while in other situations, major changes to current treatment designs may be needed, such as in ponderosa pine ecosystems. All climate effects will be manifest in different ways on different landscapes, and as a result, there is no magic "one-size-fits-all" prescription that can be adopted everywhere. The decision to modify management actions to include climate change effects must always include an assessment of the uncertainty of that modification and most importantly, local conditions.

Climate Change Assessment Techniques

Anticipating ongoing rapid climate change, ecologists are attempting to project the effects of those changes on myriad ecosystem processes across various scales (Clark et al. 2001; Joyce et al. 2014; Schumacher et al. 2006). Using traditional ecological field methods to explore climate change response

may be difficult because of the complex interactions between ecological processes, disturbance, and climate at multiple temporal and spatial scales (McKenzie et al. 2014). It would simply be too costly and time-intensive to sample at the large spatial scales and long timespans need to quantify vegetation response (Keane and Finney 2003).

In general, there are four techniques to assess and project the effects of climate change on vegetation and any other resource concern. The first is *expert opinion,* and it involves having experts in the fields of climate change, ecology, and vegetation dynamics qualitatively assess what will happen to vegetation under various climate change scenarios. The majority of papers about climate change impacts on vegetation used in this report were w itten by experts who have evaluated future climate projections and used their valuable expe ence to dedu how vegetation will respond to different climates. Information from these papers was includ d i this report, but expert opinions were only used when there was no other information from the other assessment techniques.

The second technique involves *field assessment* wh e extensive field sampling or remote sensing projects monitor vegetation change as the climate wa ms Field sampling involves establishing plots in networks across the landscape, detecting change betwe n plot measurements, and correlating these changes to climate data. Van Mantgem and Stephenson (2007), for example, related high tree mortalities to climate change using a network of monitoring plots. Demography studies track individuals over time, rather than use periodic plot-level inventories, to fully understand the role of climate relative to other risk factors like competition, variation in physiology and function, and vulnerability to insects and pathogens. Such demography data sets are rare (Iverson and McKenzie 2013), but one study has tracked more than 27,000 individuals of 40 species for about a decade to address interactions over an area of the southeastern U.S. (Clark et al. 2011). The only demographic dataset available for the NR assessment area is the Forest Inventory and Analysis database, but this extensive dataset has yet to be summarized to describe vegetation shifts due to climate change in the NR, although it has been elsewhere (McNulty et al. 1994). While field assessment techniques are the most reliable and most useful, they are often intractable

(see previous paragraphs) because of the large areas and long time periods needed to properly sample vegetation at the appropriate scales to detect changes as a result of climate.

The third method involves the use of statistical analysis to create empirical models that project climate change response. Most of the studies that project the habitat, range, or occupational shifts of NR tree species from climate warming use species distribution models (SDMs) to project future geographical ranges (Hansen and Phillips 2015; Iverson and Prasad 2002; Warwell et al. 2007). SDMs, also called bioclimatic envelope models, niche models, and species envelope models, are developed by linking current climate with the current distribution of a species of interest by means of advanced statistical modeling (Guisan and Zimme mann 000; Watling et al. 2012). Then, using the statistical model, a future species distribution is computed using rojected future climate data as inputs rather than the past climate. However, SDMs are inherent fl wed for projecting future species distributions in that they relate past species occurrence to climate, resulting in predictions of potential species habitat, not species distribution (Iverson and McKenzie 2013). The projected potential h i at is only reflective of the species' distribution today and does not relate climate to historical distrib tion . One of the biggest limitations to this approach is that many studies have now found that most species istributions are NOT in equilibrium with climate, thereby causing SDMs to miss those areas conducive for the species but where the species is currently absent (type II error). Moritz and Agudo (2013), for example, found many species in the fossil record existed over a wider range of climates than is recorded today.

Another limitation of empirical models is that the critical ecological processes, such as pollination, cone production, seed dispersal, seed germination, seedling establishment, tree growth, mycorrhizae influences, competitive interactions, disturbance, mutualists, and mortality, as well as the many disturbance processes, are not represented in SDMs, and these are the main processes that control species abundance and presence (Iverson and McKenzie 2013; Watling et al. 2012). Dullinger et al. (2012), for example, found that range shifts predicted by SDMs retracted by over 40 percent when seed dispersal was included in the prediction process. Girardin et al. (2008) found that process models were much better at projecting climate change effects on tree growth because they accounted for changes in soil moisture and

growing season. Moreover, the climates used to develop SDMs represent a very small slice of time (50 – 100 years) relative to the long time periods that existing trees, such as the long-lived whitebark pine (>1000 years of age), have survived on the landscape today, and so SDMs cannot capture the climate for all stages of today's tree's life cycle. Most mature trees used to evaluate species occurrence in statistical models may have lived for hundreds to thousands of years and continued to survive despite major changes in climate. Along those same lines, one of the major problems of SDM modeling is that there is no sense of how long it will take for a species to be eliminated from one site and effectively populate a new site, and because migration is a slow process, the timing of SDM model results are often incompatible with management time frames. In a dition SDMs assume that the current distribution of the species is a consequence of climate one, yet we know that fire exclusion, exotic diseases, and management actions have also impacted species o nce (Gustafson 2013; Iverson and McKenzie 2013). Therefore, it is difficult to have any confidence in SDM projections for fine scale applications; they are informative, but not prognostic, especially on short time scales of decade a d half-centuries required by land management. This is especially true when addressing the high uncertainty of the GCM derived climate used by the SDMs.

The last and perhaps the most effective technique uses simulation modeling to assess climate-mediated vegetation responses (Gustafson 2013; Iverson and McKenzie 2013; McKenzie et al. 2014). Here, future projections of climate are input into simple to complex ecological models to simulate the climate change effects (Baker 1989; He et al. 2008; Keane et al. 2004; Merriam et al. 1992; Perry and Millington 2008). A variety of existing models simulate ecological change at broad (global, regional) and fine (point, ecosystem, stand) scales (Bugmann 2001; Cramer et al. 2001). However, landscape scale (38.6 to 386 square miles) models are perhaps the most critical for predicting effects of climate change because this is a key scale at which most ecosystem processes and linkages are manifest and the scale at which most management decisions are made (Cushman et al. 2007; Littell et al. 2011; McKenzie et al. 2014). Finer-scale stand models cannot incorporate important exogenous disturbance regimes because of their limited spatial extent, and coarse-scale dynamic global vegetation models (DGVMs) are unable to

simulate important plant-, species- and canopy-level competition and disturbance effects, such as successional shifts, community dynamics, and differential disturbance effects among species (McKenzie et al. 2014).

To realistically model species composition changes, a mechanistic, process-driven simulation approach might be preferable to emphasize those physical drivers of vegetation dynamics that are directly related to climate (Gustafson 2013). However, mechanistic model design is often overly complex and therefore presently intractable because of (1) overly detailed parameterization of species life histories and physiologies for all species, (2) high complexity of many interacting disturbance factors, and (3) necessary high-resolution mod ling over large areas (Lawler et al. 2006). Dynamic global vegetation models, such as the MC2 model used i this report (next section), operate at scales from regional (hundreds of miles) to global (d ees of latitude and longitude). While DGVMs project climate change across large domains, these models aggregate species into life forms or plant functional types (PFTs), using structural or functional attributes, which may be useless to local managers (Bachelet et al. 2003; Bonan 2008; Neilson et al. 2005). Most of these models project shifts to more drought-tolerant and disturbance-tolerant species or PFTs for future climates. This general shift in vegetation may be offset by physiological changes induced by CO_2 fertilization, as suggested by a DGVM (MC1) that links water-use efficiency to CO_2-simulated expansion of forests into areas where the climate is currently too dry (Bachelet et al. 2003). This particular issue deserves further study to resolve the extent and duration of such mitigating effects of CO_2; these effects could change substantially depending on the outcome of climate change projections.

To be effective at realistically predicting climate change effects, ecosystem models must simulate disturbances, vegetation, and climate, and also their interactions across multiple scales (Purves and Pacala 2008). Yet few models simulate ecosystem processes with the mechanistic detail needed to realistically represent important interactions between landscape processes, vegetation dynamics, disturbance regimes, and climate (Keane et al. 2015; Riggs et al. 2015). Direct interactions between climate and vegetation, for example, may be more realistically represented by simulating daily carbon (photosynthesis, respiration),

water (evapotranspiration), and nutrient (nitrogen, phosphorous) dynamics at the plant level than by simulating vegetation development annually using state-and-transition modeling approaches (Keane et al. [in press]). A fully mechanistic approach, however, may be difficult for both conceptual and computational reasons, and some simulated processes may always require a stochastic or empirical approach (Falk et al. 2007; McKenzie et al. 2014).

We used output from the DGVM MC2 to standardize our evaluation of change and vegetation responses for the NR. Output from this model is presented in appendix 6A, and this output was used by all authors in developing the material on future climate effects on vegetation and in the vulnerability assessment. We did not use M 2 sim lated species projections in the following sections.

MC2 model

MC2 is a new implement i of the MC1 DGVM, which was created to assess the impacts of global climate change on ecosystem structure and function at a wide range of spatial scales from landscape to global (Bachelet et al. 2001; Peterman et al. 2014). MC2 is short for "MC1 version 2." MC1 was produced by combining physiologically-based biogeographic rules, originally defined in the Mapped Atmosphere-Plant-Soil System (MAPSS) model (Neilson 1995), with biogeochemical processes packaged in a modified version of CENTURY (Parton et al. 1987) and a new fire disturbance model, MCFIRE (Lenihan et al. 1998; Lenihan et al. 2003). The three linked modules simulate biogeography (lifeform interpreter and vegetation classifier), biogeochemistry, and fire. The main functions of the biogeographic module are to (1) predict lifeforms, that is, the composition of deciduous-evergreen tree and C3-C4 grass lifeform mixtures; and (2) classify those lifeforms and their associated biomass into different vegetation classes using a climatologic rule base. The biogeochemical module simulates monthly carbon (C) and nutrient dynamics for a given ecosystem. Aboveground and belowground processes are modeled in detail and include plant production, soil organic matter decomposition, and water and nutrient cycling. Parameterization of this module is based on the lifeform composition of the ecosystems, which is updated annually by the biogeographic module. The fire module simulates the occurrence, behavior, and effects of severe fire. Allometric equations, keyed to the lifeform composition supplied by the

biogeographic module, are used to convert aboveground biomass to fuel classes. Fire effects, specifically plant mortality and live and dead biomass consumption, are estimated as a function of simulated fire behavior (fire spread and fire line intensity) and vegetation structure. Fire effects feed back to the biogeochemical module to adjust levels of various carbon and nutrient pools to alter vegetation structure (e.g., leaf area index levels and woody versus grass-dominated vegetation).

The MC2 DGVM model simulations were generated by Tim Sheehan (Conservation Biology Institute). Inputs to the MC2 model include soil (depth, texture and bulk density), annual average atmospheric CO_2 concentration, and monthly average climate variables (monthly precipitation, mean vapor pressure, and means of daily maximum and minimum temperatures). Historical climate data (1895-2008) were obtained from the PRISM group (Daly et al. 2008) and were upscaled to 30-arc-second resolution (~0.23 square mile). Soils data were derived from STAGSGO (SCS 1991) by Kern (1995, 2000) and were scaled to the resolution of the climate data. Future climate projections were available from various GCMs, and we chose the MIROC 3.2 medres (Hasumi and Emori 2004) based on its relatively high overall ranking according to Mote and Salathé (2010). GCM future projections were downscaled to 0.23 mi^2 using the delta or anomaly method (Fowler et al. 2007). Anomalies between future and mean monthly historical (1971-2000) values were calculated to project estimates for each climate variable and each future month across the study area. We evaluated model output based on two IPCC Special Report on Emissions Scenarios greenhouse gas emission scenarios (Nakićenović et al. 2000) - A1B and A2. Future projections based on the most recent generation of emissions scenarios, the Representative Concentration Pathways, were not available across the entire NR area, but the two generations of models are relatively similar in their estimates of global temperature change and spatial patterns temperature and precipitation change (Knutti and Sedláček 2013).

To evaluate potential climate impacts on vegetation assemblages and disturbance regimes and the interaction with land management, we evaluated a suite of vegetation-related and fire occurrence variables output by the MC2 model under historical (1971-2000) conditions and future projections for mid-century and end-of-century. Specifically, we compared past vegetation distributions across the NR

with fire suppression and without, and made similar comparisons for two future years, 2050 and 2100, under both the A1B and the A2 emissions scenario (appendix 6A). Aboveground processes were examined comparing the amount of carbon in live and dead biomass for three time periods (historical, 2030-2050, 2080-2100) and with/without fire suppression (appendix 6A). Potential evapotranspiration was also evaluated to compare possible changes in aridity (over similar time spans and land management measures). Finally, projected changes in fire disturbance were examined comparing estimated fire rotation and the percent of study area burned by time period and suppression management (appendix 6A).

FOREST VEGETATION RESPONSES TO CLIMATE

In general, many scientists feel that the impacts of climate change on forest vegetation will be primarily driven by vegetation responses to shifts in disturbance regimes, and then secondarily, through direct effects of vegetation with climate through shifts regeneration, growth, and mortality processes at both individual plant and community scales (Dale et al. 2001; Flannigan et al. 2009; Temperli et al. 2013). And most of the expected climate changes are reduced precipitation and increase temperatures (see chapter 3) resulting in reduce water available to trees and understory plants. These effects will be highly variable across time, from year to year and from day to day, and across space, as the footprint of the new climate becomes manifest at fine to coarse scales. Trees will respond to projected reduced water availability, higher temperatures, and changes in growing season in diverse manners, but since trees cannot pick up their roots and move, any changes in vegetation composition and structure will be the result of changes in both a plant's life cycle processes and its responses to disturbance. This section discusses some general responses that trees and forested vegetation might have to projected climates.

Individual Plant

The impacts of climate on forest vegetation can occur as both direct and indirect effects. Direct effects are the immediate and long-term impacts of increased temperature and decreasing water availability on vegetation life cycle processes, as discussed at length throughout this document. Indirect effects, such as changes to fire, insect, and disease regimes, however, may be more important and longlasting than direct effects.

In short, there are several important modes of response of plants to changing climates (Joyce and Birdsey 2000). The first is changes in *productivity*; plant productivity may increase in the future because of increasing temperatures, longer growing seasons, more variable precipitation, and CO_2 fertilization (Aston 2010; Joyce 1995). Increases and decreases in productivity are related to changes in cone crops, tree vigor, and tree defenses. The window of successful seedling *establishment* will change (Ibanez et al. 2007); increasing drought and high temperatures may narrow the time for effective regeneration in low elevation NR forests and widen the window in high elevation forests. Climate may directly cause tree *mortality* due to temperature or moisture stress on trees; there have been increases in tree mortality around the world from drought and increasing temperatures (Allen et al. 2010; Williams et al. 2010). This of course is related to productivity, but not entirely. Extreme climate events, such as late growing season frosts and high winds causing blowdowns, may increase because of the predicted increases in climate variability (Notaro 2008), and these events may cause *catastrophic mortality* events (Joyce et al. 2014). There will also be disruptions in *phenology* as climates change; many plants may experience major damage or mortality as phenological cues and events are mistimed with new climates (e.g., flowering occurring during dry portions of the growing season) (Cayan et al. 2001). Another related mode is the *genetic* limitation of the species or tree to respond to climate change (Hamrick 2004); specialists may become maladapted to new climates (St. Clair and Howe 2007). Lastly, plants can respond to climate-mediated changes in *disturbance* in myriad ways (Aitken et al. 2008). This section only deals with those causal mechanisms that drive direct climate responses; the indirect climate-mediated disturbances responses are detailed in a later section.

Direct impacts of temperature on plant growth may increase both photosynthesis and respiration (Waring and Running 1998). Plant photosynthesis rates increase with temperature up to an optimum and then decline thereafter, with the optimum being species-dependent. If projected temperatures exceed the photosynthetic optimums for NR tree species, such as those in the lower elevation NR forests, then plant growth might suffer. However, there may be many portions of the NR where temperature increases probably will not exceed optimums, and there may be photosynthetic gains, such as in montane and

subalpine areas. This, of course, depends on whether sufficient water is available to support increased photosynthesis. Respiration also increases with temperature, thus photosynthetic gains may be lost through growth and maintenance respiration. Respiration occurs even when stomata are closed, so high temperatures coupled with low water availability may result in high respirational losses with few photosynthetic gains (Ryan et al. 1995).

Increased atmospheric CO_2 levels may also directly modify ecophysiological growth processes. Oxygen and carbon dioxide compete for active Rubisco (primary enzyme used in photosynthesis) sites. Higher atmospheric CO_2 concentrations may increase internal leaf CO_2 concentrations, thereby ensuring CO_2 reaches most of the Rubisco sites, resulting in photosynthetic increases of 2 to 250 percent depending on site and species (Ehleringer and Cerling 1995). Conifers may also experience increased water use efficiency (WUE) in future water-limited environments, and increased WUE may compensate for decreases in water availability and increase growth rates in water-rich environments (Waring and Running 1998). WUE is the ratio of water used for plant metabolism (photosynthesis and respiration) to the water lost to transpiration. With higher CO_2 concentrations in the atmosphere, the plant would obtain more CO_2 during the time the stomata are open, resulting in less transpiration losses. Leaf biomass is usually the first to increase as plants attempt to optimize photosynthesis by growing more photosynthetically active tissue (i.e., more leaf area). However, increases in leaf area index are often transitory and greatly dependent on available nitrogen and water variability. Interestingly, increases in leaf area might also result in greater rainfall interception, higher snow collection, greater canopy evaporation, and shadier forest floors that might heighten forest soil aridity. It is also postulated that elevated CO_2 levels will change root to shoot ratios, with more aboveground biomass and fewer roots due to higher photosynthesis and WUE (Chmura et al. 2011). Increased atmospheric CO_2 levels and increasing temperatures can also interact to increase growth. Photosynthesis has temperature optima that are different among tree species and warmer temperatures might be closer to the new temperature optima, especially during the cooler early growing season, perhaps resulting in faster growth.

Another major direct effect of warming temperatures is longer growing seasons (Cayan et al. 2001; McKenzie et al. 2008); that is, increases in temperatures often lengthen growing seasons for forest plants. There are concerns that future climates are projected to be highly variable, and the coupling of highly variable daily weather with highly variable growing seasons may increase the chances that plants will be more susceptible to adverse weather during fragile phenological stages (Hanninen 1995). Warm conditions in the early spring, for example, might stimulate bud burst and early growth, only to have these expanding tissues frozen by subsequent frost events. Plant phenological cues may be disrupted or triggered inappropriately because of high weather variability, and while this variability might result in minor damage for mature individuals, it may be fatal for seedlings. This may be especially true in localized frost pockets and narrow valleys that accumulate cold air, resulting in frequent frost during the early growing season. Warmer temperatures may reduce and perhaps eliminate growing season frosts in mountain valleys, thereby allowing more frost-susceptible species, such as ponderosa pine and western larch, to exist in traditional lodgepole pine, subalpine fir (*Abies lasiocarpa*), and Engelmann spruce (*Picea engelmannii*) habitats. Chmura et al. (2011) note that increased temperatures may result in decreased winter chilling that could result in delayed bud burst, reduce flowering, and seed germination. Winter dormancy prevents trees from growth flushes during warm winter periods, and future climates may trigger changes in winter dormancy and subject trees to high mortality during those cold snaps after the winter warming.

Snowpack dynamics are also directly influenced by changes in temperature and precipitation and declining snowpacks are expected under future climates (Mote et al. 2005). Since most of the water used by NR trees usually comes from snowmelt (Waring and Running 1998), the amount and duration of snowpack have the potential to influence regeneration and growth patterns of forest communities throughout the NR. Warming temperatures may cause earlier snowmelt, leading to an earlier start of the growing season. However, earlier snowmelt could also result in longer periods of low soil water during the remaining part of the growing season, effectively shortening the growing season. Earlier snowmelt may also result in greater competition for water across the plants and species that comprise the complex

plant communities of the NR. Plants with roots in the topmost layers of the soil might be able to more effectively capture the rainfall that used to occur as snowfall. This may favor grasses and some forbs over shrubs and trees (Daly et al. 2000). The lower snowpack may allow longer growing seasons in those subalpine and upper subalpine communities where cold and snowpack duration govern tree regeneration and growth; production and regeneration will likely increase with decreasing snowpacks, especially in those high mountain environments where water is rarely limiting.

An indirect effect of climate change will be the shift in distribution of microsites that facilitate tree regeneration (Jones 2013). While effects of climate change at coarser scales mostly relate to tree growth and mortality, changes to microsite conditions will likely govern tree regeneration (Petrie et al. 2016). Microsites suitable for tree regeneration must be addressed in a spatial and temporal context; suitable conditions for tree establishment may be suitable all year on small microsites of up to 1.2 square-yards, for example, while larger microsites may only be conducive for regeneration during the spring. Researchers in Washington State found that even with major changes in climate, there probably will be ample microsites that are suitable for regeneration of trees (Little et al. 1994). In the NR, however, projected climate changes will probably result in smaller and more ephemeral microsites for regeneration, and it could be that the size, distribution, and duration of suitable microsites will vary more each year and most regeneration will only occur during "wave" years (i.e., years with favorable weather conditions) where plentiful suitable microsites are widely available for long periods of time (see next section).

Climate change can also indirectly impact vegetation by altering mycorrhizae dynamics (Amaranthus et al. 1999). Nearly all NR conifers depend on mycorrhizae for enhanced water use and nutrient absorption. Even whitebark pine, a species that lives in areas with the highest precipitation in the NR, enjoys a mutualistic relationship with several species of fungi (Mohatt et al. 2008). Many trees, particularly those in the seedling and sapling stages, need mycorrhizae to survive, especially in areas of periodically severe water shortage (Walker et al. 1995). The migration of NR tree species to more favorable sites in future climates may be entirely governed by the ability of the mycorrhizae to also populate these areas to allow or facilitate tree species establishment (Lankau et al. 2015). Allison and

Treseder (2008) found warming increased fungal interactions, but drying caused significant decreases. Without viable populations of mycorrhizae, tree species movement might be significantly slowed or stopped. New microsite conditions created by predicted future climates may be inhospitable to mycorrhizae, but so little is known about how these fungi shift with climate that it is difficult to evaluate how they will respond to climate change (Fitter et al. 2000). However, mycorrhizae responses to climate change after increased fire may be more important; fire may reduce the fungi in some areas. This may be especially true if the large, severe fires projected for the future actually occur (Stephens et al. 2014). Severe fires may kill all trees in a large burn, thereby eliminating the host for the mycorrhizae, and perhaps eventually the mycorrhizae itself. Establishment of trees into these burned areas can be delayed for long periods, decades or even centuries, as both mycorrhizae and trees revegetate the area together (Schowalter et al. 1997).

Perhaps the most important future indirect ecological concern is the role of today's forest conditions and how they affect the ability of tree species to respond to future climate change. Ample research has shown that past and future human land use activities often result in ecological impacts that overwhelm any direct or indirect climate change effects (Moritz and Agudo 2013). Nearly a hundred years of fire suppression activities have resulted in increased tree regeneration and denser forest canopies, coupled with increases in duff, litter, and downed, dead woody fuel (Arno 1998; Ferry et al. 1995; Keane et al. 2002). Trees in these dense forests are in greater competition for the little water that is available for growth, along with light and nutrients. As a result, trees in many fire-excluded stands are stressed, making them highly susceptible to mortality from secondary stressors, such as insect and disease outbreaks (Anderegg et al. 2012; Wikars and Schimmel 2001), drought (Allen et al. 2010), and fire (Hood et al. 2007). Increased tree densities may also foster increases in severities of subsequent disturbances, resulting in more individuals dying and creating larger patches of mortality.

Another ecological concern closely related to fire exclusion is the current climate-mediated decline in forest communities that have recently become established as a result of fire exclusion. Some forests in the NR, including the limber pine (*Pinus flexilis*) communities along the Rocky Mountain Front, became

established during the fire exclusion era but may now be declining in some portions of the NR because of increased drought. Other NR forests, such as ponderosa pine, now have atypical forest compositions and structures due to the century of fire exclusion, and these now denser forests are stressed from both overcrowding and climate change (Millar et al. 2007b). Had fires been allowed to burn, there would probably be significantly less mortality, either from climate change or disturbance, as compare to what we are experiencing today, and the mortality levels probably would not be projected to be as high in the future (Holsinger et al. 2014). Moreover, there are areas in the NR where trees have encroached into dry grasslands (Arno and Gruell 1986), montane meadows, and subalpine forb fields (Butler 1986). Now, due to increased temperatures and decreased water availability, some of these recently established trees are now dying. Examples include the limber pine expansion along the Rocky Mountain front (Taylor and Sturdevant 1998), Douglas-fir encroachment into dry prairie (Arno and Gruell 1986), and subalpine fir into GYA forb fields (Bigler et al. 2005). There is concern as to whether climate change represents a threat to these modern forest types that were probably rare in the historical record. Does increased vulnerability in 100-year-old limber pine forests really constitute a management concern? Or is the increase in mortality expected because the forests established in wet periods of the fire exclusion era?

Many forest species in the NR may respond to direct climate warming and drying by expanding their range into new habitats. Migrating to a new site has historically been the main response of plants to climate change (Huntley 1991). Migration requires that the species have the ability to quickly occupy newly desirable sites of the future before other species get there or outcompete other species once they are there. Neilson et al. (2005) detail four basic components of migration (moving to a new site): fecundity, dispersal, establishment, and growth. To be successful in the future, a species must produce enough seeds or propagules (*fecundity*) that are easily dispersed to new sites (*dispersal*), and the seedlings that become established on these sites must be able to grow (*establishment*) so that they can also produce ample propagules that are then dispersed even further (*growth*). But, as Davis et al. (2005) note, the species also has to have the genetic capacity to migrate to the new climate and survive into maturity. Adapting *in situ* can take many forms, by reducing leaf area to minimize transpiration losses, or by surviving perturbations

in the new disturbance regimes created by climate change. Most NR tree species are long-lived and genetically plastic so that they can survive the wide fluctuations of weather in the future, but the ability to handle both deep drought and modified disturbance regimes may be the most important factor dictating future distributions of forest species (Allen et al. 2010).

It is widely thought that warming climates will result in upward shifts in the elevational distribution of plant species. For example, Lenoir et al. (2008) found that some plant species have moved upward in elevation at a rate of 31.7 yards per decade. However, it is unclear whether such elevational shifts will drive long-term changes in forest communities, or if other predominating forces will outweigh these upward trends. For example, fire plays a dominant role in most NR ecosystems, determining landscape structure and processes. Since even more extensive wildfires are expected as climates change, effects of these large events may overwhelm any shifts in distributional ranges of forest species resulting from climate warming. Also, most plants in the NR have slow migration rates, mostly because they are adapted to fire and as such rely more on regenerative organs (e.g., sprouting) than seed dispersal. Finally, implications of an upward elevational migration on forest communities need to be considered within a temporal and spatial context. That is, it may take a century or two for tree species to demonstrate significant elevational shifts due to their long life cycles, old maturation ages, highly variable weather, and low dispersal potentials. The potential for tree species to migrate may be entirely different in each of the unique mountain ranges in the NR area, depending on a host of abiotic and biotic factors (e.g., precipitation levels, invasive species) and available colonizing species.

Most projections for the response of vegetation to climate shifts are for populations of species, not for communities. Little is known about how composition and abundance of biota will change at a community level in response to climate shifts. Will new plant communities be dominated by generalist species that can exist across a wide variety of biophysical settings? Or, will future communities be similar to historical analogs where fire-adapted species dominate? Will future communities be composed of species collections that were historically rare? Answers to these questions have important implications for future land management in that there is a great deal of synergy between plants and species in historical

communities, such as interacting via root-grafting, sharing mycorrhizae, and relying on common pollinators, and future community composition may not have as many interactions. Moreover, future communities may not be as diverse because they may be dominated by a limited suite of species.

Climate change can impact important phases of the life cycle processes of plants: reproduction, regeneration, growth, and mortality. Moreover, it can impact plants at various scales from the needle to the tree to the forest, and over seconds to days to years to centuries (Eamus and Jarvis 1989). The following sections detail possible climate change effects by life cycle processes.

Reproduction

Cone and seed crops for many NR trees could be both adversely and beneficially affected by climate change (Ibanez et al. 2007; LaDeau and Clark 2001). Low elevation, xeric forests might experience fewer and smaller cone crops because of increased stand density and water stress. Cone crops might also have a lower percentage of viable seed because of increased tree stress. The infrequency of cone crops coupled with low seed numbers may result in the lack of regeneration in recently burned areas, thereby causing a shift to non-forest vegetation.

The opposite might be true in higher, colder environments where increased temperatures will increase growing season length and thereby increase potential for more cone crops with greater number of seeds. Spruce-fir communities might produce so much seed that they may overwhelm regeneration of other conifers, especially after mixed-severity fires. Subalpine pine species such as whitebark and lodgepole pine have unique cone characteristics (whitebark pine cones facilitate bird dispersal, while lodgepole pine cones may be serotinous and opened only by fire), so they may need to rely on disturbance for increased cone abundance.

An indirect result of the interaction of fire, vegetation, and climate is that as fire becomes frequent, some species, primarily trees, may be killed by fire before they reach reproductive maturity and fail to set cones. Holsinger et al. (2014), for example, found that future fires were so frequent in a western Montana watershed that lodgepole pine seedlings were killed by fire before they were reproductively mature (around 15 years). Keane et al. (1990) found that ponderosa pine forests needed occasional inter-fire

periods to be greater than 35 years to allow pine seedlings to grow above the lethal scorch height. If fire is too frequent, plants will not be able to grow to reproductive maturity or the reproductive organs might always be scorched by fire.

Climate warming and increased variability will also affect the phenology of cone crops, but impacts may be minimal as plants adapt to new conditions. Some predict higher frost mortality of emerging cones due to an earlier onset of the growing season coupled with high daily temperature variability and lower flowering and seed germination because chilling requirements will not be met (Chmura et al. 2011). Others suggest that frequency and abundance of cone crops will be reduced in the future because of high tree stress from drought (Ibanez et al. 2007). However, the increased productivity projected for many NR forests may overwhelm minor losses from extreme weather events over the long run.

With changing climate, some tree species might be restricted from their current range because warmer temperatures may not allow chilling requirements for the seed (Shafer et al. 2001). The chilling requirement was a major evaluation factor in determining climate change vulnerability in Devine et al. (2012). Similarly, new climates may be asynchronous with many tree species' phenology. Seed dispersal, for example, may occur at the driest or warmest times. Phenological keys may be out of sync with new climates, especially in a highly variable future, resulting in reduced flowering, growth, and reproduction. Interestingly, these phenological mis-cues may also occur in disturbance agents; highly variable weather may result in occasional deep frosts that kill beetle larvae, for example.

Regeneration

The life cycle phase where tree species are perhaps most susceptible to shift in climate is regeneration (Solomon and West 1993). Most tree species in the NR reproduce by producing seeds that fall to the ground to germinate and then grow into seedlings that then become mature trees. Microsite conditions needed for successful establishment are so demanding that seed germination and survival, especially for seeds that are wind-dispersed, is rarely successful (Anderson and Winterton 1996). The successfully germinated seed produces a fragile radicle (embryonic root) that must penetrate the litter, then duff, then soil to put down a root system that will eventually feed the growing aboveground tissue. This penetration

process demands moist soil conditions or the radicle and associated cotyledon (developing leaves) and hypocotyl (stem) will dry and die. To succeed in becoming a seedling, suitable moisture conditions must persist for long periods of time. Since few seeds become seedlings, many tree species often rely on high seed production to overcome mesic site conditions to ensure successful regeneration; by producing millions of seed, hopefully some will land on moist microsites suitable for establishment. For dry xeric forests, most of the successful regeneration occurs in those wet years when soils are moist for a suitable time and solar insulation does not kill developing leaves and stems. These moist years are often called "wave" years, and the pulses of regeneration that occur in these years results in even-aged patches. Projected climate change will likely decrease the frequency of these wave years, and on the driest sites, the frequency of wave years may be so low that no regeneration may occur, depending on the species. Planting on these newly dry sites may also be ineffective because of the short window of high soil moisture.

At the highest elevations, where the depth and duration of snow cover often governs tree regeneration, regeneration may be enhanced by warming. Most years are moist enough for regeneration at high elevations, but snow remains on sites too long for successful regeneration in many years. With warming temperatures, snow will likely melt earlier, giving more time for seedlings to survive and grow. Previous warm wave years in upper subalpine ecosystems are often dated using seedling and sapling tree ages. Recent observations of invasions of subalpine meadows and balds by subalpine fir, alpine larch (*Larix lyallii*), and Engelmann spruce is testimony of the high number of sequential warm years over the last decade that have facilitated high mountain regeneration (Butler 1986). Therefore, climate warming is expected to enhance regeneration at the subalpine and upper subalpine forest ecosystems.

Future climates and their high variability may also impact the ability of forest species to successfully germinate. Seed chilling requirements may not be met during mild winters, thereby reducing germination, and it could be that germination will be delayed to the driest parts of the growing season. Nitschke and Innes (2008) found that the chilling requirements were not being met for the majority of low elevation

3987 tree species in British Columbia. Soil temperatures may be too high, causing greater mortality of both
3988 germinants and established seedlings (Rochefort et al. 1994).

3989 Climate change may also affect the dispersal properties of the reproductive propagules. Rodents that
3990 disperse seeds of ponderosa and western white pine, for example, may migrate or decline because of
3991 warmer, drier habitat conditions. Whitebark pine is dispersed by the Clark's Nutcracker (*Nucifraga*
3992 *columbiana*) that might shift habitats because of climate-mediated changes; nutcrackers usually nest in
3993 high elevation areas with ample snowpack (Tomback 1998), and these nesting habitats are predicted to
3994 decline in the future (Westerling et al. 2006). Longer and drier summers and autumns also mean that seed
3995 dispersal may take place when the ground and litter is the driest and least hospitable for seed germination
3996 and establishment (Neilson et al. 2005). Human- and ungulate-mediated seed dispersal of exotic species
3997 could also be different in future climates; warmer, drier climates might reduce human and ungulate use to
3998 lower exotic seed dispersal. Changes in landscape spatial heterogeneity may also influence mechanisms
3999 of non-wind seed dispersal by shifting potential seed sources and changing patch sizes.

4000 *Growth and Mortality*

4001 It is possible that there will be increases in productivity in some NR forests with warming climate,
4002 resulting in increased vigor and more resistance to stressors (Joyce 1995). Worldwide, Lin et al. (2010)
4003 compute increases in biomass of over 12 percent (20 percent in forests) with climate warming. However,
4004 Chmura et al. (2011) note that even with increased productivity, most forests will experience reduced
4005 growth and survival as the climate interacts with the entire tree species life cycle.

4006 Climate can adversely impact growth and mortality in a number of ways (Bugmann and Cramer 1998;
4007 Keane et al. 2001). Projected decreases in water availability may result in shorter effective growing
4008 seasons and longer periods of continued drought in the drier NR forests (Williams et al. 2010). Longer
4009 drought might require NR conifers to close stomata longer to conserve the little water available. Some
4010 xeric conifers, such as ponderosa pine and limber pine, have excellent stomatal control and are able to
4011 remain closed for long periods of time. Other conifers, such as Douglas-fir, have poor stomatal control,
4012 and this may drive leaf water potentials to extremely low values that might result in intercellular

cavitation, tissue damage, and perhaps plant mortality (Sala et al. 2005). The projected increased temperatures will increase both maintenance and growth respiration, especially during the periods when stomata are closed, and this will require additional photosynthetic gains to counterbalance respiration losses, thus demanding even more water in a drier future. If photosynthetic production cannot exceed respiration demands, then the plant becomes stressed, thereby increasing the probability of mortality and susceptibility to insects and disease.

In the most mesic and montane ecosystems, it is likely that a warming climate will enhance growth and decrease mortality. Wu et al. (2011) found increases in plant growth for many forest and rangeland ecosystems with warming worldwide. Earlier growing seasons with ample moisture, such as that predicted for mesic montane NR forests, will likely result in increased productivity and greater growth. Although this increased biomass could result in additional foliar material to increase canopy bulk density and therefore result in higher crown fire potential, it could also result in higher growth rates for timber production and forage. This will be especially true in the higher mountain environments where cold temperatures, not moisture, limit tree growth. Longer, warmer growing seasons might result in higher productivities and greater biomass. The increased biomass will also increase competitive interactions between species, thereby favoring the more shade-tolerant individuals in the absence of disturbance. However, increased biomass could foster more intense fires, and maybe greater insect and disease outbreaks, such that the more disturbance-tolerant species might ultimately inherit the landscape.

Genetics Concerns

It is widely accepted that climate limits species distributions. Climate is also a major environmental factor affecting plant phenotypes and a critical agent of natural selection, molding among-population genetic variation. Plant adaptations to local environments have often developed a clinal or continuous response to abiotic and biotic factors such as temperature, frost-free periods, precipitation, fire, insects, and disease. More recently, a wider appreciation of ecotypic or a discontinuous response to environmental gradients is being recognized based on different soil or edaphic properties. The combination of clinal and

4038 ecotypic environmental gradients across the landscape enhances or limits plant survival and long-term
4039 persistence.

4040 A plant's hardiness is determined by its genetic background. Ecological genetics or genecology is a
4041 field of study investigating a species genetic architecture, phenotypic plasticity and adaptive capacity in
4042 the context of interactions among and between plant populations and environmental gradients. Ecological
4043 genetics and common garden studies are employed to study individual species. Well-designed common
4044 garden studies provide information on a species' adaptive strategy (e.g., generalist, intermediate, or
4045 specialist; table 6.1) (Rehfeldt 1994). Processes that shape a species' genetic architecture include natural
4046 selection, migration, genetic drift, and its mating system. Thus, the ability of plant populations to respond
4047 to climate change is influenced by the underlying patterns of genetic variation.

4048 Molecular markers can reveal significant genetic diversity and divergence among populations
4049 associated with variation among populations (table 6.1). Past historical events shaping divergence among
4050 populations can be shaped by fire, volcanic activity (e.g., range shifts east of the Cascades indicated
4051 ponderosa pine was replaced with lodgepole pine, and later repopulated by ponderosa pine after the
4052 Pleistocene [Hansen 1942, 1947, 1949]), glaciation (Hamrick 2004), seed dispersal agents (whitebark
4053 pine, limber pine, and ponderosa pine) (Lorenz and Sullivan 2009), and pollinator history. Plants that are
4054 insect-pollinated or rely on animal-dispersed seed are more vulnerable to climate change because of the
4055 requirement for interaction with another organism.

4056 Genetic diversity imparts a species' ability to adapt to changing environments, colonize new areas,
4057 occupy new ecological niches, and produce substantial and robust progeny that persist in the long term
4058 (Ledig and Kitzmiller 1992). The entire species does not adapt to environmental change over time, but
4059 populations within a species do. Genetic diversity is important to species ability to colonize new areas and
4060 occupy new ecological niches (USDA 2006). Species and populations of plants most vulnerable to
4061 climate change are rare species, genetic specialists, species with limited phenotypic plasticity, species or
4062 populations with low genetic variation, populations with low dispersal or colonization potential,
4063 populations at the trailing edge of climate change, populations at the upper elevational limit of their

4064 distribution, and populations threatened by habitat loss, fire, disease or insects (Spittlehouse and Stewart
4065 2003; St. Clair and Howe 2011). The underlying assumption regarding forest and rangeland species is as
4066 climate continues to change, populations will become poorly adapted to their local climates, whereby
4067 poorly-adapted populations will become stressed. A species ability to respond to environmental change is
4068 closely tied to its adaptive strategy and the mechanisms that shape its genetic structure, thus this
4069 assumption may be false. Some species such as Douglas-fir, juniper (*Juniperus* spp.) and sagebrush
4070 (*Artemisia* spp.) may show range expansion in the future (Hansen and Phillips 2015).
4071 Historical gene flow (seed and pollen movement) creates patterns of genetic differentiation that may
4072 allow some populations to be more predisposed to respond to climate change than others. Fragmentation
4073 is a critical issue for plant populations because isolation and a relatively few number of individuals can
4074 promote inbreeding and loss of genetic diversity (Broadhurst et al. 2008; Potter et al. 2015). Information
4075 from this field also informs research and management of each species' adaptive capacity and vulnerability
4076 to climate change (i.e., its direction and magnitude). Gene flow from adjacent populations that are more
4077 typical of future climates have the ability to increase the rate of adaptation by introducing genetic
4078 variation that is pre-adapted to warmer or drier climates (Aitken et al. 2008). A practical application of
4079 this field of study facilitates evaluating options for responding to environmental gradients and climate
4080 change, for example choice of the appropriate population or seed source to increase the likelihood of
4081 attaining a desired reforestation, restoration or revegetation outcome.
4082 The majority of species may not be able to adapt quickly enough to keep pace with projected
4083 migration rates of 328 to 3280 ft y^{-1} with climate change (Davis 1989; Malcolm et al. 2002). Davis and
4084 Shaw (2001) and Davis et al. (2005) suggest plant adaptation may be a more important factor in response
4085 to climate change due to the slow rates of plant migration impeded by population fragmentation as a
4086 result of land use patterns. Where Hamrick et al. (1992) and Hamrick (2004) suggest that long-lived
4087 species with high levels of genetic variation are well-positioned for climate change, Etterson and Shaw
4088 (2001), Jump and Peñuelas (2005), and Parmesan et al. (2006) argue the ability of forest trees to adapt or

migrate and follow climatic shifts may be *restricted* by their long life spans, long generation intervals and long juvenile phases.

Long-lived or perennial species often maintain high levels of genetic variation and gene flow, which facilitates their ability to evolve in response to changing climates (Hamrick 2004; Hamrick et al. 1992). Whitebark pine is an example of a long-lived species with high levels of genetic variation (Mahalovich and Hipkins 2011) and extensive gene flow (Richardson et al. 2002) attributed both to long distance seed caching by Clark's Nutcracker and an outcrossed mating system involving wind pollination (Richardson et al. 2002). Since plant populations are genetically adapted to local climates, the climatic tolerance of individual populations is often considerably narrower than the tolerance of the entire species.

Existing knowledge of the adaptation of NR plant species is well documented for conifers (Rehfeldt 1994) but incomplete or lacking for other native plants. A species does not necessarily have *one* adaptive strategy, though most do. Differences in adaptive strategy can be characterized by varietal differences (e.g., *P. ponderosa* var. *ponderosa* or Rocky Mountain ponderosa pine [*P. ponderosa* var. *scopulorum*]), changes in elevation and geography. For example, *P. ponderosa* var. *ponderosa* is characterized as having an intermediate adaptive strategy; however, at high elevations (>5,000 ft), ponderosa pine has a specialist adaptive strategy. Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) is characterized as having a specialist adaptive strategy (i.e., its genetic variation is organized into numerous local populations, finely tuned to site-specific gradients); however, at higher elevations east of the Continental Divide, Douglas-fir has a generalist adaptive strategy (i.e., its genetic variation is organized into one or a few populations capable of surviving, growing and reproducing over a broad range of environments) (Rehfeldt 1989). Species possessing a generalist adaptive strategy are proposed to fair better than their intermediate and specialist counterparts with respect to climate change.

Other native plants' (e.g., shrubs, forbs, grasses, and sedges) patterns of adaptive variation are more complex, being both clinal and ecotypic, involve multiple life forms (e.g., annual, biennials, and perennials) and different ploidy levels (multiple copies of DNA, 4X, 6X, 8X, etc.) where 2X is the base level where one copy of DNA is inherited on both the maternal and paternal sides. Grasses are

4115 hypothesized to be largely generalists and less vulnerable to climate change; however, ecotypic variation
4116 can overlay the generalist adaptive strategy. Forbs are largely insect-pollinated and coupled with longer
4117 growing seasons and changes in phenology and are more vulnerable to climate change.

4118 *Soil Responses*

4119 Each soil in the Northern Rockies has an inherent ability to produce vegetation based on climate,
4120 parent material, topography, soil biology and soil development (Armson 1977). Soil supports production
4121 of vegetation through interactions of nutrient cycling, soil hydrology, soil biology, physical support, and
4122 filtering (or buffering) (Attiwill and Leeper 1987). Amount of soil organic matter (quality and quantity),
4123 moisture (season and amount), temperature, and acidity may all be affected by climate change and
4124 ultimately affect functional properties of soils and perhaps productivity (Bonan 2008).

4125 Climate change affects the growth, mortality, and decomposition of vegetation, which in turn impact
4126 soil biology (Waring and Running 1998). Warmer temperatures, increased CO_2, and longer growing
4127 season contribute to higher vegetative growth. Warmer temperatures, increased drought, and greater
4128 susceptibility to insects and disease may lead to increased mortality. Although higher temperatures will
4129 increase decomposition rates, the moisture required for decomposition may increase or decrease, leading
4130 to variable changes in decomposition rates (Davidson and Janssens 2006). Decomposition will increase
4131 with a combination of warmer temperature and higher moisture, whereas decomposition will decrease if
4132 summer droughts extend later (Rustad et al. 2000). Increased fire frequency and would generally reduce
4133 soil organic matter across large landscapes (Dooley and Treseder 2012).

4134 Higher air temperatures will directly increase soil temperature. Increased vegetative cover would
4135 provide dense shade, thus decreasing soil temperature, whereas decreased vegetative cover would result
4136 in more heating at the soil surface. Dry soil, which is expected to be more common during future drought,
4137 would have wider temperature fluctuations than wet soil, which is buffered by the high heat capacity of
4138 water. In addition, if snow cover is lower but extreme cold periods continue to occur, soils will experience
4139 lower minimum temperatures (Davidson and Janssens 2006).

The vulnerability of soils to future climate change is summarized in table 6.2. Effects will differ greatly, depending on local soil characteristics, the magnitude and trend of climate change, and vegetation response.

Stressors – Biotic and Abiotic Disturbances

A warming climate will rarely be the direct agent of change for the NR tree species and communities. Most of the changes in vegetation will likely be a result of responses to disturbance or some combination of other stressors to climate change (Keane et al. [in press]). Climate change has marginally to severely altered disturbance regimes in the western U.S. (Liu et al. 2011). As we consider past climate variability and then add the projections in temperature and precipitation, there may be significant changes occurring across NR forests because of a changing water balance and the role of disturbances such as wildfires, insects and diseases. Whether it is invasive species (e.g., white pine blister rust), drought, uncharacteristic wildfires, elevated native insects and disease levels, loss of historically fire-adapted tree species, unusually high forest densities compared to historical conditions, or some other combination of disturbance agents that serve to stress trees and forest ecosystems, recent research suggests that climate change will likely further exacerbate those stressors and "stress complexes" (Iverson and McKenzie 2013). The following sections present a short summary on four major classes of stressors important in the NR. More detailed summaries of disturbance responses and their interactions to climate change are presented in chapter 8 of this report.

Wildland Fire

Wildland fire is pervasive throughout NR forest ecosystems and was historically the dominant landscape disturbance in the region (Baker 2009; Barrows et al. 1977; Wellner 1970). Fire exclusion since the 1920s has disrupted annual occurrence, spatial extent, and cumulative area burned by wildfires, resulting in increased surface fuel loads, tree densities, and ladder fuels, especially in low-elevation, dry conifer forests. Since climate change impacts to fire regimes are overlaid on a century of ecological changes to forest vegetation and fuels, observed differences between current fire patterns and historical ones are a product of management legacies as well as anthropogenic changes to climate.

Wildland fire regimes, defined by fire frequency, annual area burned, severity and pattern, are greatly influenced by variability in landscape environmental conditions including vegetation distribution, climate, weather, and topography (McKenzie et al. 2011). Climate and fuels are the two most important factors controlling patterns of fire within forest ecosystems. Climate controls the frequency of weather conditions that promote fire, whereas the amount and arrangement of fuels influences fire intensity and spread. These wildland fuels - the live and dead biomass that burn in fires - lose moisture and become flammable in the region's typically warm and dry summers, during which there are ample sources of ignition from lightning strikes and humans. Therefore, the active fire season (period conducive to active burning) is in the summer, typically from late June through October, with shorter seasons at higher elevation sites where snowpack can persist well into July. Regionally, widespread fire years are correlated with drought (Heyerdahl et al. 2008). At landscape scales, topography can influence the spatial pattern of fire spread; for example, in dissected mountainous areas, topographic features (e.g., barren slopes) can form barriers to fire spread (Grissino-Mayer et al. 2004), but where drainages are aligned with prevailing winds, topography can facilitate the spread of large fires (Sharples 2009).

Compositions and structures of forests in the NR are strongly determined by fire history. In general, fire regimes vary along environmental gradients, with fire frequency decreasing and fire severity increasing with elevation. For example, at the lowest and driest elevations where forests are dominated by ponderosa pine, frequent surface fires historically consumed litter and dead wood and killed seedlings and smaller trees. Adaptive traits such as thick bark allowed mature ponderosa pines to survive many repeated fires over time and tree densities were kept low. As mentioned above, fire exclusion since the 1920s has increased surface fuel loads, tree densities, and ladder fuels, especially in low-elevation, dry conifer forests (Schoennagel et al. 2004). As a result, fires here may be larger and more intense, and may cause higher rates of tree mortality, than historical fire. In middle and higher elevation forests, however, where fires were historically infrequent because of relatively cold, wet conditions, fire exclusion has not affected the fire regimes (Romme and Despain 1989; Schoennagel et al. 2004). However, earlier onset of snow melt, predicted to occur with changing regional climate, will reduce fuel moistures during fire season,

making middle to high elevation forested systems flammable for longer periods of time (Miller et al. 2009). As these forested systems are not fuel-limited, fire occurrence and extents are likely to increase in the future (Littell et al. 2009, 2010; Westerling et al. 2006).

Insect Outbreaks

Regional insect activity and outbreaks, climate drivers, and potential climate change impacts to insect activity are also highly correlated with climate and will dictate future forest composition and structure. The mountain pine beetle (*Dendroctonus ponderosae*) is an integral component of forest ecosystem processes because of its role in stand thinning and redistribution of resources and nutrients important for tree regeneration. It is also recognized as an aggressive and economically important forest insect responsible for tree mortality across large areas (Logan et al. 2003). Both bark beetle populations and their host trees are being influenced by changing climate. Many bark beetle life history traits that influence population success are temperature-dependent (Bentz and Jönsson 2015), and warming temperatures associated with climate change have directly influenced bark beetle-caused tree mortality in some areas of western North America (Safranyik et al. 2010; Weed et al. [in press]). Host tree distribution across the NR, and tree vigor that influences susceptibility to bark beetle attack (Chapman et al. 2012; Hart et al. 2013), will also be influenced as climate continues to change. Future bark beetle-caused tree mortality will therefore depend not only on the spatial distribution of live host trees and heterogeneity of future landscapes, as described in this chapter, but also on the ability of beetle populations and their associates to adapt to changing conditions when existing phenotypic plasticity is surpassed.

Pathogens

Forest diseases are found in all forest ecosystems of the NR. They are one of three major disturbance groups that affect ecosystem development and change, yet impacts of forest diseases on various resources and services in the region are difficult to estimate. The major groups of forest diseases in the NR that impact ecosystems and ecosystem services are fungi and rusts (fungi that infects needles and causes damage and mortality, the most important being white-pine blister rust), dwarf mistletoes (*Arceuthobium*) (a group of parasitic seed plants that are widespread across the region and which mainly cause reduced

tree growth and productivity), root diseases (a major cause of growth loss and mortality), needle casts and blights (diseases that cause crown thinning and loss of lower branches), and abiotic diseases (damage to trees resulting from impacts of adverse environmental factors on tree physiology or structure).

Effects of climate changes on forest diseases are difficult to predict. Climate change can alter pathogens through direct effects on the development and survival of the pathogen, physiological changes in tree defenses, or indirect effects on the abundance of natural enemies, mutualists and competitors (Ayres and Lombardero 2000). These dynamics are not well-captured by GCMs, because pathogens' ecology and impacts are based on local site and environmental conditions. Epidemics also depend on local conditions for spread and infection to occur. Although models usually generate mean climatic conditions, it is often the extremes that have the greatest influence on pest conditions (Hepting 1963), and these are also not well represented by GCMs. However, modeling efforts to date suggest that among the major NR diseases, root disease is projected to cause the highest basal area loss as a percent of total basal area in the NR. Projected losses from root diseases ranged from zero percent on most national forests east of the Continental Divide to 15 – 19 percent on west-side forests (Krist et al. 2014). Klopfenstein et al. (2009) used a subset of GCMs to predict how the geographic distribution of the climate envelope for Armillaria root rot (*Armillaria solidipes,* formerly *A. ostoyae*) and Douglas-fir could change in the interior northwestern U.S. Their analysis suggests that Douglas-fir will have a considerably smaller geographic space that matches its current climate envelope and that this space will shift, while *A. solidipes* will experience only minor changes. They suggest that areas where Douglas-fir is maladapted could increase, which could increase its susceptibility to Armillaria root rot. Climate-mediated changes to forest tree diseases will be dictated by disease and host responses to new climates, and their interactions (Sturrock et al. 2010), and the interactions between biotic diseases, abiotic stressors, and host status will be drive future pathogen outbreaks. Predicted increases in temperature and drought will probably serve to increase pathogen populations in the future (Chakraborty et al. 2008). The roles of pathogens as important disturbance agents will likely increase in the future because they are able to migrate to new environments at a faster rate than trees.

Drought

Soil type and depth, aspect, and elevation all contribute to effective moisture availability for tree establishment and growth, producing patterns of forests in the NR study area. Additionally, the impact of stand condition on overall water balance and the effect of site and soil conditions on moisture availability are important to consider. The Montana Natural Resources Conservation Service (NRCS) and the Natural Resource Information System of the Montana State Library have mapped the relative effective annual precipitation (REAP) for the State of Montana (http://nris.mt.gov/nrcs/reap/index.asp). REAP is an indicator of the amount of moisture available at a location, taking into account precipitation, slope and aspect, and soil properties. For example, two sites that receive the same amount of precipitation may have different effective precipitation due to unique soil and landform factors at each site. Depending upon the geographic location within Montana and degree of slope, the actual precipitation for southerly aspects may be adjusted downward while northerly aspects may be adjusted upward.

Future climate change models indicate that the NR will have longer, drier summers and warmer conditions. Pioneer (seral) species such as ponderosa pine have the unique ability to establish on bare soil surfaces where high surface temperatures (>149 °F) exclude other species. One of the adaptations of these seral species are deep rooting characteristics that allow the tree to find an adequate water supply and avoid extensive competition with shallow- and fibrous-rooted grasses and forbs. As the shade from these species limits sun-loving grasses and forbs, shade tolerant tree species establish and grow, and these species usually have a shallower rooting characteristic that allows them to gather soil water from the nutrient-rich soil surface. The overall rooting structure in essence becomes much more competitive as succession progresses. In addition, the overall leaf surface area that develops over time on a given site increases. Grass/forb and shrublands usually develop a maximum total leaf area of about 3.23 ft^2 per 1.08 ft^2 of soil surface area. Forests can develop leaf areas in excess of 6.46 ft^2 per 1.08 ft^2 of soil surface area. With increasing leaf area comes increased water transpiration that can deplete the soil water storage capacity needed to keep trees hydrated throughout the summer. The additional canopy interception of rain and snow in dense forests, which directly evaporates back into the atmosphere, further compounds this

effect, reducing soil water recharge. The end result is a water-stressed forest that not only becomes more susceptible to insects and disease, but also more prone to supporting severe wildfires because live fuel moisture is relatively low.

CLIMATE CHANGE ASSESSMENTS

This section contains the information that was used to assess vulnerability for all tree species, vegetation types, and resources of concern. There are four subsections for each item (e.g., tree species) to detail the (1) ecology, (2) disturbance interactions, (3) current and historical conditions, and most importantly (4) potential climate change responses. The first subsection presents important ecological information needed to understand how a species, type or concern might respond to future changes in climates, such as its drought and shade tolerance. The disturbance interactions subsection contains information on those agents that impact that species, type, or concern, and important projections of how those disturbance agents might change in the future. Historical and current conditions are included as a subsection, because any climate change response is greatly dependent on current status and past actions. Lastly, the anticipated climate change responses for the species, types, and concerns are included in perhaps the most important subsection. This material was ultimately the basis for any evaluation of vulnerability or development of potential adaptation actions.

Most of the material in this section was taken from published literature, but there are also substantial amounts of anecdotal and observational information that was included for context. However, due to imperfect knowledge across the evaluated entities and the high uncertainty in climate predictions and ecosystem responses, we admit that many of our projected climate change responses and resultant vulnerability assessments are based on our own professional experiences. Moreover, some climate change response material may appear uneven across species, types, and concerns because some species, types, or concerns do not have the detailed information of others; more information is available for timber tree species than non-timber species, for example.

Tree Species

Most of the background information used in this section was synthesized from three primary sources. The Bollenbacher (2012) report presents characteristics of the major tree species of the NR, adapted from the autecological synthesis developed by Minore (1979). The commonly used silviculture reference edited by Burns and Honkala (1990) was used throughout, and the climate change report compiled by Devine et al. (2012) for the Pacific Northwest was also used for genetics and autecological information. Table 6.3 provides a general summary of important ecological and genetic characteristics by tree species that will be important under future climate change. In this section, we attempted to integrate the genetic, morphological, ecological, and disturbance response characteristics summarized in Table 6.3 to predict how a tree species would respond under future climate warming. We also integrated any material available in the literature to aid and support our predictions.

The climate change responses subsections were synthesized from information in the literature and the MC2 modeling results (appendix 6A) to evaluate the effects of climate change on important species, vegetation types, and resource concerns. These subsections are the foundation material to support our vulnerability assessments and the adaptation strategies and tactics. Many of these climate change responses are based on the species characteristics and current ecosystem condition presented in this section.

The most astonishing finding in this section is that the literature is inconsistent on the response of tree species to future climate change. Results from SDM modeling are often, but not always, different from most other sources that include gap modeling, mechanistic ecosystem simulation, and field data summaries. As a result, we put a lesser emphasis on the SDM results in our vulnerability assessment evaluations in appendix 6B. Another finding is that the amount of climate change really matters. Most climate change studies predict few species changes after moderate warming (e.g., the B1, B2, A1B, RCP4.5 scenarios), but major species shifts under the most extreme emission scenarios (e.g., the A1 and RCP8.5 scenarios). Third, the time frame used in the climate change study is also important. Management time frames of 10 to 50 years are not long enough to effectively evaluate changes in fire, beetles, and tree growth. Ecosystem response to disturbance takes time, often two to five times the disturbance return

4321 interval. Lastly, the GCMs used to simulate and quantify climate change are incredibly important in
4322 understanding climate change study results and subsequent ecosystem responses. Some GCMs predict
4323 minor warming for the NR, while others predict major changes.

4324 Based on a thorough review of the literature, we feel that there are basically three modes of response
4325 to climate change for the major tree species of the NR: modification, contraction, and expansion. First, the
4326 species could increase or decrease in productivity *in situ* within its current range due to increasing
4327 temperatures and adequate precipitation (*acclimatization*); for example, the majority of information seem
4328 to support that most lands in NR will increase in productivity (Aston 2010). Next, the species could die in
4329 those parts of its range where conditions will change enough to become inhospitable to that species (Allen
4330 et al. 2010) (*contraction*). Lastly, the species could migrate to areas that are more conducive for
4331 establishment and growth (Johnstone and Chapin 2003) (*expansion*). Any species can have multiple
4332 modes of response to climate change, and most species will respond to future climates via all three
4333 modes.

4334 Application of these three modes to determine future species dynamics demands a thorough
4335 integration of variability and scale. For example, the ebb and flow of species migration demands a
4336 relatively long temporal scope to properly evaluate species range shifts (Prentice et al. 1991). A tree
4337 species could become established in a "new" environment made suitable by climate change, such as
4338 subalpine tree expansion into snow glades, but the great variability in climate may result in one year of
4339 drought or high snow that kills all established seedlings. Conversely, one year of drought could kill many
4340 individuals in the grassland-woodland ecotone, but several wet years in a row might facilitate
4341 reestablishment of tree species into the high mortality zone. Also, the rate of climate change shifts will be
4342 governed by disturbance, not competition, so disturbance adaptions will be more important than climatic
4343 niches. Management actions, such as fire exclusion, may facilitate species expansion into areas that will
4344 eventually burn, causing extensive mortality.

4345 All of the climate change response evaluations in this chapter have a high level of uncertainty; they
4346 are essentially best guesses from a wide variety of resource specialists. The information in the following

section may provide a starting place, a possible prioritization, or assistance in addressing climate change in forest plans, but it is in no way accurate enough to provide valid predictions of what will happen in the future.

Limber Pine (Pinus flexilis)

Autecology

Limber pine is a shade intolerant, early seral to pioneer species in the NR (Steele 1990). Its seeds are dispersed by rodents, but more importantly, by a bird (Clark's Nutcracker) that will cache limber pine seed anywhere there is microsite pattern that they use for finding the seed (Lanner 1980; Lanner and Vander Wall 1980). Limber pine has difficulty in competing with other encroaching species on more productive mesic sites and is often succeeded by Douglas-fir and subalpine fir. There is often little to no reproduction once tree densities are below 25 trees per hectare, mostly because of the lack of an effective pollination cloud, and those seeds that are produced have increased likelihood of inbreeding. Moreover, a minimum of 25 cone-bearing trees per 2.47 acres is needed for dispersal by the Clark's Nutcracker (McKinney et al. 2009). This tree species is quite slow growing but long-lived, and some of the oldest trees in the NR are limber pine.

Limber pine is a puzzling species in the ecosystem land management context. It is a tree species that occupies xeric sites across a wide range of elevations (2600 to 8900 ft elevation) in the NR that are often marginal for timber production (Jackson et al. 2010). Historically, it was often found on the margins between grasslands and forest ecosystems at the lower timberline on fire refugia (Steele 1990). Since limber pine is easily killed by fire, the species was mostly found in fire-protected cove sites that experienced rare fires of low severity, such as rocky outcrops, barren areas, and moist north slopes (Steele 1990). In these lower timberline areas, limber pine is often associated with Douglas-fir, Rocky Mountain ponderosa pine, and quaking aspen (*Populus tremuloides*). On upland montane sites, it can be often found on limestone substrates and droughty soils, but in these areas it is associated with many other NR conifers, especially lodgepole pine, subalpine fir, and Engelmann spruce (Steele 1990; Langor 2007).

Limber pine seedlings are poor competitors with grass, but do well on rocky substrates and in shrub environments.

Limber pine is quite tolerant of drought and can become established and grow in some of the most arid environments in the NR (Steele 1990) (table 6.3). It is associated with both ectomycorrhizae and arbuscular mycorrhizae that facilitate its ability to exist in extremely dry environments. Seedlings are very drought tolerant but have a low tolerance for competition, especially from herbaceous plants.

Genetically, limber pine has high outcrossing rates with average genetic diversity and average population differentiation (Devine et al. 2012). The fundamental and realized niche for limber pine is very broad in the NR, indicating that this species has a generalist adaptive strategy with wide phenotypic plasticity.

Disturbance Interactions

As mentioned previously, limber pine's thin bark and low foliage make the species highly susceptible to damage from wildland fire. Limber pine is also highly susceptible to white-pine blister rust, and many communities are currently experiencing high mortality when the disease infects trees in a new region (Smith et al. 2013). Limber pine also facilitates the expansion of currant into traditional grasslands (Baumeister and Callaway 2006), thus increasing rust infections and mortality.

Other insects and pathogens are also impacting limber pine, but at a much reduced severity. Some have detected mortality from mountain pine beetle in parts of the species range (Jackson et al. 2010). Others have noted that limber pine stands on mesic sites may have severe dwarf mistletoe infections that could result in mortality levels similar to those observed from white-pine blister rust. Porcupine (*Erethizon dorsatum*) damage is also quite prevalent east of the Continental Divide.

Historical and Current Conditions

With fire exclusion, limber pine has expanded its range from fire-protected cove sites into areas where it was historically restricted by frequent fires (Arno and Gruell 1983; Brown and Schoettle 2008). As a result of the diminished fire activity and active nutcracker caching, limber pine has expanded into grass and shrub rangelands, and this expansion has also allowed other species to inhabit historical non-

forest areas (Jackson et al. 2010). It appears that limber pine can facilitate the establishment of other forest species, especially Douglas-fir, in rangeland settings (Baumeister and Callaway 2006). As a result, NR limber pine is currently occupying areas that were traditionally grasslands, and it is difficult to determine if this is inside or outside the range of variability of this ecosystem.

Ironically, the newly established limber pine forests throughout the NR are experiencing dramatic declines due to white-pine blister rust, mountain pine beetles, and red belt (Jackson et al. 2010; Langor 2007; Taylor and Sturdevant 1998). Increasing fires are also burning some of these stands that have become established after 1910. There is some white-pine blister rust resistance in the species, but it is low, perhaps lower than 1 in 100 individuals.

Climate Change Responses

Some anticipate that warming temperatures on the east side of the NR, along with increasing but more variable precipitation, especially during the growing season, and waning snowpack will result in increased growth in many limber pine communities (Aston 2010). Increases in vigor are usually accompanied by larger cone crops, higher seed viability, greater number of seeds per cone, wider seed dispersal, and greater resistance to disease. Increased seed dispersal includes both denser caching by birds and mammals, and probably more distant caching by the Clark's Nutcracker. Increases in vigor might also extend to limber pine's competitors, so there could be increased competition from wind-dispersed conifers, especially on the more mesic portions of limber pine's range.

Warm temperatures, even with increased precipitation, could also result in drier conditions, especially for seed germination and seedling growth. Even if there are more seeds cached by mammals and birds, the subsequent establishment of seedlings from the unclaimed caches might be low because of longer drought seasons and hotter ground temperatures. Any seed dispersal to new areas, especially non-forested stands, might have limited limber regeneration success because of the lack of ectomycorrhizal associations and increased competition from grasses and dense shrubs (Coop and Schoettle 2009).

Disturbance interactions with warming climates will likely be important to future limber pine dynamics. Increasing fire frequency and intensities may burn more limber pine stands, causing higher

4424 mortality (Coop and Schoettle 2009). Increased fire may stem the encroachment of limber pine into
4425 grasslands in areas where grazing is low. Warmer, drier conditions may also reduce blister rust infection
4426 by disrupting the blister rust cycle, especially during the late summer when *Ribes* spp. to pine infection
4427 occurs, and there may be fewer "wave years" where temperature and humidity are optimal for pine
4428 infection by white-pine blister rust. Where precipitation is projected to increase, such as the eastern
4429 portions of the NR, there may be higher blister rust and dwarf mistletoe infections, and this may cause
4430 higher limber pine mortality. Continued fire exclusion could enhance currant facilitation under mature
4431 limber pines and result in even greater white-pine blister rust mortality. Warmer temperatures also favor
4432 expansion of alternate host species such as currant, lousewort (*Pedicularis*) and Indian paintbrush
4433 (*Castilleja*) (Keane et al. [in press]).

4434 Limber pine has an intermediate genetic adaptive strategy under changing climates largely driven by
4435 timing of pollen cloud dispersal (elevational effect) and bird dispersal (Feldman et al. 1999). The species
4436 is highly adapted to populating the increasing burned areas projected for the future because of mammal
4437 and corvid-mediated dispersal (Lanner and Vander Wall 1980). If future fires are larger and more severe,
4438 there may be less competition from other competing conifers, especially in the eastern NR along the
4439 timber-grassland ecotone. Limber pine has moderate genetic variation (capacity) in blister rust resistance,
4440 but major gene resistance to blister rust has not been identified in several studies of interior populations.
4441 There is probably little to no opportunity to hybridize with western white pine due to non-overlapping
4442 species distributions, and it will probably not hybridize with whitebark pine because the two species only
4443 overlap on limestone substrates. There is a high risk of loss of disjunct and isolated populations due to
4444 genetic drift, ineffective pollen cloud, and substrate availability.

4445 Given all available information, limber pine responses to future climates may be minor and governed
4446 mostly by wildland fire and white-pine blister rust. If fires increase, limber pine forests, some of which
4447 are already declining from rust, will see some major declines, especially in those places where they have
4448 encroached as a result of fire exclusion. Given its minor role in the NR prior to European settlement, we
4449 feel that this species is at most moderately vulnerable to climate change based on its high tolerance to

drought and ability to populate severe environments, but high susceptibility to the introduced white-pine blister rust and fire damage may put this species in peril.

Ponderosa Pine (Pinus ponderosa)

Autecology

Ponderosa pine shows distinct geographic variation over its range. The ponderosa variety (*P. ponderosa* var. *ponderosa*) ranges from the Fraser River drainage of southern British Columbia south through Washington, Oregon and into northern California (Oliver and Ryker 1990). In the NR, it extends from the Canadian border to the central part of Montana on the west side of the Continental Divide. Rocky Mountain ponderosa pine extends east of the Continental Divide to North and South Dakota and south into Wyoming and further. Within the wide range of both ponderosa pine variants, it is absent from several areas, including a large portion of southwestern Montana. This may be due to the lack of rainfall in the summer months, which prevents establishment except at higher elevations; however, it is also limited by the shorter growing season at these elevations.

In most of western Montana and Idaho, the upper elevational limit of the ponderosa variety is around 1500 m, depending on latitude (Pfister et al. 1977). Moisture is the factor most often limiting growth, especially in the summer. Seasonal rainfall deficiency is evident from July and August precipitation (Fowells and Kirk 1945; Tarrant 1968). The distribution of ponderosa pine on drier sites is closely related to supplies of available soil moisture, which is closely related to soil textures and depth. Low temperatures, however, may dictate the success of ponderosa pine regeneration; seedlings of the species are highly susceptible to frost damage and the occurrence of frosts often excludes the pine from low valley settings, especially in frost pockets and cold air drainages (Shearer and Schimidt 1970).

Ponderosa pine is a shade-intolerant, drought-adapted species of the low elevation, dry forests of the NR (Minore 1979) (table 6.3). It can be a climax species at the lower elevational limits of NR coniferous forests, or a seral species in the higher elevation mesic forests, especially the Pacific variety. In dry climax forests, there is generally a mosaic of small even-aged groups. As a seral species, it is often associated with Douglas-fir, lodgepole pine, grand fir, and in the northwest NR, western larch. Ponderosa

pine is mostly intolerant of shade, but it is generally more tolerant than western larch and less tolerant than grand fir and western white pine. While it reaches its greatest site indexes on the mesic grand fir, western redcedar, and western hemlock sites (Cooper et al. 1991), it is rapidly replaced by a suite of more shade tolerant competitors.

Ponderosa pine is a "drought avoider" meaning it tolerates dry soil conditions by efficiently closing stomata to avoid water loss and xylem cavitation and stay alive during deep droughts (Sala et al. 2005) (table 6.3). This allows the species to tolerate intense drought better than its associates, specifically Douglas-fir, because it is a "drought tolerator" and able to obtain water at lower moisture conditions. Drought tolerators attempt to draw ground water at such low soil water potentials that they might experience extreme xylem cavitation that may cause eventual death. Ponderosa pine has been associated with several species of ectomycorrihizae, giving it a high capacity to survive in dry environments.

Cone crop periodicity varies greatly with ponderosa pine; observations indicate it is a poor seeder west of the Continental Divide and a fair seeder east of the Divide. Throughout the NR, natural regeneration is sporadic; it is best when there is a heavy seed crop followed by favorable weather during the next growing season (Heidmann 1983; Shearer and Schimidt 1970). Potter et al. (2015) performed molecular work that indicates that Rocky Mountain ponderosa pine is one of the most inbred conifers in the NR, and its vulnerability could be further compromised with limited gene flow between populations. With cone crop periodicity or masting events that only occur every 7-10 years, there appears to be increasing natural regeneration problems on the east side. Soil texture, plant competition, and seedbed conditions have the greatest effect on seedling survival. Moisture stress reduces seed germination and limits seedling survival and growth. Competing vegetation deters seedling. As mentioned, young seedlings (<36 days old) are susceptible to cold night temperatures and deep frosts, and occasionally the pine trees suffer winter desiccation in drying winds. Older seedlings (>110 days) can often withstand higher temperatures than Douglas-fir, grand fir and Engelmann spruce, making it likely they will be more successful under future climates.

Ponderosa pine has a moderate potential for outcrossing with a high outcrossing rate. It has average genetic variation, but is weakly differentiated geographically. While it has a strong population differentiation, it may be considered to be intermediate in adaptive strategy because both individuals and populations may be suited to diverse environments. There are steep clines in elevation, but gentle clines in latitude and longitude. There is high genetic variation between east- and west-side ponderosa pine in growth, survival, needle length, season pattern of root growth, and ability to germinate under moisture stress (Oliver and Ryker 1990).

Disturbance Interactions

Fires have a profound effect on ponderosa pine where competing tree species are considerably less fire tolerant; this allows ponderosa pine to maintain dominance over large areas (Arno 1988; Steele et al. 1986). Fires historically allowed ponderosa pine to maintain its dominance across most of the low elevation savannas by killing competitors. Ponderosa pine has a great capacity to survive fire, better than nearly all of its competitors (Ryan and Reinhardt 1988).

There are around 108 species of insects that attack west-side ponderosa pine and over 59 species that attack east-side ponderosa pine. The most damaging of the tree-killing insects are several species of *Dendroctonus* Erichson, 1836 (Oliver and Ryker 1990). Among bark beetles, *Ips* species are second in destructiveness only to *Dendroctonus*. *Ips* are present naturally in all stands, where they usually breed in slash. Dwarf mistletoe is ponderosa pine's most widespread disease but is rarely fatal in the NR. Western pine shoot borer (*Eucosma sonomana*) is also a concern in the future.

Historical and Current Conditions

Ponderosa pine forests have been experiencing a severe decline due to the combination of logging and fire exclusion. Large pine trees in the open pine savannas were harvested from nearly all but the most remote, inaccessible, or protected areas in the NR. Wildland fires have been excluded from remaining pine forests, causing advanced succession that was most rapid in the mesic habitat types (Arno 1988; Gruell et al. 1982). This has resulted in dense forests with overstories of stressed pines and dense understories of its shade-tolerant competitors, most commonly Douglas-fir. There are often buildups of

duff and litter, and an atypical accumulation of downed dead woody fuels on the soil surface. The dense crowns, coupled with high surface fuel loadings, ensure that when these forests are burned by wildfires, the damage from the fire will be severe with high tree mortality, deep soil heating, high fuel consumption, and abundant smoke (Keane et al. 2002).

Climate Change Responses

We expect ponderosa pine in the NR to handle increasing temperatures and deeper, longer droughts with only moderate difficulty. Its ability as a "drought avoider" to close stomata when soil water potential is low make it one of the few forest species, besides juniper, that maintains its presence in many low elevation settings (Stout and Sala 2003). Morales et al. (2015) projected an 11 percent increase in range of ponderosa pine in the western U.S., and Nitschke and Innes (2008), using a gap modeling approach, projected the replacement of dry Douglas-fir dominated communities of British Columbia with ponderosa pine. Hansen et al. (2001) projected an expansion of ponderosa pine across the western U.S. and specifically in the Pacific Northwest, when most other tree species ranges were retracting in area. Rocky mountain ponderosa pine is more intermediate in adaptive strategy than the *ponderosa* variety and therefore has a high phenotypic plasticity and is better adapted to drought (table 6.3).

However, declining precipitation and variable spatial and temporal rainfall patterns may caused declines in ponderosa pine regeneration and range contractions, except in the eastern portion of the northern region where precipitation is expected to increase. Crimmins et al. (2011) estimated that ponderosa pine environments may rise over 700 m in elevation by 2050 in its range. Similarly, Gray and Hamann (2013) estimated ponderosa pine might move over 500 km northward and almost 300 m higher in elevation by 2050 in the NR. However, Franklin et al. (1991) projected future ponderosa pine forests will cover about a third of its current range in landscapes of the eastern Cascades, and Bell et al. (2014) projected losses of over 60 percent of its range by 2090.

Increases in mountain pine beetle outbreaks, advancing competition resulting from fire exclusion, western pine shoot borer occurrence, and increases in fire severity and intensity will dictate the future of ponderosa pine in the NR. If fires are too frequent, established regeneration will never grow above the

lethal scorch height, and mature individuals will not become established. Increasing fire severity and occurrence could also eliminate many of NR relict ponderosa pine trees that provide the critical seed sources for populating future burns.

Douglas-Fir (Pseudotsuga menziesii)

Autecology

Douglas-fir has been a major component of forests of western North American since the mid-Pleistocene era (Hermann and Lavender 1990). Only Rocky Mountain Douglas-fir (var *glauca*) is found in the NR. Its range extends from central British Columbia through the Rocky Mountains into central Mexico. The range is fairly continuous in northern Idaho, western Montana, and northwestern Wyoming, with several outlying areas in eastern-central Montana and Wyoming. In the NR, Douglas-fir grows in areas with maritime influence and mild climate in all seasons except a dry period in July and August. In the central Rocky Mountains, the winters are long and severe, summers are hot and in some parts very dry. West of the Continental Divide in the NR, the rainfall may be evenly divided between winter and summer. The altitudinal distribution of Douglas-fir increases from north to south, due to the effect of climate on the distribution. The limiting factors are temperature in the northern part of the range and moisture to the south. Thus, Douglas-fir prefers southerly slopes in the northern part of its range, and northerly exposures in the southern part of its range (Pfister et al. 1977).

Douglas-fir in the NR grows in pure stands on dry, cold sites, both in an even- and uneven-aged condition (Hermann and Lavender 1990). On other sites, the associated species are dependent on the climate, and by proxy, elevation and region. Montane, low elevation, mesic Douglas-fir is often associated with western larch, western white pine, grand fir, western redcedar, and western hemlock, while on low elevation, xeric sites, Douglas-fir is associated with ponderosa pine, juniper, and quaking aspen. At upper elevational limits, the species is often found with lodgepole pine, subalpine fir, and Engelmann spruce. It is rarely found at the highest elevations associated with mountain hemlock (*Tsuga mertensiana*), whitebark pine, and alpine larch. Most of the NR Douglas-fir forests are found on droughty sites, and the species is often associated with ponderosa pine; Douglas-fir is often the primary climax

4579 species whenever it is found with ponderosa pine (Keane 1985; Ryker and Losensky 1983; Steele and
4580 Geier-Hayers 1989). Again, proportion of other species growing with Douglas-fir varies widely
4581 depending on aspect, elevation, soil type and past history, particularly fire history, of the area.
4582 Regeneration is most successful where Douglas-fir is seral, especially in the area of strong maritime
4583 influence in northern Idaho and western Montana, where it is associated with more montane species (e.g.,
4584 grand fir, western redcedar, and western larch). Regeneration is poor where it has attained climax status in
4585 the cool, dry habitats (Ryker and Losensky 1983). Seedling growth the first year is relatively slow,
4586 limited generally by moisture, which triggers initiation of dormancy in midsummer. Competing
4587 vegetation may promote the establishment of a variety of seedlings by reducing temperature stress, but
4588 may inhibit seedlings growth by competing strongly for moisture; this is most pronounced in the southern
4589 portion of the range. In the Rocky Mountains, it is a seral species in moist habitats and climax in the
4590 warmer, drier areas of its range.
4591 In the interior portion of its NR range, Douglas-fir ranks intermediate in shade tolerance, being more
4592 tolerant than western larch, ponderosa pine, lodgepole pine, and aspen (Table 6.3). Old growth Douglas-
4593 fir shows a wide range of age classes, indicating it established over long periods after major fires. It is
4594 gradually replaced by more tolerant western hemlock, western redcedar and true fir on mesic montane
4595 sites. Douglas-fir tolerates drought better than nearly all of its competitors except for ponderosa pine. The
4596 species is a drought “tolerator” in that it keeps stomata open to extract soil water at extremely low soil
4597 water potentials, thereby subjecting it to potential xylem cavitation and potential death (Sala et al. 2005;
4598 Stout and Sala 2003).
4599 The species exhibits a great deal of genetic differentiation, which is strongly associated with
4600 geographic or topographic features (Rehfeldt 1978). The pattern of genetic variation in growth and
4601 phenological traits among clines (ecotypes or forms of species that exhibit gradual phenotypic and genetic
4602 differences over a geographical area as a result of environmental heterogeneity) have been observed along
4603 north-south, east-west and elevational transects. There is evidence of low genetic variation within local
4604 regions. For example, in southern Oregon, seed collected on the more xeric southern aspects grew slower,

set bud earlier, and had larger roots compared to seedlings grown from north-facing slopes. Seedlings from seed sources on southerly aspects have adaptive characteristics for a shorter growing season and drier soils and may survive under drought stress better than seedlings from north-aspect seed sources.

Disturbance Interactions

Douglas-fir has a great capacity to survive fire because of its thick corky bark and its deep main roots. The species' capacity to form adventitious roots is another adaptation that has enabled Douglas-fir to survive fire. However, young Douglas-fir have thin bark and low height to live crown, greatly increasing mortality from fire (Ryan and Reinhardt 1988). Ponderosa pine and western larch have better ability to survive fire across all life stages, so on sites with frequent fires where Douglas-fir is associated with other species, its cover is usually kept low by fire (Agee 1991). However, on cold, dry sites where the species is the indicated climax, frequent fire may create Douglas-fir savannas, especially east of the Continental Divide and the high valleys of southwestern Montana.

Douglas-fir is subject to serious damage from a variety of agents that may increase under future climates (Hermann and Lavender 1990). Western spruce budworm (*Choristoneura occidentalis*) and Douglas-fir tussock moth (*Orgyia pseudotsugata*) are the most important insects affecting Douglas-fir. Both insects attack trees of all ages at periodic intervals throughout the range of interior Douglas-fir, often resulting in severe defoliation of stands. Many Douglas-fir stands in the central NR are currently devastated by budworm and beetle. The Douglas-fir beetle (*Dendroctonus pseudotsugae*) is a destructive insect pest in old-growth stands of coastal and interior Douglas-fir. Armillaria and annosus (*Heterobasidion annosum*) root diseases may intensify in infection and widen in distribution to cause high tree mortality. Annosus root disease is particularly lethal in Douglas-fir (Hagle 2003). Of the many heart rot fungi (more than 300) attacking Douglas-fir, the most damaging and widespread is red ring rot (*Porodaedalea pini,* Murrill 1905). Knots and scars resulting from fire, lightning, and falling trees are the main paths of infection. Losses from this heart rot far exceed those from any other decay. Other important heart rot fungi in the NR are brown trunk rot (*Fomitopsis officinalis*)*, Fomitopsis cajanderi*, and *Phaeolus schweinitzii*.

Historical and Current Conditions

Historical frequent wildland fires kept Douglas-fir from becoming established on those dry sites where it was associated with ponderosa pine (frequent fires favored ponderosa pine establishment). It often became established after long inter-fire periods, such as during the Little Ice Age, and easily attained dominance if fire frequency was decreased. However, in the more montane portions of the species NR range, Douglas-fir was often one of the major dominants, as it was a major competitor under historical mixed-severity fire regimes (Arno et al. 2000).

Today, however, cumulative effects of the fire exclusion era coupled with logging have allowed Douglas-fir to become the dominant species across its range, especially where it successionally replaced the historically-dominant ponderosa pine forests (Arno and Gruell 1983; Arno et al. 2000; Gruell et al. 1982). As a result, we have seen an expansion of Douglas-fir into areas where fire was frequent historically, but also a densification of the forests where it is associated with more mesic species. This has created large, contiguous areas where canopy fuels have increased and become denser, and surface fuels that have been converted from grass and shrubs to heavy downed, dead woody fuels (Keane et al. 2002). This predisposes many Douglas-fir forests to severe future fires. Moreover, these dense stand conditions have contributed to decreased vigor that predisposes the species to western spruce budworm and Douglas-fir beetle outbreaks. Many Douglas-fir forests of southwestern and central Montana are currently experiencing high budworm and beetle mortality.

Climate Change Responses

Several studies suggest that Douglas-fir will respond positively with future changes in climate. Morales et al. (2015) projected a seven percent increase in the range of the species in the western U.S. by 2060. Soulé and Knapp (2013) found almost doubled radial growth in Douglas-fir in the western portions of the NR in the latter half of the 20th century, but they attributed some of this increase to other factors such as CO_2 fertilization. Rose and Burton (2009), using SDMs, projected that Douglas-fir forests in British Columbia will nearly triple by 2080, while Franklin et al. (1991) project no net loss of Douglas-fir

habitat in the future in the Pacific Northwest. Using a gap model, Cumming and Burton (1996) also found little change in the Douglas-fir zone in the future in British Columbia.

However, it is likely that myriad factors will contribute to decline of Douglas-fir forests in some parts of the NR in the future. Recent Northern Region seedling survival survey results from 2014 show significant increases in Douglas-fir three-year seedling mortality (approximately 50 percent) due to increasing drought, high temperatures, and severe conditions, presumably related to climate change. In addition, Kemp (2015) found that natural postfire regeneration of Douglas-fir on sites that burned in 2000 and 2007 varied across gradients in elevation, aspect, and burn severity, and findings indicated that Douglas-fir regeneration was significantly reduced with increased heat loading (incoming solar radiation derived from site latitude, aspect, and slope); specifically, the probability of successful Douglas-fir regeneration was lower at lower elevation sites and on sites with higher heat load (steep, southwest aspects). Likewise, Douglas-fir abundance was lower on sites at lower elevations and with higher heat loads.

On dry lower elevation southerly aspects in the southern NR, ponderosa pine will likely cope with moisture deficits better than Douglas-fir because it does not have the high potential for xylem cavitation (Stout and Sala 2003). In addition, Douglas-fir might not have the genetic potential to rapidly migrate to more conducive sites (Aitken et al. 2008). More importantly, there are a suite of insects and diseases that are increasing in NR Douglas-fir forests that are creating heavy mortality, especially in southwestern NR areas. The spruce budworm is killing many Douglas-fir stands in southwestern Montana, while the Douglas-fir bark beetle is attacking stands in other parts of the NR. Nitschke and Innes (2008) predict major losses of Douglas-fir from parts of British Columbia because of hot, dry conditions, while Shafer et al. (2001) predict major transitions in Douglas-fir in most of the US Pacific Northwest, and raise some major concerns that the climate might be too warm to meet the chilling requirements of Douglas-fir seed. Using SDM approaches, Gray and Hamann (2013) projected that Douglas-fir will migrate over 400 km north and 170 m upwards in elevation by 2050, and Bell et al. (2014) projected major losses of over 40 percent of its range in the NR by 2090.

Increases in wildland fires, coupled with adverse effects of the fire exclusion era in NR forests, could also present some problems for Douglas-fir. Increasing fire danger in Douglas-fir stands with high canopy and surface fuels may promote wildland fires that kill the majority of Douglas-fir, even the most mature individuals. If fires increase in the future, regardless of fire suppression efforts, they may be so frequent that Douglas-fir seedlings cannot become established and become mature trees.

Douglas-fir might be one of the NR tree species most limited in range expansion because of its limited genetic diversity and structure (St. Clair and Howe 2007). The species has a specialist genetic adaptive strategy at low to mid elevations and a more generalist strategy at higher elevations. With warming temperatures and a possible decrease in summer moisture conditions, Rocky Mountain Douglas-fir may contract from the driest portions of its range. Current natural regeneration failures may be exacerbated by reduced seed sources owing to large wildfires and hot and dry microclimate conditions, especially on southerly exposures at lower elevations. On moist sites (mixed mesic forest), there may be increases in root disease mortality because of increasing moisture stress.

Western Larch (Larix occidentalis)

Autecology

Western larch grows in the Upper Columbia River Basin of northwestern Montana, and in north and west central Idaho (Schmidt and Shearer 1990). It grows in the relatively moist-cool climatic zone. Limiting factors to western larch are low temperatures at the upper elevations, and lack of moisture at the lower extremes (Habeck 1990). Western larch grows on a wide variety of soils; most soils suitable for growth are deep and well drained. It is commonly found on valley bottoms, benches, and northeast-facing mountain slopes (Schmidt et al. 1976).

Western larch is adapted to extreme environmental heterogeneity, from maritime climates in the west and northwest to more continental climates, as westerly air masses move across the Bitterroot and Cabinet Mountains (Rehfeldt 1982). At comparable elevations, the frost-free period in western Montana is 30 days shorter than in northern Idaho, and thus populations from western Montana are better adapted genetically to short frost-free growing seasons as compared to similar elevations in northern Idaho (Rehfeldt 1995b).

Moreover, as elevation increases and frost-free periods decrease, growth potential decreases. Early fall cold snaps are a major temperature factor affecting seedling and sapling survival, before resting buds have had an opportunity to fully lignify (Rehfeldt 1995a). Drought is another major climatic factor affecting mid- to late-season survival. (Schmidt 1995). It is most likely to affect seedlings under heavy shade because of the heavy moisture use by the overstory and other competing vegetation. Zhang and Marshall (1994) and Zhang et al. (1994) characterize western larch as having low water-use efficiency, as compared to other conifers in the NR. Plants that have low water-use efficiency tend to be larger in stature and produce more biomass, which may be trait-limiting in future warmer and more arid or variable-precipitation climates. The lower water-use efficiency of western larch may explain its absence on xeric sites (Gower et al. 1995).

Cone and seed production in western larch is most prolific at ages older than 30 to 50 years, with seed crops occurring every 14 years in Idaho and every 10 years Montana (Owens 2008). Good cone crops may occur in successive years if conditions are favorable (Owens and Molder 1979). Spring frosts often reduce pollen, cone and seed production in western larch, leading to sporadic seed years. Cone production is higher in stands that have larger crowns, such as stands that have been thinned (Shearer 1976). Cooler, wetter springs favor foliar diseases such as larch needle cast (*Meria larisis*); successive years of infection lead to reductions in available cone crops. Cone maturation follows elevation gradients, where cones at lower elevations are generally mature in mid-August and seed dispersal occurs into September. As such, seed may be available for dispersal during the fire season.

Seed germinates best on seedbeds exposed by burning or mechanical scarification (Antos and Shearer 1980; Beaufait et al. 1977; Schmidt 1969; Shearer 1976). Western larch seedlings survive poorly on undisturbed litter, humus, sod or heavy root competition; seedlings germinated on duff do not often survive (Beaufait et al. 1977). High solar irradiation is the most important physical factor affecting seedling survival (Shearer 1976). South and west exposures are generally too severe for western larch seedlings to establish, particularly in drier sites at the lower elevational limits of its range. In the mid- and northern portion of its ranges, western larch grows well on all exposures. Young seedlings grow fast on

desirable sites. Only lodgepole pine is similar to western larch in seedling growth; Douglas-fir grows about half the rate, and spruce and subalpine fire about one quarter the rate of western larch. Site productivity has the most effect on height growth on western larch sites.

Western larch is a long-lived early seral species. It is a fast-growing species with tall, open crowns making the species easily able to out-grow all of its competitors on the more mesic sites (Milner 1992). It is also the most shade-intolerant conifer in the NR (Minore 1979) (table 6.3); it can tolerate partial shading only in the seedling stage. Western larch is replaced through succession by all other conifers except for ponderosa pine. Western larch is moderately drought tolerant and can survive seasonal drought, but performs poorly when droughts last more than one or two years. Douglas-fir is the most common associate, but others include ponderosa pine on lower drier sites, western hemlock, western redcedar, and western white pine on moist sites, and Engelmann spruce, subalpine fir, lodgepole pine and mountain hemlock on cool, moist subalpine sites (Schmidt and Shearer 1990). It has been associated with mycorrhizal fungi in many portions of the NR (Harvey et al. 1978).

Western larch has average genetic diversity with a weak population differentiation. Its low levels of differentiation indicate that it is more a generalist than specialist. The species has a moderate outcrossing rate, and the patterns of genetic variation are mostly dominated by latitude and longitude. Populations need to be separated by 1640 ft in elevation before genetic differentiation is expected.

Disturbance Interactions

Wildland fire is essential to the maintenance of western larch populations. Western larch depends on the open-canopy, high light environments, and mineral soil seedbeds created by fire for successful, widespread regeneration (Schmidt et al. 1976). Western larch has unique characteristics that allow it to survive intense fire, including the thickest bark (Ryan and Reinhardt 1988), high crowns with high moisture contents, deep roots and epicormic branch production (Fiedler and Lloyd 1995; Harrington 2012; Schmidt et al. 1976; Schmidt and Shearer 1995). Western larch is one of the few NR tree species that has adapted to survive mixed to stand-replacement fires (Hopkins et al. 2013; Marcoux et al. 2015). Tall surviving western larch can produce copious seeds that are wind-dispersed across large burns to land

4760 on mineral soil seedbeds and ensure continued western larch domination (Stoehr 2000). However, if
4761 serotinous mature lodgepole pine trees occur with western larch, regeneration may be dominated by both
4762 species (e.g., Hopkins et al. 2013). Since western larch grows quicker and taller, it often outcompetes
4763 lodgepole pine to attain dominance (Pfister et al. 1977).

4764 Western dwarf mistletoe (*Arceuthobium campylopodum*) is perhaps the most damaging disease-
4765 causing parasite of western larch (Schmidt and Shearer 1990). It can infect seedlings as young as three to
4766 seven years old and continue throughout the life of the tree. In addition to killing treetops, reducing seed
4767 viability, creating conditions suitable for entry of other diseases and insects, and causing burls, brashness,
4768 and some mortality, it decreases height and diameter growth. Three other important diseases are found in
4769 western larch: needlecast caused by *Hypodermella laricis*, brown trunk rot, and red ring rot. The exotic
4770 larch casebearer (*Coleophora laricella*) and native western spruce budworm are currently the two most
4771 serious insect pests of western larch (Schmidt and Fellin 1973). However, neither of these agents causes
4772 substantial mortality. Western larch is susceptible to defoliation as a result of the recent western spruce
4773 budworm outbreak (DeNitto et al. 2013). Larch needle cast results in substantial needle damage in cooler,
4774 moister springs. Episodic outbreaks of larch casebearer and western spruce budworm can also cause
4775 severe enough defoliation as to reduce the current year's tree growth (Schmidt et al. 1976) and disrupt
4776 cone production.

4777 *Historical and Current Condition*

4778 The more mesic montane western portions of the NR were often dominated by extensive western
4779 larch forests that had regenerated after major fires. The species dominated northwestern Montana and was
4780 the major timber species for most of the 1950's to 1970's. However, extensive logging beginning as early
4781 as 1908 on US Forest Service lands (Arno 2010) removed many of the large tall western larch that could
4782 have survived fire and cast seed across the landscape, and effective fire exclusion has removed the
4783 burned, mineral soil seedbeds where western larch can regenerate. Continued fire exclusion has served to
4784 densify the forest and increase surface fuel loads so that future fires may be more severe.

4785 *Climate Change Responses*

Western larch is a species that is highly susceptible to climate warming. Most climate change studies predict major losses of western larch throughout the NR. Morales et al. (2015) used an SDM approach to project a 41 percent loss of western larch in its range in the western U.S., and Aston (2010) mentions major declines in western larch habitat in the northern Rocky Mountains. Rehfeldt and Jaquish (2010) projected major shifts in western larch in western NR, with major losses in Montana and gains in Idaho. Nitschke and Innes (2008) used gap modeling approaches to simulate major losses in western larch in most of British Columbia. Coops and Waring (2011) mention that western larch may invade many areas vacated by lodgepole pine in the future in some portions of the Pacific Northwest. In addition, considering western larch associates, comp titive interactions among species may play a critical role in the current and projected distributio of tree speci such as western larch (Thuiller et al. 2008). While temperature–precipitation interactions tend t the limits where species can successfully compete, temperature alone seems primarily responsible for ada tation of popu ations within those limits (Rehfeldt et al. 2014).

Western larch will probably migrate to more northe ly nd higher areas in the NR, but not without surviving major fires. Gray and Hamann (2013) estimate western larch could migrate over 500 mi northward and over 1100 ft higher in elevation by 2050 in the R. Wes rn larch has the ability to quickly take advantage of changes in productivity of colder sites, providing these are burn and the western larch will survive the fires to provide sufficient seed for colonization. Increasing ires may serve to return western larch to the NR landscape, but this may require significant as istance from management through planting burns with western larch before other species become established. Continued fire exclusion will probably result in major declines of western larch in the western NR, because increased competition will reduce vigor, making the trees more susceptible to damaging agents, and surface and canopy fuel buildups will be so great that many relic western larch trees will die in uncharacteristically severe fires (Arno et al. 1997; Davis 1980; Norum 1974). Keane et al. (1996) simulated major declines in the future for western larch under fire exclusion and moderate climate change, but found it increased as more fire was allowed to burn in the Glacier National Park landscape.

Western larch exhibits an intermediate adaptive strategy, and geographic clines for most adaptive traits are relatively flat (Rehfeldt 1994, 1995a). Populations from northerly latitudes and higher elevations exhibit the lowest growth potential, least tolerance to larch needle cast and the lowest survival. Using a common garden study of 143 populations, Rehfeldt (1995a) demonstrated an increase of 9 °F would produce a mean annual temperature exceeding the current ecological distribution of the species. A molecular study using allozymes indicated low levels of genetic differentiation among populations from the inland Northwest (Fins and Steeb 1986). Evolutionary bottlenecks are commonly cited as a mechanism of reduced genetic differentiation among populations, and increased differentiation within populations.

Western larch may b highly susce tible to future changes in climate primarily because of its narrow geographic and elevational di ib tion in the NR and its uncertain association with wildland fire. If wildland fires increase, western lar h may h ve a stinct colonization advantage, providing fire mortality is low in those communities that have exten ive fuel buil u s from fire exclusion. However, if fires decrease and exclusion is continued, western larch m y b outcompeted by its shade-tolerant competitors, and those seed-producing western larch that remain mi ht be killed by severe fires created by abnormal fuel accumulations. If the NR plants western larch in those severely burned a as, the species will surely remain on the landscape in the future.

Western White Pine (Pinus monticola)

Autecology

In the interior west, western white pine grows from near Quesnal Lake, British Columbia, south through the Selkirk Mountains of eastern Washington and northern Idaho and into the Bitterroot Mountains of western Montana (Graham 1990). Isolated populations are found as far east as Glacier National Park (Loehman et al. 2011a). The climate of the interior portion of western white pine range is influenced by the Pacific Ocean, where summers are dry and the majority of the precipitation occurs in the fall and winter. Western white pine is limited by moisture at lower elevations and temperatures at upper elevations. The southern boundary is limited by a balance of precipitation and evaporation.

Western white pine grows on a diversity of soil types in the NR (Harvey et al. 2008), but it primarily grows in areas where the upper soil layers are composed of loess or loess-like material. In the NR, it generally grows between 1640 and 5906 ft elevation and where the topography is steep with v-shaped and round-bottomed valleys. It grows on a variety of slopes, but is common along moist creek bottoms, lower benches, and northerly slopes. Western white pine grows in association with a variety of species, and in the western hemlock/bride's bonnet (*Clintonia uniflora*), western redcedar/bride's bonnet, and grand fir/bride's bonnet habitat types (Cooper et al. 1991).

Western white pine seeds require 20 to 120 days of cold, moist conditions before germination occurs. Germination occurs in the spring when soil moisture is at field capacity from melting snow. Western white pine seedling establishment is favored by partial shade on severe to moderately severe sites (Graham 1990) but little to no shade on n rth slo es. Under full sun, germination begins earlier and ends earlier than in shaded conditions. M neral so l surf ces are preferred over duff. Once established, western white pine grows best in full sunlight on all ites. Seedli gs have low drought tolerance, and seedling mortality late in the first growing season is attributed to h gh surface temperatures on exposed sites, and drought in heavily shaded areas where root penetration s slow. Early root and shoot development is not rapid.

Western white pine is almost always a seral species and is classed as intermediate in shade tolerance (Minore 1979). It attains dominance in a stand only following wildfire or silvicultural systems that favor it. It is tolerant of cold when it is dormant, and similar to lodgepole pine in cold tolerance.

Genetic variation of western white pine is high, with the greatest difference being among trees within a stand. Differences occur among stands and elevational zones, but the proportion of variation is smaller than that for trees within a stand. The adaptation of western white pine to different conditions (topographic, climatic, geographic, and edaphic) is governed more by phenotypic plasticity (ability of an organism to change its phenotype in response to changes in the environment) than by selective differences. The species has a high outcrossing rate and average genetic diversity with moderate genetic

4862 differentiation. It is a generalist species with broad climate and environmental tolerances (Devine et al.
4863 2012).

4864 *Disturbance Interactions*

4865 Historically, western white pine forests mostly originated from wildfires, especially stand-
4866 replacement burns, but were also maintained by frequent low severity fires (Barrett et al. 1991). The
4867 species, especially when mature, is more tolerant of heat and can better survive fire than nearly all of its
4868 shade-tolerant competitors. Its relatively thick bark and moderately flammable foliage make it
4869 intermediate in fire resistance among its conifer associates (Graham 1990). Native American burning was
4870 probably the primary source of fire that created the pure stands of western white pine in northern Idaho,
4871 but lightning was also important (Graham 1990).

4872 The most prominent agent causing th sever declines in western white pine is white-pine blister rust
4873 (Fins et al. 2002; Harvey et al. 2008 . A com inati n of climate, extensive white-pine blister rust,
4874 abundant alternate hosts, and susceptible w tern white ne caused significant losses in the recent past.
4875 Selection of naturally resistant trees as seed sources nd p anting of rust-resistant nursery stock can
4876 reduce losses. In the absence of blister rust, western wh te pine is long-lived, commonly surviving to 300
4877 to 400 years old.

4878 The foremost root disease of western white pine is Armillaria root rot, which causes fading foliage,
4879 growth reduction, root-collar exudation of resin, dead and rotten roots, and black rhizomorphs. Annosus
4880 root disease and laminated root rot (*Phellinus sulphurascens*) also cause some mortality of individuals
4881 and groups. In periods of drought, pole blight, a physiological disorder, can occur in stands of the 40- to
4882 100-year age class, causing yellow foliage and dead resinous areas on the trunk. Later, the top dies and,
4883 after a few years, the tree dies. The disease does not appear to be caused by a primary pathogen but results
4884 from rootlet deterioration in certain soils, restricting the uptake of water. Bark beetles are the most
4885 important insects that attack western white pine, and the most important is the mountain pine beetle,
4886 which kills groups of trees, primarily in mature forests. The mountain pine beetle often attacks trees

4887 weakened by blister rust. Likewise, the red turpentine beetle (*Dendroctonus valens*) sometimes attacks
4888 weakened trees.

4889 *Historical and Current Conditions*

4890 Western white pine stands were once extensive across northern Idaho and parts of Montana, with
4891 large, tall pine trees dominating the montane landscapes (Harvey et al. 2008). As a result of logging, fire
4892 suppression and extensive white-pine blister rust infection, western white pine forests are nearly gone,
4893 and the species occurs only as scattered individuals in mixed conifer stands (Fins et al. 2002). This is
4894 truly an ecosystem in decline, and it may be doomed to extinction without active restoration.

4895 *Climate Change Responses*

4896 Western white pine presents a special challenge in forest management in the future. Recent
4897 studies have shown that western white pine might be the species best adapted to changes in climate
4898 change in the northwestern portions of the NR (Loehman et al. 2011a). Using SDMs, Gray and Hamann
4899 (2013) estimated western white pine could move almost 250 mi northward and 500 ft higher in elevation
4900 in the NR by 2050. Its superior growth rates, ability su vive fire, and high timber value make it a
4901 species to promote in the creation of future forests with high resilience (Baumgartner et al. 1994; Graham
4902 1990). It has the unique ability to disperse seeds into burned areas, which will likely increase in the
4903 future, and the predicted increases in productivity in the areas where it occurs could mean that it might
4904 achieve the most significant benefits from changing climates, especially in the context of timber
4905 production. However, the species is currently ravaged by white-pine blister rust, and it has not yet
4906 developed the genetic capacity to overcome the damaging effects of this exotic disease to populate future
4907 northwestern NR landscapes (Fins et al. 2002). The species simply has not achieved a sufficient level of
4908 rust resistance to allow it to dominate future stands (Harvey et al. 2008). With white-pine blister rust and
4909 its alternate hosts (e.g., currant) predicted to also increase in the future, creating a rust-resistant population
4910 of western white pine is critical to maintaining it in the mesic grand fir/western redcedar/western hemlock
4911 habitat types (Baumgartner et al. 1994). Without a comprehensive western white pine restoration
4912 program, there is little chance that this species will play an important role in the future.

There are other issues that may govern future western white pine dynamics. While wildland fire may increase growing space, thereby providing for high regeneration potential, there may be few western white pine trees to provide the seed source needed to regenerate these large burns. Also, in some portions of the NR, the species may be highly dependent on ash cap soils (Graham 1990), which may prevent its migration to warmer sites. The species is also dependent on a unique assemblage of ectomycorrhizae whose availability in some areas might be reduced in the future; suitable substrate may not exist upslope so migration may not occur.

In summary, we feel that western white pine is highly predisposed to declines in the future due to the interacting effects of continued fire exclusion, low levels of white-pine blister rust-resistance in native populations, and rapid succession to more shade-tolerant conifer communities. While it may be a species of special interest for northwestern portions of the NR, its populations and future under changing climates is especially precarious because of white-pine blister rust. Abundance of western white pine is currently low in isolated landscapes, and thus the magnitude of an d cline may be large relative to current and past populations.

Aspen (Populus tremuloides)

Autecology

Quaking aspen is the most widely distributed native tree species in North America and is abundant in the mountains of western and southwestern Montana and northern Idaho (DeByle 1985; Perala 1990). Its habitat is limited primarily to areas of water surpluses (annual precipitation exceeds evapotranspiration), and it is also limited by minimum or maximum growing season temperatures. Deterioration of aspen stands is often related to warmer summer temperatures (Perala 1983). Aspen grows on a variety of soils, but growth and development are strongly influenced by both physical and chemical properties of the soil. The best soils for aspen growth are usually well drained, loamy, and high in organic matter, calcium, magnesium, potassium, and nitrogen. Aspen has an important role in nutrient cycling because of its rapid growth and high nutrient demand. Aspen is limited by both shallow and deep water tables (>8.2 ft) because the roots need sufficient water and good aeration, especially during the growing season.

Compared to most conifer species, aspen is a short-lived, disturbance-maintained seral species (Mueggler 1985; Rogers 2002). It is shade intolerant and aggressively sprouts following any disturbance (usually fire), which kills most of the live stems, thus stimulating vegetative reproduction (i.e., suckering) (Bartos 1978). Aspen reproduces primarily by asexual root sprouting. Parent trees (genets) produce stems/trees (ramets), and this results in a clone or stand of genetically identical aspen stems (trees). Damage to parent trees alters the growth hormones (auxins and cytokinens) and stimulates a sprouting response (Perala 1990). Soil temperature is the most critical abiotic factor affecting suckering. Light is not needed for suckering but is needed for secondary growth. Eventually, most of the original root connections are severed as the ramets develop their own root systems to support nutrient uptake (Rogers et al. 2007; Shepperd and Smith 1993). This reproductive strategy allows aspen to establish quickly on disturbed sites and out-compete conifers for soil moisture, nutrients and light. In addition, the shared root system maintains overall stand vigor by allowing sharing of resources during the early stages of stand development (Mitton and Grant 1996; Romme et al. 1997).

While there are a number of different aspen classifications (Mueggler 1988; Shepperd et al. 2001), it is widely recognized that aspen occurs as both stable climax communities and as seral, disturbance-maintained communities (Mueggler 1988, 1985). Stable aspen communities occupy sites with both high soil moisture and solar radiation, which appears to preclude establishment of conifers for very long periods (or they never establish). Stable climax aspen communities do not require disturbance to maintain aspen dominance. Seral aspen seems to occur in two forms in the NR. First, there are mesic stands in northwest Montana and northern Idaho, where aspen is a common seral component, but it rarely dominates stands unless there are several consecutive burns (Campbell and Bartos 2001; Cooper et al. 1991; DeByle 1985). The second seral type occurs in the drier forested areas in the NR, such as east of the Continental Divide and southwestern Montana. In these seral types, which are created by fire and sprouting, aspen occurs as the major stand component; these stands will eventually succeed to more shade tolerant conifers (e.g., Douglas-fir, subalpine fir, and Engelmann spruce) in the absence disturbance (DeByle 1985; Mueggler 1988).

Aspen has a high genetic diversity, because it is essentially a trans-boreal broadleaf tree. It has weak genetic differentiation geographically, but strong differentiation at the population level. There is substantial phenotypic variation in the species, found both in the field and in genetic studies, as documented by varied leaf sizes, shapes, and phenologies.

Disturbance Interactions

Numerous factors other than competition will be important for quaking aspen under changing climate. Perhaps the most important factor affecting aspen regeneration and distribution is browsing by ungulates that frequently damage reproduction by browsing and by rubbing their antlers against the stems (Eisenberg et al. 2013; White et al. 1998). Elk and moose can also damage pole- and saw log-size trees by "barking" them with their incisors. Such injuries often expose individuals to secondary attack by insects or pathogens. Heavy use by overwintering ungulates can greatly reduce the number of aspen trees in localized areas. Cattle and sheep browsing is a serious problem in many areas of the NR because livestock are allowed to range through recent aspen clearcuts. Mature aspen stands adjacent to livestock concentrations (water holes, salt blocks, and isolated stands in large open areas) often have root damage, are declining, and have few if any suckers present.

Fire can kill aspen stands (Bartos 1998), but it also creates conditions conducive to aspen regeneration and suckering by eliminating shade-tolerant conifers, which compete for light and eventually overtop and shade out aspen, leading to aspen decline (Campbell and Bartos 2001; Shepperd et al. 2001). Mature aspen trees may not survive fire as well as the fire-adapted conifers of the NR, but aspen is easily the most competitive after fire because it can aggressively regenerate from suckers (Shinneman et al. 2013). It would appear that aspen could do quite well in a warmer climate with increased fire frequency, but moisture will limit its success, with varied results (Anderegg et al. 2012; Hogg and Hurdle 1995; Kulakowski et al. 2013; Worrall et al. 2013).

Following disturbance, aspen normally dominates a site for 40 to 80 years. Natural thinning from disease, aging, and succession (shading) by competing conifers eventually reduces aspen abundance (Mueggler 1985; Rogers 2002). In central Utah, Shepperd et al. (2001) found that both regenerating and

nonregenerating clones had stems of various age classes, which suggests that periodic sucker events occurred in these clones. In addition, they found that all of the non-regenerating clones had fewer roots than their regenerating neighbors, which indicates that root systems decline when clones are not periodically regenerating. Many aspen clones are known to be associated with ectomycorrhizae (Cripps and Miller 1993).

Aspen has low susceptibility to insect damage, except in urban plantings, but stem canker diseases have a significant impact on aspen ecosystems. Depending on the fungus, cankers may kill trees within a few years or persist for decades. Hypoxylon canker caused by *Hypoxylon mammatum* is probably the most serious aspen disease east of the Rockies, killing one to two percent of the aspen annually (Perala 1990). Young trees are killed by small rodents and mammals, particularly large ungulates (Eisenberg et al. 2013).

Historical and Current Conditions

Since around 1970, aspen has been in a period of general decline that is thought to be the result of wildfire exclusion, which has allowed plant succession to proceed toward conditions that ordinarily exclude aspen (Campbell and Bartos 2001; Frey et al. 2004). Recent episodes of aspen dieback have been superimposed on this general decline. Dieback can be recognized by the suddenness of the impact and by an epidemiology that begins with the death of branch tips, death of mature trees, and eventually death of entire clones (Frey et al. 2004). The dieback is suspected to be caused by drought. The condition is generally referred to as sudden aspen decline because of the suddenness of the impact.

Climate Change Response

Aspen is a species that may experience both gains and losses under future climate, depending on local site conditions, particularly soil moisture. Seral aspen communities will respond differently than stable, climax aspen communities. Aspen communities on warmer, drier sites could experience high mortality because of increasing water deficit. Ireland et al. (2014) found that drought was the major factor causing recent high mortality in southwestern aspen stands. In the boreal forests of western Canada, Hogg and Hurdle (1995) estimate that even with an 11 percent increase in precipitation, boreal forests in which

aspen is a major component will decline due to drought stress. Sudden aspen decline has been associated with severe, prolonged drought, particularly in aspen stands that are on the fringe of the species' distribution (warmer and drier sites than those typically considered optimal for aspen persistence) (Frey et al. 2004). Recent research efforts have found that extreme weather events (e.g., drought, thaw–freeze events), insect defoliation, and/or pathogens have led to aspen mortality (Brandt et al. 2003; Candau et al. 2002; Hogg et al. 2002). Marchetti et al. (2011) found that aspen mortality from various insects and disease (e.g., Cytospora canker [*Cytospora*], bronze poplar borer [*Agrilus liragus*], and aspen bark beetles *Trypophloeus populi* and *Procryphalus mucronatus*) was greater in those stands that were drought-stressed and declining due to sudden aspen death. Further exacerbating the situation is that declining stands may have little or no regeneration due to intense ungulate herbivory, and those smaller stands that persist may be smaller and fewer with increased plant stress due to increased severity of summer droughts (Rogers et al. 2013). Growth may increase because photosynthetic rates appear to increase more in aspen than other tree species as atmospheric carbon increases, but this may be offset by increased atmospheric ozone, which reduces photosynthesis and may increase susceptibility to insects and disease.

Increased fire frequency, particularly on moist sites, will likely favor aspen regeneration in the future by removing shading conifers, and younger stands (<40 years old) created by fire may be more resilient to drought. However, if future fires are severe, they may kill the shallow root systems and eliminate aspen. Increased herbivory on regenerating stands may occur as adjacent upland vegetation senesces and desiccates earlier in the growing season. Areas with mountain pine beetle-caused conifer mortality (especially in lodgepole pine) may release aspen, and it will regenerate once the conifer canopy is thinned or removed, again given sufficient soil moisture.

Grand Fir (Abies grandis)

Autecology

Grand fir is found on a wide variety of sites, including stream bottoms, and valley and mountain slopes of the northwestern U.S. and southern British Columbia (Foiles et al. 1990). Average precipitation in its range varies from 1.6 to 8.2 ft but in northern Idaho the average is from 1.6 to 4.3 ft. The average

growing season temperature is 57.2 to 66.2 °F. In the inland portion of its range, grand fir grows best on rich mineral soils of valley bottoms but also grows well on shallow exposed soils of mountain ridges if moisture is adequate (Antos 1972).

Grand fir is either a seral or climax species, depending on site moisture (Ferguson and Johnson 1996). On productive mesic sites, it grows rapidly to compete with other seral species in the overstory, but it is outcompeted by western redcedar and western hemlock. On drier sites where western redcedar and western hemlock are excluded because of drought, it is the most shade-tolerant species and can easily dominate the understory, which eventually assumes the dominant position in the climax condition. Grand fir is a major climax species in a variety of habitat types in Montana and northern Idaho, but it rarely grows in pure stands; one exception is on the Clearwater River drainage in north-central Idaho (Cooper et al. 1991; Pfister et al. 1977). In Montana and parts of Idaho, grand fir can also share dominance, even in the climax state, with subalpine fir, especially in narrow valley bottoms where subalpine fir can exert dominance in lower elevational zones (Antos 1972). In most of its range, grand fir is often associated with Douglas-fir, ponderosa pine, western larch, western white pine, and subalpine fir.

Grand fir has a high tolerance to shade but a low tolerance to drought, even though it can tolerate drought better than any of the conifers that may succeed it in the absence of disturbance (e.g., western redcedar and western hemlock). Grand fir forms associations with ectomycorrhizae and arbuscular mycorrhizae, which may allow it to outcompete some shade-tolerant conifers. It has a very low frost tolerance but can tolerate seasonally fluctuating water tables. It is monoecious and it produces large, winged seed dispersed by wind. It has average levels of genetic diversity but weak geographic differentiation. There are apparently genetic differences between the northern Idaho and western Montana populations.

Disturbance Interactions

Grand fir is susceptible to fire damage in moist creek bottoms but is more resistant on dry hillsides where roots are deeper and bark is thicker (Ryan and Reinhardt 1988). Grand fir is less resistant to fire than western larch, ponderosa pine, and Douglas-fir but more resistant than subalpine fir, western

hemlock, and Engelmann spruce. Most fires that burn grand fir sites are stand-replacement or mixed-severity, and these fires burn in fuels that generate sufficient heat to kill most grand fir trees (Arno 1980; Arno et al. 2000).

Grand fir is susceptible to heart rot and decay. Armillaria root rot and annosus root disease are common root diseases causing high tree mortality (Hagle et al. 2003). Numerous insects attack grand fir. The western spruce budworm and Douglas-fir tussock moth have caused widespread defoliation, topkill, and mortality in grand fir. The western balsam bark beetle (*Dryocoetes confusus*) and the fir engraver (*Scolytus ventralis*) are the principal bark beetles attacking grand fir (Foiles et al. 1990).

Historical and Current Conditions

Fire exclusion has increased grand fir on both dry and mesic sites, but increased tree densities have also stressed grand fir trees, contributing to increased fuel loadings, higher root rot, and greater insect damage and mortality. Historically, grand fir sites were probably dominated by western larch, western white pine, Douglas-fir, and ponderosa pine because of frequent fires, but these sites have since succeeded to the more shade-tolerant grand fir, and on the productive mesic sites, to western redcedar and western hemlock. Therefore, the condition of most grand fir stands depends on the last severe fire; if fire exclusion has caused grand fir to dominate in both the overstory and understory, then these stands are usually highly stressed because of increased root rot and insect agents. However, in earlier seral stands that have not yet experienced high grand fir regeneration, a rise in grand fir cover types is likely with continued fire exclusion.

Climate Change Responses

On xeric sites, increased drought and longer growing seasons will exacerbate grand fir stress from competition, resulting in high mortality mainly from insects and disease. Nitschke and Innes (2008), using a gap modeling approach, projected major declines in grand fir, and Coops and Waring (2011) used a mechanistic model to simulate a nearly 50 percent decrease in the range of grand fir compared to historical distributions. Franklin et al. (1991) projected that grand fir will nearly disappear from the east slope of the Cascades.

Yet, projections of increased productivity may lead to increased grand fir populations on moderate sites (Aston 2010). Urban et al. (1993) projected an expansion of grand fir forests into upland, xeric sites of the Pacific Northwest. On mesic sites where grand fir is seral to western redcedar and western hemlock, the longer growing seasons coupled with higher temperatures may increase growth rates and regeneration success, thereby increasing tree density and competition and effectively reducing grand fir components. The opposite is true on those sites where grand fir is the indicated climax; grand fir will increase in both the overstory and understory in the absence of disturbance.

Disturbance, specifically fire, could be the major factor in the rearrangement of grand fir communities across the NR landscape. Longer fire seasons and high fuel loadings from both fire exclusion and increased productivity will serve to foster large, severe fires that may reduce grand fir, especially on those sites where it is the indicated climax species (i.e., grand fir habitat types). Fire will reduce grand fir dominance at both landscape and stand scales.

In summary, while many grand fir forests are highly stressed from high tree densities, the species will probably tolerate changes in climate and remain on the landscape at levels that are closer to historical conditions rather than the high abundance observed now.

Western Redcedar (Thuja plicata)

Autecology

The inland range of western redcedar extends from the western slope of the Continental Divide in British Columbia south through the Selkirk Mountains into western Montana and northern Idaho (Minore 1990). The southern limit is Ravalli County and the eastern limit is near Lake McDonald in Glacier National Park. A few trees may exist east of the Continental Divide near St. Mary's Lake (Pfister et al. 1977). Western redcedar is abundant in many forested swamps as well as sites that are too dry for western hemlock; it has better root penetration than western hemlock (Habeck 1978). Western redcedar dominates wet ravines and poorly-drained depressions. Where there is sufficient precipitation, low temperatures limit the species range. It is not resistant to frost and can be damaged by freezing temperatures in late spring and early fall.

Western redcedar only occurs in pure stands where fire has been excluded for a long time, or where fire has been used to maintain western redcedar dominance (Barrett 1988; Barrett and Arno 1991). It is commonly associated with a wide array of tree species, specifically grand fir, western white pine, western hemlock, western larch, and ponderosa pine. Only western hemlock in the NR is more tolerant to shade than western redcedar, but western redcedar can be overtopped by Douglas-fir, grand fir, western hemlock, and western white pine (table 6.3). Its relative shade tolerance may be higher in warm than in cool areas, but western redcedar is very tolerant wherever it grows. Often present in all stages of forest succession, western redcedar can occupy pioneer, seral, and climax positions, but in the NR, most western redcedar stands are in the late seral stages; it is usually considered a climax or near climax species. It has little tolerance for drought but can exist in seasonally wet areas, especially near riparian systems (Devine et al. 2012).

Western redcedar regenerates best on disturbed mineral soil, although scorched soil is not beneficial to its regeneration. Rotten wood that is in contact with the soil is a preferred seedbed in western redcedar groves. Western redcedar also propagates by clones, and clones tend to be more abundant than young trees established by seed. Establishing seedlings survive best in partial shade, as they are not tolerant of high soil temperatures or frost. Young branches can sunscald. Roots of young seedlings grow more slowly than Douglas-fir but faster than western hemlock, and shoots have the longest growing period of any of the associated conifers.

Western redcedar has very low levels of genetic diversity, and this diversity is weakly distributed geographically and within populations. Clines are very gentle and seed zones narrow. This species cannot tolerate wide ranges of environmental conditions.

Disturbance Interactions

Relative to its associates, western redcedar is not as affected by damaging agents, but because it is long-lived, damaged trees are common (Minore 1990). Although western redcedars are somewhat wind-firm, especially on dry sites, western redcedars are often wind thrown in wetter environments. Western redcedar is less susceptible to fire damage than Engelmann spruce, western hemlock, grand fir, and

subalpine fir in the NR. Western redcedar is also less susceptible than other associated species to root pathogens. However, root disease still impacts western redcedars, and fungi eventually invade heartwood typically resistant to decay. In North America, the most important fungi attacking western redcedar are root, butt, and trunk rots, most importantly laminated root rot, honey fungus (*Armillaria mellea*), and stringy butt rot (*Perenniporia subacida*).

Historical and Current Conditions

Compared to historical distributions, there has not been a significant increase or decrease in western redcedar distribution in the NR. However, there has likely been an increase in western redcedar dominance in those stands occupying mesic western redcedar sites due to fire exclusion.

Climate Change Responses

With warmer temperatures, mesic northern Rocky Mountain ecosystems may increase in productivity (Aston 2010), and western redcedar may expand into more upland communities. Hamann and Wang (2006) projected that the western hemlock/cedar forests of British Columbia would double in range by 2050, and Urban et al. (1993), using gap modeling, simulated an expansion of western redcedar into upland western Oregon sites. Devine et al. (2012) rated western redcedar as having moderate vulnerability in the Pacific Northwest Region. With increased western redcedar productivity could come increased cone production and seed dispersal into new areas that might be more conducive for long-term seedling establishment.

Although warmer conditions in the future may benefit western redcedar, drier conditions in the future would likely result in retraction of western redcedar to the warmer, wettest NR sites; upland western redcedar stands might have high mortality from declining productivity. Woods et al. (2010) noted recent declines in western redcedar in British Colombia and attributed the decline to increased drought that decreased vigor and increased insects attacks and disease in western redcedar. Warming may also result in a loss of chilling required for western redcedar (Nitschke and Innes 2008), and western redcedar's narrow genetic potential (Devine et al. 2012) may limit its expansion into new habitats. Using SDMs, Gray and Hamann (2013) estimated western redcedar might move 400 mi northward and 1,000 ft higher in

elevation by 2050 in the Pacific Northwest. However, in some of the NR, redcedar is mostly associated with ash cap soils, so it may be that even though new climates create new habitats, the potential of non-ash soils to sustain productive western redcedar may be limited.

It is uncertain how disturbance will affect western redcedar in the future. Fire can serve to maintain western redcedar communities if it burns at low severities and kills only seedlings and saplings. However, high severity wildfires could eliminate seed sources. Continued fire exclusion may maintain current western redcedar distributions, but without proactive fuel treatments, wildfire that occurs after long periods of exclusion may burn with sufficient severity to cause extensive western redcedar mortality. Also, new warm-cold cycles may facilitate red belt and adversely affect young western redcedar, as evidence by increased flagging during past dry seasons.

In summary, western redcedar may not be severely affected by future climate warming. The species may remain its current range, and productivity may increase in some settings.

Western Hemlock (Tsuga heterophylla)

Autecology

The inland range of western hemlock includes the west side of the Continental Divide of the Rocky Mountains in Montana and Idaho, north to Prince George, British Columbia (Packee 1990). Western hemlock thrives in mild humid climates and in environments with abundant soil moisture throughout the growing season (Hann et al. 1994). Where the growing season is relatively dry, western hemlock is confined primarily to northerly aspects, moist stream bottoms, or seepage sites. Western hemlock grows on a variety of soil types, although it is a shallow-rooted species and does not develop a taproot. Abundant roots, especially fine roots, grow near the soil surface and are easily damaged by fire.

Western hemlock is considered very shade tolerant and is perhaps the most shade tolerant tree species in the NR (table 6.3). It is a major climax or near climax species in the NR and is found with nearly all of the other conifer species, including western redcedar, grand fir, Douglas-fir, western larch, western white pine, lodgepole pine, and ponderosa pine. Seed germination and germinant survival occurs when there is adequate moisture. Western hemlock can germinate on a variety of materials and in both organic and

mineral seedbeds. Decaying logs and rotten wood are often favorable seedbeds; decayed logs have the added benefit of good nutrition. Western hemlock is highly susceptible to drought and demands abundant water throughout the growing season (Baumgartner et al. 1994). It is associated with some ectomycorrihizae. Its seedlings are highly susceptible to frost.

Western hemlock has relatively low genetic diversity and low geographic differentiation. It has a high outcrossing rate and average heterozgosity (Devine et al. 2012). Growth rate is more related to soil conditions that to genetics.

Disturbance Interactions

A variety of root and bole pathogens cause significant damage and mortality in western hemlock. It is also very susceptible to fire damage because of its shallow roots and thin bark, and it is also susceptible to wind throw owing to shallow roots. On droughty sites, top dieback is common, and entire stands of western hemlock saplings have been killed in exceptionally dry years. Western hemlock is highly susceptible to annosus root disease and Indian paint fungus (*Echinodontium tinctorium*), but seems to have a high tolerance to Armillaria root rots (Packee 1990).

Historical and Current Conditions

The current distribution of western hemlock is similar to its historical distribution. However, most stands with western hemlock have become denser and the western hemlock component has increased in both the overstory and understory. Overly dense western hemlock stands may be experiencing declines in vigor, thereby becoming more susceptible to disease, insects, and abiotic perturbations (e.g., windthrow).

Climate Change Responses

In the past, milder, western hemlock/western redcedar forests were associated with wetter conditions in the low elevation forests of the NR, but this type declined as fires and drought increased (Gavin et al. 2007). Thus, increased drought and area burned may decrease western hemlock abundance and distribution. Several studies have projected contractions in western hemlock distribution. For example, Hansen et al. (2001) simulated major contractions in western hemlock range, and Franklin et al. (1991) project that western hemlock will occupy about half its current range on the western slopes of the

Cascades. Shafer et al. (2001) noted that western hemlock may decrease in range because chilling requirements for the seeds will not be met. Using a mechanistic landscape model, Keane et al. (1996) simulated losses of western hemlock and cedar under moderate climate warming in Glacier National Park, mostly as a result of severe fires. Cumming and Burton (1996) projected minor changes in the western redcedar-western hemlock zone in British Columbia under moderate warming. Hamann and Wang (2006), on the other hand, predicted that western hemlock would increase its range by over 200 percent in British Columbia, and using gap modeling, Urban et al. (1993) simulated an expansion of western hemlock into upland western Oregon sites.

It is possible that western hemlock will maintain its current range under changing climate. It may not have the diversity in growth habit that will allow it to expand its range into the more upland sites as temperatures warm. Since the species is dependent on ash cap soils, any migration may be relegated to those wetter and warmer sites without ash cap soils.

Lodgepole Pine (Pinus contorta)

Autecology

Lodgepole pine has wide ecological amplitude, but only the inland form (var. *latifolia*) is found in the NR (Lotan and Critchfield 1990). Lodgepole pine has the widest range of environmental tolerance of any conifer in North America (Lotan and Critchfield 1990). It is relatively resistant to frost injury and can often survive in frost pockets where other species cannot (Pfister et al. 1977). In Montana, lodgepole pine does not grow on highly calcareous soils derived from dolomitic limestone (Lotan and Perry 1983). Lodgepole pine is mainly found on moist soils developed on colluviums from other types of limestone and calcareous glacial till. It grows well on gentle slopes and in basins, but it is also found on rough and rocky terrain, on steep slopes and ridges, and bare gravel (Lotan and Critchfield 1990). Compared to other associated species, lodgepole pine is intermediate in its needs for water, requiring more than Douglas-fir or ponderosa pine but less than spruce and subalpine fir in the NR.

Lodgepole pine is intolerant of shade but highly tolerant of frost and drought (table 6.3). Occasionally seedlings become established under a forest canopy, but these individuals rarely do well and remain in a

5251 stunted form for long periods of time (decades to centuries). In the absence of fire, lodgepole pine is
5252 usually succeeded by its more tolerant associates, such as Douglas-fir in xeric environments and
5253 Engelmann spruce and subalpine fir in subalpine environments. Succession proceeds at variable rates,
5254 however, and is particularly slow in some high elevation forests (Arno et al. 1993). Lodgepole pine grows
5255 both in pure stands and in association with many conifers, primarily subalpine fir, spruce, Douglas-fir,
5256 and western larch (Steele et al. 1983). Its successional role is dependent on environmental conditions and
5257 on competition. It is seral in most mesic NR forest communities (Arno et al. 1986). However, on cool dry
5258 habitats, such as those found in the Greater Yellowstone Area and southeastern Idaho, it is dominant and
5259 tends to be persistent and form near climax communities (Despain 1983). Its ability to remain on xeric
5260 landscapes is enhanced by its association with many types of mycorrhizae.

5261 Lodgepole pine has a great ability to regenerate due to a combination of cone serotiny, high seed
5262 viability, early rapid growth, and ability to survive a wide variety of microsite and soil conditions (Hardy
5263 et al. 2000). The serotinous cone habit, where cones only open after being heated by wildland fire, is
5264 common in the Rocky Mountains, but in general, the highest serotiny is found in the northern parts of the
5265 NR. Large quantities of stored seeds are available for regeneration after fire, and annual seed fall from
5266 non-serotinous cones helps in restocking in areas of relatively minor disturbance and maintaining
5267 lodgepole pine presence in mixed stands.

5268 The best lodgepole germination occurs in full sunlight and on bare mineral soil or disturbed duff, with
5269 little competition. Adequate soil moisture is required for germination and survival, with the first few
5270 weeks being most critical. In southwest Montana most of the season's total germination occurs during the
5271 two weeks following snowmelt in late June when soil is saturated and temperatures most favorable.
5272 Drought is a common cause of mortality in first year seedlings. Freezing temperatures may kill seedlings,
5273 but seedlings vary in frost resistance based on seed source. Frost heaving also causes mortality. Height
5274 growth begins earlier than other associated species, except for other pines and western larch.

5275 There is moderate genetic variation in strains of lodgepole pine, resulting in some strains growing
5276 well in cold climate and on poor sites. Lodgepole pine has an average genetic diversity but a weak

differentiation across its NR range and strong differentiation among populations. The species is a prolific seed producer and has a good cone crop at about one to three year intervals. It is wind-pollinated and its seeds are wind-dispersed.

Disturbance Interactions

Fire plays a critical role in lodgepole pine forest succession (Brown 1973; Lotan et al. 1984). Typically, many NR lodgepole pine forests were borne from stand-replacement fires, but extensive fire scars in NR lodgepole pine forests indicate the existence of a low severity, non-lethal fire regime component in lodgepole pine forests, especially in many areas east of the Continental Divide (Arno et al. 1993; Stewart and Arno 1997). Lodgepole pine appears to be able to survive low intensity fires quite well even though it has thin bark (Ryan and Reinhardt 1988). However, most NR lodgepole pine forests have a mixed severity fire regime in space and time, where all possible fire severity types are possible depending on available fuels, antecedent drought, and wind conditions (Arno et al. 2000). The end result is that lodgepole is a tree species that will be well adapted to the fires of the future. Repeated fires, however, can eliminate lodgepole pine seed sources if the fires occur before existing lodgepole has become reproductively mature (approximately 10 years) (Larson et al. 2013). In most cases, lodgepole pine natural regeneration often overwhelms a burned site with abundant seed from serotinous cones and thereby excludes other species (Lotan and Perry 1983; Nyland 1998).

The mountain pine beetle is the most significant insect pest and has played a significant role in the dynamics of lodgepole ecosystems (Roe and Amman 1970). Past research has tried to link fire, beetles, and lodgepole pine in a complex web of interactions (Brown 1973; Geiszler et al. 1980). However, recent findings have shown that fire and beetles often act independently to influence lodgepole pine dynamics (Axelson et al. 2009; Moran and Corcoran 2012; Schoennagel et al. 2012).

Historical and Current Conditions

Advancing succession due to fire exclusion is contributing to replacement of lodgepole pine with subalpine fir in many areas of the NR. Keane et al. (1994) found that upper subalpine landscapes have experienced successional advancement of subalpine communities from under eight percent of the Bob

Marshall Wilderness landscape to over 22 percent. Concurrent increases in burn areas are creating many new lodgepole stands and some may become dense thickets, but coupled with increased drought, these dense lodgepole stands may exacerbate stress from other factors, including competition, endemic insects and diseases, and wind. Warming temperatures have heightened bark beetle activity, resulting in more frequent and severe outbreaks that have devastated many mature lodgepole pine communities in the central NR (Carroll et al. 2003).

Climate Change Responses

Longer drought periods and warmer temperatures in the lower, south-facing, drier lodgepole pine subalpine environments may cause decreased tree growth and regeneration potential, perhaps resulting in a transition to more xeric trees species, such as Douglas-fir. Chhin et al. (2008) found that recent warming has decreased lodgepole pine growth rates in the foothills lodgepole pine communities of the low elevation forests in Alberta, Canada. Coops and Waring (2011) used process modeling to simulate minor declines with moderate warming in lodgepole pine in the Pacific Northwest (Oregon, Washington, and British Columbia), but major type conversions to other species with major warming. Using an SDM approach, Hamann and Wang (2006) projected a net 50 percent loss of lodgepole pine in British Columbia under severe warming. Nigh (2014) projected that lodgepole pine heights may decrease by roughly one yard in moderate future warming, but the species has the genetic capacity to mitigate this height loss, while Rehfeldt et al. (1999) found substantial decline in lodgepole pine growth and height with minor changes in climate. Chhin et al. (2008) also found decreases in lodgepole pine growth were correlated with high summertime temperatures, presumably related to summer drought. However, they also found that increases in lodgepole pine growth with high fall temperatures. Gray and Hamann (2013) estimated lodgepole pine would move over 250 miles northward and over 650 ft higher in elevation by 2050 in the NR using SDM techniques. Bell et al. (2014), using SDMs, project major losses of over 70 percent of its NR range by 2090. Given that lodgepole pine is a generalist that is capable of regenerating and growing in a wide range of environments, it is likely that the decline of lodgepole pine from drier sites will only occur under extreme warming scenarios (e.g., RCP 8.5 and A2) over longer time periods.

5329 Another possibility is that, in the higher elevational areas of the NR subalpine, where seasonal
5330 drought is not a problem, warming climates may actually increase lodgepole pine productivity because of
5331 high precipitation (Aston 2010). Johnstone and Chapin (2003) show that lodgepole pine is not in
5332 equilibrium with current climate, and this means that the species' response to climate shifts will be
5333 difficult to predict using SDM approaches. However, they found that there are places where lodgepole
5334 pine will be positively affected by climate change. Wang et al. (2006) found major increases in lodgepole
5335 pine productivity under future climates with moderate warming, but major decreases and perhaps local
5336 extinctions under extreme warming. Romme and Turner (1991) projected increases in the lodgepole pine
5337 zone in the GYA under moderate warming.
5338 A third possibility is that lodgepole pine will migrate into areas where it is currently excluded by
5339 harsh cold, windy conditions, such as the upper subalpine and timberline. This relocation process will
5340 likely be catalyzed by fire, especially in those areas with high serotiny. Clark et al. [in review] found that
5341 under moderate warming, lodgepole pine would remain on the GYA landscape, but it would also expand
5342 into higher elevation environments historically occupied by whitebark pine. Most studies have projected
5343 the migration of lodgepole pine into the whitebark pine zone (Hamann and Wang 2006; Romme and
5344 Turner 1991).
5345 Lodgepole pine is well-adapted to increases in fire occurrence, depending on level of serotiny (Turner
5346 et al. 1999). Smithwick et al. (2009) simulated some positive increases in GYA lodgepole pine after fire
5347 and under climate change. However, if fire is too frequent, lodgepole may be eliminated from sites where
5348 fires reburn stands before established seedlings and saplings become reproductively mature. Clark et al.
5349 [in press] simulated major and rapid decreases in GYA lodgepole pine under high climate warming due to
5350 both inhospitable environments and too frequent fire.
5351 In mesic subalpine sites, continued fire exclusion coupled with higher productivities will certainly
5352 heighten competitive interactions and put more lodgepole pine trees into stress, thereby increasing
5353 mortality, insect and disease vulnerability, canopy and surface fuels, and accelerating succession toward
5354 subalpine fir (Smithwick et al. 2009). Severe fires that then occur in these advanced successional

communities could covert back to lodgepole pine, providing there is not a loss of seed source. Fire exclusion, especially in areas of high serotiny, might delay the expansion of lodgepole pine.

Projected increases in climatic conditions that facilitate mountain pine outbreaks could reduce lodgepole pine populations and forest extents (Creeden et al. 2014; Gillette et al. 2014). Lodgepole pine is highly susceptible to bark beetle mortality, especially on those landscapes where fire exclusion has resulted in an abundance of mature hosts (Temperli et al. 2013). Bark beetle outbreaks will favor the more shade tolerant, non-host tree species, thereby creating dense stands that may be subject to severe crown fires after 10-20 years. If beetle-killed stands burn, lodgepole pine can occupy the burned area only if viable seed sources still remain. The varying levels of serotiny and beetle mortality will dictate future stand conditions in beetle-killed stands. Landscape heterogeneity is the only hedge against massive declines of lodgepole pine in the future (Logan and Powell 2001).

In summary, lodgepole pine is expected to both expand and contract in range, but as long as fire remains on the landscape, the species will likely maintain its presence in the NR at roughly the same proportions as during the last 100 years, albeit in different areas. The species is highly exposed to any climate changes because of its wide range and diverse growing environments, but Soulé and Knapp (2013) note that the steep clines associated with lodgepole pine seem to be driven more by density-dependent selection than by environmental selection, so this species may be well-adapted to future changes in climate. In addition, while the magnitude of climate effects will likely be great for tree growth, it may be only moderate for the species survival compared to other species, and the likelihood of these effects are highly uncertain, mainly because of the role that fire will play in the maintenance of lodgepole as a major component on future landscapes.

Whitebark Pine (Pinus albicaulis)

Autecology

Whitebark pine is an important component of high-elevation upper subalpine forests in the western U.S. and Canada (Arno and Hoff 1990). It is a keystone species because it supports unique community diversity, and it is a foundation species because of its roles in promoting community development and

stability (Tomback and Achuff 2010; Tomback et al. 2001). Since more than 90 percent of whitebark pine forests occur on public lands in the U.S. and Canada, maintaining whitebark pine communities requires a coordinated effort across federal, state, and provincial land management agencies (Keane et al. 2012).

Whitebark pine is a long-lived tree of moderate shade tolerance (Minore 1979) (Table 6.3). It is common to find mature whitebark pine trees well over 400 years of age, especially on harsh growing sites; the oldest is more than 1,275 years (Luckman et al. 1984). Well-formed, thrifty individuals often have smooth, grey bark, especially in the tree crowns, which may appear whitish in bright sunlight (Arno and Hoff 1990). Whitebark pine is slowgrowing in both height and diameter, and it rarely grows faster than most of its competitors, except on the most severe sites (Arno and Hoff 1990). In general, whitebark pine grows where summers are short and cool, most precipitation comes in the form of snow and sleet, with rain only in June through September. Whitebark pine survives strong winds, thunderstorms, and severe blizzards, and is one of the few upper subalpine species that can tolerate long periods of drought (Callaway et al. 1998).

Whitebark pine is a major component of high elevation forests throughout the upper subalpine and timberline zones in the NR (Arno and Hoff 1990). Whitebark pine forests occur in two high mountain biophysical settings. On productive upper subalpine sites, whitebark pine is the major seral species that is replaced by the more shade-tolerant subalpine fir, Engelmann spruce, and mountain hemlock, depending on geographic region (Arno 2001). These sites, referred to as “seral whitebark pine sites”, support upright, closed-canopy forests in the upper subalpine lower transition to timberline, just above or overlapping with the elevational limit of the shade-intolerant lodgepole pine (Pfister et al. 1977), and the two pine species can often share dominance. Other minor species found with whitebark pine on these sites are Douglas-fir, limber pine, and alpine larch (Keane et al. 2012). Sites where whitebark pine is the only tree species able to successfully dominate high elevation settings (called “climax whitebark pine sites”) occur in the upper subalpine forests and at treeline on relatively dry, cold slopes. Other species, such as subalpine fir, spruce, and lodgepole pine, can occur on these sites, but as scattered individuals with truncated growth forms. Whitebark pine can also occur as krummholz, elfin forests, clusters, groves, tree

islands, and timber atolls in the alpine treeline ecotone (Tomback 1989) and as a minor seral in lower subalpine sites (Cooper et al. 1991; Pfister et al. 1977).

Whitebark pine is eventually replaced, in the absence of fire, by the shade-tolerant subalpine fir, spruce, and mountain hemlock on the productive, seral whitebark pine sites (Arno and Hoff 1990). It can take 50 to 250 years for subalpine fir to replace whitebark pine in the overstory, depending on the local environment and previous fire history (Keane 2001). Whitebark pine competes with lodgepole pine during early successional stages in the lower portions of its elevational range. Lodgepole pine usually has the competitive advantage over whitebark pine when it establishes from seed after a stand-replacing disturbance event because of its fast growth, serotiny, and copious seed production.

A bird, the Clark's Nutcracker, and whitebark pine have coevolved into mutualistic relationship to ensure their continued presence on the landscape (Tomback 1982, 1983). Whitebark pine has evolved a nearly exclusive dependence on nutcrackers to disperse its large wingless seeds, and in turn, nutcrackers utilize the large whitebark pine seeds as an important food source. The key behavior that benefits the whitebark pine is the tendency of nutcrackers to bury thousands of whitebark pine seeds each year as food stores in small clusters or "seed caches" across diverse forest terrain (Keane et al. 2012). Nutcrackers retrieve these seed caches primarily in spring and summer months as an important food source for themselves and their young. However, not all seed caches may be recovered, particularly following a large cone crop. Snowmelt, spring rains, and summer showers stimulate seed germination, leading to whitebark pine regeneration. While whitebark pine depends nearly exclusively on nutcrackers, nutcrackers often harvest and cache seeds of other large-seeded pines.

Whitebark pine is a genetically diverse species because of its dependence on bird-mediated seed dispersal (Keane et al. 2012). As a result, the species is highly adapted to exist across many environments, and is only limited by competition, even at the lowest elevations. It has only six seed zones across its entire range, so it is easily able to migrate across local landscapes to rapidly take advantage of newly burned areas. Whitebark pine has weak geographic differentiation in the NR, but a moderate level of inbreeding. One concern in the future is that the breeding of rust-resistance in future whitebark pine

5433 seedlings may compromise other important traits; Mahalovich et al. (2006) found lower cold tolerance in
5434 high rust-resistant seedlings grown in the nursery.

5435 *Disturbance Interactions*

5436 Whitebark pine fire regimes are quite complex and variable in space and time, but in general, all three
5437 types of fire severities describe whitebark pine fire dynamics: non-lethal, stand-replacing, and mixed-
5438 severity (Morgan et al. 1994b). Some whitebark pine stands may experience fire events that burn in low-
5439 intensity, non-lethal surface fires (sometimes called underburns or low-severity fires) because of sparse
5440 surface and canopy fuel loadings and unique topographical settings. However, most fires in the upper
5441 subalpine burn in mixed-severity patterns that best facilitate continued existence of whitebark pine
5442 (Keane et al. 1994).

5443 Mountain pine beetle is by far the most damaging insect in mature stands of whitebark pine. Much of
5444 the mature whitebark pine in the NR was killed by this insect between 1909 and 1940. Epidemics
5445 evidently spread upward into the whitebark pine forest after becoming established in the lodgepole pine
5446 forests below. The GYA whitebark pine ecosystems have recently experienced one of the most severe
5447 mountain pine beetle mortality events in recorded history.

5448 The principal disease of whitebark pine is the introduced white-pine blister rust (Schwandt 2006).
5449 Blister rust is particularly destructive where the ranges of whitebark pine and blister rust coincide with the
5450 rust's alternative host, currant. Where there is a source of inoculum from lowland forests, the spores that
5451 infect pine can be carried by wind to the trees, but cool, moist conditions are needed for infection in
5452 whitebark pine. Blister rust damage is severe and prevents tree development in many upper subalpine
5453 settings of northern Idaho and northwestern Montana. Whitebark pine has some resistance to the disease,
5454 and efforts at developing rust-resistant seed for regenerating burned and treated areas have been quite
5455 successful.

5456 *Historical and Current Conditions*

5457 Whitebark pine has been declining since the early 20th century from the combined effects of native
5458 mountain pine beetle outbreaks, contemporary fire exclusion policies, and the spread of the exotic white-

pine blister rust (Schwandt 2006; Tomback and Achuff 2010). Losses of whitebark pine in some areas of the NR exceed over 80 percent (Keane et al. 2012). Whitebark pine is listed as endangered in the province of Alberta, Canada, it is a candidate species for listing under the U.S. Endangered Species Act (U.S. Fish and Wildlife Service 2011), and it is listed as endangered in Canada under the federal Species at Risk Act. Within the last decade, major outbreaks of pine beetle and increasing damage and mortality from blister rust have resulted in cumulative whitebark pine losses that have altered high-elevation community composition and ecosystem processes in many regions of the U.S. and Canada.

Climate Change Responses

There is much confusion in the research and management communities about the fate of whitebark pine as climates slowly warm. Some maintain that projected warmer conditions will severely reduce whitebark pine habitat and push whitebark pine "off the tops of mountains" (Lenoir et al. 2008) or restrict the species to north of the Canadian border (Koteen 1999; Schrag et al. 2007; Warwell et al. 2007). This assumes that less hardy, shade-tolerant conifer species would establish in those higher elevation stands where whitebark pine currently dominates, and whitebark pine would "migrate" upslope to the limited areas above its current elevational range (Romme and Turner 1991). Bell et al. (2014), using SDMs, project minor losses (10 - 20 percent) in whitebark pine's range in the NR by 2090. Others hold that climate-mediated changes in the disturbance regimes will serve to keep whitebark pine within its current range, albeit at lower levels (Loehman et al. 2011b). The fate of whitebark pine is uncertain because of high uncertainty in regional climate change predictions, the high genetic diversity and resilience of the species, and the localized changes in disturbance regimes and their interactions (Keane et al. [in press]).

Climate change has the potential to significantly impact whitebark pine ecosystems (Bartlein et al. 1997). Devine et al. (2012) rated whitebark pine the most vulnerable of all the PNW tree species, primarily because of restricted range and white-pine blister rust infections. However, taking a historical perspective, whitebark pine was able to persevere through many major climatic cycles in the past. Historical analogs of warmer climates in the paleoecological record indicate whitebark pine was maintained and even increased in some places under past warmer and drier climates in some parts of its

range (Whitlock and Bartlein 1993; Whitlock et al. 2003). Whitebark pine can grow within a broad upper elevation zone in the west; it just happens to grow best at high elevations where there is little competition from other tree species. For example, Arno et al. (1995) found that whitebark pine's elevational range extended over 500 ft below the current lower elevation limits of whitebark pine in the Bitterroot Mountains of Montana. Nitschke and Innes (2008) suggested that temperature alone would exclude whitebark pine from British Columbia landscapes. However, whitebark pine occupies the largest range of any five-needled pine in the U.S. and Canada, including about 18˚ of latitude and 21˚ of longitude, indicating a great deal of tolerance to different climates (Tomback and Achuff 2010), and because it is bird-dispersed, it is planted and grows in many environments and only dies from competition (Arno and Hoff 1990). Moreover, its longevity provides potential buffering against changing climates (Morris et al. 2008).

The same three responses of tree species to climatic change will occur for whitebark pine: ranges will decline, stay the same, and expand. SDM studies have projected dramatic decreases in whitebark pine habitat over the next 50 years (McDermid and Smith 2008; Warwell et al. 2007). Hamann and Wang (2006) project a 100 percent decline in whitebark pine in British Columbia with high levels of warming. These same models also predict that whitebark pine will probably transition to timberline environments that are above the current elevational range, but these transitional areas are much smaller in size than whitebark pine's traditional range, thereby resulting in a net loss of the species. Climate can adversely impact growth and mortality of whitebark pine in a number of ways (Bugmann and Cramer 1998; Keane et al. 2001). Projected decreases in water availability may result in less water being available for some droughty sites. Longer drought might cause whitebark pine to shut their stomata longer to conserve the little water available, resulting in slow growth.

However, many whitebark pine stands may have positive responses to warming climates. Anecdotal evidence shows that some whitebark pine forests are experiencing abnormally high growth and more frequent cone crops with warmer summers and longer growing seasons. These observations are consistent with some region-based scenarios using computer modeling (Loehman et al. 2011b). Recent modeling

efforts have shown that whitebark pine might be maintained on the landscape in the future, providing that projected increases in large, stand-replacement fires create large, competition-free burned areas (Clark et al. [in review]; Loehman et al. 2011b). If tree dispersal enables range shifts to occur, this will lead to a new northern distributional range of whitebark pine (Hamann and Wang 2006; McKenney et al. 2007). Moreover, whitebark pine shows promise for being maintained in the NR because of high levels of genetic diversity (Mahalovich and Hipkins 2011; Richardson et al. 2002); moderate to high heritabilities in key adaptive traits (Mahalovich [in press]); demonstrated blister rust resistance (Hoff et al. 2001; Mahalovich et al. 2006); minimal inbreeding (Bower and Aitken 2007; Mahalovich and Hipkins 2011); and generalist adaptive strategies (Mahalovich [in press]).

Future climates may enhance whitebark pine diameter and height growth and decrease mortality, especially in mesic seral whitebark pine forests. Earlier growing seasons with ample moisture, such as those projected for the upper subalpine forests, will result in increased productivity and greater growth. Longer, warmer growing seasons may also result in higher productivities and greater biomass, especially considering the high amounts of precipitation that currently fall in upper subalpine forests. The abundant moisture may enable longer high elevation tree growth, thereby increasing growing seasons. Increased biomass could result in higher growth rates for timber production and forage, especially in the widespread higher mountain areas where cold, not moisture, limits tree growth, creating potential for the inclusion of whitebark pine in the timber base. Increased biomass could also foster more intense, severe fires, and maybe insect and disease outbreaks, but more importantly, the increased biomass will probably increase cone crop abundance and frequency. However, this increased production may also heighten competitive interactions between whitebark pine and its associated species, thereby favoring the more shade-tolerant individuals in the absence of disturbance. However, if disturbances increase, the more fire-tolerant whitebark pine might inherit the landscape.

Whitebark pine cone and seed crops could be both adversely and beneficially affected by climate change. In high elevation, historically cold environments, increased temperatures may increase growing seasons and thereby increase potential for more frequent and more abundant cone crops with greater

numbers of seed. This is important because decreases in species abundance and associated cone production may be offset by climate-driven increases in cone crops. Climate warming and its variation will also affect the phenology of cone crops, but these impacts may be minimal as plants adapt to the new conditions. Some predict higher frost mortality of emerging cones due to earlier onset of the growing season, coupled with high daily temperature variability (Chmura et al. 2011), while others suggest that cone crops will be reduced in the future because of high tree stress from drought resulting in less frequent and abundant cone crops. Since whitebark pine is both drought-tolerant and cold-tolerant, many expect that changes in climate variability and timing will have low impact on species reproduction.

Perhaps the most critical whitebark pine life stage is regeneration, where most species, but especially trees, are most susceptible to shifts in climate (Solomon and West 1993). The microsite conditions needed for successful regeneration are so demanding that seed germination, especially from seeds that are wind-dispersed, is rarely successful (McCaughey and Tomback 2001). Bunn et al. (2003) emphasized the importance of accounting for microsite variability in assessing climate change response; high-elevation microsite changes, coupled with increased fire activity, could increase whitebark pine regeneration and growth as climates change. The depth and duration of snow cover often governs high elevation tree regeneration. Most years are moist enough for regeneration, but snow remains on sites for a long time, thereby limiting the number of days that a seedling can actually photosynthesize and grow. If temperatures increase, then snow might melt earlier, giving more time for seedlings to survive and grow. Warm years often result in waves of regeneration and can be dated in upper subalpine ecosystems using seedling and sapling tree ages (Little et al. 1994; Rochefort et al. 1994). Recent observations of invasions of subalpine meadows and balds by subalpine fir, alpine larch, and spruce are testimony to the high number of sequential warm years over the last decade that has facilitated high mountain regeneration. Moreover, there is often abundant precipitation in upper subalpine settings, and projections for the future indicate roughly the same amount, so seedling mortality from drought might continue to be minimal.

Many climate change studies consistently project drier conditions in the range of whitebark pine, which would result in large increases in the annual number, area burned, and severity of wildfires

(Flannigan et al. 2009; Krawchuk et al. 2009; Marlon et al. 2009). With increased fire, whitebark pine will have a unique opportunity to maintain its range or even increase in distribution in the future because it has bird-mediated seed dispersal mechanisms that can disseminate seed great distances into large, severe burns, well before wind can disperse the seeds of its competitors (Tomback 1977, 1982, 1989; Lorenz et al. 2008). Whitebark pine also has morphology that enables it to survive low- to moderate-severity fires (Ryan and Reinhardt 1988). Therefore, whitebark pine is uniquely positioned as a species that can increase under the more frequent fire regimes that result from warming climates. Also, since nutcrackers may be harvesting seeds from trees that have survived blister rust, there is some chance that seeds from unclaimed nutcracker caches may become blister rust-resistant trees. It is entirely possible that as long as wildland fire creates areas where birds will cache seeds and resultant seedlings can grow without competition, whitebark pine will continue to thrive throughout its range.

Current mountain pine beetle outbreaks are killing more whitebark pine than historical records indicate, and these outbreaks are probably a result of warmer winter temperatures that facilitate expansion of and establishment of beetle populations in the higher-elevation whitebark pine zone (Logan and Powell 2001; Logan et al. 2003). A warmer climate may also accelerate the spread of blister rust (Koteen 1999).

In summary, whitebark pine is not expected to do well under future climates, not because it is poorly-adapted to shifts in climate regimes, but rather because it is currently experiencing major declines from the exotic disease (white-pine blister rust) that preclude its immediate regeneration in future burned areas. Moreover, these declines from white-pine blister rust and mountain pine beetle have served to reduce whitebark pine populations to severely low levels, and now the nutcracker is acting more as a seed predator than a seed disperser (Keane and Parsons 2010). Climate shifts will only exacerbate this decline and complicate restoration efforts. Whitebark pine will be highly exposed to any climate changes because of its (1) confined distribution to the upper subalpine environments; (2) severely depressed populations; and (3) lack of an ability to regenerate when populations are low because of nutcracker predation. However, the species has the genetic capacity to overcome both white-pine blister rust and new climates to thrive over the next century, but only with extensive restoration efforts.

Subalpine Fir (Abies lasiocarpa)

Autecology

Subalpine fir grows in the coolest and wettest forest areas of the western continental U.S. (Alexander et al. 1990). Although widely distributed, it grows within a narrow range of mean temperatures of 25° to 40 °F; however, January temperatures average 5° to 25°F degrees. Compared to other subalpine species, cool summers, cold winters, and deep winter snowpack are more important than precipitation in determining where subalpine fir grows.

Subalpine fir occupies the lower valleys to upper subalpine zone in the NR. In the lower valley bottoms and footslopes, it is often associated with grand fir, western larch, Douglas-fir, western redcedar, and western white pine (Pfister et al. 1977). At the mid-subalpine, it is often associated with lodgepole pine, Douglas-fir, and Engelmann spruce, while at the upper subalpine, it is associated with whitebark pine, alpine larch, mountain hemlock, and Engelmann spruce (Arno 2001). In the Rocky Mountains, subalpine fir is commonly found with Engelmann spruce, and the two together are often called spruce-fir forests (Moran-Palma and McTague 1997). The subalpine fir habitat types are probably the most common forest habitat types in the NR (Pfister et al. 1977).

Subalpine fir is shade-tolerant, and is often the most shade-tolerant of all its associates, except for grand fir and mountain hemlock in isolated cases (Alexander et al. 1990; Minore 1979) (table 6.3). Although subalpine fir can grow under nearly all light conditions, seedling establishment and early survival are usually favored by partial shade (Knapp and Smith 1982). In the absence of grand fir and mountain hemlock, subalpine fir will survive under closed-forest conditions with less light than Engelmann spruce. It may not compete well with the spruces, lodgepole pine, or interior Douglas-fir in the lower subalpine when light intensity exceeds 50 percent of full shade. Subalpine fir is quite intolerant of drought, and many seedlings can be killed if droughts are overly long or deep. The species is highly tolerant of frosts and can remain alive in seasonally wet conditions. Subalpine fir is usually the climax tree species in most subalpine areas of the NR, although it sometimes shares climax status with spruce.

Subalpine fir is a prolific seeder, often having large cone crops every two or three years (Alexander et al. 1990). Its seedfall usually occurs in late autumn, over snow in most places. The species is restricted to cold, humid habitats because of its seedlings' low tolerance to high temperatures and dry conditions (Knapp and Smith 1982); newly germinated subalpine fir seedlings rarely tolerate high solar radiation, and they are susceptible to heat girdling and drought (Little 1992). Seedlings are also killed or damaged by spring frosts, competing vegetation, frost heaving, damping off, snowmold, birds, rodents, and trampling and browsing by large animals, but losses are not different than for any of the species' common associates (Alexander et al. 1990). However, the fir's abundant seedfall, coupled with cool conditions in the subalpine, often create dense mats of seedlings in stands that contain partial shade and overwhelm seedling establishment of all other species. Subalpine fir has average genetic diversity for an NR tree species and weak geographic differentiation. There are strong clinal variations in phenological and morphological characteristics.

Disturbance Interactions

Subalpine fir is highly susceptible to fire damage because of thin bark, low hanging dense foliage, and shallow roots (Ryan and Reinhardt 1988). Even the lowest-severity fire can cause high mortality in subalpine fir. Frequent fires often eliminate subalpine fir from both the overstory and understory, thereby maintaining the more fire-adapted species of lodgepole pine, whitebark pine, western larch, and western white pine (Little et al. 1994; Murray et al. 1995; Wadleigh and Jenkins 1996). Invariably, some fir trees survive even the most severe fires in refugia, thereby providing a seed source for future stands (Murray et al. 1998; Veblen et al. 1994).

In spruce-fir forests, the most important insect pests are the western spruce budworm and western balsam bark beetle. The silver fir beetle (*Pseudohylesinus sericeus*) and the fir engraver may at times be destructive, but only in local situations in the NR. Fir broom rust (*Melampsorella caryophyllacearum*) and wood rotting fungi are responsible for most disease losses, but root and butt rots may be important locally. Wood rots and broom rust weaken affected trees and predispose them to windthrow and windbreak. Decades of intense competition, coupled with a period of moderate to severe drought, often

cause extensive mortality in subalpine fir stands. These high mortality events are often attributed to a complex of disease, insects, and other agents, but the underlying cause is low vigor in existing trees from over-competition.

Historical and Current Conditions

Effects of one hundred years of fire exclusion have not yet become manifest in most subalpine fir ecosystems because of historically infrequent fire and slow successional advancement. However, abundance of subalpine fir cover types has increased in many subalpine and upper subalpine landscapes (Keane et al. 1994), and many stands that had low subalpine fir components now have fir dominating the understory and encroaching in the overstory. This densification has resulted in many stands becoming stressed from competitive interactions, resulting in increasing susceptibility to disturbances. Recent dry, droughty conditions have led to high elevation subalpine fir mortality of undetermined origin called subalpine fir "die off", usually attributed to a complex of causal mechanisms such as drought, heightened competition, higher temperatures, and increasing diseases. Therefore, as fire is progressively kept off the subalpine landscape, the subalpine fir stands that replaced the pine communities will progressively decline in vigor and be more susceptible to fire, insects, and diseases. A concern is that if these overly dense, unhealthy stands continue to escape fire, the seed sources of the fire-adapted pines will be eliminated, and high elevation sites may be converted to grass and shrublands (Keane 2001). Another concern is that as fire is excluded from these dense subalpine fir forests, canopy and surface fuels will accumulate to such levels that, when burned, fires will be of extremely high severities (Keane 2001; Morgan et al. 1994b).

Climate Change Responses

It is challenging to predict responses of subalpine fir to future climate change. It is a species that is highly adapted to moist growing conditions, so it will likely respond poorly to increasing temperatures and drought (Alexander et al. 1990). On the other hand, it is a fierce competitor that can outcompete all subalpine tree species for shade, and it is a species that has a diverse range throughout the NR. Subalpine fir could expand its range into the timberline, become more or less productive in its current range, and

5666 decline in productivity and occurrence in those areas that become inhospitable for the species, presumably
5667 the warmer, drier portions of its current range. Most paleo-reconstructions over the Holocene show
5668 subalpine fir dominated during periods of cold, moist conditions but declined in extent as climates
5669 warmed (Brunelle et al. 2005; Whitlock 1993, 2004). Hamann and Wang (2006) projected that future
5670 losses of subalpine fir from drought will exceed gains from range expansion, resulting in a 97 percent
5671 decrease in the species' range in British Columbia. Romme and Turner (1991) estimated major to minor
5672 losses in subalpine fir in the future in the GYA, depending on degree of warming, and Bell et al. (2014)
5673 modeled little loss of subalpine fir in the NR. Using SDM techniques, Crimmins et al. (2011) estimated
5674 that the subalpine fir/spruce zone would move upward in elevation by 300 ft by 2050. Woodward et al.
5675 (1994) speculated that subalpine fir will experience less frequent and lower cone crops in the future.
5676 However, seedling establishment may be the bottleneck for subalpine fir establishment in the future; the
5677 species needs long periods of high moisture for seeds to germinate and seedlings to thrive (Urban et al.
5678 1993), and those years that meet these conditions may be less frequent in the future in the lower
5679 subalpine.

5680 In those areas with abundant precipitation, longer growing seasons and reduced snowpacks may
5681 increase regenerative success of subalpine fir, especially in those subalpine areas where snow historically
5682 controlled regenerative success (Means 1990; Urban et al. 1993). These areas constitute the majority of
5683 the fir's range in the subalpine to timberline. Little and Peterson (1991) found that most fir regeneration
5684 occurred in low snow years because there were more suitable microsites. Villalba et al. (1994) found
5685 subalpine fir growth was positively correlated with increasing summertime temperature. Higher
5686 productivity in these subalpine forests may also increase cone crops, tree growth, and species densities.
5687 Denser stands may eventually result in high competitive stress, making these fir stands even more
5688 vulnerable to high mortality from insects, disease, and abiotic factors, and therefore less resilient.
5689 However, declines in whitebark pine and lodgepole pine from beetle- and rust-caused mortality may
5690 facilitate fir regeneration and growth, resulting in more fir trees and more stands dominated by subalpine
5691 fir.

Those NR areas in high elevation (timberline) settings may see an increase in subalpine fir as the heavy snow and cold conditions that precluded fir regeneration at timberline become less frequent (Cayan et al. 2001; Rochefort et al. 1994). However, the decline of whitebark pine trees that act as nurse crops to facilitate subalpine fir establishment may contribute to the inability of the fir to gain purchase in the high elevation settings. Establishment of populations at the upper subalpine and timberline may only be possible when fire is absent long enough to allow enough subalpine fir to gain reproductive maturity so that sufficient seed can be dispersed over enough years to ensure suitable environmental conditions for seedling establishment (Little and Peterson 1991; Little et al. 1994).

Increases in wildland fire would decrease subalpine fir throughout the NR, and those decreases would be much more extensive and steeper than any resulting from direct climate change effects. Frequent fires would favor nearly all of subalpine fir's associates because it is the least adapted to survive fire (Arno and Hoff 1990; Keane 2001). Little et al. (1994) found little subalpine fir regeneration over 30 years after a fire at Mt Rainier, USA, but those regeneration events that did occur happened after low snow years. Heusser (1998) found that subalpine fir increased in growth with warmer temperatures during the spring of the growth year, but growth was negatively correlated with high summer temperatures the previous years.

In summary, the future of subalpine fir will depend on both the future level of fire and the degree of climatic warming. Subalpine fir will likely be a species that shifts across the high mountain landscape, with gains in expansion balancing losses of contraction (caused directly by changes in climate). However, future increases in fire, disease, and insects may limit its abundance. Since fir is an aggressive competitor, it is expected that its gains through advanced succession in the upper subalpine will probably be balanced or exceed its losses from the drier, lower subalpine caused by fire, drought, and pathogens.

Engelmann Spruce (Picea Engelmannii)

Autecology

Engelmann spruce is widely distributed in the western U.S. and is a major component of the high elevation NR forests (Alexander and Shepperd 1990). It grows in humid climates with long, cold winters

and short, cool summers, and occupies one of the highest and coldest environments of the western U.S. The range of mean annual temperature in which this species occurs is narrow considering its wide distribution. Engelmann spruce grows best on moderately deep, well-drained, loamy sands and silts, and clay loam soils from a variety of volcanic and sedimentary materials. It also grows well on glacial and alluvial soils where the water table is accessible.

Engelmann spruce is rated tolerant in its ability to endure shade, but is less shade tolerant than its major associate, subalpine fir (Minore 1979) (table 6.3). It is more shade enduring than interior Douglas-fir, western white pine, lodgepole pine, quaking aspen, western larch, or ponderosa pine (Alexander and Shepperd 1990). The species does not tolerate drought well and it is perhaps the least adapted to drought conditions of the subalpine tree species (Alexander and Shepperd 1990). It is highly frost-tolerant and one of the few upper subalpine species that can tolerate seasonal standing water. It is associated with mycorrhizae but does not seem to be dependent on the fungi for survival. It is wind-pollinated and its seeds are wind dispersed.

In the NR, Engelmann spruce is mostly associated with subalpine fir but grows with many other tree species, including mountain hemlock, whitebark pine, western larch, Douglas-fir, quaking aspen, lodgepole pine, limber pine and western hemlock. In most upland subalpine NR sites, Engelmann spruce is a minor species associated with subalpine fir in later seral communities. It is often found in the upper subalpine as scattered individuals with the greatest height and diameter (Arno 2001). Pure Engelmann spruce communities are found in wet areas and riparian settings, and in severe frost pockets where all frost-sensitive tree species are excluded.

Spruce seeds germinate in a variety of substrates, including duff, litter, and decomposed humus, and seedlings have best initial survival on duff seedbeds, rather than on mineral soil. Engelmann spruce has low tolerance to high temperatures and drought, especially in the first five years of establishment. Due to its slow initial root penetration and sensitivity to heat in the succulent stage, drought and heat girdling kill many first-year spruce seedlings. Drought losses can continue to be significant during the first five years

of seedling development, especially during prolonged summer dry periods (Alexander and Shepperd 1990). After establishment, adequate soil moisture, cool temperatures, and shade favor survival.

Engelmann spruce is similar to subalpine fir in that it has an average genetic diversity with weak geographic differentiation. It is considered intermediate in its adaptive strategy, being neither a generalist nor a specialist. Populations show habitat specificity. Engelmann spruce has a high outcrossing rate and possesses the ability to cross with white spruce (*Picea glauca*).

Disturbance Interactions

Engelmann spruce is highly susceptible to fire injury and death, but some spruce survive severe burns because of their large size (Bigler et al. 2005; Wadleigh and Jenkins 1996). The species can survive fire better than its primary associate, subalpine fir (Ryan and Reinhardt 1988). Surviving large spruce trees can provide abundant seed in burned areas, but rarely do these seeds germinate to create forests dominated by Engelmann spruce; these spruce-dominated forests only occur in seasonally-wet habitats (Pfister et al. 1977).

Engelmann spruce is susceptible to windthrow, especially after any cutting in old-growth forests. The spruce beetle (*Dendroctonus rufipennis*) is the most serious insect pest of Engelmann spruce. It is restricted largely to mature and over-mature spruce, and epidemics have occurred throughout recorded history. The western spruce budworm also attacks Engelmann spruce.

Historical and Current Conditions

It is difficult to determine recent trends in Engelmann spruce forests across the NR because the species is rarely the dominant component in a stand. One would expect that advancing succession under a century of fire exclusion has increased spruce in the subalpine and upper subalpine. However, logging and fire has reduced spruce in lower elevation areas where it occurs in seasonally wet areas and frost pockets.

Climate Change Responses

Similar to subalpine fir, some losses of spruce are likely in the drier portions of its range, especially in those seasonal moist sites that will be mostly dry in the future. Liang et al. (2015) found that major

5769 mortality events have occurred in Engelmann spruce over the last twenty years because of increased
5770 drought, presumably related to changing climate. Alberto et al. (2013) found that this species had a
5771 reduced growth the year following warm, dry years in the U.S. Cascades. Using SDMs, Morales et al.
5772 (2015) projected a 47 percent contraction in Engelmann spruce in the northern Rocky Mountains by 2060,
5773 and Hamann and Wang (2006) projected a 27 decrease in the range of Engelmann spruce in British
5774 Columbia by 2050. Gray and Hamann (2013) estimated Engelmann spruce would move 230 ft northward
5775 and 550 ft higher in elevation by 2050 in the NR. Using SDMs for the southwestern US, Notaro et al.
5776 (2012) projected that Engelmann spruce would disappear by 2050. Using gap modeling, Burton and
5777 Cumming (1995) project a precipitous collapse of Engelmann spruce in the mesic forests of British
5778 Columbia. Coops and Waring (2011) used mechanistic modeling to simulate a retraction in spruce range
5779 by over 50 percent.

5780 Spruce may be the first species to become established in high elevation areas where snow precluded
5781 conifer regeneration historically, but where there now may be a seasonal wetland or subalpine wet
5782 meadow (Schauer et al. 1998). Jump and Peñuelas (2005) note that Engelmann spruce has the genetic
5783 capacity to adapt to large swings in climate *in situ* by taking advantage of shifts in microsites. Due to its
5784 great seed dispersal ability and tall stature, spruce is able to disseminate into previously unforested areas,
5785 such as glades, meadows, and balds, to expand its range. Whitlock (2000) found increased spruce
5786 regeneration during the warmest periods of the past several centuries, and Luckman et al. (1984) found
5787 Engelmann spruce growth positively correlated with increasing summertime temperature. Various SDM
5788 approaches project minor changes in the spruce-fir subalpine zone (Bell et al. 2014; Crimmins et al. 2011)

5789 Engelmann spruce is poorly-adapted to fire, and thus major declines are expected with the projected
5790 increases in area burned. These declines, however, may be offset by increased regeneration on burned
5791 areas with mineral soil substrates. Continued fire suppression activities may maintain spruce on the
5792 landscape, but it may persist at lower abundance because of increased drought. Fire suppression may also
5793 ensure the demise of Engelmann spruce in that, when fires eventually burn, the severities may be so great
5794 that they kill all spruce seed sources. In addition, Bentz et al. (2010) note that future climates will likely

be more conducive to the spruce beetle, and Stout and Sala (2003) note that future climates may foster more spruce budworm events, leading perhaps to further declines in spruce.

In summary, while Engelmann spruce is a species that is highly-sensitive to climate, it is likely going to persist in future NR landscapes because of its superior ability to seed into new areas, especially burned areas, and its ability to remain in the high mountain landscape. Projected increases in subalpine productivity will also serve to keep spruce on the NR landscape.

Mountain Hemlock (Tsuga mertensiana)

Autecology

Mountain hemlock is usually found on cold, wet, snowy upper subalpine sites where it grows slowly and sometimes lives to be more than 800 years in age. The species appears to be limited by late snowmelt, short growing seasons, and cool summer temperatures throughout much of its range in the Pacific Northwest. Earlier snowmelt, higher summer temperatures, and lower summer precipitation in the lower portions of its range produce conditions under which growth is limited (West et al. 2009). Areas occupied by mountain hemlock generally have a cool to cold maritime climate that includes mild to cold winters, a short, warm to cool growing season, and moderate to high precipitation. The presence of mountain hemlock in the Rocky Mountains is closely correlated with the eastward penetration of moist maritime air masses (Woodward et al. 1994). Mountain hemlock occurs in mixed upper subalpine stands in the western portions of the NR, often relegated to the moist north slopes.

Mountain hemlock is considered highly tolerant of shade and other forms of competition, and it is probably more tolerant than any of its NR associates, even subalpine fir in some places (Minore 1979). Mountain hemlock is considered a minor climax species in most of its limited habitats; mountain hemlock often succeeds lodgepole pine or subalpine fir (Means 1990). The species has a low tolerance for drought but a high tolerance for frost and standing water. It is wind-pollinated, and the seeds are wind-dispersed.

Mountain hemlock has large cone crops about every three years. It reaches reproductive maturity quickly by around twenty years, and most of the seedfall occurs during the fall months. It has average genetic diversity, weak geographic differentiation, but moderate population differentiation.

Disturbance Interactions

Mountain hemlock is considered susceptible to fire because it often retains branches almost to the ground, grows in clusters, and often has shallow roots that are throughout well-developed forest floors that dry out in the summer (Dickman and Cook 1989). It has thick bark and can withstand some low intensity fire, but overall, it will often succumb to fire damage over time. Fire is a rare visitor to these mesic, cold stands, so any increase in fire frequency will reduce mountain hemlock populations.

The most striking damage to mountain hemlock is probably that caused by laminated root rot. This fungus spreads from centers of infection along tree roots so that all trees are killed in circular areas that expand radially. Mountain hemlock is the most susceptible species to root rot in subalpine forests (Means 1990).

Historical and Current Conditions

There have been few evaluations of mountain hemlock distributions in the NR, and thus it is difficult to gauge trends in this species over the last century. The fire exclusion era has advanced succession in those subalpine sites where mountain hemlock can be found, thereby increasing the numbers and density of the species. These dense forests are probably not currently stressed because of high productively in these areas. Mountain hemlock has a limited range in the NR, so any significant warming and drying could drive the species to be locally extinct.

Climate Change Responses

With warming climate in western North America, existing mountain hemlock forests will probably increase in productivity, especially in the upper and lower elevational boundaries of the mountain hemlock zone (Means 1990). Near Mount Baker, Washington, ring width of mountain hemlock increased with increasing monthly temperatures in the preceding 12 months, decreasing winter precipitation, and decreasing snow depth, implying that productivity should increase with predicted temperature increases (Woodward et al. 1994). Graumlich et al. (1989) estimated that productivity increased 60 percent in the last century in four high-elevation stands in Washington, three of which contained 48 to 96 percent mountain hemlock. They related this increase most strongly to the increase in growing season temperature

during this period (about 2.7 °F). West et al. (2009) projected that mountain hemlock growth and productivity will likely increase throughout much of its range in Washington and northern Oregon, but increased summer drought stress will reduce productivity in mountain hemlock forests of southern Oregon and near the species lower elevation limit. Peters and Lovejoy (1992) estimated that if mean annual temperatures increase 4.5 °F, the mountain hemlock zone may be shifted upwards 1800 ft and decrease in area from nine to two percent in Oregon. An increase of 9.0 °F may induce an upward shift of 3700 ft, which is above all but the tallest peaks, effectively eliminating the species from the NR (Means 1990). Woodward et al. (1994) speculated the mountain hemlock will experience less frequent and lower cone crops in the warm future.

In summary, the high productivity of mountain hemlock sites in the western NR may mitigate the potential decline of mountain hemlock over the next fifty years. There will likely be local shifts of the species where it is established in droughty low elevation areas of Idaho and western Montana, but overall, the species might be somewhat stable under climate warming, and it might even increase in productivity and make range expansions into the lower timberline. The species is not highly exposed to climate changes because of its limited range in the NR and its somewhat confined niche. The magnitude of climate effects on mountain hemlock responses will be great, but mostly positive, and the likelihood of these effects have a high uncertainty, mainly because of the role that fire will play in the dynamics of mountain hemlock populations in future landscapes.

Alpine Larch (Larix lyallii)

Autecology

Alpine larch is a deciduous conifer that occupies the highest and most remote environments in the NR, growing in and near the timberline on high mountains across the inland Pacific Northwest (Arno 1990). In the Rocky Mountains, alpine larch extends from the Salmon River Mountains of central Idaho northward to Lake Louise in Banff National Park, Alberta (Arno 1990). Within this distribution, alpine larch is common in the highest areas of the Bitterroot, Anaconda-Pintler, Whitefish, and Cabinet Ranges of western Montana. It is also found in lower abundance in isolated stands atop many other ranges and

peaks in western Montana and northern Idaho (Arno and Habeck 1972). Alpine larch grows in very cold, snowy, and generally moist climates where for more than half of the year, mean temperatures are below freezing. Mean annual precipitation for most alpine larch sites is between 32 and 75 inches, the larger amount being more prevalent near the crest of the Cascades; most stands in the Montana Bitterroot Range receive 39 to 59 inches. About 75 percent of this precipitation is snow and sleet. Ridgetop alpine larch stands are exposed to violent winds; most alpine larch stands annually experience winds reaching hurricane velocity or more, especially during thunderstorms or during the passage of frontal systems.

Alpine larch is perhaps the most drought-susceptible conifer in the NR because of its reliance on sub-surface water during the dry summer months (Arno 1990). It achieves its best growth in high cirque basins and near the base of talus slopes where the soils are kept moist throughout the summer by aerated seep water. It can also tolerate boggy wet meadow sites having very acidic organic soils. The species is most abundant on cool, north-facing slopes and high basins where it forms the uppermost band of forest. It also covers broad ridgetops and grows locally under relatively moist soil conditions on south-facing slopes. The NR may have a droughty period for a few weeks in late summer, but the effect is minor in most alpine larch sites; however, dry surface soils may prevent seedling establishment in certain years.

Alpine larch is the most shade-intolerant conifer growing at high elevation NR sites and is classed as very intolerant (Minore 1979) (table 6.3). Its evergreen associates attain their best development in forests below the lower limits of larch. An exception is whitebark pine, another timberline inhabitant, which is most abundant on warm exposures and microsites and thus tends to complement rather than compete with larch. Alpine larch grows mostly in pure stands but it can be found with whitebark pine, subalpine fir, and Engelmann spruce near their upper limits. Alpine larch roots extend deep into fissures in the rocky substrate. Trees are well anchored by a large taproot and large lateral roots and are very windfirm. Alpine larch is easily replaced by subalpine fir in most upper subalpine sites, but the species can act as a climax species in the lower timberline (Arno and Habeck 1972).

Alpine larch is one of the few deciduous conifers in the NR, and as a result, it has a high capacity to survive wind, ice, and desiccation damage during the winter because the needles are off the trees. The

5899 species also has an evergreen sapling stage that allows it to quickly take advantage of the short growing
5900 season in the early summer after snowmelt (Arno and Habeck 1972). Alpine larch seedlings are frost
5901 tolerant. Mature trees produce good cone crops every fifth year, and these seeds drop in early fall. It is
5902 assumed that the species has an average genetic diversity and weak geographic differentiation, but there
5903 has been little genetic work done on this species.

5904 *Disturbance Interactions*

5905 Fire is an occasional but localized visitor in alpine larch stands, causing injury or death in most cases.
5906 Large fires are infrequent in the cool, moist, and rocky sites where alpine larch occurs, and fire spreads
5907 poorly on these sites because of light and discontinuous fuels. Unlike its thick-barked, fire-resistant
5908 relative, western larch, alpine larch has thin bark, has low resistance to surface fire, and often dies after
5909 low-intensity fires (Ryan 1998).

5910 Powerful winds in alpine larch stands often damage crowns, in conjunction with loads of clinging ice
5911 or wet snow (Arno and Habeck 1972). Nevertheless, this tree's deciduous habit and supple limbs make it
5912 more resistant to wind damage than its associates. Death usually occurs when advanced heart rot has so
5913 weakened the bole that high winds break off the trunk. Brown trunk rot produces the only conks
5914 commonly found on living trunks (Arno 1990); this fungus is evidently the source of most heart rot. Snow
5915 avalanches and snowslides are an important source of damage in many stands, but again, this species is
5916 better adapted to survive these disturbances than its evergreen associates.

5917 *Historical and Current Conditions*

5918 This species is rarely studied, and as a result, very little is known about its population trends in the
5919 NR. Our best guess is that alpine larch populations have stayed roughly the same across most of its range
5920 in the NR over the last 100 years. There have been some losses from fire in some areas, especially the
5921 Bitterroot Mountains of Montana, but there have also been gains. Recent anecdotal observations have
5922 found that alpine larch has been increasing in ribbon forests glades and high elevation open areas where
5923 snow accumulated historically, but over the last two decades, these heavy snow areas have been clear of
5924 snow enough of the year to foster alpine larch regeneration.

Climate Change Responses

We feel alpine larch has a high potential to experience decreases in both productivity and abundance with climate change. On one hand, alpine larch is a shade- and drought-intolerant species, indicating that it does not do well in areas of increasing dryness and competition (Arno and Habeck 1972). Its high demand for sub-surface water during the growing season appears to be the main factor limiting its range in the NR (Arno 1990), making it highly susceptible to increasing drought in the future. Alpine larch growth is highly correlated with high snowpack, especially in April, which is usually indicative of high subalpine moisture throughout the year (Colenutt and Luckman 1991; Peterson and Peterson 1994). The lack of summertime ground water would be more likely in the southern part of alpine larch's range in the NR, specifically western Montana and central Idaho.

On the other hand, alpine larch can produce copious amounts of seed that may land on upper subalpine and timberline areas that were historically covered with snow the majority of the year, but in the future may be sufficiently snow-free to allow wind-dispersed seed to germinate and grow into viable seedlings. There is ample anecdotal evidence documenting alpine larch encroachment into snowfields, glades, and ribbon forests. These seedlings could become mature trees, provided there is sufficient moisture. With higher rates of productivity in a warming climate, seedlings and trees may have greater growth and cone production. However, short-term increases in alpine larch regeneration may be offset by the high variability in drought in the upper subalpine to eventually cause declines in the larch. Another possibility is that the more shade tolerant subalpine conifers, such as spruce and subalpine fir, might become established in these new open areas and outcompete alpine larch for dominance. Along those same lines, the more drought-tolerant whitebark pine may also become established in the snow free areas and survive the anticipated long droughts.

While alpine larch does not seem to have the morphological, ecophysiological, and genetic capacity to adapt to new environments, it does have the ability to genetically integrade with western larch to produce hybrids that may be more tolerant of drought and competition (Carlson et al. 1990). Moreover, its superior seed dispersal capability may allow it to become established in treeline areas made

environmentally favorable by climate change, mainly from decreasing snowpacks and higher temperatures. These areas, however, may be significantly smaller and more isolated than areas in its current range, where it will decline because of lack of water.

Alpine larch is not well-adapted to survive wildland fire (Arno 1990), and as its existing range becomes drier and fires become more probable, it is expected that more alpine larch will burn, providing there are sufficient fuels. Those upper subalpine forests that are co-dominated by whitebark pine and alpine larch are probably the most susceptible of subalpine larch habitats to increases in fire. Rocks, scree, and fuel-free areas protect many alpine larch communities, so it may be years before fire, or the more shade-tolerant competitors, invade pure alpine larch woodlands (Arno and Habeck 1972). While alpine larch does not seem to be impacted by major insects and pathogens (Arno 1990), it could be that future climates may increase the possibility that insects and diseases that were relatively minor in the past could become more significant in the future, especially in timberline environments where damaging agents were depressed by cold (Woods et al. 2010).

In summary, alpine larch is one of the most susceptible tree species in the NR to climatic shifts that result in increasing drought and fire. Its exposure to climate change will likely be high, because upper subalpine areas may experience the greatest climatic change (Luce et al. 2013). Due to its specialized habitat, alpine larch has the highest risk for major range shifts, and impacts to the species may be great if there are insufficient environments created upslope.

Green Ash (Fraxinus pennsylvanica)

Autecology

Green ash is the most widely distributed of all the American ashes (Kennedy 1990), but primarily occurs in the eastern and central U.S. In the NR, green ash is restricted to the northern Great Plains, which is the northwestern edge of its range (Girard et al. 1987; Lesica 2009). Naturally a moist bottomland or stream bank tree, it is well-adapted to climatic extremes and has been widely-planted in the Plains states and Canada. It is probably the most adaptable of all the ashes, growing naturally on a range of sites, from clay soils subject to frequent flooding and overflow, to sandy or silty soils where the amount of available

moisture may be limited. In the northern Great Plains, green ash grows best on fertile, moist, well-drained alluvial soils, primarily along river bottomlands and woody draws. It also occurs in broad upland depressions and ridges, which have subsurface water early in the growing season (Girard et al. 1987; Lesica 2003; Lesica and Marlow 2013). Natural stands of green ash are almost completely confined to bottomlands, but the species grows well when planted on moist upland soils. It lines the watercourses in the western parts of its range where rainfall is insufficient to support upland growth.

Green ash varies from intolerant to moderately shade tolerant in woody draws. It is an early seral species, colonizing alluvial soils. It regenerates from seed when exotic grass (which inhibits germination through competition for soil moisture) is absent or has low cover (Lesica 2003; Lesica and Marlow 2013). It also regenerates vegetatively through stump sprouting. Uresk and Boldt (1986) reported 90 percent sprouting success following trunk removal in an experimental study in North Dakota. Lesica (2009) found that stump sprouts can achieve full tree height in 20 years. While green ash is generally drought-tolerant, since it is at the most arid edge of its range, prolonged drought may affect regeneration success (Severson and Boldt 1974). Kennedy (1990) found that a population from the arid, northwestern part of the green ash range was more drought resistant than one from the moister central Great Plains and northeast.

Disturbance Interactions

Green ash is easily killed by fire, but stumps of most size classes of green ash sprout readily after both fire and mechanical trunk or stem removal (Lesica 2009). The species has several insect and disease agents; it is particularly susceptible to white stringy heartroot (*Perenniporia fraxinophila*), which weakens the plant and makes it more susceptible to wind or ice breakage (Lesica and Marlow 2013).

Historical and Current Conditions

Very little is known about the range expansion or contraction of green ash. However, green ash in the NR is at the northwestern (most arid) edge of its range (Lesica 2009), and there is evidence suggesting that many of the green ash communities on the western fringe of the Northern Great Plains are declining (Boldt et al. 1978; Lesica 1989, 2001).

Climate Change Responses

Green ash has a broad ecological amplitude and can survive droughty conditions, but it grows optimally on moist sites. As soil moisture declines with a warmer, drier climate, marginal sites may become less favorable for regeneration and survival of young green ash trees. With increases in fire frequency, there will likely be increased vegetative regeneration and decreased production of seedlings following fire; fire often kills green ash seed on or near the soil surface, restricting seedling recruitment to surviving seed-producing trees. Green ash may benefit from increased temperatures, because seedling and mature tree growth may increase with increasing soil temperatures. However, those green ash populations associated with moist upland microsites (e.g., northeast facing residual snow-loaded depressions) may experience severe drought stress as snowpack declines and melts sooner, and regeneration may decrease, eventually resulting in loss of those communities.

Since most mature green ash communities are somewhat resistant to wildland fire, given that the species can sprout afterward, the projected increases in fire in the future may not impact most green ash stands, especially the moist communities. Low-severity fires might promote regeneration by thinning stands and stimulating sprouting; green ash has both root crown and epicormic sprouts, and both are typical following fire events, especially in the woody draws and riparian areas of the Great Plains. High severity fires, however, may result in mortality. Browsing pressure on green ash communities will also likely increase with increased drought, as upland grasses and forbs desiccate and senesce earlier, or are replaced by invasive, less palatable species.

Cottonwood (Populus spp.)

Autecology

Black cottonwood (*Populus trichocarpa*) is the largest of the American poplars and the largest hardwood tree in western North America (Debell 1990). Narrowleaf cottonwood (*P. angustifolia*) and black cottonwood grow primarily on seasonally wet to moist open canopy sites (typically along streams and rivers) in the western portion of the NR. Plains cottonwood (*Populus deltoides*) occurs in eastern Montana and the Dakotas portion of the NR. All three species typically occupy fluvial surfaces along floodplains of streams and rivers.

Cottonwoods typically dominate riparian communities on alluvial sites at low to mid-elevations. Various riparian shrubs (e.g., willows (*Salix*), alder (*Alnus*), birch (*Betula*), dogwood (*Cornus*) and a variety of graminoids and forbs occur in the understory of cottonwood stands (Merigliano 2005). Cottonwood is very shade intolerant, and shade-tolerant conifers (e.g., Douglas-fir, Rocky Mountain juniper (*Juniperus scopulorum*), ponderosa pine, Engelmann spruce, subalpine fir) may encroach and become dominant in upland cottonwood forests (typically on river and stream terraces). The species is also drought intolerant, and requires an accessible water table (i.e., free, unbound water) during most of the growing season (Rood et al. 2003). Older cottonwood individuals become can access very deep water tables. Plains cottonwood is likely more able to extract water in the unsaturated zone once the water table has dropped below the extent of the roots (Merritt et al. 2010). The finer textured soils in the northern Great Plains hold more water, but it is harder to extract due to the finer soil texture. However, plains cottonwood appears to have adapted to extract water and will likely be more resilient to drought than the other species.

For all three species of cottonwood, high streamflows are required for successful seedling establishment; the associated scouring action and deposition of fresh alluvium creates optimal surfaces for germination. All species of cottonwood are prolific seed producers, and the windborne seeds disperse widely once the catkins have matured and seeds are released. Seeds are only viable for about two weeks, and thus timing of seed release and recession of flood flows is essential to successful germination (Malanson and Butler 1991). Black and narrowleaf cottonwood seedlings are usually established on a yearly basis, depending on flood frequency, timing and duration. Plains cottonwood establishment is less frequent and more episodic, since flows are more variable in both magnitude and frequency. Scott et al. (1997) found that approximately 72 percent of the plains cottonwoods along the Missouri River of eastern Montana established after a very large flood event (flow >1831 yd^3/s with a recurrence interval of 9.3 years). High numbers of seedlings become established in the first year after a flood, but they naturally thin out up to several years later, if they have not been scoured away by high flow events. The young

6054 seedlings and saplings that survive are frequently injured and sometimes killed by unseasonably early or
6055 late frosts (Debell 1990).

6056 *Disturbance Interactions*

6057 Cottonwood is mildly fire-tolerant owing to its thick bark, high branches, and foliage that is too moist
6058 to burn in most years. It is considered a weak stump sprouter, but unlike aspen, cottonwood rarely
6059 regenerates from suckers (Brown 1996). Gom and Rood (1999) found that black and narrowleaf
6060 cottonwood were more successful at coppice (stump) sprouting and suckering than plains cottonwood.
6061 Cottonwood is able to survive low intensity fires in the short term, but fire injuries can lead to the
6062 introduction of diseases that weaken and perhaps kill the tree (Borman and Larson 2002).

6063 Although several insects attack cottonwood, none has yet been reported as a pest of economic
6064 significance. Tent caterpillars (*Malacosoma*) are the most important foliar feeders that affect the NR. At
6065 least 70 fungal species cause decay in cottonwood, but only six fungi cause significant losses; two of
6066 these (brown stringy heart rot (*Spongipellis delectans*) and yellow laminated butt rot (*Pholiota populnea*)
6067 cause 92 percent of the loss. Russian olive (*Elaeagnus angustifolia*) and saltcedar (*Tamarix ramosissima*)
6068 are aggressive invasive trees that often outcompete plains cottonwood, particularly during or following
6069 drought (Shafroth et al. 2009). These species, along with invasive herbaceous species, are a threat to
6070 cottonwoods in general.

6071 *Historical and Current Conditions*

6072 Black cottonwood was common throughout the Columbia River watershed in Lewis and Clark's day,
6073 and can still be found today, but it is greatly reduced in extent.

6074 *Climate Change Responses*

6075 As the snowpack declines and melts earlier with warming temperatures, there will be reduced,
6076 attenuated river flows (loss of extreme high and low flows), along with a possible shift in timing of
6077 peakflows to earlier in the season, before cottonwood seed is viable for germination. These shifts in
6078 timing, magnitude and variability may result in both decreased germination and establishment of young
6079 cottonwoods (Whited et al. 2007). There will also likely be increased human demands for water in the

6080 future, which will likely result in creation of additional diversions and reservoir expansions. Any
6081 alteration of hydrologic flow regime (i.e., timing, magnitude and duration) will affect both floodplain
6082 interaction and available water to cottonwoods, which in turn may reduce recruitment and establishment
6083 of seedlings (Auble and Scott 1998; Beschta and Ripple 2005). Decreased streamflows and floodplain
6084 interactions may result in a conversion of streamside vegetation from cottonwood to upland species, along
6085 with reduced growth and regeneration (recruitment) and increased mortality of cottonwood (Beschta and
6086 Ripple 2005). Upland conifers (e.g., Engelmann spruce, lodgepole pine, and Douglas-fir) typically
6087 establish once the stream and local water table have dropped, and they can shade out the remaining
6088 cottonwoods. In addition to competition from upland conifers, there may also be increased browsing
6089 pressure on cottonwoods, which will further contribute to declines in cottonwood regeneration and
6090 recruitment.

6091 Plains cottonwood may be more persistent under changing climate because of greater plant available
6092 soil water in the unsaturated zone (as a result of finer textured soils) in its habitat. Black and narrowleaf
6093 cottonwood typically occur in coarser substrate, which will become much drier as flows are lower and
6094 recede earlier than in the past, or are attenuated due to diversions. Seedling and sapling mortality may
6095 increase in these species. Plains cottonwood regeneration occurs with episodic flooding, whereas black
6096 and narrowleaf cottonwood regenerate with 1-3 year bankfull flow return intervals (typically an annual
6097 recruitment cycle); therefore, plains cottonwood will likely be more adapted to irregular flows that may
6098 occur with climate change. Black and narrowleaf cottonwood will likely be at greater risk to changing
6099 climate because of soil water characteristics in their habitats and their narrow amplitude in terms of
6100 germination and flood events on specific fluvial surfaces.

6101 **Vegetation Types**

6102 Vegetation types are broad species assemblages that are used to identify the geographic distribution
6103 of vegetation in the NR. Vegetation types are different than species in that species can be a major to
6104 minor component in a vegetation type, but vegetation types can be composed of a number of species.
6105 Here we describe generally the likely response of forest vegetation types in the NR to climate change.

This section is less detailed than the species section (above), because we assumed that individual species for each vegetation type could be referenced above.

Dry Ponderosa Pine/Douglas-Fir Forests

Ecology

Dry ponderosa pine and Douglas-fir forests are the driest forests in the NR. These forests are relatively rare in northern Idaho, more common in western Montana, and prominent in central and eastern Montana where moisture is most limited. They are often found at the foothills of mountain ranges in the NR, but also in extensive flatlands bordering perennial grasslands and shrublands. Historically, frequent fires often maintained pure to mixed ponderosa pine woodlands and savannas in areas currently occupied by this type. However, fire exclusion has led to increased tree density and abundance of Douglas-fir, making these forests susceptible to uncharacteristically severe fire.

Disturbance Interactions

These forests recover from disturbance by slowly transitioning from fire-tolerant pioneer species to less fire-tolerant and shade-tolerant "climax" species over time. This successional process can occur over 200 to 1000 years. Ponderosa pine is often able to colonize the hot dry surface conditions of a disturbed site. Over time, as it matures, it provides a shaded environment where less heat-tolerant Douglas-fir can establish. In a frequent low-severity fire regime, the thick-barked ponderosa pine survives fire, while the thinner-barked Douglas-fir and ponderosa pine seedlings do not. If frequent fires are sustained, the ponderosa pine forest can develop into large patches of open grown old-growth, intermixed with relatively small openings that can persist for centuries. During a cool wet climatic period, or through fire suppression, Douglas-fir or denser ponderosa pine can become established. The increased biomass and structural heterogeneity of these denser forests allow fires to develop into active crown fires that return the site back to the initial stand establishment phase. If fires re-burn these areas, forest establishment may be limited because of loss of seed source, limited soil moisture, and high surface temperature.

Historical and Current Conditions

A century of fire exclusion, coupled with extensive logging and grazing, has changed these open dry woodlands to closed, dense forests that are often dominated by Douglas-fir.

Climate Change Responses

This vegetation type may be reduced in some areas of its current range under changing climate because of dry, hot conditions. However, this type may expand into the mixed mesic forest type (next section), especially on south slopes, as drought increases. This forest type will probably be the most dynamic in the future, with many of the current areas of this type seeing losses in Douglas-fir, balanced by gains in ponderosa pine. Dry Douglas-fir communities that are currently too cool to support ponderosa pine may support more ponderosa pine with warming climate. Fire exclusion in this type has resulted in forest densification and accumulation of surface fuels that will likely support high-severity fires in the next century (Keane et al. 2002).

Western Larch Mixed Mesic Forests

Ecology

Western larch mixed conifer forests, found in northern Idaho and northwestern Montana, evolved under a mixture of moist air masses from the west and cold air masses from Canada, resulting in a patchy forest condition with a mixture of western larch, ponderosa pine, lodgepole pine, Douglas-fir and spruce subalpine forests. Western larch is most prominent on cooler, moist topographic positions (Touzel 2013), and thus, the influence of a warming climate may change the potential distribution of western larch to the more northerly aspects with soils most capable of retaining needed moisture during the growing season (Rehfeldt and Jaquish 2010).

Disturbance Interactions

These forests evolved under a mixed-severity fire regime, which produced a diverse pattern of shade intolerant western larch, ponderosa pine, lodgepole pine and Douglas-fir. High-severity fire was more common on moist and cool sites, and produced very large burn patches, often with legacy western larch (Marcoux et al. 2015). Under fire exclusion, many of these forests have become denser, putting them at risk from high-severity fire (Arno 2010; Harrington 2012; Hopkins et al. 2013).

Historical and Current Conditions

In the past, wildland fire maintained extensive stands of western larch across Montana and Idaho. Due to its great value as a timber species, many older western larch stands were harvested across much of the NR, and these forests were often planted back to western larch after extensive site treatments. With fire exclusion, succession advanced and western larch was replaced with mixed stands of lodgepole pine, Douglas-fir, and grand fir.

Climate Change Responses

The western larch mixed conifer forests of northern Idaho and northwestern Montana are a forest type that has been changing and will likely continue to change. Fire exclusion, coupled with climate change, will likely continue to reduce western larch and increase the more shade-tolerant Douglas-fir, grand fir, and subalpine fir in some areas. Continued fire exclusion will result in further accumulation of surface and canopy fuels, and coupled with hotter and drier conditions with climate change, put these forests at risk of high-severity fire, which may result in high mortality of the seed-bearing western larch and ponderosa pine.

There are some attributes of this cover type that may serve to make it more resilient in the future. Western larch is not susceptible to the wide range of insects and diseases common to its associated tree species, and it has the best ability to survive fire of all its tree associates. As such, it makes an excellent candidate to feature in management to increase resilience. Overall, however, western larch mixed mesic forests are one of our most vulnerable forests to climate change impacts, mainly because past land management has made natural western larch forests susceptible to the damaging effects of uncharacteristically high-severity wildfires. Management of these forest types to create stand and landscape conditions within the historical range of variability will likely increase resilience to climate change.

Mixed Mesic Western White Pine, Cedar, Hemlock, Grand Fir Forests

Ecology

The moist forests within the NR range from 500 to 1750 ft and occasionally occur at 1900 ft (Jain and Graham 2005). These forests are influenced by a maritime climate with wet winters and dry summers. Precipitation ranges from 20 to 91 inches and predominantly occurs from November to May. A defining characteristic of these forests is a layer of fine-textured ash (up to 24 inches thick) that caps the residual soils. In addition, these forests are characterized by complex topography, including dissected slopes and varying degrees of slope angle, all of which influence soil development and ash cap depth. Disturbance is also a main component of these forests that contributes to creating vegetative mosaics. Thus, the combination of disturbance, topography, moisture and temperature regimes, parent material, soil weathering, and ash cap depth esults in productive and complex vegetation in terms of composition and structure. For example, ght to nine an sometimes ten different tree species can occupy a given square yard of this forest type (Jain a d Graham 005).

The primary nine tree species that grow ogeth r in this wet forest type, outside of riparian areas, are ponderosa pine, western larch, Douglas-fir rand fir, w te n white pine, western redcedar, western hemlock, lodgepole pine, and Engelmann spruce. Th niche that these species occupies varies by habitats. For example, western redcedar is a mid-seral species in weste hemloc types but is late-seral on western redcedar riparian and upland habitat types. The genetic adaptive capacity and utecological characteristics of individual trees species and their tolerances for light, moisture, temperat re, and disturbance is also highly variable among the different tree species in this forest type (M nore 1979). Some species are more adapted to regenerating in shade (western hemlock and western redcedar), while other species can regenerate in a wide range of conditions (western white pine). Some have a stronger competitive capacity than other species when growing together (western larch cannot compete with western hemlock). Some are drought tolerant (ponderosa pine, western larch, and western white pine), et al. are drought intolerant (western hemlock).

Disturbance Interactions

Natural disturbances (snow, ice, insects, disease, and fire), when combined, create heterogeneity in patch sizes, forest structures, and composition in this forest type. Ice and snow create small gaps and

openings, reducing forest densities and altering species composition. Native insects (e.g., bark beetles) and diseases (e.g., Armillaria root rot and dwarf mistletoes) infect and kill the very old or stressed individuals, and tend to diversify vegetation communities (Hessburg et al. 1994). A mixed-severity fire regime also plays a role in creating a mosaic of forest compositions and structures. Historically, non-lethal surface fires occurred at relatively frequent intervals (every 15 to 25 years) in a quarter of the area of this forest type. Lethal crown fires burned about a quarter of the area at intervals of 20 to 150 years, occasionally extending to 300 years. A mixed-severity fire regime characterized the rest of the moist forests, with return intervals of 20 to150 years. Fires typically started burning in July and were usually out by early September (Hann et a 1997

Historical and Current Conditions

In addition to white-pine li r rust and salvage that removed most of the western white pine, harvesting removed the early-seral, shade-intolerant species (e.g., ponderosa pine and western larch) that were resistant to fire and other disturbances. Partial can y emoval and minimal soil surface disturbance in these harvests were ideal for Douglas-fir and gran fir which regenerated aggressively, rather than the shade-intolerant pines and larch species. Fire exclusion also prevented the creation of canopy openings and receptive seedbeds for the regeneration of pine and larch. Similar to the d y forests, high canopies (>55 yds) of western white pine, western larch, and ponderosa pine and oth r early and mid-seral species are currently are absent. In their place, the present forest structure and composition (grand fir and Douglas-fir) favor the compression of nutrients, microbial processes, and root activity toward the soil surface (Harvey et al. 2008). When wildfires occur, surface organic layers can be consumed, decreasing the nutrition and microbial processes important for sustaining these forests. In general, the lack of the early-seral species and historical structures most likely have altered the disturbance regimes that sustained these forests.

Climate Change Responses

Habitat types are not static but reflect the operational environment that supports a particular set of plant species. As the moist forests experience climate change, the competition among species and how

these forests evolve will be particularly dynamic. Thus, any discussion concerning climate change and an individual tree species that grows in moist mixed conifer (and dry mixed conifer) must be placed within the context of species cohorts, an individual tree species adaptive capacity, the interaction of disturbance, and how environmental niches change over time and space. For example, if future moisture regimes no longer support the current distribution of western hemlock, the remaining species that thrive on the upland western redcedar habitat types will likely become dominant (Graham 1990). How disturbance changes (intensity, extent, and return interval) with a warming climate can also influence the subsequent effects on particular tree species. In a drier climate, western redcedar may become the late-seral species in what we consider to be western hemlock habitat types.

Lodgepole Pine Mixed Subalpine Forests

Ecology

Lodgepole pine forests straddling and occurring east of the Continental Divide are associated with the cold continental air mass that influenced their development. The higher elevations combined with the relatively dry cold climate associated with this type exclude many of the warm and moisture-dependent tree species found on the west side of the Continental Divide. Aspen, which is often associated with moisture seeps, swales, and other moist sites within this type, is released from conifer suppression by fire. Disturbance is needed to maintain aspen in this type and to keep seral lodgepole pine communities from becoming dense with subalpine fir.

Disturbance interactions. Lodgepole pine mixed subalpine forests in the NR evolved with both high-severity and mixed-severity fire regimes. Mixed-severity fire regimes were common in central Montana on flatter slope positions and produced a diverse pattern of various-sized patches of different ages and tree sizes. Stand-replacing fire return intervals were 100 to 500 years (Fischer and Clayton 1983). However, stands reaching 60 to 80 years of age often experienced severe mortality from mountain pine beetle, creating snags and down fuel (Jenkins et al. 2008).

Historical and Current Conditions

6259 This forest type was probably the most extensive in the NR, with vast subalpine areas dominated by
6260 even- and multi-aged stands of lodgepole pine, mixed with aspen, created by mixed-severity fire. There
6261 have likely been increases in subalpine fir as a result of fire exclusion, but more importantly, most of this
6262 type is currently dominated by large, mature lodgepole pine. Landscapes of these mature forests have
6263 fostered the large mountain pine beetle outbreak observed in many parts of the NR (central and GYA).

6264 *Climate Change Responses*

6265 This type will probably see expansion and contraction, but provided that fire is not excluded from
6266 these areas, it will likely not change substantially under changing climate.

6267 *Whitebark Pine Mixed Upper Subalpine Forests*

6268 *Ecology*

6269 Perhaps the most threatened forest type, whitebark pine mixed upper subalpine forests are associated
6270 with high elevations, and the distribution of this type is primarily influenced by the cold continental air
6271 masses in Montana and higher elevations in northern Idaho. In this type, whitebark pine is found with
6272 subalpine fir, Engelmann spruce, and mountain hemlock, and subalpine larch in the area west of the
6273 Continental Divide. This type occurs on approximately 5 million acres in the NR, primarily on the higher
6274 ridges and mountaintops. At the lower elevations within the range of this type, whitebark pine typically
6275 serves as a minor early seral species in mixed conifer stands. At the uppermost elevations, whitebark pine
6276 can serve as a major climax species.

6277 *Disturbance Interactions*

6278 Whitebark pine and its associates developed under both a stand-replacing fire regime on steep north
6279 slopes, and under a mixed-severity fire regime on other aspects and flatter slope positions. Various sized
6280 patches are common within the range, with density depending on moisture availability. The future could
6281 bring more intense fire that could further threaten whitebark pine distribution.

6282 There have been three outbreaks of mountain pine beetle in the northern Rockies over the last 100
6283 years. The first one in the 1920s-30s killed significant areas of whitebark pine (Tomback et al. 2001).

Snags from this outbreak can still be seen today. There was another major outbreak in the early 1980s, but the largest outbreak started in the mid-2000s and has continued, especially in the GYA.

Historical and Current Conditions

Over 14 percent of the NR could have consisted of whitebark pine forests, with late-seral mixed fir-spruce patches mixed throughout, prior to 1910. However, with extensive white-pine blister rust epidemics and mountain pine beetle outbreaks over the last several decades, the upper subalpine landscape has slowly shifted from whitebark pine to more spruce and fir and non-forest vegetation in some places (Tomback et al. 2001).

Climate Change Responses

There may be substantial change in the upper subalpine forests over the next century. However, that change will likely be driven by whitebark pine mortality from the exotic white-pine blister rust rather than climate change, and the changes will primarily be in forest composition and structure rather than distribution. Over the last forty years, whitebark pine has become a minor component of this forest type in many parts of the western NR because of white-pine blister rust, allowing subalpine fir to become dominant in both the overstory and understory. While the GYA has yet to see massive die-offs from white-pine blister rust, it has not escaped recent mountain pine beetle outbreaks, and the whitebark pine mortality rates in cone-bearing trees from these outbreaks exceed 50 percent in most areas. Recent fires in the upper subalpine have served to reset the successional clock to the earliest seral stages of shrub and herbaceous communities, but whitebark pine regeneration levels are low in these burns because of low population levels (Leirfallom et al. [in press]). It appears that the nutcracker is eating most of the seeds from the few remaining whitebark pine trees and not enough of their seed caches go unclaimed to germinate and grow into trees (Keane and Parsons 2010). This has served to keep recently burned areas in the shrub/herb stage for long periods, which may allow time for other wind-dispersed tree species to populate the burn. Thus, whitebark pine may continue to decline in this type, and species dominance will likely shift to subalpine fir, Engelmann spruce, and lodgepole pine.

It is likely that most of the range shifts of this forest type will be in wilderness areas, since about 50 percent of this type is found in wilderness (Keane 2000). Many NR wilderness areas have lands that are above the elevations at which this type occurs, so there are potential areas for this type expand. Wildland fire will be the catalyst for any range shifts in this forest type. Continued fire exclusion may seem appropriate for whitebark pine types, but it is contra-indicated in many situations; most whitebark pine will eventually succumb to white-pine blister rust, and thus suppressing fire does not necessarily protect it. Fire is needed to create conditions in which whitebark pine can become established and grow to maturity. If fires are suppressed and no rust-resistant trees are planted, then whitebark pine will likely remain a minor component of this forest type. However, if wildland fires occur and burned areas are planted with rust-resistant trees, then whitebark pine may become more abundant in the high-elevation settings of the NR. Therefore, land management will likely be more critical than climate in dictating the future composition and extent of this forest type.

Resource Concerns

Landscape Heterogeneity

Background

Historically, most Northern Rockies landscapes were shaped by disturbance regimes interacting with vegetation and climate creating shifting mosaics of diverse vegetation assemblages. Wildfire was the primary sculptor of historical landscape composition and structure, especially at lower elevations (including ignitions by Native Americans and lightning), with other disturbances (mountain pine beetle outbreaks, root rot pockets, windthrow) woven into the patchwork of forestlands. Forest patterns were constantly shifting over time and space at rates governed by interactions among vegetation, disturbance, and climate, resulting in different patch sizes, shapes, and distributions. Therefore, understanding the variability and scale of disturbance and succession is critical to quantifying historical landscape heterogeneity, which in turn affects biological diversity and ecosystem resilience.

High landscape heterogeneity creates diverse biological structure and composition that are considered more resilient and resistant to disturbances (Bannerman 1997; Cohn et al. 2015; Haire and McGarigal

2010; Turner 1987). For example, the effects of mountain pine beetle outbreaks are less severe in landscapes with diverse age structures of host tree species (Schoettle and Sniezko 2007). Heterogeneous landscapes also promote population stability (Oliver et al. 2010), because fluctuations in plant and animal population are less when landscape structure is diverse (Turner et al. 1993). Heterogeneous landscapes may also have more corridors, buffers, and refugia for wildlife and plant migration.

During the past 100 years, land management practices have altered the temporal and spatial characteristics of Northern Rockies landscapes. Timber management has modified patch shape and structure at lower elevation, and fire exclusion has changed patch size and diversity. Fire exclusion has in many cases created landscapes with large contiguous patches of old, dense stands with high surface and canopy fuel accumulations (Keane et al. 2002), although some areas with frequent disturbance (e.g., frequently burned ponderosa pine forest) are also homogeneous compared to pre-settlement montane forests (Romme 2005). Since we have directly or indirectly managed for late-seral conditions, some Northern Rockies landscapes are highly susceptible to insects and disease, owing to low tree vigor from intense competition, and have an abundance of live and dead fuels that will contribute to the severity of future wildfires.

Climate Change Responses

Many current Northern Rockies landscapes have less ability to buffer potential climate change effects because of widespread forest densification with shade tolerant species, although some landscapes, especially in subalpine forests, still have structures and compositions similar to those observed in the historical record. Recent wildfires, restoration activities, and timber harvest have helped return some heterogeneity, especially in wilderness areas and national parks. However, most Northern Rockies landscapes are outside their historical range and variability (HRV) in landscape structure, making it challenging to implement effective climate change adaptation.

Landscape heterogeneity may increase if climate-mediated changes in disturbance regimes increase (Funk and Saunders 2014). During the past 20 years, wildfire area burned and mountain pine beetle outbreaks have both increased, replacing late-seral forests with younger age and size classes and thereby

increasing heterogeneity. Continued increases in wildfire and other disturbances are projected in a warmer climate (Bentz et al. 2010; Marlon et al. 2009), so projected declines in biodiversity (e.g., Botkin et al. 2007) could be balanced by gains in landscape heterogeneity (Kappelle et al. 1999).

Continued fire exclusion in a warmer climate may promote late-seral forests that would be stressed from competition and drought (van Mantgem and Stephenson 2007). Wildfires that will eventually burn these landscapes may become large and burn more severely, thereby creating large patches of homogeneous post-burn conditions (Flannigan et al. 2005, 2009). These fires may also create semi-permanent shrublands and grasslands in areas that have become too dry for conifer establishment or where seed sources are eliminated (Fulé et al. 2004). However, some have found a high degree of heterogeneity in severity and vegetation conditions following large fires (Collins and Stephens 2010; Keane et al. 2008). Although the size, shape, and distribution of forest management treatments are a concern for landscape heterogeneity, the effects of management on landscape properties may be overwhelmed by other disturbances.

Is there an appropriate level of heterogeneity for Northern Rockies landscapes? How can management facilitate landscape heterogeneity and minimize adverse climate change effects? Mechanistic ecosystem models can be used to simulate landscape structure and composition in the future and for understanding effects of management actions (Keane 2013), but cannot generate heterogeneity metrics as design criteria for ecosystems. Using the HRV of landscape characteristics is a more straightforward and useful approach (Keane 2013; Morgan et al. 1994a; Nonaka and Spies 2005) (box 6.1). The HRV of landscape metrics may not represent future conditions (Millar 1997; Millar and Woolfenden 1999), but does provide an estimate of landscape conditions under which ecosystems have developed over the last thousand years, conditions that produced functional, heterogeneous ecosystems (Landres et al. 1999). It is preferable to first use HRV as a reference for landscape heterogeneity (Keane et al. 2015), then ecological models can be parameterized for historical conditions and used to generate a set of useful landscape metrics (Keane 2012).

Timber Production

Background

The area managed for timber production as one of the objectives for management is approximately 8,600 out of 34,000 square miles of forested lands throughout the Northern Region of the U.S. Forest Service. This area includes approximately 2,600 square miles in northern Idaho, 3,800 square miles in western Montana, 1,400 square miles in central and eastern Montana, and 460 square miles in the Greater Yellowstone portion of the Northern Region.

During the 1970's and 1980's, an average of 98 square miles were harvested each year, which amounted to about 1,900 square miles that had some type of harvest treatment implemented to meet various management objectives including timber production. During the time period from 1990 through 2014, an average of 39 square miles were harvested each year, which amounted to about 970 square miles. Recent harvest during 2014 of 32 square miles may be more typical of current and near term future harvest levels.

The species composition of timber harvests has fluctuated during the past 45 years, as harvest has often followed some disturbance agent such as mountain pine beetle in western white pine and lodgepole pine, spruce beetle in Engelmann spruce, white-pine blister rust in western white pine, root disease in Douglas-fir and grand fir, Douglas-fir beetle and spruce budworm in Douglas-fir, and wildfire in a variety of species types. The current percentage of total hectares in each of the major species composition groups within the approximately 8,687 square miles of lands suitable for timber production across the Northern Region is 6 percent ponderosa pine, 13 percent dry Douglas-fir, 27 percent lodgepole pine, 6 percent western larch, 12 percent mixed subalpine fir and Engelmann spruce, and 35 percent mixed western white pine, grand fir, western hemlock, moist site Douglas-fir and western redcedar forests.

Many of the current timber harvests in mixed mesic types of northern Idaho and western Montana are removing grand fir, Douglas-fir and western hemlock, and replanting western white pine, western larch and ponderosa pine. Other harvests involve removal of lodgepole pine and replanting of western larch. Thinning in ponderosa pine and dry Douglas-fir forests is also common. Within the eastern Montana and

6412 the GYA, harvesting is concentrated on mountain pine beetle-susceptible or dead lodgepole pine and
6413 ponderosa pine, and thinning in ponderosa pine and dry forest Douglas-fir forests is also common.
6414 *Climate Change Responses*
6415 With increasing temperatures and the potential for increases in forest productivity (Aston 2010; Joyce
6416 1995) and biomass accumulation (Lin et al. 2010) will probably come increases in timber production for
6417 most NR forests (Garcia-Gonzalo et al. 2007). Since the majority of NR forested lands are in the mesic
6418 montane, subalpine, and upper subalpine, the productivity increases are projected to be substantial. The
6419 increase in biomass might result in higher basal areas, greater timber value, and increased regeneration
6420 (Sohngen et al. 2001). However, these mesic temperate forests might also become denser, which may
6421 result in decreased vigor that may offset gains in productivity from climate alone. Depressed vigor might
6422 also increase susceptibility to insects and disease, and since insect and disease outbreaks are projected to
6423 increase in severity and frequency, there may be some major timber losses from forest pathogen and
6424 insect mortality (Joyce et al. 2008). There will also be an increase in potential mortality from wildland
6425 fire with increased fuel, drier conditions, and longer fire seasons, and this might facilitate even more
6426 timber losses. Future timber harvests from mature timberland might be a race against losses from
6427 increased insects, disease, and fire. The greatest climate change impacts on commercial forestry may
6428 come from changes in the disturbance regimes rather than changes in productivity (Kirilenko and Sedjo
6429 2007).
6430 There are other considerations in addressing how timber resources in the NR will change with
6431 warming climates. First, the majority of roads on NR lands are in drier, lower elevation forests where
6432 productivity may decline and more trees are projected to die from drought. Fewer roads are in the
6433 subalpine and upper subalpine where productivities and associated timber values are likely to increase,
6434 resulting in limited ability to transport timber to markets. Creation of new roads is expensive, risky, and
6435 environmentally damaging. These higher lands are distant from timber markets and sawmills, and are also
6436 more topographically complex and steep, thereby limiting the potential for mechanized timber removal
6437 while also increasing harvesting costs. These higher elevation lands are also where most of the threatened

6438 and endangered plant and animal species are found, especially grizzly bear (*Ursus arctos*), Canada lynx
6439 (*Lynx canadensis*), and wolverine (*Gulo gulo*), making it more difficult to implement timber harvest
6440 projects in these sensitive areas. If increases in insects, diseases, and fire are realized, the quality of
6441 timber will probably be reduced, and the value of the timber for building material will drop dramatically
6442 (Gillette et al. 2014; Kirilenko and Sedjo 2007; Spittlehouse and Stewart 2004). Longer fire seasons will
6443 probably mean there will be less time to perform forestry tasks, such as inventory, sale layout, and
6444 cruising. This may also mean that less agency money will be spent on forestry projects, such as ecosystem
6445 restoration, fuel treatments, and timber harvest sales, and more money will be spent on fire suppression
6446 activities. As the risk of uncharacteristic fire severity due to uncharacteristically high forest density
6447 increases, there will most likely be reductions in timber production opportunities, especially in dry forest
6448 areas that may be lost and converted to grass and shrub lands (Allen et al. 2010).

6449 Timber species will also shift in the future. Increases in temperature and soil moisture deficits may
6450 result in shifts of desirable timber species, such as western larch, to species compositions that are
6451 susceptible to root disease, such as Douglas-fir and grand fir. Any increases in production at mid and
6452 higher elevations from warming temperatures could be offset by losses from root disease because of
6453 continued fire exclusion. Land management efforts that create late-seral, shade-tolerant communities,
6454 namely fire exclusion and some fuel treatments, will increase the risk that any standing timber will be
6455 affected by damaging agents before it can be harvested.

6456 Many new forest practices, harvesting techniques, and markets are being proposed to offset carbon
6457 emissions from fossil fuels with carbon emissions from harvested biomass (Kirilenko and Sedjo 2007).
6458 Most of these new technologies will result in better utilization of timber resources and a more diverse and
6459 vibrant timber market. Biomass burning for energy, for example, could provide a market for non-
6460 commercial material removed from proposed fuel treatments. Slash piles could have value as biomass for
6461 energy. A more diverse market for wood products would surely enhance potential timber harvests in the
6462 NR, but it is essential that any proposed cutting activity be done in an ecological context, especially in
6463 this time of rapidly changing climates. Proposed harvesting activities must address a wide diversity of

issues, such as landscape character, species mix, successional dynamics, and fuels, to ensure these activities are effective and to minimize the long-term environmental impact.

It is essential that ecological principles be used to design harvest treatments of the future to ensure the creation of resistant, resilient forests that can withstand major impacts of climate change. Designing fuel treatments without considering ecosystem restoration concerns, for example, might create forests that are highly susceptible to insects and disease or fire. Favoring shade-tolerant, fire-susceptible species over fire-tolerant, sun-loving, early-seral trees species is ecologically inconsistent and will likely create landscapes that are intolerant of future climate change.

One proposed management alternative, carbon sequestration (see next section), might be cause for concern. The main assumption of most carbon sequestration options is to maximize biomass to sequester carbon from the atmosphere and put it into timber products to offset fossil fuel burning. The problem is that this approach must recognize the role of disturbance to be effective in the long term. Many studies have shown that the most resilient forests are ones with sub-optimal carbon sequestration.

Again, the major issue related to climate change and timber production in the near term is loss from disturbance. The anticipated increases in drought, severe large wildfires, root disease, other diseases such as white-pine blister rust, and insect damage such as that from large-scale bark beetle outbreaks, need to be addressed throughout the NR. Tactics to increase landscape heterogeneity overall, and reduce forest density in the dry forest types will be key climate change responses in the near term. Additionally, in the short and long term, adjusting species composition and distribution will be very important to sustaining long-term timber production.

Carbon Sequestration

Background

North American forests are considered important carbon sinks and currently offset about 13 percent of annual continental fossil fuel emissions (Pacala et al. 2007). Size and persistence of forest carbon sinks depends on land use and land management and environmental factors such as vegetation composition, structure, and distribution, climate, and disturbance processes including wildfire. Carbon accumulates in

6490 woody biomass and soils for decades to centuries until a disturbance event releases this stored carbon into
6491 the atmosphere. Although long intervals between disturbance events, such as wildfires or insect
6492 outbreaks, can allow carbon to accumulate for years to centuries, probability of disturbance increases with
6493 time (Loehman et al. 2014). Thus, disturbance-prone forests will eventually move stored carbon to the
6494 atmosphere, regardless of management strategies designed to limit or prevent disturbance events.
6495 However, unless structural or functional ecosystem shifts occur, net carbon balance in disturbance-
6496 adapted systems at steady state is zero when assessed over long time periods and at landscape scales**.** This
6497 is significant to management for two reasons: (1) disturbance-prone ecosystems cannot be managed to
6498 increase stored carbon over historical amounts without limiting the occurrence and magnitude of
6499 disturbance events; and (2) major shifts in vegetation composition, distribution, and structure resulting
6500 from climate change will result in different patterns of carbon storage on the landscape as compared with
6501 the historical period. Thus, it is important to develop expectations for landscape carbon storage potential
6502 in the context of projected climate change effects on both disturbance dynamics and vegetation patterns,
6503 and the relationships between them.

6504 Vegetated landscapes play an important role in storing carbon in the form of plant and animal
6505 materials (both live and dead), aboveground and in soils. Forests store carbon in soils (approximately 45
6506 percent of total storage), above and belowground live biomass (approximately 42 percent), deadwood
6507 (approximately 8 percent), and litter (approximately 5 percent) (Bonan 2008; Pan et al. 2011). Since
6508 forests contain large reservoirs of carbon (i.e., carbon sinks) and facilitate flows of carbon from the
6509 atmosphere to the biosphere (i.e., carbon sequestration), they are an important component of the global
6510 carbon cycle and are thought to have the potential to mitigate climate change (Ingerson 2007; Pan et al.
6511 2011). For example, North American forests currently offset about 13 percent of annual continental fossil
6512 fuel emissions (Pacala et al. 2007). The carbon sequestration potential of Earth's forests is about 33
6513 percent of global anthropogenic emissions from fossil fuels and land use (Denman 2007). Size and
6514 persistence of forest carbon sinks, and thus their potential to mitigate climate change, depends on both
6515 anthropogenic activities such as land use and land management, and environmental factors such as

vegetation composition, structure, and distribution, climate, and disturbance processes including wildfire (Loehman et al. 2014). Carbon typically accumulates in woody biomass and soils for decades to centuries until a disturbance event releases this stored carbon into the atmosphere (Goward et al. 2008). Disturbance is recognized as the primary mechanism that shifts ecosystems from carbon sinks to carbon sources (Baldocchi 2008), and wildfire in forested ecosystems is one of the primary disturbances that regulates patterns of carbon storage and release (Kasischke et al. 2000a,b). Forest insect outbreaks can also release carbon through decomposition of needles and other fine fuels from attacked trees (Kurz et al. 2008). The amount and rate of carbon release from a disturbance event depends on the extent and severity of the disturbance, as well as predisturbance site conditions and productivity (Bigler et al. 2005; Falk et al. 2007). In the case of both wildfires and insect outbreaks, although long intervals between events can allow carbon to accumulate for years to centuries, probability of disturbance increases with time (Clark 1989). Climate changes, in combination with other ecosystem stressors such as disturbance, may be sufficient to cause structural or functional changes in ecosystems, and thus fundamentally alter carbon dynamics of landscapes.

Climate Change Responses

As described in chapter 8, future warmer, drier conditions are likely to result in more frequent, larger wildfires, and greater annual area burned, that will serve to move carbon from biomass storage to the atmosphere. Warmer temperatures and increased drought stress are also projected to increase the area susceptible to or affected by beetle outbreaks. Regrowth of forests following disturbance may be delayed if the climatic conditions stress remaining or re-establishing species. Disturbance events in combination with additional climate-caused stressors may also result in functional transitions, such as a shift from forests to montane woodland or grassland-dominated vegetation types, which would likely result in less stored carbon. Frequent fires may also maintain open woodlands and savannas that might sequester less carbon than forests, but these carbon pools may be more stable and resilient to climate shifts.

Strategies that aim to manage carbon resources should consider the following:

1. Is the system disturbance-prone? If so, is it reasonable to expect the system to accumulate carbon over historical (steady-state) levels, especially given future climatic conditions that may increase the frequency, severity, and magnitude of disturbance events?
2. What are appropriate temporal and spatial scales over which to measure carbon storage? For example, in forests with multi-century disturbance cycles, it may take hundreds of years for forests to attain pre-disturbance levels of carbon, but this does not mean that they have become carbon sources at the appropriate, ecological scale of measurement?
3. Can potential future disturbance events be managed? For example, will it be possible to suppress or exclude wildfires from the system in the future, and at what economic or ecological costs?
4. Can additional stressors (e.g., drought stress, invasive weeds, and other management activities) be mitigated, to help maintain existing vegetation communities?
5. How might the system change with changing climate and disturbance? For example, are future climatic conditions conducive to persistence of forests, or will conditions become too warm or dry for the current dominant species?
6. Do planned carbon accounting methods assess ecological benefits of natural disturbance processes in carbon-equivalent units so that they can be weighed against carbon losses from disturbance? For example, wildfires confer many important ecological benefits not measurable in carbon units (e.g., nutrient release and redistribution and stimulation of plant growth, increased productivity in soil systems from decomposition of burned material, initiation of vegetation succession and forest regeneration, and increased availability of resources for surviving trees) that may actually increase carbon sequestration rates.

Two complementary activities, monitoring and modeling, can improve our understanding of cross-scale ecological drivers and responses to disturbance (Loehman et al. 2014). Monitoring programs can be used to quantify long-term carbon dynamics before and after disturbance, evaluate responses of ecosystems to changes in climate, and identify shifts in ecosystem patterns and processes emergent under

changing climates. Monitoring data can also be used to provide inputs to, calibrate, and validate models. Models, in turn, can be used to simulate emergent environmental patterns, compare effects of potential treatments, identify vulnerable landscapes or ecosystem components, and bridge gaps between landscape-scale ecological processes and variables measured in small areas and over short periods of time. There is room for improvement on both fronts, as described previously in this chapter. Although it may be tempting to meet policy-driven goals of increased carbon storage via management strategies designed to exclude or limit the extent and magnitude of disturbance events (e.g., wildfires), it is important to remember that native disturbance processes confer many important ecological benefits not measurable in carbon units (e.g., nutrient release and redistribution and stimulation of plant growth, increased productivity in soil systems from decomposition of burned material, initiation of vegetation succession and forest regeneration, increased availability of resources for surviving trees). Thus, it will be important to develop accounting methods that can assess ecological benefits in carbon-equivalent units so that they can be weighed against carbon losses from disturbance.

VULNERABILITY ASSESSMENT

All items in each of the three scales of assessment were rated as to their vulnerability to climate change using the same rubric employed across all chapters in this report (Table 6.4), and the results are summarized in detail in appendix 6B. We populated a table with valuable information for the eight categories in Table 6.4 using a thorough consideration of five factors: (1) climate; (2) disturbance; (3) life history; (4) dependencies; and (5) other stressors. For climate, we considered whether the species, vegetation type, or resource concern was sensitive to changes in direct effects of climate (temperature and precipitation) or indirect effects of climate (e.g., soil moisture, snowpack, seasonality of flows, climatic water deficit, altered flow regimes, and stream temperature). For example, we asked, "Does the system inhabit a relatively narrow climatic zone or does it experience large changes in composition or structure with small climatic changes?" We also considered both direct sensitivity to climate change (e.g., ecophysiology and life history) and indirect sensitivity to climate change (e.g., ecological relationships such as competition, dispersal, and migration). Vulnerability to disturbance was assessed in reference to

whether the species, type, or concern was sensitive to major disturbances, mainly wildland fire, insect outbreaks, drought, and pathogens. Disturbances are major catalysts for vegetation change and can combine with climate stressors and non-climate stressors to create a broader stress complex with multiple interactions. Life history aspects of the species and vegetation type were considered to address the impact of a species' growth rate, susceptibility to mortality, longevity, and reproductive strategy, which may influence sensitivity to climate change. Species with long life spans may have lower vulnerability than short-lived species. We also addressed the species dependencies on other ecosystem processes or landscape elements. Riparian species, for example, are dependent on wet conditions. Lastly, non-climate stressors, such as land use, grazing, and timber harvest, and fire exclusion were integrated into our assessment.

The appendix 6B vulnerability assessment is further summarized in Table 6.5 for only the tree species included in this report. We ranked each species by the NR geographic regions (fig. 6.1) and removed those species that did not occur in those regions. We also included the rankings of two other efforts for comparison purposes. The Devine et al. (2012) report assessed vulnerability for a number of tree species in the Pacific Northwest, and the Hansen and Phillips (2015) effort assessed vulnerability for some NR tree species using SDMs. This information is presented as a means to aid land managers to integrate climate change impacts into their planning documents and analyses.

ADAPTATION STRATEGIES AND TACTICS

This chapter documents what could happen to NR forest resources under potential future climates. However, the real question facing land managers is what they should do to adapt to climate change and mitigate any adverse impacts incurred as a result of changing climate. Adaptation can be defined as initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects (IPCC 2007). Adaptation actions range from the simple, such as doing nothing or increasing the harvest rotation age, to the complex, such as implementing fuel treatments to reduce the risk of high-severity fire in ecosystems with rare plants (Spittlehouse and Stewart 2004). Most land managers have the tools, knowledge, and resources to begin to address climate change, but as

Swanston and Janowiak (2012) note, managers need to expand their thinking to consider new issues, spatial scales, timing, and prioritization of efforts. For example, managers need to account for the high variability and trend of climate in the design of alternative land management actions.

There are some fundamental principles that can serve as starting points in the development of adaptation approaches (Joyce et al. 2008; Millar et al. 2007a; West et al. 2009). First, it will be increasingly important to prioritize management actions based on both the vulnerability of resources and on the likelihood that actions to reduce vulnerability will be effective (i.e., prioritization). Next, adaptive management principles provide a decision-making framework that maintains flexibility and incorporates new knowledge and experience over time (i.e., adaptive management). Management actions that result in a wide variety of benefits under multiple scenarios but have little or no risk may be initial places to look for near-term implementation (i.e., low-hanging fruit). Where vulnerability to a particular resource is high, precautionary actions to reduce risk in the near term, even with existing uncertainty, may be extremely important (i.e, triage). It is important to remember that climate change is much more than increasing temperatures; increasing climate variability across all components of climate, such as precipitation, humidity, and radiation, will lead to equal or greater impacts that will need to be addressed (i.e., increased uncertainty). Lastly, many adaptation actions are often complementary with other land management actions, and any actions to adapt forests to future conditions may also help restore these forests to healthy conditions (i.e., multiple objectives). When designing adaptation actions, it is important to address and integrate these principles to maximize efficiency.

The concepts of resistance, resilience, and response serve as the fundamental options for managers to consider when responding to climate change using adaptation (Millar et al. 2007a; Swanston and Janowiak 2012). *Resistance options* improve the ecosystems defenses against anticipated climate change responses or directly defend the ecosystem against disturbance to maintain current conditions. Resistance actions are often effective in the short term, but it is likely that resistance options may require greater effort over the long term as the climate shifts further from historical norms. Moreover, there is a real risk that the ecosystem will undergo irreversible change because of large climatic shifts, thereby rendering all

6645 resistance activities ineffective. *Resilience options* allow some change, but emphasize a quick return to
6646 prior conditions after a disturbance. Resilience actions are also short-term and should be used for high-
6647 value resources or areas that are buffered from climate change impacts. *Response options* intentionally
6648 accommodate change and allow ecosystems to adaptively respond to changing and new conditions. A
6649 wide range of actions exists under this option, all working to influence ways in which ecosystems adapt to
6650 future conditions.

6651 Resistance, resilience, and response options serve as the broadest and most widely applicable level of
6652 a continuum of management responses to climate change. Along this continuum, adaptation actions
6653 become increasingly specific from options to strategies to tactics. Adaptation *strategies* describe how
6654 adaptation options could be employed, but they are still broad and general in their application across
6655 ecosystems, while *tactics* are more specific adaptation responses, and they can provide prescriptive
6656 directions on how actions can be applied on the ground.

6657 There are many broad strategies and associated tactics that can be used to adapt to climate change
6658 impacts in the NR, and the major ones that were identified by managers and scientists in a series of
6659 workshops in the fall of 2015 are detailed in Table 6.6 and described below. Adaptation tactics for all NR
6660 species, vegetation types, and resource concerns discussed in this chapter are summarized in Table 6.7.
6661 Adaptation tactics were designed at different scales and levels of organization. Some concern NR
6662 managers at the highest levels of agency organization, while others concern ecologists, silviculturists, and
6663 resource specialists at the lower levels of organization. Some tactics concern multiple species or
6664 resources, while others are specific to just one entity. These tactics were design so that NR managers can
6665 use these recommendations to directly address climate change impacts in their planning and
6666 implementation of any action, specifically National Environmental Policy Act analysis.

6667 As in other adaptation efforts, many tactics developed by NR managers were focused on protecting
6668 forests from severe disturbance, mainly fire (Table 6.6). For example, managers identified promoting
6669 disturbance-resilient forest structure and species as key strategies. Thinning and prescribed fire can both
6670 be used to reduce forest density and promote disturbance-resilient species. Disturbance-resilient species

can also be planted. Managers recognized the importance of promoting and planting site-adapted species, specifically western larch and western white pine on moist sites, ponderosa pine on dry sites, Douglas-fir on extremely dry sites, and lodgepole pine on harsh sites that are difficult to regenerate.

Preparing for disturbance will also be important under a changing climate. Tree regeneration after severe fire may be more limited in the future with increased drought. Promoting legacy trees of disturbance-resilient species may help to increase postfire regeneration. Managers may also want to increase seed collection and ensure that adequate nursery stock is available for post-disturbance planting.

Another theme in the adaptation strategies and tactics developed by NR managers was promoting diversity, including species diversity, genetic diversity, and landscape diversity. Increasing diversity is a "hedge your bets" strategy that reduces risk of major forest loss. Areas with low species and genetic diversity will likely be more susceptible to the stressors associated with climate change, and thus, promoting species and genetic diversity, through plantings and in thinning treatments, will likely increase forest resilience to changing climate. Promoting landscape heterogeneity, in terms of species and structure, will also likely increase resilience to wildfire, insects, and disease.

There is a lot of uncertainty associated with climate change, and managers identified several ways to increase knowledge and manage in the face of uncertainty. Implementation of an adaptive management framework can help managers deal with uncertainty and adjust management over time. In the context of climate change adaptation, adaptive management involves: definition of management goals, objectives and timeframes; analyzing vulnerabilities; determining priorities; developing adaptation strategies and tactics; implementing plans and projects; and monitoring, reviewing, and adjusting (Millar et al. 2014). Development of a consistent monitoring framework that can capture ecosystem changes with shifting climate is a key component of the adaptive management framework. For example, tracking tree species regeneration and distribution will help managers determine how species are responding to climatic changes and how to adjust management accordingly (e.g., guidelines for planting). Integration between research and management and across resource areas (e.g., forest management and wildlife) will also be key in implementation of the adaptive management framework to ensure that the best available science is

6697 being considered in on-the-ground management and that management approaches do not conflict (e.g.,
6698 what effects will particular thinning treatment have on wildlife?).

6699 Managers also identified adaptation strategies and tactics to maintain particular species or community
6700 types of concern. For example, climate change will likely lead to increased whitebark pine mortality
6701 through increased mountain pine beetle activity, fire and white-pine blister rust. There will also likely be a
6702 loss of site conditions that support whitebark pine. To promote resilient whitebark pine communities,
6703 managers may want to focus restoration efforts on sites less likely to be affected by climate change (i.e.,
6704 refugia). A variety of management strategies can be implemented to promote whitebark pine, including
6705 fire management, planting at lower elevations, and removing other dominant species (e.g., lodgepole pine,
6706 spruce and fir). Genetically selected seedlings can also be planted to promote blister rust resistance.

6707 Finally, managers recognized that stressors associated with climate change cross boundaries, making
6708 it increasingly important that agencies coordinate and work across boundaries. Agencies can coordinate
6709 by aligning budgets and priorities for programs of work, communicating about projects adjacent to other
6710 lands, and working across boundaries to maintain roads, trails and access that will likely be more
6711 frequently impacted by fire and flood events under changing climate.

6712 **DISCUSSION**

6713 Given the high uncertainties in predicting climate, vegetation, and disturbance responses to increasing
6714 CO_2, we feel that assessing vegetation change and vulnerabilities is currently more of an educated guess
6715 based on inconsistent and contradictory studies rather than a highly confident evaluation of
6716 comprehensive scientific investigation. Many of the techniques used to predict tree species response to
6717 climate change in the literature present only one possible future out of seemingly unlimited possibilities.
6718 These predictions would change if a new climate change scenario were used; if new data were augmented
6719 with existing data; if new variables were included in the analysis; if simulation parameters were modified;
6720 or if new algorithms were included in existing models. Moreover, there are still many unknowns in
6721 ecosystem science, and if you link those unknowns to the unknowns in climate systems, these

uncertainties would certainly swamp any educated guesses that we might have. The end result is that these projections and assessments must be interpreted in the context of high uncertainty.

One important lesson that we learned while writing this chapter is that climate change is only one of the many challenges facing land managers, and some of these other challenges might be more important than mitigating climate change. We found that by successfully mitigating ecosystem impacts from past management actions, such as fire exclusion and exotics introductions, will also mitigate against climate change impacts. Restoring fire-prone ecosystems declining due to fire exclusion, for example, might successfully solve two issues – it would increase ecosystem health and create resilient forests that could thrive under future climate changes. These fire-dominated forests have already experienced great variation in past climate and clearly have broad amplitudes of resilience with respect to climate. In another example, fostering greater rust-resistance in our native five-needle pines may allow us to create those forests that are less vulnerable to changes in climate. There will be places in the NR where the primary challenge will be climate change impacts, such as drought at the lower treeline, but overall, we feel that the best approach is to integrate climate change considerations into current management actions rather than conduct management actions for the sole purpose of climate change mitigation. Ecosystem restoration, as a prime example, could be the best approach for preparing for climate change.

The main question then, is how do we restore ecosystems in the NR? Managers need reference conditions at the stand and landscape scales to prioritize, plan, design, and implement effective restoration activities. This becomes somewhat problematic when we need that reference to include the trend and variability of future climate. Considering the high uncertainty of future climate and vegetation projections, and knowing the resilience of fire-adapted species, we suggest that any conclusions about the infeasibility of ecosystem restoration under changing climate are imprudent. On one hand, it may be more prudent to wait until simulation technology has improved to include credible pattern and process interactions with realistic regional climate dynamics for the future so that we base decisions on the restoration of ecosystems on better information. But improving ecosystem models may take decades before simulations can be used to predict species and landscape response to climate change with

reasonable accuracy, and while we wait, we lose valuable populations and rust-resistant trees, and our options for restoration diminish greatly. Even with climate change, restoration activities will probably be appropriate considering the considerable genetic variation across the range of this species, which provides the foundation for adaptation (Rehfeldt et al. 1999; Bower and Aitken 2006, 2008, Mahalovich and Hipkins 2011). Therefore, we believe that the current emphasis on ecosystem restoration in the NR will lead to more resilient ecosystems for the future. Until we have realistic models and less uncertain climate change projections, we desperately need a construct to use as a reference for restoration. It may be less uncertain to use historical data to guide future management actions rather than build new references based on uncertain climate change projections. Therefore, we believe that historical ranges and variability (HRV) may provide sufficient reference conditions in the future.

We feel that the concept of HRV still has a valid place in land management, at least for the near future. Landscape models can be used to simulate fire regimes and their interaction with climate and vegetation to create HRV time series that can be used as reference conditions to assess, plan, evaluate, design, and implement ecosystem restoration treatments. HRV should only be used to guide land management; not as a target on which to evaluate success or failure. There are few measures of ecosystem health that match the scale, scope, flexibility, and robustness of HRV analysis. HRV might provide a useful, but not ideal, reference for land management over the next several decades until simulation modeling advances to a level where future models can forecast both accurate climate and climate responses by the ecosystems.

CONCLUSIONS

Climate change is one of many challenges facing land managers, and some of these other challenges might be more important than climate change. In addition, mitigating past ecosystem damage (e.g., fire exclusion and nonnative introductions) is a climate-smart practice. For example, restoring fire-prone ecosystems can both improve ecosystem function and create forests that will be resilient in a warmer climate. Fire-prone forests have already experienced variation in past climate and have broad amplitudes of resilience with respect to climate. There will be places in the NR where climate change will be the

primary challenge (e.g., drought at lower treeline), but integrating climate change considerations into current management operations is preferable to a climate-centric management strategy. Even with climate change, restoration will be appropriate considering the high genetic variation across the range of forest species, providing a foundation for adaptation (Bower and Aitken 2006, 2008; Mahalovich and Hipkins 2011; Rehfeldt et al. 1999).

Multi-resource monitoring will be critical for managing ecosystems in the future, building on existing monitoring systems but with additional elements to accommodate the effects of climate change (Janowiak et al. 2014). Although costly in terms of money and personnel, an extensive monitoring system will save money in the long run by evaluating the effectiveness of adaptation tactics and providing a means to adjust them. Without monitoring, it will be impossible to know the magnitude and trend of climate effects on vegetation, or if actions proposed in this document (see adaptation section) are useful for planning and management. Monitoring data can also be used to provide inputs to, calibrate, and validate models. Models, in turn, can be used to simulate emergent environmental patterns, compare effects of potential treatments, identify vulnerable landscapes or ecosystem components, and bridge gaps between large-scale ecological processes and variables measured in small areas and over short periods of time. Therefore, any future land management planning will be complete only if a plan for monitoring proposed actions is included.

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Chapter 7: Effects Of Climate Change On Rangeland Vegetation

Matt C. Reeves, Mary E. Manning, Jeff P. DiBenedetto, Kyle A. Palmquist, William K. Lauenroth, John B. Bradford, and Daniel R. Schlaepfer

INTRODUCTION

Rangelands are dominated by grass, forb, or shrub species, but are usually not modified using agronomic improvements such as fertilization or irrigation (Lund 2007; Reeves and Mitchell 2011) as these lands would normally be considered pastures. Rangeland includes grassland, shrubland, and desert ecosystems, alpine areas, and some wo dlands (box 7.1). Within the Northern Rockies, rangelands occupy more than 65 mil ion acres (R eves and Mitchell 2011). Ecosystem services derived from rangelands in the Northern Region include, but are not limited to, forage for millions of domestic and wild ungulates, greater sage-grouse (*Centrocercus urophasianus*) habitat, and numerous recreational opportunities (see chapter 10).

The sustainability of goods and services is threatened by land-use change, including residential development, energy development, and invasive (nonnative) plant species (see chapter 11). These threats, expressed against the backdrop of climate change, pose unique challenges for managers in the Northern Region**.** The effects of climate change on rangelands have received less attention than forests, but similar to forests, past and future human land-use activities may exceed climate change effects, at least in the short term (Peilke et al. 2002). Interactions between land-use change, management, and climate change are not well understood and difficult to forecast. Therefore, this analysis of potential climate change effects on rangelands does not explicitly include estimates of future land-use change or management, and instead focuses estimated regeneration success, response to disturbance (especially fire), and life history traits.

Relative to forests, rangelands usually occur in more arid environments, either due to edaphic (e.g., some montane grasslands, subalpine shrublands, and fell-fields) or climatic factors. These arid conditions

present challenges for studying the effects of climate change because some rangelands will be less resilient to changes in environmental influences such as fire regimes and periodicity of precipitation. Understanding resistance and resilience for rangelands is important for estimating possible effects of climate change. Generally speaking, resilience refers to the capacity of ecosystems to regain structure, processes, and functioning in response to disturbance (Allen et al. 2005; Holling 1973), whereas resistance describes capacity to retain these community attributes in response to disturbance (Folke et al. 2004). These concepts are especially critical when considering establishment of nonnative plants and interactions between climate change stressors (Chambers et al. 2014). In the Northern Rockies, areas receiving higher precipitation and cooler temperatures generally result in greater resources and more favorable conditions for plant growth and reproduction (Alexander et al. 1993; Dahlgren et al. 1997). These concepts are demonstrated in figure 7.1, which indicates that management for ecosystem services derived from rangelands will be relatively more effective in more mesic rangelands.

In this chapter we explore potential effects of climate change on selected rangeland habitats. The evaluation of risk was qualitatively and synthetically determined using a combination of workshop output, literature (where available) and our judgement and that of two reviewers. It is meant to represent our best guess as to the relative vulnerability of each system to estimated perturbations brought forth by expected changes in climate across the Northern Region.

VEGETATION CLASSES

The rangeland assessment focuses largely on groupings of vegetation types but also references individual species where information and data suggest inferences can be made for species. Identifying rangeland vegetation to be included in the vulnerability assessment was accomplished by first reviewing the extent of rangelands within the conterminous United States (Reeves and Mitchell 2011). The National Resources Inventory (NRI) definition (box 7.1) of rangelands was used to identify rangelands within the Northern Rockies. The list of U.S. Ecological Systems designated as rangelands that were retained for evaluation is found in table 7.1. The great complexity of rangeland vegetation combined with a paucity of climate change effects studies suggests that a grouping) of individual vegetation types into classes would

be useful. The resulting grouping and the final groups to be analyzed include Northern Great Plains (mixtures of cool and warm-season species), montane shrubs, montane grasslands (referred to as "western grasslands" and dominated by cool season species), and sagebrush systems. It is important for the reader to understand that multiple vegetation types comprise each of the four broad classes of vegetation. In the case of sagebrush systems, however, four groups were identified (short sagebrushes, big sagebrushes, sprouting sagebrushes, and mountain sagebrush) which were subsequently further permuted by individual types (table 7.1).

The Northern Great Plains has a broad geographic expanse and mixture of both cool-season (C3) and warm-season (C4) species. Montane shrubs are comprised of species important for browsing by native ungulates. Montane grasslands have a unique position on the landscape, dominance of cool-season species, relative scarcity and specific types of habitats they provide in juxtaposition to forest vegetation.

Sagebrush systems (dominated by species in the genus *Artemisia*) provide critical wildlife habitat, including for the imperiled greater sage-grouse, and are a ubiquitous and iconic species in much of the western United States. In addition, sagebrush systems, especially those dominated by big sagebrushes (Wyoming big sagebrush [*Artemisia tridentata* ssp. *wyomingensis*], mountain big sagebrush [*A. tridentata* ssp. *vaseyana*], and basin big sagebrush [*A. tridentata* ssp. *tridentata*]) have been more widely studied, at least partially as a result of recent research on sage-grouse habitat. Therefore, the vulnerability of some sagebrush species is supported by a richer body of information than for other vegetation. However, this does not mean that all sagebrush types have been studied equally in the context of climate change. To reflect the disparate amount of study on climate change effects on sagebrush species, four sagebrush types were delineated for the Northern Rockies for the purposes of this study (fig. 7.2, sagebrush types):

- Big sagebrushes—Wyoming big sagebrush and Basin big sagebush
- Low sagebrushes—low sagebrush (*A. arbuscula*) and black sagebrush (*A. nova*)
- Sprouting sagebrushes—silver sagebrush (*A. cana*) and three-tip sagebrush (*A. tripartita*)
- Mountain big sagebrush

Figure 7.2 does not represent an exact accounting of these four vegetation classes but suggests an estimated distribution where each grouping is usually found. In addition, using Ecological Systems mapped at this level it is not possible to differentiate the distribution of silver and three-tip sage as they are often disjunctively commingled with other types. As a result, only three categories are mapped but within the largest category, the big sagebrushes, and sprouters are all represented in one estimated distribution.

The Wyoming and basin big sagebrush types were aggregated for their similar life histories, stature, and areal coverage in the Northern Region, and because they represent critical habitats for many species of birds and wild and domestic ungulates. Despite having similar life history traits, basin big sagebrush occupies sites with deeper soils (often on alluvial fans). These conditions tend to increase available moisture with higher coverage by perennial bunchgrasses, suggesting these sites may be more resilient and resistant to various threats (Chambers et al. 2007). Similarly, the low sagebrushes were chosen for the unique habitats they represent (especially black sagebrush) and similar life histories. Both silver sagebrush and three-tip sagebrush can resprout after fire, making them unique in that regard among the sagebrush species, with the exception of periodic sprouting by some variants of mountain big sagebrush.

Finally, mountain big sagebrush was chosen for its (usually) distinct positioning on the landscape, in addition to being the most mesic of sagebrush communities in the Northern Rockies. Communities dominated by Wyoming big sagebrush are by far the most common and occupy the greatest area (table 7.2), whereas the low sagebrush type occupies the least. However, although basin and Wyoming sagebrush are common throughout the Northern Region, mountain big sagebrush communities occupy the greatest extent on lands managed by the Forest Service, U.S. Department of Agriculture. Although the communities dominated by the Artemisia species listed here were subdivided for evaluating possible effects of climate change, four species (Basin-big, Wyoming, three-tip, and silver) were grouped for mapping purposes as the “big or sprouter” category (table 7.1) since differentiating these across the landscape was impractical.

VEGETATION PRODUCTIVITY IN RESPONSE TO CLIMATE CHANGE

Although the current extent of rangeland in the Northern Rockies can be accurately described, uncertainty in the underlying global climate models (GCMs) used to estimate climate change effects (see chapter 3), and uncertainty in models of physiological response, make it difficult to confidently project the effects of climate change on rangelands. Our understanding of the potential effects of climate change can be improved if comparisons of impacts are made with other areas our understanding of the relative effects in the Northern Region can be improved.

The primary inference about climate change effects on rangeland vegetation nationally is one of increasing temperature, lower soil moisture, changing phenology, and decreasing annual production. However, projected temperatures exhibit far less variability among scenarios and GCMs than precipitation. Therefore, areas where projections suggest temperature rather than precipitation is a dominant driver may be more reliable. Figure 7.3 suggests that, relative to much of the rest of the country, the Northern Region could experience an increase in annual net primary productivity (NPP). In addition, the modeled overall increases in productivity appear to be more consistent in the Northern Rockies compared with other areas because there is less disagreement among the three emission scenarios evaluated (Nakicenovic et al. 2000; Reeves et al. 2014).

Changing climate regimes will also influence phenology in unexpected ways. For example, in tallgrass prairie (a rare type in the Northern Rockies), a 7.2 °F increase in ambient temperature caused earlier anthesis among spring blooming species and later anthesis in fall-blooming species (Sherry et al. 2007), implying that climate change will influence vegetation in complex ways (Suttle et al. 2007; Walther 2010). In addition, effects of climate change may be greater at higher elevations (Beniston et al. 1997) (fig. 7.3, panel A), a logical projection for the Northern Rockies where the primary factor limiting plant growth at high elevations is growing-season length and cold temperatures.

The modeled overall effect of projected climate change in the Northern Rockies appears to be increased growing season length and increased NPP, which may be especially pronounced at higher elevations. Removal of growth limitations could result in significant changes in vegetation at higher

8688 elevations, such as the Greater Yellowstone Area subregion. Higher NPP may seem counterintuitive
8689 because increased temperatures suggest greater moisture stress and therefore potentially less favorable
8690 growing conditions. Indeed, if all other factors besides temperature remained constant in the future, then
8691 vegetation might experience significant reductions in productivity from increased evaporative demand
8692 and reduced soil moisture. Conversely, some high elevation areas may experience increased production
8693 with increasing temperatures (Reeves et al. 2014), especially some relatively more mesic areas supporting
8694 mountain sagebrush.

8695 Increased atmospheric CO_2 concentrations may modify ecophysiological growth processes in
8696 rangeland vegetation. Carbon dioxide enrichment can enhance water use efficiency through reduced water
8697 lost through stomata (see chapter 6), but the response is not consistent across all vegetation. For example,
8698 in tallgrass prairie, Owensby et al. (1999) found that elevated CO_2 could increase productivity of above-
8699 and below-ground biomass, but response depended on water stress. These findings are consistent with
8700 results from Reeves et al. (2014) and suggest that desiccation effects of increased temperature can be
8701 offset to some extent by CO_2 enrichment via reduced transpirational demand (Leakey 2009; Morgan et al.
8702 2004b, 2011; Woodward and Kelly 2008), and higher water use efficiency (Bachelet et al. 2001;
8703 Christensen et al. 2004; Morgan et al. 2008, 2011; Polley et al. 2003).

8704 Recent experimental research on the Northern Great Plains is particularly relevant to the managers in
8705 the Grassland subregion where northern mixed grass prairie dominates. The Prairie Heating and CO_2
8706 Enrichment (PHACE) study reported an increase of aboveground productivity by an average of 33
8707 percent over three years (Morgan et al. 2011), which substantiates estimates of Reeves et al. (2014) of a
8708 28 percent increase in productivity for the Northern Great Plains by 2100.

8709 As a footnote to the discussion above, it is important to note that all models are a simplification of
8710 reality, and interpretation of model results needs to consider uncertainty, inputs, and model assumptions.
8711 Models cited here have increasing disparity as time progresses, especially in more arid regions where
8712 changing precipitation amounts and patterns may be the primary driver of change.

8713 **Management Concerns**

The primary management and ecological concerns affecting rangelands in the Northern Rockies identified include uncharacteristic fire regimes, improper grazing, and invasive species. Uncharacteristic fire regimes, which are based on the historic fire regime, threaten some rangeland habitats, especially sagebrush steppe, across much of the western United States including the Northern Rockies. It is suggested, however, that the overall concern over uncharacteristic fire regimes is smaller than for other regions such as the Great Basin. On one end of the spectrum, it appears "too much" fire presently affects the landscape relative to historic fire regimes, because many sagebrush habitats now have shortened fire return intervals. It is widely documented that increasing dominance of invasive annual grasses have created a positive feedback cycle characterized by frequent fire followed by increased dominance of annual grasses that further create fuel conditions that facilitate combustion (Chambers et al. 2007). These conditions are exacerbated by wetter and warmer winters, which are projected throughout the study area in the future.

On the other end of the spectrum, fire exclusion has led to decreased fire return intervals that may be responsible for Douglas-fir (*Pseudotsuga menziesii*) encroachment into montane grasslands (Arno and Gruell 1986), and in higher elevation sagebrush habitats, especially those dominated by mountain big sagebrush (Heyerdahl et al. 2006) (fig. 7.4). Overall, the invasive species of greatest concern throughout rangelands of the Northern Region in sagebrush communities is cheatgrass (*Bromus tectorum*), although Japanese brome (*B. japonicus*) and leafy spurge are also concerns in the Northern Great Plains. Recent range expansion of cheatgrass is particularly prominent in the western half of the Northern Rockies and can be somewhat explained by genetic variation leading to increased survival and persistence in otherwise marginal habitats (Merrill et al. 2012; Ramakrishnan et al. 2006). This rapid range expansion may be enhanced by elevated atmospheric CO_2 concentrations and increased soil disturbance (Chambers et al. 2014). Improper grazing, a term referring to the mismanagement of grazing that produces detrimental effects on vegetation or soil resources, can exacerbate these conditions (see chapter 6). However, U.S. rangelands are generally not improperly grazed (Reeves and Bagget 2014; Reeves and Mitchell 2011) to the point of degradation. Although improper grazing does occur, it is not the normal condition across the

extent of rangeland rangelands in the Northern Region. Where improper grazing does occur, it can accelerate the annual grass invasion/fire cycle, especially in some sagebrush types, the Northern Great Plains, and montane grasslands.

BROAD-SCALE VULNERABILITY OF RANGELANDS TO CLIMATE CHANGE

Determining the vulnerability of rangeland vegetation is a difficult task inherently wrought with great uncertainty. Uncertainty exists in the projections of future climatic conditions as well as in expected effects of vegetation. Given the lack of studies focused on manipulated climate on vegetation performance, we are limited to past observations; some published scientific studies, and our collective best judgement. Despite the lack of focused studies on the effects of climate change on rangeland vegetation and the large uncertainty of projected climates, there are a few elements of climate change that are increasingly recognized as potential outcomes. As a result, in this section, we briefly discuss some overarching expected climatic conditions against which the estimation of likely future vegetation outcomes of each previously identified vegetation class is formulated.

Of all the estimated future climate outcomes, projected temperature increases (IPCC 2014; chapter 3) are expected to increase evaporative demand (e.g. potential evapotranspiration; Klos et al. 2014) and pose greater overall temperature stress (Polley 2013). Projected changes in precipitation patterns and increasing potential evapotranspiration could encourage more frequent and intense fires from the combined effects of early season plant growth combined with the desiccating effects of warmer, drier summers (Morgan et al. 2008). Collectively, these changes may result in considerably drier soils, particularly in the summer months when plants are phenologically active (Bradford et al. 2014; Polley et al. 2013). However, winter precipitation is projected to increase by 10 to 20 percent in the Northern Region (IPCC 2014; Shafer et al. 2014; chapter 3), which may compensate for increasing severity and frequency of droughts. In addition, rising CO_2 levels may offset water loss due to higher evaporative demand by increasing stomatal closure and water use efficiency.

Warmer winters, and decreasing snowpack may also be significant factors affecting rangeland vegetation classes discussed below. Minimum temperatures are expected to increase more than maximum

temperatures, providing longer frost-free periods. Warmer, wetter winters would favor early-season plant species and tap-rooted species that are able to access accumulated early growing season soil water (Polley et al. 2013). These conditions are projected to significantly increase annual area burned and fire intensity (Westerling et al. 2006).

Montane Grasslands

Montane grasslands are associated with mountainous portions of the Northern Rockies including the Palouse prairie and canyon grasslands of northern and central Idaho. Montane grasslands occur in intermountain valleys, foothills, and mountain slopes from low to relatively high elevation. They are dominated by cool-season (C3) grasses, along with a large number of forbs and upland sedges. Shrubs and trees may occur with low cover. Dominant species include bluebunch wheatgrass (*Pseudoroegneria spicata*), rough fescue (*Festuca campestris*), Idaho fescue (*F. idahoensis*), Sandberg bluegrass (*Poa secunda*), needle-and-thread (*Hesperostipa comata*), western wheatgrass (*Pascopyrum smithii*), prairie junegrass (*Koeleria macrantha*), western needlegrass (*Achnatherum nelsonii*), and Richardson's needlegrass *(A. richardsonii*).

Many low elevation grasslands have been converted to agricultural use or are grazed by domestic livestock. They have also been subject to extensive human use and land-use conversion. Those grasslands that remain, particularly at lower elevations, are typically highly disturbed, fragmented, and frequently occupied by many nonnative, invasive plant species. Prolonged improper livestock grazing, native ungulate herbivory, and nonnative invasive plants are the primary stressors in these grasslands (Finch 2012). Loss of topsoil can occur if vegetation cover and density decline and bareground increases. Lack of fire is also a chronic stressor because conifers from lower montane forests can become established in some areas, and increase in density and cover with fire exclusion (Arno and Gruell 1986; Heyerdahl et al. 2006). As conifer density and cover increase with fire exclusion, grass cover declines, because most grassland species are shade intolerant (Arno and Gruell 1983). Although lack of fire has been a stressor, if fires become hotter and more frequent, there is an increased risk of mortality of native species and invasion by nonnative plant species but invasive plants may not always establish and dominate a site

8792 (Ortega et al. 2012; Pearson et al. in review) under these conditions. It is thought, however, that greater
8793 spring and winter precipitation may facilitate exotic annual grasses, particularly cheatgrass, which
8794 germinates in the winter/early spring, to establish and set seed earlier than native perennial grasses (Finch
8795 2012). This creates an uncharacteristic, continuous fine fuel load that is combustible by early summer,
8796 burning native perennial grasses often before they have matured and set seed (Bradley 2008; Chambers et
8797 al. 2007). Other nonnative species, such as spotted knapweed (*Centaurea melitensis*), Dalmatian toadflax
8798 (*Linaria dalmatica*), butter-and-eggs (*Linaria vulgaris*), and sulphur cinquefoil (*Potentilla recta*) respond
8799 favorably after fire and can increase in cover and density.

8800 Nonnative, invasive plant species will probably expand particularly in the lower elevation grassland
8801 communities as these communities become warmer and drier since resistance to invasion may decrease
8802 (Chambers et al. 2014). Greater disturbance will likely increase the rate and magnitude of infestation
8803 (Bradley 2008). In addition, drier site conditions coupled with ungulate effects (grazing, browsing, hoof
8804 damage) may increase bare ground along with associated increases in surface soil erosion (Washington-
8805 Allen et al. 2010). Low-elevation grasslands may shift in dominance towards more drought tolerant
8806 species. Some model output, such as MC2 (Bachelet et al. 2001) suggests that cool season (C3)
8807 grasslands will decline and that warm season (C4) grasslands will expand based solely on temperature
8808 trends. However, research indicates that elevated CO_2 favors C3 grasses and enhances biomass
8809 production, whereas warming favors C4 grasses due to increased water use efficiency (Morgan et al.
8810 2004a, 2007). Although C3 grasses dominate Western montane grasslands, a warmer and drier climate
8811 may allow C4 grasses (primarily northern Great Plains species) to expand westward into montane
8812 grasslands. In general, it is likely that with increased warming and more frequent fires, grasslands will
8813 become a more dominant landscape component as shrublands and lower montane conifer forests are
8814 burned more frequently and unable to regenerate. Increasing fire would also encourage more invasive
8815 species in grasslands (Bradley 2008; D'Antonio and Vitousek 1992).

8816 *Risk Assessment*

8817 Magnitude of effects: High

Likelihood of effects: High

Communities Dominated by Montane Shrubs

Montane shrubs are typically associated with montane and subalpine forests, and occur as large patches within forested landscapes. Species such as Rocky Mountain maple *(Acer glabrum*), oceanspray *(Holidiscus discolor*), tobacco brush *(Ceanothus velutintis var. velutinus),* Sitka alder (*Alnus viridus* subsp. *sinuata)*, thimbleberry *(Rubus parviflorus)*, chokecherry *(Prunus virginiana)*, serviceberry (*Amelanchier alnifoli*a), currant *(Ribes* spp.), snowberry (*Symphoricarpos albus*), Scouler willow (*Salix scouleriana)*, and mountain ash (*Sorbus scopulina)* are common.

Montane shrubs persist on sites where regular disturbance kills the top of plants. This, along with full sunlight and adequate soil moisture, stimulates regrowth from the root crown, rhizomes and roots. Stressors include fire exclusion and conifer establishment, browsing by both native and domestic wildlife, and insects and disease. Loss of topsoil following frequent, hot fires, can lead to loss of these species over time (Larsen 1925; Wellner 1970). Mesic shrubs are well adapted to frequent fire, and under the right conditions can expand and outcompete regenerating conifers. However, with declining snowpack and warmer temperatures, fires may be hotter and sites may be drier, causing variable amounts of mortality, depending on site conditions.

Mesic shrubs are well adapted to frequent fire (Smith and Fisher 1997) and sprout vigorously following fire enabling them to quickly regain dominance on the site. As sites become drier and fires become more frequent and severe, however, there may be a shift away from mesic species to more xeric specie such as rubber rabbitbrush (*Ericameria nauseosa*), green rabbitbrush (*Chrysothamnus viscidiflorus*), and spineless horsebrush (*Tetradymia canescens)*. Nonnative invasive plant species may also expand into these communities, particularly following fire (Bradley 2008; D'Antonio and Vitousek 1992). With warmer temperatures and drier soils, some mesic shrub species (e.g., Sitka alder and Rocky Mountain maple) may shift their distribution up in elevation or to cooler, moister sites (e.g., northeast facing depressions).

Risk Assessment

Magnitude of effects: Moderate

Likelihood of effects: High

Communities Dominated by Short Sagebrushes (Black and Low Sagebrush)

The current distribution of low sagebrush ecosystems in the Northern Rockies is restricted to about one percent of the total sagebrush habitat as indicated in the LANDFIRE existing vegetation type (EVT) database. The western portion of the Northern Rockies contains 50 percent of the low sagebrush habitat, but limited patches are also found in the Eastern Rockies subregion and in the Greater Yellowstone Area subregion, especially on the western edge. Most of these sites support low sagebrush but not black sagebrush. Low sagebrush sites are characterized as relatively low production areas over shallow, claypan soils that restrict drainage and root growth. Low sagebrush is found on altitudinal gradients from 2,300 to more than 11,500 ft (Beetle and Johnson 1982), and it is generally found between 6000 to 9000 ft in Montana and Idaho. In contrast, black sagebrush is considerably more restricted in ecological amplitude and is found on shallow, dry, infertile soils. Current stressors are predominantly improper use by livestock and invasion by nonnative species.

Despite growing across large altitudinal gradients, low and black sagebrush exhibit a relatively more limited distribution than other sagebrush systems. Thus, it is reasonable to assume that as climates change, ranges could be further restricted, resulting in small islands being isolated, although this is more likely for black sagebrush because of its poor competitive ability (West and Mooney 1972). Both species depend heavily on seeding for reproduction (Wright et al. 1979) and recovery from disturbance. In addition, several traits make low sagebrush sensitive to climate change. There is high mortality in the first year of growth (Shaw and Monsen 1990). Establishment is probably greatest when a thin layer of soil covers the seeds, and if erosion increases from drought-induced reductions of plant cover, the already thin soils may not provide suitable seedbeds for germination. Seed development and establishment is best in years with ample precipitation, and if unfavorable conditions for seeding persist following disturbance, it is reasonable to assume that low sagebrush may disappear from some stands, especially if annual grass invasion occurs concomitantly with unfavorable growth conditions.

Climate change will result in shifts in the distribution of conditions suitable to support low sagebrush and hence the spatial configuration of low sagebrush habitats. Both low and black sagebrush are intolerant of fire and do not resprout. Therefore, increased fire activity will have negative consequences for both species. Fire return intervals vary considerably among communities dominated by low sagebrush. Estimates of fire-return intervals for xeric sagebrush communities of the Great Basin range from 35 to over 100 years (Brown 2000; Riegel et al. 2006), but intervals of 100 to 200 years for low-productivity black sagebrush communities have been reported. Especially for black sagebrush, which usually occupies quite unproductive sites with small buildup of fuels, these fire return intervals may be overestimated (Baker 2013). Within the boundaries and on the periphery of the Greater Yellowstone Area subregion, MC2 results indicate that the proportion of landscape burned will increase substantially in the future (fig. 7.5), allowing a higher likelihood of ignition and flaming fronts to reach some low sage communities. The extent to which these sites will carry fire depends on herbaceous production and probably on magnitude of invasion by annual grasses (especially cheatgrass). In summary, climate change may influence low sagebrush systems by reducing seedling establishment in unfavorable years. In addition, projected increased fire activity will decrease the abundance of low sagebrush relative to other species, especially if nonnative annual grasses, such as medusahead (*Taeniatherum caput-medusae*) and cheatgrass, become more prevalent.

Relative to other sagebrush species, low and black sagebrush have limited adaptive capacity. Black sagebrush hybridizes with silver sagebrush, and sprouting is thought to be a heritable trait in crosses between non-sprouting and sprouting sagebrushes (McArthur 1994). However, in the Northern Rockies, it is unlikely that silver sagebrush will exhibit a significant presence in areas that support low sagebrush, since the distribution of these species is usually disjunctive so the possibility of inheriting sprouting traits is unlikely. In addition, the relatively low productivity characterizing low sagebrush sites may also limit adaptive capacity, especially if other risk factors are present.

Risk Assessment

Magnitude of effects: High. The resiliency of many of these areas is low given the thin and argillic soil properties characterizing these sites. The magnitude of effects will likely increase if other perturbations such as improper recreational or grazing schemes are present. The low adaptive capacity of this sagebrush type, intolerance of fires, and low rate of reproduction act in concert to increase the magnitude of effects.

Likelihood of effects: Moderate to high. Models suggest increased production at higher elevations (Reeves et al. 2014), increasing the likelihood of fires carrying through otherwise relatively unburnable landscapes. The problem of increased flammability will increase, especially if invasive annual grasses exhibit a significant presence on low sagebrush sites in the future.

Shrublands Dominated by Sprouting Sagebrush Species (Threetip and Silver Sagebrush)

Significant areas of threetip and silver sagebrush shrublands have been converted to agricultural lands. Those that remain are often used for domestic livestock grazing because of the palatable herbaceous undergrowth in this sagebrush type. Those that have had chronic improper grazing typically have a large amount of bare ground, low vigor of native herbaceous species, and as a result, nonnative plant species present in varying amounts. Prolonged improper livestock grazing, native ungulate herbivory, and nonnative invasive plants are the primary stressors. Loss of topsoil can occur if vegetation cover and density declines and bare ground increases, primarily caused by ungulate impacts (e.g., grazing and mechanical/hoof damage) (Sheatch and Carlson 1998; Washington-Allen et al. 2010).

Both species can sprout from the root crown following top kill (primarily from fire) (Bunting et al. 1987) but this trait depends on site conditions and fire severity. Silver sagebrush is a vigorous sprouter (Rupp et al. 1997), whereas threetip sagebrush is less successful as a sprouter, and its response varies based on site characteristics (Akinsoji 1988; Bunting et al. 1987). Both species occur on mesic sites; threetip sagebrush is often associated with mountain big sagebrush communities, and silver sagebrush typically occupies moist riparian benches or moist toe slopes. Although these species will sprout, increased fire frequency and severity (particularly in threetip communities) may cause a shift in community composition to dominance by fire-adapted herbaceous species or nonnative species. Other

fire-adapted shrub species (e.g., rubber rabbitbrush, green rabbitbrush, spineless horsebrush) may increase, particularly following fire. In addition, more spring and winter precipitation may facilitate exotic annual grasses to establish and set seed earlier than the native perennial grasses, particularly in lower-elevation communities (Bradley 2008; D'Antonio and Vitousek 1992). This creates an uncharacteristic, continuous fine fuel load that can burn by late spring/early summer, burning sagebrush and native grasses often before they have matured and set seed (Chambers and Pellant 2008). Other nonnative invasive species (e.g., spotted knapweed, Dalmatian toadflax, butter-and-eggs, sulphur cinquefoil) respond favorably after fire, and if present, will increase in cover and density.

Historical fire return intervals for both species are relatively short and research shows that threetip sagebrush cover can return to preburn levels 30-40 years after fire (Barrington et al. 1988; Neuenschwander, n.d.). Lesica et al. (2007) found that after a fire in southwest Montana, threetip sagebrush cover did not increase (presumably from resprouting), but instead established from seed. These generalizations will vary considerably depending on site conditions and postfire management. All three subspecies of silver sagebrush sprout after fire, and along with threetip, also typically occur on more mesic sites. With a warmer and drier climate, frequent, high severity burns may not only cause initial mortality, but sites may not be as favorable for postfire vegetation regeneration (from sprouting, regrowth, or from seed). Invasive species will likely either expand into these communities after fire or increase in abundance in altered conditions that are less favorable to the native plant community.

Understory composition in both communities may possibly shift to more xeric grassland species (e.g., bluebunch wheatgrass, needle-and-thread), which are more adapted to warmer and drier conditions. Both of these sagebrush species may shift landscape position to sites with more moisture and cooler temperature (e.g., higher elevation, lower landscape position, and northeast aspects).

Risk Assessment

Magnitude of effects: Moderate

Likelihood of effects: High

Communities Dominated by Wyoming Big Sagebrush and Basin Big Sagebrush

The current distribution of Wyoming big sagebrush ecosystems in the Northern Region is generally patchy throughout most of Montana with more spatially consistent cover in the Eastern Rockies and Grassland subregions (Comer et al. 2002). As previously mentioned, the distribution of basin big sagebrush habitats is generally restricted to deeper soils, often including alluvial fans. Stressors to both Wyoming and basin big sagebrush communities include prolonged improper livestock grazing, native ungulate herbivory, and nonnative invasive plants. Loss of topsoil can occur if vegetation cover and density decline and bare ground increases, primarily caused by ungulate impacts (e.g., grazing and mechanical/hoof damage). Compared with mountain and basin big sagebrush habitats, Wyoming big sagebrush is habitats spatially coincide with oil and gas development, which is prominent on the eastern edge of its distribution. The Grassland and Greater Yellowstone Area subregions contain the largest extent of big sagebrush, although the Western Rockies subregion may contain the largest amount of basin big sagebrush.

Big sagebrush ecosystems have decreased in spatial extent in the 20th century (Bradley 2010; Knick et al. 2003; Manier et al. 2013; Noss et al. 1995) because of oil and gas development leading to habitat destruction and fragmentation (Doherty et al. 2008; Walston et al. 2009), big sagebrush removal to increase livestock forage (Shane et al. 1983), plant pathogens and insect pests (Haws et al. 1990; Nelson et al. 1990), improper grazing (Davies et al. 2011), invasive species (D'Antonio and Vitousek 1992, Davies 2011), and changes in disturbance regimes (Baker 2011; Balch et al. 2013). Oil and gas development, along with urbanization and land conversion for agriculture and livestock grazing, not only lead to habitat loss, but to fragmented habitat patches (Naugle et al. 2011), resulting in barriers to plant dispersal, greater sage-grouse avoidance, and loss of obligate and facultative wildlife species (Rowland et al. 2006). In addition to habitat destruction of big sagebrush ecosystems, several stressors can cause big sagebrush dieback and reduce its biomass and density, including insect pests (Haws et al. 1990), plant pathogens (Cárdenas et al. 1997; Nelson et al. 1990), and frost damage (Hanson et al. 1982). Improper use by domestic livestock alters the structure and composition of big sagebrush ecosystems through the loss of palatable components of the plant community (i.e., perennial grasses and forbs), along with reducing or

8973 increasing big sagebrush cover (Anderson and Holte 1981; Brotherson and Brotherson 1981), and
8974 increasing the probability of nonnative annual grass invasion (Cooper et al. 2007; Davies et al. 2011;
8975 Knapp et al. 1996). Cheatgrass has reduced the spatial distribution and habitat quality of sagebrush
8976 ecosystems throughout much of the western United States (Balch et al. 2013; Brooks et al. 2004).
8977 Cheatgrass invasion poses a continued and heightened threat to big sagebrush ecosystems in the
8978 future, because its biomass production and fire frequency are projected to increase in response to rising
8979 temperature and CO_2 levels (Westerling et al. 2006; Ziska et al. 2005). Although less studied, field brome
8980 (*Bromus arvensis*) can also negatively affect big sagebrush plant communities, because it can colonize
8981 readily after stand-replacing fires that eliminate big sagebrush (Cooper et al. 2007).
8982 Several life history traits of big sagebrush make it sensitive to direct and indirect effects of climate
8983 change. Amount and timing of precipitation control seeding establishment at low elevation, whereas
8984 minimum temperature and snow depth control germination and survival at high elevations (Nelson et al.
8985 2014; Poore et al. 2009, reviewed by Schlaepfer et al. 2014a). Drought events are projected to increase in
8986 the western United States in the future (IPCC 2014), although the likelihood of increased drought in the
8987 Northern Rockies is uncertain (see chapter 3). Thus, big sagebrush ecosystems remain vulnerable to
8988 drought, which may affect germination and survival of seedlings, because soil water content primarily
8989 controls seedling survival (Schlaepfer et al. 2014a). Big sagebrush seedling survival may be highest in
8990 intermediate temperature and precipitation regimes (Schlaepfer et al. 2014b). Even after seedling
8991 establishment, drought and increased summer temperature can affect survival and growth of adult plants,
8992 because growth is positively correlated with winter precipitation and winter snow depth (Poore et al.
8993 2009). As a result, if drought events increase in frequency and severity in the Northern Rockies, big
8994 sagebrush biomass and the abundance and diversity of perennial grasses and forbs may decrease.
8995 It is uncertain if big sagebrush can move in concert with shifting temperature and precipitation
8996 regimes and disperse to available habitat patches and colonize them. Most big sagebrush seeds (50-60
8997 percent) are not viable in the seedbank after two years, with few viable seed in the upper soil (Wijayratne
8998 and Pyke 2009, 2012). Furthermore, big sagebrush is a poor disperser (Schlaepfer et al. 2014a; Young et

8999 al. 1989) and seed production is episodic (Young et al. 1989). Even if big sagebrush seeds successfully
9000 disperse and germinate in response to a changing climate, probabilities of seedling establishment and
9001 adult survivorship are uncertain, because big sagebrush is a poor competitor relative to associated
9002 herbaceous species (Schlaepfer et al. 2014a).

9003 Big sagebrush is sensitive to fire and cannot resprout (Shultz 2006), and because recovery from seed
9004 dispersal can take 50-150 years (Baker 2006, 2011), postfire recovery may become a problem in the
9005 future, if the frequency and intensity of fires increase as projected (Abatzoglou and Kolden 2011;
9006 Westerling et al. 2006). Regeneration of big sagebrush postfire is strongly linked to winter precipitation
9007 (Nelson et al. 2014), which is expected to increase by 10-20 percent in the Northern Rockies by 2100
9008 (IPCC 2014; Shafer et al. 2014). Although more frequent fire may result in larger losses of big sagebrush
9009 habitat in the future, recovery of big sagebrush may be less impeded. It is also possible that much of this
9010 increased precipitation will come as rainfall (Klos et al. 2014), which could, in turn, promote herbaceous
9011 growth which might suppress sagebrush recovery in some instances.

9012 Climate change will result in shifts in the distribution of conditions suitable to support big sagebrush
9013 and hence the spatial configuration of big sagebrush habitat, with direct and indirect effects on sagebrush-
9014 dependent species (e.g., greater sage-grouse). Several studies using species distribution modeling (SDM)
9015 have projected that big sagebrush will move northward and up in elevation in response to increased winter
9016 temperatures and summer drought associated with climate change (Schlaepfer et al. 2012; Shafer et al.
9017 2001). Although big sagebrush may expand northward and upslope, its habitat is predicted to contract
9018 significantly due to increased soil moisture stress, primarily at southern latitudes and lower elevations
9019 (fig. 7.6).

9020 The probability of big sagebrush regeneration has been projected to increase at the leading edge of its
9021 range (i.e., northern range limit) under future climate conditions, suggesting potential northward range
9022 expansion with climate change (Schlaepfer et al. in review). This is in part due to changes in habitat
9023 suitability, because soil water conditions at the leading edge will be similar to current soil water patterns
9024 in big sagebrush systems. Habitat suitability for big sagebrush is predicted to increase primarily in

9025 northeast and north-central Montana (Schlaepfer et al. in review; Schrag et al. 2011) (fig. 7.6). In contrast,
9026 habitat suitability is predicted to decrease in parts of the Western and northwest Greater Yellowstone
9027 Area subregions (fig. 7.6), primarily from summer drought (Schlaepfer et al. 2012; Schlaepfer et al. in
9028 review). However, expansion of big sagebrush out of unsuitable habitat and into suitable habitat is
9029 contingent on its ability to disperse to available habitat patches and compete with other species.
9030 In addition to changes in big sagebrush distribution, shifts in community composition and
9031 productivity are expected with climate change. Since there is uncertainty about length and severity of
9032 drought events in the future, the projected shifts in community composition and productivity in big
9033 sagebrush ecosystems in response to climate change remain uncertain. If drought events do increase in the
9034 Northern Rockies, native herbaceous plant diversity and cover may be reduced. In contrast, in non-
9035 drought years, warming temperatures and increased levels of CO_2 may lead to increased biomass
9036 production (Reeves et al. 2014), more frequent fires, and increases in herbaceous biomass at the expense
9037 of fire-intolerant shrubs, such as big sagebrush.
9038 Paleoecological studies have shown that species move individualistically and at different rates in
9039 response to climate change, resulting in novel combinations of species (Delcourt and Delcourt 1981).
9040 Even species in the same functional group (e.g., grasses) may respond differentially to climatic change
9041 (Anderson and Inouye 2001). Thus, big sagebrush plant communities are unlikely to migrate as a unit in
9042 response to altered temperature and precipitation. The response of individual species to climate change
9043 will depend on both physiological tolerances and competitive ability.
9044 Shifts in disturbance regimes (e.g., fire, insects, pathogens) associated with climate change may affect
9045 big sagebrush ecosystems in the future. Disturbances affect vegetation directly by killing individuals and
9046 removing aboveground biomass, and indirectly by altering soil conditions. Climate change and
9047 disturbance may have additive effects on soil water balance in big sagebrush ecosystems, decreasing soil
9048 water content (Bradford et al. 2014) and resulting in diminished growth and regeneration (Poore et al.
9049 2009). Since big sagebrush is incapable of resprouting after disturbance (Shultz 2006), increased
9050 disturbance frequency could reduce the spatial extent of big sagebrush in the future, despite increased

habitat suitability and regeneration potential. As with other vegetation types, there is great uncertainty and variability regarding estimates of fire return intervals of stands dominated by big sagebrush. For example, in the Northern Rockies, Lesica et al. (2007) suggest that fire return intervals for Wyoming big sagebrush are longer than for basin big sagebrush and mountain big sagebrush, and range from 50 to 150 years while (Baker 2011, 2013; Bukowski and Baker 2013) estimate ranges of 200 to about 350 years.

The long fire return intervals to which Wyoming big sagebrush is adapted are related to its very slow postfire recovery, as low as two percent recovery 23 years after fire (Lesica et al. 2007). The slow recovery of these systems is partly due to slow growth rates and harsher environmental conditions in many sites in the Northern Rockies. In contrast, basin big sagebrush canopy cover development and growth are faster than for Wyoming big sagebrush (Booth et al. 1990; Lesica et al. 2007; McArthur and Welch 1982). Invasive annual grasses such as cheatgrass may exacerbate slow growth.

Big sagebrush ecosystems have some capacity to adapt to climate change. Big sagebrush occurs over a large geographic area with high diversity in topography, soils, and climate, suggesting that it can withstand a relatively broad range of ecological conditions and may tolerate shifting climates. Various subspecies of big sagebrush often hybridize and have a high level of polyploidy, providing it with the capacity to undergo selection and adapt to shifting climatic regimes relatively quickly (e.g., Poore et al. 2009).

Although lower soil water availability may pose a threat to big sagebrush ecosystems, long periods of sustained drought would be needed to cause mortality (Kolb and Sperry 1999). In addition, big sagebrush habitat suitability is projected to change across space (e.g., decreasing suitability in northwest Wyoming and across much of western Montana), big sagebrush may still persist in relatively "unsuitable" habitat for some time, perhaps in a degraded state.

Risk Assessment

Magnitude of effects: Highly variable. In northwestern Wyoming and western Montana, the effects of climate change will likely be low to moderate, because lower water availability may cause declines in big sagebrush growth and regeneration, facilitating some habitat contraction. However, big sagebrush may

9077 expand northward into northern and eastern Montana, as habitat suitability increases in future decades.
9078 Despite this generalization, it is also possible that an increase in fire activity will decrease the extent of
9079 big sagebrush communities in many locations.

9080 Likelihood of effects: Variable. Some contraction in big sagebrush habitat may occur in northwest
9081 Wyoming and western Montana, particularly at lower elevations because of increased temperature and
9082 evapotranspiration. However, if big sagebrush can successfully exploit changing climatic conditions, the
9083 total area covered by big sagebrush in the Northern Rockies may increase by the end of the 21st century.
9084 Potential expansion may be tempered by faster rates of loss if the cheatgrass-fire cycle tracks new habitats
9085 in the northeastern part of region. It is conceivable that drier sites, such as those with sandy soils, may
9086 lose the ability to regenerate sagebrush, whereas more mesic sites might still be able to regenerate.

9087 **Mountain Big Sagebrush Shrublands**

9088 Some areas of mountain big sagebrush shrublands have been converted to agricultural lands, and
9089 those that remain are used for domestic livestock grazing, primarily because of the palatable herbaceous
9090 undergrowth. Those that have had chronic improper grazing typically have high bare ground, low vigor of
9091 native herbaceous species, and as a result, have nonnative plant species present in varying amounts.
9092 Prolonged improper livestock grazing, native ungulate herbivory, and invasive nonnative plants are the
9093 primary stressors. Loss of topsoil can occur if vegetation cover and density decline and bare ground
9094 increases, primarily caused by ungulate impacts (e.g., grazing and mechanical/hoof damage). In addition,
9095 lack of fire is also a chronic stressor, facilitating conifer establishment which increases in density and
9096 cover over time (Arno and Gruell 1986; Heyerdahl et al. 2006), while grass cover declines (Arno and
9097 Gruell 1983).

9098 Mountain big sagebrush is killed by fire. With increased fire severity and frequency, there will be a
9099 shift in community composition to dominance by fire-adapted shrub and herbaceous species and possibly
9100 nonnatives. Fire-adapted shrub species (e.g., rubber rabbitbrush, green rabbitbrush, white horsebrush)
9101 may increase in abundance following fire (Fischer and Clayton 1983; Smith and Fischer 1997). In
9102 addition, more spring and winter precipitation may facilitate nonnative annual grasses (particularly

cheatgrass which germinates in winter/early spring)) establishment, although this is less likely in cooler, moister mountain big sagebrush communities compared to lower elevation Wyoming and basin big sagebrush communities. However, with a warmer, drier climate, the conditions may be conducive to cheatgrass establishment. An abundance of cheatgrass creates an uncharacteristic, continuous fine fuel load that can burn by late spring/early summer, burning sagebrush and native perennial grasses often before they have matured and set seed (Chambers et al. 2007; Pellant 1990; Whisenant 1990), especially in the Great Basin. However, other research in the northern edge of the Great Basin indicates that some sagebrush communities may be less susceptible to cheatgrass invasion following fire, at least under the current climate (Lavin et al. 2013; Seefeldt et al. 2007). Other nonnative species (e.g., spotted knapweed, Dalmatian toadflax, butter-and-eggs, sulphur cinquefoil) respond favorably after fire and if present, will increase in cover and density.

Historically, the fire return intervals were relatively short but variable—a few decades (Lesica 2007) to more than 100 years (Baker 2013)—compared to Wyoming big sagebrush (more than 100 years) (Heyerdahl et al. 2006; Lesica et al. 2005, 2007). Mountain big sagebrush regenerates from seeds shed from nearby unburned plants. It will fully recover between 15-40 years after fire (Bunting et al. 1987), depending on site characteristics and fire severity. In a warmer and drier climate, frequent, high-severity burns (facilitated by cheatgrass) may not cause initial mortality and create unfavorable conditions for postfire regeneration (from sprouting, regrowth, or seed). Since there is no viable sagebrush seed bank, if fires burn large areas and there are no live, seed-bearing sagebrush nearby, there may be a type conversion to grassland. In addition, invasive, nonnative species will likely either expand into these areas after fire, or they will increase in abundance due to altered conditions that no longer favor the native plant community (Bradley 2008; D'Antonio and Vitousek 1992).

Mountain big sagebrush is not fire adapted, and may decline in cover and density or becomes extirpated in response to warmer temperatures and increased fire frequency and severity. Over time, especially if fine fuels such as senesced cheatgrass are present, more frequent fires may eliminate mountain big sagebrush from a community (Chambers and Pellant 2008; D'Antonio and Vitousek 1992;

Whisenant 1990). However, because mountain big sagebrush occurs at higher elevations, typically on more productive cooler, mesic sites, these communities are typically less invaded by nonnative species. However, if these sites become warmer and drier, herbaceous understory composition could shift to more xeric species that are better adapted, and bareground may increase (Chambers et al. 2014). As a result, invasive species, particularly cheatgrass, could expand into and establish dominance in these altered communities.

It is possible that mountain big sagebrush distribution may shift to cooler and moister sites (e.g., higher elevation, northeast-facing snow-filled depressions). With climate change, it may be able to persist only in sites with higher moisture and deeper soils than the surrounding landscape. Understory composition may shift to more xeric grassland species (e.g., bluebunch wheatgrass, needle-and-thread), which are more tolerant of warmer, drier conditions.

Risk Assessment

Magnitude of effects: Moderate

Likelihood of effects: Moderate

Northern Great Plains, Dominated by Mixtures of Cool-Season and Warm-Season Grasses

Eastern grasslands are expansive across the northern Great Plains extending from the foothill grasslands along the east slope of the northern and central Rocky Mountains in Montana to the Red River basin in eastern North Dakota. Annual precipitation increases from west to east changing from dry temperate steppe to humid temperate prairie parkland provinces along this gradient (ECOMAP 2007). Grasslands are the predominant potential vegetation type, occupying approximately 80 percent of the northern Great Plains landscape. Küchler (1975) divides the potential natural vegetation of this area into shortgrass prairie, northern mixed grass prairie, and tallgrass prairie, reflecting the changing precipitation regime. The shortgrass prairie borders the foothills grassland and extends to eastern Montana. The typical grassland vegetation types are characterized by grama (*Bouteloua* sp.)/needlegrass/wheatgrass and a mix of C3 and C4 plant species. The northern mixed grass prairie borders the shortgrass prairie in eastern Montana and extends to eastern North Dakota. Typical grassland vegetation types are characterized by

wheatgrass/needlegrass in the west and wheatgrass/bluestem (*Andropogon* sp.)/needlegrass to the east, including a mix of C3 and C4 plant species. The tallgrass prairie borders the northern mixed grass prairie in eastern North Dakota and South Dakota and borders the eastern hardwood forest to the east. The typical grassland vegetation types are characterized by bluestem and a dominance of C4 grasses, although C3 grass species are present.

Frequent fire was a major factor in maintaining grassland dominance, particularly in the eastern Great Plains. Settlement in the late 19th and early 20th centuries altered fire regimes by reducing fire frequency and changing the seasonality of fire. The predominant land use and land cover changed from grasslands to crop agriculture and domestic livestock production, affecting the continuity of fuels and fire spread. Reduced fire coupled with increased CO_2 has encouraged woody plant encroachment, primarily in the eastern Great Plains (Morgan et al. 2008).

Other stressors include increased presence and abundance of competitive invasive grass and forb species. These species reduce plant diversity of native grasslands and alter grassland structure. Noxious weeds such as leafy spurge (*Euphorbia esula*) are abundant in places, and other invasive nonnative species include Kentucky bluegrass (*Poa pratensis*), Japanese brome, and cheatgrass. Additionally, energy development and the associated infrastructure fragments grassland patterns where it occurs locally. Roads and traffic increase opportunities for introduction and spread of invasive species.

Soil water availability and water stress are principal driving factors in semi-arid grasslands, influencing plant species distribution, plant community composition and structure, productivity, and associated social and economic systems of the northern Great Plains. Soil water availability is influenced by complex interactions among temperature, precipitation, topography, soil properties, and ambient CO_2 (Ghannoum 2009; Morgan et al. 2011). These physical factors interacting with plant species physiological mechanisms, particularly those of C3 and C4 plants, will influence how grasslands will respond to climate change and elevated atmospheric CO_2 levels (Bachman et al. 2010; Chen et al. 1996; Ghannoum 2009; Morgan et al. 2011).

Available soil water is unevenly distributed across landscapes and a function of landform, topography, and soil properties. Soil moisture loss through evapotranspiration is influenced by slope, aspect, and solar loading at the ground surface, and water holding capacity is influenced by soil properties. These characteristics in the northern plains may modify the effects of climate change and enhanced CO_2 locally. Landscape patterns of available soil water may result in uneven patterns of vegetation change and productivity under changing temperature and moisture regimes and elevated CO_2 levels. The desiccating effect of higher temperature and increased evaporative demand (Morgan et al. 2011) is expected to offset the benefit of higher precipitation, resulting in lower soil water content and increased drought throughout most of the Great Plains (Morgan et al. 2008). Elevated CO_2 may counter the effects of higher temperatures and evaporative demand by improving water-use efficiency of plants (Morgan et al. 2011).

Rising CO_2 and temperature combined with increased winter precipitation may favor some herbaceous forbs, legumes, and woody plants (Morgan et al. 2008). Plant productivity is expected to increase with projected changes in temperature and moisture combined with elevated CO_2 (Morgan et al. 2008). Forage quality may decline as a result of less available forms of soil nitrogen and changes in plant species and functional groups (Morgan et al. 2008). A major shift in functional groups from C3 to C4 plants is possible but uncertain, because warmer temperature and longer growing seasons favor C4 grasses, but the effects of higher CO_2 on water-use efficiency may benefit C3 grasses. Since most invasive species are C3 plants, they may become more problematic with the benefits of increased CO_2 (Morgan et al. 2008).

The adaptive capacity of Great Plains grasslands during the 1930s and 1950s drought was documented for the central plains (Weaver 1968). There was a shift in C4 grasses, in which big bluestem (*Andropogon gerardii*) and little bluestem (*Schizachyrium scoparium*) were replaced by the shortgrass species blue grama (*Bouteloua gracili*) and buffalograss (*Bouteloua dactyloides*). Shifts from tallgrass prairie to mixed grass prairie were also documented with an increase in the C3 plants western wheatgrass and needlegrass. This shift was later reversed during the higher precipitation period of the 1940s,

indicating an adaptive capacity of Great Plains grasslands to the effects of long-term drought. These shifts were also affected by grazing condition of the grasslands prior to the drought.

Risk Assessment—

Magnitude of effects: Moderate magnitude for change from temperate grassland to sub-tropical grassland by 2050 under no fire suppression. Change toward increased woody vegetation by 2050 with fire suppression. High magnitude for change from temperate grassland to sub-tropical grassland by 2100. Moderate magnitude for change towards woody vegetation by 2100.

Likelihood of effects: Moderate likelihood for a change from temperate grassland to sub-tropical grassland by 2050 under no fire suppression; change toward increased woody vegetation by 2050 with fire suppression. The response of C3 and C4 species to the combined effects of higher temperature and elevated CO_2 is uncertain.

ADAPTING RANGELAND VEGETATION MANAGEMENT TO CLIMATE CHANGE IN THE NORTHERN ROCKIES

Rangeland vegetation in the northern Rockies will likely be affected by changing fire regimes, increased drought, and increased establishment of invasive species in a changing climate. Effects of climate change will also compound existing stressors on rangeland ecosystems caused by human activities. Thus, adaptation strategies and tactics for rangeland vegetation focused on increasing the resilience of rangeland ecosystems, primarily through invasive species control and prevention (table 7.3).

To control invasive species in rangelands, managers stressed the importance of using ecologically based invasive plant management (EBIPM) (Krueger-Mangold et al. 2006; Sheley et al. 2006). The EBIPM framework focuses on strategies to repair damaged ecological processes that facilitate invasion (James et al. 2010). For example, prescribed fire treatments can be used where fire regimes have been altered, and seeding of desired natives can be done where seed availability and dispersal of natives is low.

Another adaptation strategy is to increase proactive management actions to prevent establishment of invasive species. Early detection, rapid response (EDRR) for new invasions was the most frequently suggested tactic to prevent invasive species establishment. Other tactics include implementing weed free

policies, conducting outreach to educate employees and the public about invasives (e.g., teach people to clean their boots), and developing weed management areas that are collaboratively managed by multiple agencies, non-governmental organizations, and the public.

In addition to invasive species control and prevention, grazing management will be important in maintaining and increasing resilience of rangelands to climate change. Climate changes will lead to altered availability of forage, requiring some reconsideration of grazing strategies. For example, reducing grazing in July and August may encourage growth of desired perennials in degraded systems. Livestock grazing can also be managed through the development of site-specific within-season triggers and end point indicators that would inform livestock movement guides and allow for the maintenance and enhancement of plant health.

A changing climate has led to a decline of pollinators in some communities (Potts and others 2010) and may lead to phenological mismatches between pollinators and host plants (Forrest 2015). Pollinator declines may negatively affect the health of grasslands in the Northern Rockies, and encouraging native pollinators may be key to sustaining these ecosystems. Tools to promote native pollinators include re-vegetation with native species, appropriate herbicide and insecticide use, and education. Implementing long term monitoring of pollinators can help to identify where treatments can be prioritized.

In montane shrublands, existing stressors include fire exclusion and conifer establishment, browsing by both native and domestic ungulates, and insects and disease. Characteristic species can be lost in these systems with loss of topsoil following frequent, hot fires. Warmer temperatures and drier conditions with climate change may lead to an increase in high-severity fires. Adaptation tactics include implementing fuel reduction projects such as brush cutting, slashing, mastication and targeted browsing, and reestablishing appropriate fire regimes may prove beneficial in maintaining these shrublands and increasing their resiliency. To control invasives, EDRR and EBIPM can be applied, along with maintenance of adequate shrub cover, vigor, and species richness. Educating specialists on ecology and disturbances affecting shrublands, effects of repeated burns, reforestation needs, and reporting on weeds will also help to maintain these systems.

More specific details on adaptation strategies and tactics for the NRAP subregions are in Appendix 7A.

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Chapter 8: Effects of Climate Change on Ecological Disturbance

Rachel A. Loehman, Barbara J. Bentz, Gregg A. DeNitto, Robert E. Keane, Mary E. Manning, Jacob P. Duncan, Joel M. Egan, Marcus B. Jackson, Sandra Kegley, I. Blakey Lockman, Dean E. Pearson, James A. Powell, Steve Shelly, Brytten E. Steed, and Paul J. Zambino

INTRODUCTION

This chapter describes the ecology of important disturbance regimes in the region encompassed by the Northern Rockies Adaptation Partnership, and potential shifts in these regimes as a consequence of observed and projected climate change. The term *disturbance regime* describes the general temporal and spatial characteristics of a *disturbance agent*—insect, disease, fire, weather, even human activity—and the effects of that agent on the landscape (table 8.1). More specifically, a disturbance regime is the cumulative effect of multiple disturbance events over space and time (Keane 2013). Disturbances disrupt an ecosystem, community, or population structure and change elements of the biological and/or physical environment (White and Pickett 1985). The resulting shifting mosaic of diverse ecological patterns and structures in turn affects future patterns of disturbance, in a reciprocal, linked relationship that shapes the fundamental character of landscapes and ecosystems. Disturbance creates and maintains biological diversity in the form of shifting, heterogeneous mosaics of diverse communities and habitats across a landscape (McKinney 1998), and biodiversity is generally highest when disturbance is neither too rare nor too frequent on the landscape (Grime 1973).

A changing climate may already be altering characteristics of disturbance agents, events, and regimes, with additional effects expected in the future (Dale et al. 2001). Climate changes can alter the timing, magnitude, frequency, and duration of disturbance events, as well as the interactions of disturbances on a landscape. Interactions among disturbance regimes, such as the co-occurrence in space and time of bark beetle outbreaks and wildfires, can result in highly visible, rapidly occurring, and persistent changes in landscape composition and structure. Understanding how altered disturbance patterns and multiple

9728 disturbance interactions might result in novel and emergent landscape behaviors is critical for addressing
9729 climate change impacts and for designing land management strategies that are appropriate for future
9730 climates (Keane et al. 2015).

9731 We summarize five disturbance types present in the Northern Rockies that are sensitive to a changing
9732 climate. Wildfires, bark beetles, white pine blister rust (*Cronartium ribicola*), other forest diseases, and
9733 nonnative plant invasions acting individually or synergistically can transform landscape patterns and
9734 ecological functions. This chapter provides background that can help managers understand the important
9735 role of disturbances on Northern Rockies landscapes, and anticipate how, when, where, and why climate
9736 changes may alter the characteristics of disturbance regimes.

9737 **WILDFIRE**

9738 **Overview**

9739 Wildland fire is ubiquitous throughout forest ecosystems of the Northern Rockies and was historically
9740 the most important and extensive landscape disturbance in the region (Helj et al. 1995). Wildfire emerged
9741 as a dominant process in North America after the end of the last glacial period, about 16,500-13,000 years
9742 before present, commensurate with rapid climate changes and increased tree cover (Marlon et al. 2009).
9743 In the Northern Rockies, many forest types are fire prone and fire adapted, meaning that fire is an integral
9744 and predictable part of their maintenance and ecological functioning. Wildfire, as well as other
9745 disturbances such as insect outbreaks, disease, drought, invasive species, and storms, is part of the
9746 ecological history of most forest ecosystems, influencing vegetation age and structure, plant species
9747 composition, productivity, carbon (C) storage, water yield, nutrient retention, and wildlife habitat (Agee
9748 1993).

9749 Climate and fuels are the two most important factors controlling patterns of fire in forest ecosystems.
9750 Climate controls the frequency of weather conditions that promote fire, whereas the amount and
9751 arrangement of fuels influence fire intensity and spread. Climate influences fuels on longer time scales by
9752 shaping species composition and productivity (Dale et al. 2001; Marlon et al. 2008; Power et al. 2008)
9753 and large-scale climatic patterns such as the El Niño Southern Oscillation (ENSO) and Pacific Decadal

Oscillation (PDO) are important drivers of forest productivity and susceptibility to disturbance (Collins et al. 2006; Kitzberger et al. 2007). Current and past land use, including timber harvest, forest clearing, fire suppression, and fire exclusion through grazing have affected the amount and structure of fuels in the United States (Allen et al. 2002; Falk et al. 2011; Pausas and Keeley 2014).

Disturbance impacts can overwhelm the direct effects of climate changes on ecosystems. As described in other chapters in this publication, climate changes influence forests directly; for example, it has been suggested that drought and heat stress are linked to increased tree mortality, shifts in species distributions, and decreased productivity (Allen et al. 2010; Van Mantgem et al. 2009; Williams et al. 2013). However, the most visible and significant short-term effects of climate changes on forest ecosystems will be caused by altered disturbances, often occurring with increased frequency and severity. Climate changes are likely to increase fire frequency, fire season length, and cumulative area burned in the coming decades in the western United States, in response to warmer, drier conditions (Flannigan et al. 2006; McKenzie et al. 2004). Climate changes may also increase the frequency or magnitude of extreme weather events that affect fire behavior (Kurz et al. 2008; Lubchenco and Karl 2012). Although shifts in vegetation composition and distribution caused by climate alone may occur over decades or centuries, wildfires can temporarily or persistently reorganize landscapes over a period of days (Overpeck et al. 1990; Seidl et al. 2011).

The role of fire in ecosystems and its interactions with dominant vegetation is termed a fire regime (Agee 1993). Fire regimes are defined by fire frequency (mean number of fires per time period), extent, intensity (measure of the heat energy released), severity (net ecological effect), and seasonal timing (table 8.2). These characteristics vary across vegetation types and depend on the amount and configuration of live and dead fuel present at a site, environmental conditions that favor combustion, and ignition sources (Agee 1993; Krawchuk et al. 2009). Ecosystems in the Northern Rockies have been subject to a range of historical fire regimes, including (1) frequent (1-35 years), low- or mixed-severity fires that replaced less than 25 percent of the dominant overstory vegetation; (2) moderate-frequency (35-200 years), mixed-severity fires that replaced up to 75 percent of the overstory; and (3) infrequent (200+ years), high-

9780 severity fires that replaced greater than 75 percent of the dominant overstory vegetation (fig. 8.1). More
9781 detailed information on fire regimes specific to individual vegetation species and vegetation types can be
9782 found in chapter 6 of this volume.

9783 Wildland fire behavior is influenced by variability in environmental conditions including vegetation
9784 type and distribution, climate, weather, and topography. Despite major human influences on western U.S.
9785 wildfires since Euro-American settlement, climate is generally considered to be the primary control on
9786 fire regimes in the region, influencing vegetation production and condition as well as the physical
9787 environment (Marlon et al. 2012). Where rates of vegetation production outpace decomposition, sufficient
9788 biomass is available to support fires, although higher elevation regions with abundant fuels do not always
9789 experience sufficiently dry conditions to sustain a fire. In these systems short-duration drying episodes
9790 generally do not create sufficiently dry conditions to sustain a fire, but prolonged dry weather conditions
9791 (about 40 days without precipitation) can sufficiently dry live fuels and larger dead fuels to carry large,
9792 intense fires once they are ignited (Schoennagel et al. 2004). Wildland fuels lose moisture and become
9793 flammable in warm and dry summers typical in the Northern Rockies, during which time there are ample
9794 sources of ignition from lightning strikes and humans. Therefore, the active fire season (period conducive
9795 to active burning) is in the summer, typically from late June through October, with shorter seasons at
9796 higher elevation sites where snowpack can persist into July (Littell et al. 2009).

9797 At annual time scales, weather is the best predictor of fire characteristics such as area burned and fire
9798 size. Correlations between weather and annual area burned by fire or the number of large fires are similar
9799 for both pre-20th century fires and fires that have occurred during the past few decades. Fire-weather
9800 relationships exist for forested ecosystems of the Pacific Northwest (Hessl et al. 2004; Heyerdahl et al.
9801 2002, 2008a) and Northern Rockies (Heyerdahl et al. 2008b; Littell et al. 2009; Westerling et al. 2003,
9802 2006), constructed using tree-ring and fire-scar records and independently reconstructed climate, or
9803 observed fire events and observed weather occurring in the seasons leading up to and during the fire
9804 where records are available. Regionally, widespread fire years are correlated with drought (Heyerdahl et
9805 al. 2008b; Morgan et al. 2008), and these regionally synchronous fires have generally occurred in the

Northern Rockies (Idaho and western Montana) during years with relatively warm spring-summers and warm-dry summers (Heyerdahl et al. 2008a; Morgan et al. 2008).

In non-forested systems in the eastern Northern Rockies, precipitation amount, at both short (weeks to months) (Littell et al. 2009) and long (decades to centuries) (Brown et al. 2005) time scales is the dominant control on fire. During the fire season, the amount and timing of precipitation largely determine availability and combustibility of fine fuels, and short periods of dry weather are sufficient to precondition these systems to burn (Gedalof et al. 2005; Westerling and Swetnam 2003). In contrast to the grasslands of the southwestern United States, antecedent precipitation has not been found to be a significant driver of large fires in the northern grasslands; rather, large fires are most strongly correlated with low precipitation, high temperatures, and summer drought (July through September) in the year of the fire (Littell et al. 2009).

Humans are also important drivers of wildfire, via altered ignition patterns associated with land clearing and land cover change, agriculture, introduction of exotic species, and fire management (fuel treatments and fire suppression/exclusion). Grazing and the introduction of nonnative species have altered ecological processes that affect fire, including fuel loading and continuity, forest composition and structure, nutrient cycling, soils, and hydrology (Marlon et al. 2009; Swetnam et al. 1999). For many sagebrush ecosystems of low to moderate productivity, fire intervals are 10 to 20 times shorter today than what is estimated for pre-20th century conditions (Peters and Bunting 1994; Whisenant 1990; chapter 7), because of the spread and dominance of the nonnative annual cheatgrass (*Bromus tectorum*). Dry forests, shrublands, and grasslands in the region exist in a state of "fire deficit" as the result of fire exclusion, leading to less frequent wildfire, higher stand densities, higher fuel quantities, and higher fuel continuity. This has increased the potential for crown fires in forests that historically experienced low-severity fire regimes (Agee 1998; Peterson et al. 2005) and in some forests that experienced mixed-severity regimes (Taylor and Skinner 2003).

Wildfire Shapes Landscape Patterns

The composition and structure of forests in the Northern Rockies is determined by climate, elevation, topographic position, and history of fire. In general, fire regimes vary along environmental gradients, with fire frequency decreasing and fire severity increasing with elevation (although aspect and slope position can influence fire patterns). For example, low-severity fires are typical in many ponderosa pine (*Pinus ponderosa*) forests at low elevations. Historically, fires here burned frequently enough to maintain low fuel loads and an open stand structure, producing a landscape in which fire-caused mortality of mature trees was rare (Agee 1998; Jenkins et al. 2011; Moritz et al. 2011). Adaptive traits such as thick bark also allowed mature ponderosa pines to survive many repeated fires over time. Conversely, high-severity fires occurring at intervals of more than 300 years are typical in subalpine forests and tend to result in high mortality of mature trees ("stand replacement") because long intervals between fires result in dense, multi-storied forest structures that are susceptible to crown fires (Agee 1998) (fig. 8.2).

Fire exclusion since the 1920s has increased surface fuel loads, tree densities, and ladder fuels, especially in low-elevation, dry conifer forests (Schoennagel et al. 2004) (fig. 8.3). As a result, fires in these forests may be larger and more intense, and may cause higher rates of tree mortality than historical fires. In higher elevation forests where fires were historically infrequent, fire exclusion has not altered fire regimes (Romme and Despain 1989; Schoennagel et al. 2004). For example, lodgepole pine (*Pinus contorta* var. *latifolia*) forests in Yellowstone National Park historically experienced large, stand-replacing fires (Romme 1982), and many (but not all) lodgepole pine trees can regenerate prolifically when heating from fires releases seed from serotinous cones (Schoennagel et al. 2003).

Wildfires and Forest Carbon Sequestration

Concerns about projected changes in global climate have raised an expectation that forests can help mitigate climate changes via management for increased carbon sequestration and storage (Sommers et al. 2014). Forests contain large reservoirs of carbon in soils (~45 percent of total storage), aboveground and belowground live biomass (~42 percent), deadwood (~8 percent) and litter (~5 percent) (Pan et al. 2011). The carbon sequestration potential of Earth's forests is about 33 percent of global emissions from fossil fuels and land use (Denman 2007), and North American forests currently offset about 13 percent of

9857 annual continental fossil fuel emissions (Pacala et al. 2007). The potential for forests to mitigate climate
9858 change depends on human activities such as land use and land management, and environmental factors
9859 such as vegetation composition, structure, and distribution, disturbance processes, and climate (Loehman
9860 et al. 2014).

9861 Carbon typically accumulates in woody biomass and soils for decades to centuries until a disturbance
9862 event like wildfire releases this stored carbon into the atmosphere (Goward et al. 2008). Wildfire in
9863 forested ecosystems is one of the primary disturbances that regulates patterns of carbon storage and
9864 release (Kasischke et al. 2000). The amount and rate of carbon release from a wildfire depends on the
9865 extent and severity of the fire, as well as pre-disturbance site conditions and productivity (Bigler et al.
9866 2005; Dale et al. 2001; Falk et al. 2007). For example, high-severity fires typical of mid- to upper-
9867 elevation forests in the Northern Rockies may consume a large amount of aboveground biomass, resulting
9868 in an instantaneous pulse of carbon (i.e., the area affected becomes a carbon source to the atmosphere);
9869 however, these fires typically occur infrequently, and carbon is stored in woody biomass as forests
9870 regrow. Low-severity fires such as those that occur in low-elevation, dry forest types typically release less
9871 carbon per fire event (although total emissions are dependent on area burned) at more frequent intervals
9872 than with stand-replacing regimes, and favor long-lived and fire-resistant (or tolerant) forest species that
9873 typically survive multiple fire events (Ritchie et al. 2007). Carbon losses from wildland fire are balanced
9874 by carbon capture from forest regrowth across unmanaged fire regimes and over multiple decades, unless
9875 a lasting shift in dominant plant life form occurs or fire return intervals change (Kashian et al. 2006;
9876 Wiedinmyer and Neff 2007).

9877 There are several important ideas to consider when managing forests and fires for carbon resources.
9878 First, as stated above, unless structural or functional ecosystem shifts occur, net carbon balance in
9879 disturbance-adapted systems at steady state is zero when assessed over long time periods and at large
9880 spatial scales. Under these conditions, although a fire may result in a temporary loss of stored carbon
9881 from a forest to the atmosphere (i.e., be a carbon source), this effect is transitory and balanced by carbon
9882 accumulation as the forest regrows. The time required for the postfire environment to shift from carbon

9883 source to sink varies among forest types and climates. For example, in simulations of effects of stand-
9884 scale fuel treatments on carbon-fire relationships in Northern Rockies forests, postfire carbon recovery
9885 occurred in 10 to 50 years, depending on vegetation type and whether stands were treated before fire to
9886 reduce woody fuels (Reinhardt and Holsinger 2010).

9887 Second, quantifying or projecting wildland fire emissions is difficult because their amount and
9888 character vary greatly from fire to fire, depending on biomass carbon densities, quantity and condition of
9889 consumed fuels, combustion efficiency, and weather (Loehman et al. 2014). Emissions measured for an
9890 individual fire event may not be characteristic of large-scale emissions potential, because of complex
9891 ecological patterning and spatial heterogeneity of burn severity within fire perimeters. Although long
9892 intervals between wildfires can allow carbon to accumulate for years to centuries, disturbance-prone
9893 forests will eventually lose stored carbon to the atmosphere, regardless of management strategies
9894 designed to limit or prevent disturbance events.

9895 Third, wildfire confers many important ecological benefits not measurable in carbon units (e.g.,
9896 nutrient release and redistribution, stimulation of plant growth, increased productivity in soil systems
9897 from decomposition of burned material, initiation of vegetation succession and forest regeneration,
9898 increased availability of resources for surviving trees). Thus, it will be important to develop accounting
9899 methods that can assess ecological benefits in carbon-equivalent units so that they can be weighed against
9900 carbon losses from disturbance.

9901 Finally, climate changes in combination with other ecosystem stressors may be sufficient to cause
9902 structural or functional changes in ecosystems and thus alter carbon dynamics of landscapes. For
9903 example, if climate changes increase wildfire frequency, extent, and/or severity in forested ecosystems,
9904 forests will likely lose carbon to the atmosphere that will not be rapidly replaced by new growth. This will
9905 cause forests to act as carbon sources for a period of time, until disturbance regimes and biomass
9906 stabilize. Future landscapes could have the potential to store less, or more, carbon than under current
9907 climate and disturbance regimes.

9908 **Potential Future Wildfire Regimes and Wildfire Occurrence**

Potential mid to late 21st century climate-driven changes to regional fire regimes include longer fire seasons and increases in fire frequency, annual area burned, number of high fire danger days, and fire severity as compared with modern fire patterns (Bachelet et al. 2003; Brown et al. 2004; Dillon et al. 2011; Krawchuk et al. 2009; Rocca et al. 2014; Westerling et al. 2006) (figs. 8.4, 8.5). In particular, lengthening of the fire season (the period of the year when fires can burn) will allow for more ignitions, greater likelihood of fire spread, and a longer burning duration. A longer burning window combined with regionally dry fuels will promote larger fires and increased annual area burned relative to modern recorded fire activity. Earlier onset of snowmelt will reduce fuel moistures during fire season, making a larger portion of the landscape flammable for longer periods of time (McKenzie et al. 2004; Miller et al. 2011). This shift may be especially pronounced in middle to high elevation forested systems where fuels are abundant.

Earlier snowmelt, higher summer temperatures, longer fire season, and expanded vulnerable area of high-elevation forests have produced observed increased wildfire activity compared to the mid-20th century, particularly in the Northern Rockies (Westerling et al. 2006). Annual area burned by western wildfires in the 20th century was greater in years with low precipitation, high drought severity, and high temperatures (Littell et al. 2009). Wildfire activity in the western United States is expected to increase if climates become warmer and drier in the future. Among western United States forests, mid-elevation forests of the Northern Rockies are projected to have a high risk of climate-induced increase in fire (Westerling et al. 2006), and increases in the area burned by fire are likely in lower and middle elevations of mountainous areas (Littell et al. 2009). However, in areas that are fuel limited, fires may become more infrequent where there is insufficient moisture for fine fuel accumulation (Littell et al. 2009).

The potential effects of climate change on wildfire area have been assessed using statistical and ecological process models for the western United States (McKenzie et al. 2004; Spracklen et al. 2009), Pacific Northwest (Littell et al. 2010), Northern Rockies (Holsinger et al. 2014; Loehman et al. 2011a, 2011b; Rocca et al. 2014), and the Greater Yellowstone Area (Westerling et al. 2011). For a mean temperature increase of 4 ºF, the annual area burned by wildfires is expected to increase by a factor of 1.4

to 5 for most western states (McKenzie et al. 2004), ultimately leading to greater damage, growth reductions, and mortality in forest ecosystems. The effects of future climate on fire severity (i.e., the proportion of overstory mortality) are less certain because severity may be more sensitive than area burned to arrangement and availability of fuels. The risk posed by future fire activity in a changing climate can be assessed by its likely effects on human and ecological systems. At the wildland-urban interface, higher population and forest density have created forest conditions that are likely to experience more area burned and possibly higher fire severity than in the historical record (Dillon et al. 2011) (figs. 8.4, 8.5).

Although fire size in historic sagebrush landscapes is poorly understood, it is generally accepted that recent large fires have been fueled by woodland encroachment and higher fine fuel loads from weed invasions (e.g., cheatgrass). These changes in fire regime and vegetation-fuel structure affect large areas in the semiarid western United States and cascade through all trophic levels. Effects are particularly harmful on landscapes where postfire recovery is slow. The trend for larger, more damaging fires in sagebrush ecosystems is expected to continue until aberrations in fuel conditions that drive fire are corrected (Keane et al. 2008).

Interactions with Other Disturbance Processes

Wildland fires and insect outbreaks are the two primary natural disturbance processes in conifer forests of western North America (Hicke et al. 2012; Jenkins et al. 2012). The interaction of wildland fire and bark beetles has been studied since the early 20th century (Evenden and Gibson 1940; Miller and Patterson 1927; Weaver 1943), with research primarily focused on the potential for increased fire hazard following outbreaks. Multiple studies have cited changes in fire behavior, extent, and severity resulting from bark beetle-caused morality in pine forests (see Hicke et al. 2012 for a summary). Drought and increased temperatures are key drivers of both wildland fires and bark beetle outbreaks. Climate change may be a causal factor in recent increases in annual area burned by wildfires (Littell et al. 2009) and area affected by bark beetle outbreaks (Bentz et al. 2010). Projections of warmer temperatures and increased drought stress suggest that the total area susceptible to or affected by beetle outbreaks and large or severe

fires may increase in the coming decades (Williams et al. 2013). Acting independently or synchronously in space and time, wildland fires and bark beetle outbreaks can substantially influence forest structure, composition, and function; abruptly reorganize landscapes; and alter biogeochemical processes such as carbon cycling, water supply, and nutrient cycles (Edburg et al. 2012; Falk 2013; Fettig et al. 2013; Hansen 2013; Kurz et al. 2008a).

Unknowns and Uncertainties

Projections of future climate are somewhat uncertain because the ultimate magnitude of climate change and the severity of its impacts depend strongly on the actions that human societies take to respond to these risks (NRC 2010). Global climate models and their downscaled products may not accurately represent climate and weather at the regional and local scales that influence fire occurrence and behavior. For example, although associations between fire and quasi-periodic patterns such as ENSO and PDO have been identified, there is incomplete understanding of how these will respond to climate warming (McKenzie et al. 2004). In addition, precipitation trends are highly variable, and projections of future precipitation reflect both uncertainty and high variation (IPCC 2007, 2012; Littell 2011). Lightning, an important ignition source for wildland fires, may increase in the future, thus increasing the potential for fire activity – for example, recent projections suggest that lightning strikes in the continental US may increase by about 50 percent over the 20th century as the result of global warming–induced increase in updraft speeds and atmospheric water content (Romps et al. 2014). However, others have concluded that confidence in projections of increased thunderstorms and severe local weather events is low (Seneviratne et al. 2012).

Thus, the influence of climate changes on future fire patterns is not precisely known. Grissino-Mayer and Swetnam (2000) note that "long-term changes in climate…. are unlikely to produce simple linear responses in global fire regimes, e.g., warmer temperatures may not necessarily lead to increased fire frequency," in large part because fire activity is strongly influenced by precipitation, which can occur at scales not well captured by climate models. Other research suggests that increases in burned area can be expected in a warming climate, but fire activity will ultimately be limited by the availability of fuels

(Brown et al. 2004; Flannigan et al. 2006; Loehman et al. 2011a; McKenzie et al. 2004; Torn and Fried 1992). In addition, climate drivers interact with legacies of human land use and local vegetation and fuel conditions at large spatial scales, making linear climate-fire predictions difficult. Specifically, decades-long fire exclusion and timber harvesting in some forests of the western US have resulted in densely stocked stands and heavy downed fuels accumulation that have likely contributed to the anomalous size and intensity of recent fires (Grissino Mayer and Swetnam 2000; Naficy et al. 2010).

BARK BEETLES

Overview

Bark beetles (Coleoptera: Curculionidae, Scolytinae) comprise a large subfamily of insects, although less than one percent of the more than 6,000 species found worldwide cause significant economic impacts. In the Northern Rockies, bark beetles of economic concern feed in the phloem of living conifers and can have extreme population amplifications over short time periods, the hallmark of outbreak species. Larval feeding, in addition to colonization by beetle-introduced fungi, typically results in death of the tree, and new host material is therefore required for each beetle generation. Historically, pulses of bark beetle-caused tree mortality have been extensive across the northern Rocky Mountain Region. Recently, between 1999 and 2013, bark beetle-caused tree mortality has had substantial impacts in the Northern Rockies across an average of 1.4 million acres each year (fig. 8.6). Mountain pine beetle (*Dendroctonus ponderosae*, hereafter referred to as MPB) caused the majority of tree mortality (82 percent of acres with mortality detected) with a cumulative impact across 8.7 million acres during this time period (fig. 8.7). Across western North America between 1997 and 2010, bark beetle-caused tree mortality resulted in a transfer of carbon that exceeded that of fire-caused tree mortality (Hicke et al. 2013).

Both bark beetle populations and their host trees are being influenced by a warmer climate. Many bark beetle life history traits that influence population success are temperature dependent (Bentz and Jönsson 2015), and warming temperatures associated with climate change have directly influenced bark beetle-caused tree mortality in some areas of western North America (Safranyik et al. 2010; Weed et al.

10012 2015). Host tree distribution across the Northern Rockies, and tree vigor that influences susceptibility to
10013 bark beetle attack (Chapman et al. 2012; Hart et al. 2013) will also be influenced as the climate continues
10014 to warm.

10015 **Bark Beetles in the Northern Rockies**

10016 Bark beetles are relative specialists, feeding on a single tree species or several species within a single
10017 genus. In the Northern Rockies, multiple tree species are affected by different bark beetle species (table
10018 8.3). Populations of several beetle species, and MPB in particular, began building in 1999, with high
10019 populations continuing in some areas through 2013 (http://foresthealth.fs.usda.gov/portal; fig. 8.6). Trend
10020 analysis indicates that a majority of subwatersheds have declining populations, although some specific
10021 locations had increases in 2012 and 2013 (fig. 8.7) (Egan 2014; Egan et al. 2013). Based on 2012
10022 vegetation characteristics, susceptibility of Northern Rockies watersheds to future MPB outbreaks is
10023 spatially variable with many areas projected to lose >25 percent of total basal area (Krist et al. 2014).

10024 **Drivers of Bark Beetle Outbreaks**

10025 Bark beetle population outbreaks require forests with extensive host trees of suitable size and age
10026 (Fettig et al. 2013). For most irruptive species, preferred hosts are large, mature trees that provide a large
10027 amount of phloem resource for a developing brood. Large landscapes of these mature stands provide the
10028 perfect scenario for years of bark beetle population growth.

10029 Although suitable host trees are critical to outbreak development, beetle populations can exist for
10030 years at low levels until release is triggered by inciting factors that allow for rapid population growth that
10031 makes use of plentiful host trees. Triggers have been difficult to quantify but include factors that make
10032 food more readily available, and increase survival and reproduction of the beetles. Stand conditions
10033 (Fettig et al. 2013), drought (Chapman et al. 2012; Hart et al. 2013), and pathogens (Goheen and Hansen
10034 1993) can make it easier for low levels of beetles to overwhelm and kill trees. Similarly, large areas of
10035 host trees recently killed by fire, wind, or avalanche provide pulses of accessible food, and have resulted
10036 in outbreaks of some species such as Douglas-fir beetle (*Dendroctonus pseudotsugae*) and spruce beetle
10037 (*D. rufipennis*) (Hebertson and Jenkins 2007; Shore et al. 1999), as well as secondary beetles including

10038 *Ips* species and fir engraver (*Scolytus ventralis*) (Livingston 1979). Weather favorable to beetle
10039 reproduction and survival also influences population fluctuations, and can both initiate and sustain
10040 outbreaks (Bentz et al. 2011; Powell and Bentz 2009; Regniere and Bentz 2007).

10041 Given a susceptible forest, climate and weather directly drive bark beetle outbreaks by affecting
10042 beetle growth and survival through temperature-dependent life history traits. For example, the process of
10043 mass attack needed to successfully overcome tree defenses requires synchronous emergence of adults, a
10044 process mediated by temperature (Bentz et al. 1991). Diapause and development rate thresholds help in
10045 this synchrony (Bentz and Jönsson 2015; Hansen et al. 2001, 2011; Ryan 1959; Safranyik et al. 1990).
10046 These same strategies also reduce the likelihood that life stages most sensitive to cold (eggs and pupae)
10047 are not present during winter. Development rates and thresholds also dictate life cycle timing, an
10048 important determinant of the number of generations per year.

10049 The western pine beetle (*D. brevicomis*) and *Ips* species can be bivoltine (two generations in one
10050 year) in the Northern Rockies (Kegley et al. 1997; Livingston 1991), although multivoltine in more
10051 southern parts of their range. Other bark beetle species require at least one year to complete a generation
10052 (univoltine), and at higher elevations where temperatures are cooler, two to three years may be required
10053 for a complete life cycle. Warm temperatures in the summer and spring extend the time that temperatures
10054 are above development thresholds, thereby allowing a reduction in generation time (Bentz et al. 2014;
10055 Hansen et al. 2001). Shorter generation times can lead to increased population growth, causing increased
10056 tree mortality. Winter temperature also influences bark beetle population success. Larvae cold-harden to
10057 survive subfreezing temperatures (Bentz and Mullins 1999; Miller and Werner 1987), although extreme
10058 fluctuations in temperature in spring and autumn, in addition to long durations of temperatures below -31
10059 °F, can cause extensive larval mortality (Evenden and Gibson 1940; Regniere and Bentz 2007; Safranyik
10060 and Linton 1991).

10061 **Bark Beetle Outbreaks Shape Landscape Patterns**

10062 Bark beetle disturbances play a significant role in successional pathways and biogeochemical cycles
10063 in Northern Rockies forests (DeRose and Long 2007; Edburg et al. 2012; Hansen 2014). At low

10064 population levels, bark beetles act locally as thinning agents, producing forest gaps that promote
10065 regeneration and the release and subsequent growth of neighboring host and non-host trees, often
10066 producing uneven-aged stands (Mitchell and Preisler 1998). At outbreak population levels, tree mortality
10067 can approach 80 percent across landscapes of homogeneous host species and age, changing age-class
10068 distributions and overstory and understory species compositions. For example, in seral lodgepole pine
10069 forests, removal of the largest trees by MPB can hasten succession by climax species when fire is absent
10070 (Hagle et al. 2000; Roe and Amman 1977). Bark beetle disturbance can have long-term effects on forest
10071 structure and composition (Pelz and Smith 2012), and future landscape patterns in some forest types will
10072 be driven by tree mortality cau ed by large outbreaks of beetles.

10073 **Potential Futu e Bark Beetle Regimes and Occurrence**

10074 Climate change will have di t and i direct ffects on bark beetle population outbreaks (table 8.4).
10075 Indirectly, changing temperature an precip tion egimes will influence the suitability and spatial
10076 distribution of host trees. Community assoc ates import t bark beetle population success, including
10077 fungi, predators and competitors, will also be affected by hanging climate and thereby indirectly affect
10078 beetle population outbreaks. Direct effects will also oc ur as c anging t mperature regimes either
10079 promote or disrupt bark beetle temperature-dependent life history s ategies that evolved through local
10080 adaptation for increased beetle population fitness and survival. Future bark eetle-caused tree mortality
10081 will therefore depend not only on the spatial distribution of live host t ees and heterogeneity of future
10082 landscapes (see chapter 6), but also the ability of beetle populations and their associates to adapt to
10083 changing conditions when existing phenotypic plasticity is surpassed.

10084 Projected changes in temperature and precipitation, in addition to a potential increase in extreme
10085 events such as windstorms, will significantly influence the spatial and temporal distribution of suitable
10086 host trees across future landscapes. For example, host tree defenses can be weakened by reduced water
10087 availability (Chapman et al. 2012; Gaylord et al. 2013; Hart et al. 2013). Increasing temperature is also
10088 associated with changing hydrologic regimes (see chapter 4), including altered inter-seasonal timing of
10089 soil water availability facilitated by snow packs that have progressively melted earlier in recent decades,

and changes in the distribution of precipitation falling as rain versus snow (Regonda et al. 2005). These factors, along with other potential climate changes, may enhance physiological drought stress in host trees that could indirectly benefit bark beetles that colonize stressed hosts in the late-spring or summer (Raffa et al. 2008). Similarly, increased wind events could provide a reservoir of stressed trees used by some bark beetle species to surpass the endemic-epidemic threshold. Species currently considered secondary (i.e., infest stressed trees) could become primary tree killers as their favored habitat increases.

Warming temperatures will also directly influence bark beetle population success, although the effects will depend on the beetle species, as well as the seasonal timing, amount, and variability of thermal input. For example, a oss MPB habitats in the western United States from 1960 to 2011, minimum temperatures i creased 6.5 ° This increase in minimum temperature resulted in an increase in MPB survival and subsequen b le-cau d tree mortality in many areas of the Northern Rockies (Weed et al. 2015). As climate continues t change howe er, extreme within-year variability in winter warming, could be detrimental to insect survival. Bar beetles prod c supercooling compounds as temperatures decrease and catabolize compounds as temperature w rm Large temperature fluctuations could result in excessive metabolic investment in maintaining approp ate levels of antifreeze compounds, leaving individuals with minimal energy stores at the end of winter. In addition, many species overwinter at the base of tree boles, garnering protection from predators and excessive cold t mperatures when insulated beneath snow. Reduced snow levels in a warming climate could ther ore add to increased overwinter mortality.

Warming at other times of the year could similarly have both positive and negative effects on bark beetle populations. Phenological flexibility allows some species to shift voltinism pathways, developing on a semivoltine (one generation every two years) life cycle in cool years, and a univoltine lifecycle in warm years (Bentz et al. 2014; Hansen et al. 2001). Warming temperatures could also cause species that are currently bivoltine (e.g., western pine beetle, *Ips* species) to become multivoltine. These types of voltinism shifts can lead to rapid increases in beetle populations and subsequent tree mortality. Some thermal regimes allow these life cycle shifts yet maintain seasonal flights. However, other thermal

10116 regimes that result in voltinism shifts could also disrupt seasonality. For example, warm summers could
10117 accelerate development resulting in reduced generation time, but also result in cold-sensitive life stages
10118 entering winter. Existing developmental thresholds and diapause strategies that serve synchrony currently
10119 reduce the likelihood of this happening. As existing phenotypic plasticity is surpassed, rapid warming
10120 without adaptation could lead to lower overall population fitness in some areas as a result of poor
10121 seasonal timing (Reǵnière et al. 2015).

10122 **Expected Effects of Climate Change**

10123 Although there are many bark beetle species in the Northern Rocky Mountains that can cause
10124 economic impact, the influenc of climate change on population outbreaks has been most studied in MPB.
10125 It is clear that multiple a pects of clim e change can positively influence MPB, including increasing
10126 winter temperature (Regniere d Bentz 2007; Weed et al. 2015) and reduced precipitation (Chapman et
10127 al. 2012). Changing thermal regimes, however, can also have both positive and negative effects on MPB
10128 population growth through phenological synchrony and en ration timing. Acknowledging potential other
10129 climate effects, here we describe expected direct effe ts o climate change using a temperature-dependent
10130 mechanistic demographic model of MPB population g wth that is based on phenological synchrony
10131 (Powell and Bentz 2009). The effect of future temperatures on univoltine pop lation growth rate relative
10132 to historic conditions is projected. Although current climates appear to rest ct MPB from successfully
10133 completing two generations in a single year (i.e., bivoltinism) (Bentz nd Powell 2015; Bentz et al. 2014),
10134 we also evaluated if future thermal regimes would promote bivoltinism. The model was driven with
10135 downscaled temperatures from two global circulation models (GCMs): CanEMS2, CCSM4, and two
10136 emission scenarios (Representative Concentration Pathways RCP 4.5 and RCP 8.5) based on the
10137 multivariate adaptive constructed analogs approach (http://maca.northwestknowledge.net). Although
10138 indirect effects of climate clearly affect host tree vigor, stand composition, and distribution across a
10139 landscape, these effects are currently not included our demographic model. We report our model results,
10140 however, in conjunction with hazard categories developed by Krist et al. (2014) based on stand conditions
10141 conducive to MPB population growth (table 8.5). Model output was considered only for locations where

pines currently grow. Model projections are presented in figures 8.8 and 8.9, and tables 8.4 and 8.5, and are summarized below. See Bentz et al. (2016) for spatial displays (for the CanEMS2 GCM).

- The proportion of areas with thermal requirements for MPB bivoltinism has historically been low in the Northern Rockies (figs. 8.8, 8.9).
- Stands at elevations less than 3,300 ft currently have relatively few pines and low hazard to MPB, and population growth of univoltine populations was historically very low. This is most likely because it was too warm, and adult emergence synchrony was disrupted. Growth rate is projected to decrease further in current (2000-2009) and future climates relative to historic periods (fig. 8.8). However, the proportion of simulation points at less th n 3300 ft with thermal regimes that allow for bivoltinism is projected to increase through 2100, p rticularly wh n the RCP 8.5 scenario temperature projections are used (fig. 8.8). The availability of pines at les an 3,300 ft in future climates may be restricted.
- Pine stands at 3,300-6,600 ft were also projected to have lower univoltine population growth rates in current and future climates than historically, and som small proportion of stands will have increasing probability of bivoltinism (fig. 8.8).
- The highest density of pine currently occurs a 6,600-10,000 ft, the elevation range also associated with a majority of stands with high hazard (56 percent) (table 8.5). These stands are predicted to have higher univoltine population growth rates than historic, through 20 0-2050. Thermal regimes for bivoltinism are unlikely at this elevation (fig. 8.8).
- Population growth rates were historically very low in stands above 10,000 ft until 2000-2009; rates are projected to increase through 2100 (fig. 8.8). These stands are too cool for bivoltinism historically and in future climates.
- Pine forests under 6,600 ft currently have low stand hazard for MPB and low univoltine growth potential in the near future (2015-2025), although bivoltine potential is moderate. Pine forests above 6,600 ft have high current stand hazard for MPB and high univoltine growth potential between 2015 and

2025, although bivoltine potential is zero. Our results suggest that pine stands above 6,600 ft, particularly between 6,600 and 10,000 ft, have the highest risk to MPB-caused tree mortality in the near future.

- The Grassland subregion contains a small amount of "Great Plains ponderosa pine," and historically temperatures were too warm for univoltine MPB population success (fig. 8.9). A high proportion of locations in these areas is projected to become thermally suitable for bivoltinism (fig. 8.9), although pine occurrence in future climates may be limited.
- In the Western, Central, and Eastern Rockies subregions, univoltine population growth is projected to decrease beginning in the 2000-2009 period, although a small proportion of locations at the lowest elevations will becom herma ly suitable for bivoltinism by 2080-2100.
- In the Greater Y llowstone Ar a subregion, univoltine population growth remains relatively high until the 2080-2100 time perio (ig. 8.9) with a small proportion of locations at the lowest elevations with the potential to become bivoltine at that time (fig. 8.9).

Interactions with Other Disturbance Processes

Bark beetle-caused tree mortality is influenced by and can influence fire, although the relationships are complex and dynamic (Hicke et al. 2012; Jenkins et al. 2014). In fact, any disturbance that influences the distribution and vigor of host trees will influence bark beetle outbreaks. Moreover, the pattern of bark beetle-killed trees across a landscape will have cascading effects on a myriad of abiotic and biotic processes such as fire, wildlife habitat, and vegetation succession and dynamics (Saab et al. 2014). During non-outbreak years, many bark beetle species survive in trees infected with root diseases. The amount of root disease in trees stressed by climate change may increase, which in turn can result in higher populations of

bark beetles causing increased tree mortality (see root disease section).

Unknowns and Uncertainties

It is important to acknowledge uncertainties with projections of future climate, in addition to uncertainties in models that describe relationships among climate, bark beetle populations, and their host trees. Mechanistic-based phenology models are good tools for projecting beetle population response in a

changing climate (Bentz and Jönsson 2015). This type of model incorporates the important role of seasonality and allows for emergent population processes when driven by climate change projections. However, data are lacking on temperature-dependent relationships of most bark beetle species in the Northern Rockies, hindering development of conceptual and empirical models. Moreover, one of the greatest uncertainties is a lack of understanding of potential adaptations in bark beetle developmental traits to a rapidly changing climate. With few exceptions (Addison et al. 2013, 2014), little is also known about climatic effects on the wide array of bark beetle community associates including fungi, bacteria, parasites, and predators.

Host trees will also respon to climate change, and responses will have cascading effects on bark beetle populations. Furth r investigatio , especially in water-limited systems, is needed to increase quantitative understanding of h climate-induced changes in trees influence bark beetle population success at different spatial scales. Due to this absence of understanding, predictive models that incorporate the integrated effects of climate and bark beetle disturbances on vegetation pathways are lacking, hindering our capacity for making projections for future forests (Anderegg et al. 2015).

WHITE PINE BLISTER RUST

Overview

White pine blister rust (*Cronartium ribicola,* hereafter referred to as WPBR) is a nonnative fungus that was inadvertently introduced to western North America from Europe around 1910 (Bingham 1983; Tomback and Achuff 2011). The WPBR fungus infects only five-needle pine species, and all nine North American white pine species are susceptible; three white pines are found in the Northern Region: western white pine (*Pinus monticola*), whitebark pine (*Pinus albicaulis*), and limber pine (*Pinus flexilis*). WPBR has been found across most of the ranges of these three pines in the Northern Region, and it has caused over 90 percent mortality in western white pine. Whitebark and limber pine WPBR are variable, but highest in the warmer, moister parts of their ranges (Tomback and Achuff 2010).

The life cycle of WBPR requires two hosts, with two spore-producing stages on white pine and three separate spore producing stages on three potential alternate hosts: *Ribes*, *Pedicularis,* and *Castilleja*. Pine

10218 infection begins when basidiospores produced on *Ribes* leaves in late summer are wind dispersed to
10219 nearby pines. The basidiospores germinate on pine needles and fungal hyphae grow through the stomata
10220 into the cell tissues, needles, and stem (Patton and Johnson 1970).

10221 Cankers form on white pine branches and main stems as the phloem is first invaded by hyphae and
10222 then becomes disrupted by blister-like structures that are filled with powdery yellow aeciospores
10223 (Hudgins et al. 2005). As tree branches and stems are girdled, branches and tops die back to the canker.
10224 Continued downward growth of the persistent cankers and poor competitive ability then kill infected
10225 trees. Depending on where the canker occurs, cone production often decreases or is prevented well before
10226 tree death.

10227 The released aeciosp res infect *Rib s* and the other alternate host species (Schwandt et al. 2013). This
10228 can occur at long distances fr i fected pines, as aeciospores are hardy and can disperse as much as 60
10229 miles (Frank et al. 2008). At most locations and for most alternate hosts, infected leaves produce
10230 urediniospores that spread only short distances from leaf to leaf or plant to plant (Newcomb 2003). These
10231 recurrent infections keep rust alive through the growing season until conditions are suitable for pine
10232 infection. For most alternate hosts, leaf infections produce hair-like structures (teliospores) that produce
10233 basidiospores in fall or when night temperatures are cool while other hosts with less vigorous leaf
10234 infections may produce teliospores directly. Locations where synergistic pairs of alternate hosts occur—
10235 one that readily spreads urediniospores, and one that produces pine-infecting basidiospores, are especially
10236 favorable for pine infection (Zambino 2010).

10237 Basidiospores have a narrow weather window for production, dispersal, and successful infection of
10238 pine needles: they infect best in periods of high humidities (greater than 98 percent) with moderate
10239 temperatures (between 60 and 68 °F) (Bega 1960). Conditions for infection are determined by
10240 temperature, with a 48-hour optimum for infection at 64 °F, though up to 5 days may be required at 39 °F
10241 (McDonald et al. 1981). Temperatures exceeding 77 °F are lethal for teliospores. Basidiospores are short-
10242 lived and most often cause infections within a few feet of *Ribes* plants, but they can be carried long
10243 distances or upslope on moist air masses, lofted in thermals over bodies of water, or carried down slope

on cold air currents to infect trees at the interfaces with temperature inversions (Hunt 1983, Van Arsdel et al. 2005, Zambino 2010).

The time required for WPBR to kill its host varies by species, distance of infection from bole (Schwandt 2013), and bole circumference. Typically WPBR kills western white pine in 5-10 years, and whitebark pines (*P. albicaulis*.) after 20 years (Hoff and Hagle 1990). WPBR-caused tree mortality greatly affects stand structure and species composition, but the most serious impact of WPBR is the long-term impact on white pine regeneration capacity, with direct mortality of rust-susceptible seedlings and saplings and the loss of cone and seed production following branch dieback and top kill. Native pine populations show some heritable resistance to WPBR but the frequency of resistance is low and variable (Zambino and McDonald 2004). Studies in the 1970s of natural stands that originated in the late 1920s estimated that fewer than 1 in 10,000 trees lacked cankers (were rust resistant) (Hoff et al. 1980). However, resistance may have increased in the 35 years since this report as a result of additional rounds of regeneration under natural selection (Klopfenstein et al. 2009; McDonald et al. 2004, 2005; Zambino and McDonald 2005).

Effects of Climate Change on White Pine Blister Rust

Climate changes may cause WPBR infections to occur earlier and with greater incidence in pine stands (table 8.6). Specific weather conditions required for basidiospore germination and infection of pine needles may occur more frequently and for longer periods in the future (Koteen 1999). “Wave” years—hot and humid weather conditions throughout most of the growing season that facilitate infections on pine and alternate hosts, followed by moist but cooler weather events for teliospore and basidiospore production and pine infection—are projected to increase in the future for whitebark pine (Keane et al. [in press]), although Sturrock et al. (2011) speculate that wave years will actually decrease for most temperate pine forests (western white and limber pine) because of hotter, drier projected climates. Helfer (2014) also believes that warmer temperatures could negatively impact rusts and that higher concentrations of atmospheric carbon dioxide (CO_2) could cause declines in rust populations. He also

10269 mentions that the highly variable and extreme weather projected in the future will aid in WPBR spore
10270 dispersal, resulting in expansion of its range and higher spore loads on existing pines.
10271 The highly variable and novel climate conditions projected in the future may serve to accelerate
10272 mutations of WPBR to create populations that may overcome the native rust resistance in five-needle
10273 pines (Simberloff 2000). Alternatively, changing climates may lead to suitable climates for WPBR
10274 variants that are in locations other than North America. Since most rust infection and mortality occur
10275 regardless of tree condition and vigor, it is doubtful that any direct responses of the tree or the *Ribes* hosts
10276 to future climates, such as increased growth, will enhance or degrade the ability of the host to ward off
10277 infections. However, climate-mediated changes in host regeneration dynamics could restrict or expand
10278 host ranges (Helfer 2014). As a result, this could alter WPBR range. Some predict higher leaf biomass for
10279 the two host species with warmer, enriched CO_2 environments, and more leaves could provide additional
10280 germination surfaces and a higher chance for rust infection on both hosts.
10281 Distribution and frequency of synergistic alternate host species combinations (Zambino 2010) could
10282 also change. Higher elevation areas may experience new climates (i.e., warming temperatures along with
10283 high precipitation) that facilitate the expansion of *Ribes* into areas that were historically too cold and
10284 snowy to support certain hosts. On the other hand, low elevation upland areas where *Ribes* are currently
10285 abundant might experience drought that causes decline of the host. Moreover, drought may cause
10286 extended and extensive stomatal closure in the pines, thus preventing hyphae entry. The shifting mosaics
10287 of the *Ribes* host populations into new higher elevation areas, driven by drought in lower elevations, may
10288 spread WPBR into areas where it has not yet occurred.

10289 **Interactions with Other Disturbance Processes**

10290 The interaction of fungal pathogens and their hosts with other disturbances may be a key factor in
10291 future WPBR infections (Ayres and Lombardero 2000). The interactive effects of wildland fire on WPBR
10292 are probably most important, but they are mostly minor and primarily indirect under future climates. The
10293 exception is the possibility that smoke may kill rust spores produced at the time of the fire (Hoffman et al.
10294 2013).

WPBR and Wildland Fire

Fire indirectly affects WPBR by changing the size, distribution, and abundance of its hosts. Most five-needle pines of the western United States are somewhat fire-adapted with thick bark, high canopies, and deep roots (Ryan and Reinhardt 1988). Mixed- and high-severity fires are currently common in most forests where WPBR is present (Arno et al. 2000; Murray 2007) and are projected to increase in size, frequency, and intensity (Westerling et al. 2011). Increases in fires and burned areas can create favorable conditions for pine regeneration because most five-needle pine seeds are dispersed by rodents and birds and are thus better adapted to spread into postfire landscapes than seeds of their tree competitors (Lanner 1989, Morgan et al. 1994). *Ribes* populations may increase after fire through regeneration by seed and sprouting from roots and rhizomes. Therefore, fire will often favor *Ribes* regeneration over other species not adapted to fire. However, re-burns soon after an initial fire can eliminate regenerating *Ribes* before they can develop a seed bank for the next forest regeneration cycle (Zambino 2010).

Severe fires that kill rust-resistant pine trees may ensure continued high rust mortality in the future because it dampens the rate of rust-resistant adaptions (Keane et al. 2012). However, where rust-resistant five-needle pines survive fire they can provide the seeds for populating future landscapes that are resilient to both rust infection and fire mortality. Fire exclusion generally increases competition stress (Heward et al. 2013), weakening pine trees. Stress from competition does not increase rust infection (Parker et al. 2006), but may facilitate mortality in pines trees under stress after being girdled by blister rust.

Trees infected with WPBR are weakened, and may be more susceptible to fire-caused damage and mortality (Stephens and Finney 2002). Ladder fuels of trees attacked or killed by WPBR may increase crowning owing to abundant pitch that can extend from base to rust bole cankers, and from dead red crowns of girdled trees. As branches and tops of white pines die back they add dead foliage and wood to the fuelbed, which may increase fire intensity and fire-caused tree mortality. In contrast, western white pine needles gradually added to the fuel bed are more similar to normal needle shed, and are quickly degraded in moist, productive environments. Mortality from WPBR often results in the elimination or thinning of the shade-intolerant pine overstory, allowing shade tolerant competitors to occupy the

10321 openings. This creates substantially different canopy fuel conditions, such as lower canopy base heights,
10322 higher canopy bulk densities, and greater canopy cover, which facilitate more frequent and intense crown
10323 fires (Keane et al. 2002, Reinhardt et al. 2010). Many shade tolerant competitors are also more susceptible
10324 to fire damage, resulting in higher postfire tree mortality in rust-infected landscapes.

10325 *WPBR and Mountain Pine Beetle*

10326 Interactions between native MPB populations and WPBR are rarely studied because they are difficult
10327 to quantify over time. In their endemic phase, MPB populations may weaken pines and facilitate infection
10328 by WPBR, but these interactions are strongly governed by climate and biophysical environment
10329 (Tomback and Achuff 2011). However, the ubiquitous presence of WPBR spores and the resistance to the
10330 disease in pine species ensures that most five-needle pines at many sites will eventually become infected
10331 and die from WPBR, regardless of MPB endemic levels (Hoff et al. 2001). More importantly, MPB
10332 influences WPBR through regulation of the tree species that are host to both disturbance agents and
10333 killing of host trees that are resistant to the rust (Campbell and Antos 2000). For example, although
10334 whitebark pine stands in the Greater Yellowstone Area show little WPBR-related mortality, levels of
10335 MPB-related mortality are high (Kendall and Keane 2001; Macfarlane et al. 2013). Many stands of
10336 healthy five-needle pines in Yellowstone have been subjected to a major MPB outbreak over the last
10337 decade as a result of high densities of large diameter trees coupled with prolonged warm, dry conditions.
10338 These outbreaks resulted in substantial mortality of rust-resistant whitebark pine trees (Logan et al. 2008).

10339 Effects of WPBR on MPB infestations are also highly variable and subtle. Archibald et al. (2013)
10340 found less MPB activity in trees that had high WPBR damage, whereas Bockino and Tinker (2012) found
10341 that whitebark pine selected as hosts for MPB had significantly higher WPBR infection, but this varied by
10342 tree size (diameter), stand type, and disturbance pattern (Larson 2011). Kulhavy et al. (1984) found that
10343 over 90 percent of western white pine trees infected by bark beetles had either WPBR or some type of
10344 root disease, whereas Six and Adams (2007) found little evidence of interaction effects between MPB and
10345 WPBR. Simulations of MPB disturbance under current climate result in a decline in both lodgepole pine
10346 and whitebark pine, with a corresponding increase in subalpine fir (*Abies lasiocarpa*) and Douglas-fir

10347 (*Pseudotsuga menziesii*), with little change from the addition of WPBR (fig. 8.10). These trends are
10348 enhanced under a warmer climate, in which lodgepole pine declines are greater and stands are mainly
10349 replaced by Douglas-fir, but WPBR interaction has minor effects on species composition (Keane et al.
10350 2015).

10351 *WPBR, Fire, and Mountain Pine Beetle*

10352 Studies of interactions among fire, beetles, and rust are rare, but we posit that MPB and WPBR serve
10353 to reduce five-needle pine populations and create fuelbeds that may support wildfires that are more
10354 intense than historical counterparts, potentially resulting in high mortality of the dominant vegetation.
10355 Although fire reduces pine abundance in the short term, it appears to ensure their long-term persistence by
10356 eliminating competitors (Keane and Morgan 1994). Modeling studies have shown that decades to
10357 centuries are required to re-establish populations of rust-resistant white pines after die-off (such as would
10358 occur with MPB) and increased frequency and extent of wildfire under climate change favored white pine
10359 regeneration and persistence over shade-tolerant species in some regions, even in the presence of WPBR
10360 and of losses of some WWP from fire (Loehman et al., 2011a,b).The largest decline in whitebark pine has
10361 been found in those areas affected by both WPBR and MPB, but not fire (Campbell and Antos 2000).

10362 Interactions among fire, MPB, and WPBR can occur only in areas that have the potential to support
10363 five-needle pines, which are rare in many landscapes. However, recent simulation efforts have found that
10364 fire frequency under current climate is 10 percent lower when all three disturbances are allowed to
10365 interact, and average tree mortality is also lower (fig. 8.10). In a warmer climate, fire frequency decreases,
10366 high severity fires increase, and interactions among disturbances create different landscapes than when
10367 each disturbance acts separately (or in the absence of disturbance) (Keane et al. 2015) (fig. 8.11).

10368 **WPBR Unknowns and Uncertainties**

10369 It is difficult to mechanistically simulate WPBR population dynamics because of the disease is
10370 governed by fine scale (e.g., microclimate, spore production and germination, tree size and health) to
10371 coarse scale (e.g., spore dispersal, wind, alternate host distributions, topographic controls) processes.
10372 Therefore, the representation of WPBR in most models will tend to be both stochastic and empirical, and

this will tend to reduce the robustness of model predictions and add to the uncertainty of future WPBR predictions.

White pine trees will also directly respond to climate change, and responses will have interacting effects on WPBR infection potential. The key to the future abundance of white pines on the Northern Rocky Mountain landscapes will hinge on the ability of the three pine species to develop rust-resistant populations that are resilient to climate change. This probably will not happen without human intervention. The rapid pace of predicted climate change coupled with the long maturation times of the three pine species may exacerbate the species decline. It is essential that natural resistance is facilitated by land management agencies to ensure that these valuable species and the forests that they create are not lost forever.

FOREST DISEASES

Overview

Forest diseases are found in all forest ecosystems of the Northern Rockies. They are one of three major disturbance groups that affect ecosystem development and change, but the overall impacts of forest diseases on various resources are difficult to quantify. This is partly due to our inability to separate predisposing effects of some of the most important diseases, which act over a long term, from mortality caused by short-term factors such as insect outbreaks and drought. The effects of forest diseases tend to be more cryptic and chronic in effects, so estimating their occurrence and abundance is difficult. Here we rely mostly on older studies and observations to quantify disease effects in what were formerly called "commercial timberlands." Spatial distributions of most forest diseases have not changed much, although the effects of individual diseases may change due to effects of climate on disease organisms, hosts, and environmental predisposition.

We focus on the major groups of forest diseases in the Northern Rockies known to have significant effects on ecosystems and ecosystem services, and for which at least some information is available on effects of climate.

Dwarf Mistletoe

Dwarf mistletoes (*Arceuthobium* spp.) are a group of parasitic seed plants that are widespread across the Northern Rockies and mainly cause reduced tree growth and productivity, but in some cases also cause tree mortality. Five species of dwarf mistletoe are found in the Northern Rockies, mostly on these primary hosts: *A. americanum* on lodgepole pine, *A. campylopodum* on ponderosa pine, *A. cyanocarpum* on limber pine (*Pinus flexilis*), *A. douglasii* on Douglas-fir, and *A. laricis* on western larch (*Larix occidentalis*). Mistletoes may occasionally infect trees of other species when they are growing interspersed with infected primary hosts.

Approximately 28 percent of lodgepole pine forest is infested by *A. americanum*. *A. cyanocarpum* occurs primarily east of the Continental Divide, although the area affected has not been estimated. Douglas-fir is infested in over 13 percent of its range by *A. douglasii*. About 38 percent of the western larch type is infested by *A. laricis*. The distribution of *A. campylopodum* in is limited to a portion of Idaho where it occurs on ponderosa pine. Drummond (1982) estimated that 2.1 million acres of national forest lands were infested by the three most important species of dwarf mistletoe in the Northern Rockies. An estimated 31 million cubic feet of wood are destroyed by these pathogens each year.

Root Disease

Caused by various species of fungi, root disease is a major cause of tree growth loss and mortality in the Northern Rockies. These diseases are primarily a problem west of the Continental Divide, but also affect local areas east of the Divide. The two most significant native pathogens in the Northern Rockies region are Armillaria and annosus root diseases. These and other root diseases co-occur in many mesic to moist forests west of the Divide. Armillaria kills conifers of all species when they are young, but is especially damaging to Douglas-fir, subalpine fir, and grand fir (*Abies grandis*) because these species remain susceptible throughout their lives (Kile et al. 1991). In addition, root diseases often affect canopy closure and create small gaps. The effects of these root pathogens are persistent on a site and affect multiple generations of trees. Armillaria and other root diseases influence forest species composition, structure, and successional trajectories by accelerating a transition to species that are more tolerant of root

10424 disease or by maintaining stands of more susceptible species in early seral stages (Byler and Hagle 2000).
10425 They can also affect ecosystem services by affecting visual and recreational resources.

10426 At least 3.3 million acres in the Northern Rockies have moderate to severe root disease, with up to 60
10427 percent caused by *Armillaria ostoyae* (Smith 1984; USDA FS 2007). A recent evaluation of Forest
10428 Inventory and Analysis data in the Forest Service, U.S. Department of Agriculture Northern Region
10429 identified 2.3 million acres of national forest lands with moderate to severe root disease (Lockman et al.
10430 in preparation). Shrub fields have replaced forest cover on three percent of forest lands in Idaho and
10431 Montana as a result of severe root disease. A study of Ecosection M333d (Bailey 1983) that includes the
10432 southern Idaho Panhandle National Forest and southern Kootenai National Forest found evidence of root
10433 disease on 94 percent of the area (Byler and Hagle 2000). Root disease has reduced forest canopy cover in
10434 affected stands in northern Idaho and western Montana by an average of 20-30 percent.

10435 The National Insect and Disease Forest Risk Assessment (Krist et al. 2014) identified locations where
10436 significant tree mortality and basal area losses from insects and diseases could occur between 2013 and
10437 2027, modeling the potential for damage in standing live basal area across all ownerships from a variety
10438 of insects and pathogens. Root disease had the highest basal area loss as a percent of total basal area, with
10439 projected losses ranging from 0 to 20 percent in most national forests.

10440 *Needle Disease*

10441 Needle diseases have historically been of limited significance in the Northern Rockies; severe
10442 infection years occur only occasionally, and effects are mostly limited to crown thinning and loss of lower
10443 branches with some mortality of young trees. Needle casts usually cause loss of needles in the year
10444 following a season that has been favorable for infection. In western larch, needle cast and needle blight
10445 are observed in the year of infection.

10446 Needle casts and needle blights in lodgepole pine, ponderosa pine, western white pine, Douglas-fir,
10447 grand fir, and western larch generally cause little damage in the Northern Rockies, although periodic
10448 outbreaks can cause severe damage in local areas (Lockman and Hartless 2008). These diseases are

favored by long, mild, damp springs. Their occurrence at epidemic levels depends on favorable weather conditions and presence of an adequate host population.

Abiotic Disease

Most abiotic diseases result from the effects of adverse environmental factors on tree physiology or structure. This group of diseases can affect trees directly or interact with biotic agents, including pathogens and insects. A number of abiotic and environmental factors can affect foliage, individual branches, or entire trees, tree physiology and overall tree vigor. The most significant abiotic damage is tree mortality.

Forests in the Northern Rockies periodically experience damage from weather extremes, such as temperature and drought. Factors such as air pollutants and nutrient extremes occur infrequently or locally. Conifers on the east side of the Continental Divide, primarily Douglas-fir and lodgepole pine, often experience injury known as red belt, caused by strong, dry, warm Chinook winds in winter that induce twig and needle necrosis and desiccation (Bella and Navratil 1987). Drought injury, an abiotic factor that can cause disease through loss of foliage and tree mortality, can initiate a decline syndrome by predisposing trees with stressed crowns and roots and low energy reserves to infection by less aggressive biotic agents, such as canker fungi and secondary beetles. A well-studied decline of western white pine called pole blight occurred in the Northern Rockies in the 1930s and 1940s (Leaphart and Stage 1971). This disease occurred on pole-sized trees, often in plantations that were growing on shallow soils with low moisture storage capacity that were exposed to extended drought.

Canker Disease

Canker diseases affect tree branches and boles, typically in trees that are poorly-adapted to the sites in which they are growing. Damage is caused by breakage at the site of the cankers, or by mortality of branches and boles beyond girdling cankers. Although canker fungi are most active on trees under stress, lack of specific data on climate effects makes it difficult to infer the effects of climate change.

Broad-Scale Climate Drivers of Forest Diseases

Climatic variability and change can alter patterns of pathogen distribution and abundance through (1) direct effects on development and survival of a pathogen, (2) physiological changes in tree defenses, and (3) indirect effects on abundance of natural enemies, mutualists and competitors (Ayres and Lombardero 2000). Sturrock et al. (2011) suggest that climate change will affect pathogens, hosts, and their interaction; changes in these interactions may become the most substantial drivers of future disease outbreaks.

Fungi cause most forest diseases in the Northern Rockies. Fungus life cycles are significantly influenced by climate-related factors such as timing and duration of precipitation, humidity, and temperature for spore germination, fungus growth, and inactivation. Fungus life cycles are short compared to their hosts, so fungi can respond more rapidly to a changing climate than their hosts, with potentially serious consequences (Boland et al. 2004). Dwarf mistletoe reproduction and infection are also affected by temperature and moisture (Hawksworth and Wiens 1996), and dwarf mistletoes are generally most prevalent in sites that have experienced past disturbances.

Overall health of host trees has a major role in determining if a pathogen successfully infects a tree or kills it. Many forest diseases, such as canker diseases, are caused by "facultative pathogens" that attack weakened hosts under specific environmental conditions. Impacts of climate change on host physiology may modify host resistance and alter stages and rates of development of pathogens (Coakley et al. 1999). Drought, or limited soil moisture availability, is a major driver that affects the incidence and severity of facultative pathogens. Soil moisture deficit, flooding, and water table fluctuation can all predispose trees to pathogens. Even if there are areas that may have a net gain in precipitation, projected longer growing seasons could cause recurring water deficit stress. Some diseases may be considered threshold diseases, that is, they are damaging but only under certain climatic conditions (Hepting 1963). These diseases may become more damaging if thresholds that trigger infections are reached more frequently, such as in recurring drought.

Effects of Climate Change on Forest Diseases

10499 One of the difficulties of predicting sensitivity to a changing climate is that the scales available for
10500 GCMs, pathogen/disease models, and microsite environments do not always match (Seem 2004). For
10501 example, some GCM projections provide only mean monthly and annual estimates, rather than daily data
10502 useful for modeling forest diseases. In addition, pathogen ecology and effects are sensitive to local site
10503 and environmental conditions that may not be well represented by GCMs. There is also considerable
10504 uncertainty and lack of knowledge of impacts of a changing climate on future forest conditions and
10505 interactions with pathogens (Woods et al. 2005, 2010). Compared to trees, for which available soil
10506 moisture is critical, pathogens are more affected by precipitation events, especially timing, duration and
10507 pattern, all of which are poorly projected by climate models. Facultative pathogens respond to weakened
10508 or less vigorous hosts, and their importance could increase if climatic conditions less favorable to tree
10509 growth become more frequent.

10510 A changing climate will affect forest disease occurrence and severity, through effects on the
10511 pathogen, the host, or their interaction (Sturrock et al. 2011) (table 8.7). Interactions between pathogens
10512 and abiotic stressors (e.g., temperature and moisture) may represent the most substantial drivers of
10513 increased disease outbreaks (Sturrock 2012). Epidemics also depend on relatively constrained conditions
10514 for spread and infection to occur. For example, increased drought could affect host susceptibility to
10515 pathogens and predispose hosts to disease outbreaks (Coakley et al. 1999). Although models usually
10516 generate mean climatic conditions, it is often the extremes that have the greatest influence on pest
10517 conditions (Hepting 1963). Increased host stress could result in increased disease occurrence and
10518 interactions among multiple agents (Coakley et al. 1999). There is likely to be an increase in declines and
10519 dieback syndromes (Manion 1991) caused by changes in disease patterns involving a variety of diseases.

10520 Indirect effects may be on competitors, antagonists, and mutualists that interact with plant pathogens
10521 (Kliejunas et al. 2009). Some of the most profound effects of temperature and moisture changes could be
10522 on soil microflora, and on and in roots and shoots where a complex of organisms live in relationships at
10523 the transition between pathogenesis, symbiosis, and saprogenesis. The balance among organisms could be
10524 upset, for example, turning a normal mycorrhizal association to pathogenesis, shifting pathogens from

saprogenic to pathogenic phases, or shifting the order of ascendency of competing organisms due to their different temperature or moisture optima, even permitting a pathogen to take dominance from a saprophyte (Hepting 1963). Given that root pathogens of trees can often exploit a large food reserve in a tree once a defense is breached and then use those reserves to bolster attacks on nearby trees, even small changes in the frequency of shifts in relationships among fungal communities could have large effects.

Although considerable knowledge exists on climatic conditions required by specific forest pathogens, little has been done to determine how changing climates may affect these pathogens (Kliejunas et al. 2009). Recent modeling work by Klopfenstein et al. (2009) used a subset of GCMs to project how the geographic distribution of the climate envelope for *Armillaria solidipes* and Douglas-fir could change in the interior northwestern United States. Their analysis suggests that Douglas-fir will have a considerably smaller geographic space that matches its current climate envelope and that this space will shift, while *A. solidipes* will experience only minor changes. They suggest that areas where Douglas-fir is maladapted could increase, which could increase its susceptibility to Armillaria root disease.

The methodology used by Klopfenstein et al. (2009) for estimating the potential effects of climate on *A. solidipes* used climatic variable information from the current distribution of the pathogen on its Douglas-fir host based on current pathogen occurrence in a network of plots. Climate space for *A. solidipes* modeled for current and 2060 climate are shown in figure 8.12. These preliminary projections are not necessarily the current or future distribution of *A. solidipes*, but identify only the modeled climate space matching where the pathogen currently occurs. It is unknown how the climate envelope could change, because of changes in distribution of competitor fungi and hosts.

Spring precipitation is projected to increase in most of the mountainous area of the Northern Rockies (see chapter 3). This may increase frequency and severity of years when needle diseases cause significant needle loss in conifer species. This could affect the energy balance of susceptible trees, with potential effects on yield and vigor, particularly for species that normally carry multiple years of needles and cannot re-flush later in the season in response to defoliation.

There may be elevation and location maladaptation in resistance to the increased needle disease pressure resulting from climate change, as areas of tree host ranges and disease occurrences shift in location. Lophodermella needle cast in lodgepole pine (caused by *Lophodermella concolor*) occurred in northern Idaho in the early 1980s (Hoff 1985), and has also had outbreaks at high elevation in some Idaho locations in recent years. Lodgepole pine at high elevation normally has only infrequent outbreaks because bud break occurs near or after the time when spring rains that favor infection have ended, whereas needles in lower elevation trees expand when spores are present and able to infect. A provenance study under natural conditions during the outbreak in the 1980s showed that low-elevation populations were generally more resistant and had heritable resistance, but high-elevation populations were susceptible. About six percent of trees in this mixed provenance planting showed no infection, but 5 percent had almost complete defoliation. If moist conditions following bud break continue to occur at high elevation where natural selection for resistance has not occurred, recurrent needle disease outbreaks could stress trees and make lodgepole pine more susceptible to other factors (Hoff 1985).

Another example of a needle disease that may increase in the Region under climate change is Swiss needle cast (caused by *Phaeocryptopus gaeumannii*). This disease severely limits productivity of Douglas-fir west of the Cascade divide in Oregon and Washington, causing growth losses of up to 50 percent (Manter et al. 2005). Needle loss is very highly correlated with increasing winter temperatures and spring needle wetness. The disease, which is expected to become more severe in forests west of the Cascade crest in a warmer climate (Stone et al. 2008), has periods of local occurrence in northern Idaho (Navratil and Bella 1988) and Montana (Weir 1917). Milder winters and wetter springs that could increase the future distributions and severity of the disease might occur, but as yet, investigations and modeling have not been conducted to map and quantify potential effects.

Kliejunas (2011) performed a qualitative risk assessment of the effect of projected climate change on a number of forest diseases, several of which occur in the Northern Rockies. Dothistroma needle blight, (caused by *Dothistroma septosporum*), provides a good example of potential effects of climate change. Kliejunas (2011) estimates that the risk potential is low if a warmer and drier climate occurs. A warmer

and wetter climate could increase the risk potential to moderate. His assessment of the effect of climate change on dwarf mistletoes indicated a high risk potential regardless of precipitation levels because dwarf mistletoe survival and infection increases with temperature. His assessment of Armillaria root disease indicated a high to very high risk potential depending on moisture availability, with drier conditions increasing the potential.

Forest Pathogen Interactions

Direct effects of fire on pathogens are generally minimal. Fire directly and indirectly influences distribution, severity, and persistence of forest diseases; similarly, forest diseases influence fire behavior and severity. Since diseases are generally host specific, removal of susceptible tree species by fire will usually reduce disease, whereas improving habitat for susceptible tree species will usually increase disease over time.

Forest pathogens are directly damaged by smoke and heat of fires. Smoke can inhibit dwarf mistletoe seed germination (Zimmerman and Laven 1987), and heat from fire can kill pathogens that cause root disease in the top 3 inches of soil (Filip and Yang-Erve 1997). Forest diseases are affected more by tree mortality from fire. Frequency and intensity of fire can affect persistence, as well as distribution and severity of certain diseases. High intensity fires can completely remove a pathogen with its host, as with lodgepole pine-dwarf mistletoe (Kipfmueller and Baker 1998; Zimmerman et al. 1990), or remove species susceptible to root disease and prepare the site for regeneration of less susceptible seral species, such as pines and western larch (Hagle et al. 2000). Low intensity fires often leave mosaics of pathogens along with their susceptible hosts, which can cause substantial increases of diseases such as dwarf mistletoe (Kipfmueller and Baker 1998). However, low intensity fires in some habitats maintain species tolerant of root disease such as western larch (Hagle et al. 2000).

Human-caused fire exclusion has led to an increase of root disease and dwarf mistletoe (Hagle et al. 2000; Rippy et al. 2005), which can influence fire behavior and severity. Root disease creates pockets of mortality and scattered mortality, resulting in standing and downed woody debris that increases fuel loading, especially large fuels (Fields 2003). Increased litter accumulation and resinous witches' brooms

10602 from dwarf mistletoe infections can provide ladder fuels that may cause a ground fire to move into the
10603 canopy (Geils et al. 2002).

10604 Climate effects that increase frequency or intensity of fires may affect incidence and severity of dwarf
10605 mistletoes (Zimmerman and Laven 1985). Fire affects dwarf mistletoes by changing canopy structure and
10606 stand density (Alexander and Hawksworth 1975; Dowding 1929), eliminating lower branches that may
10607 have the heaviest infections and mistletoe seed production, thinning stem density which may reduce
10608 lateral spread, and causing mistletoe shoots to abscise. Loss of shoots eliminates some infections directly,
10609 but even if infections remain within the bark, loss of shoots prevents seed production for several years,
10610 slowing mistletoe intensification within stands. Trees heavily infested with mistletoe often retain low
10611 infected branches and are prone to torching in fire, which could increase the risk of crown fire (Conklin
10612 and Geils 2008). Alternatively, torching in individual trees could eliminate the most heavily infected
10613 sources of mistletoe seed that infect understory regeneration.

10614 An increase in severe weather events or fires could increase occurrence of other diseases. For
10615 example, root and bole wounds could be used as “infection courts” for root disease, and such wounds
10616 from management, windfalls, and fire are major avenues of infection for true fir and western hemlock
10617 (Smith 1989) and lodgepole pine (Littke and Gara 1986). Fire damage and other stresses can release root
10618 disease infections that have been walled off by host resistance responses (Hagle and Filip 2010). Relative
10619 importance of different root diseases could be altered under some climate change scenarios. Except as a
10620 sapling, western larch is considered resistant to Armillaria root disease due to its ability to generate
10621 multiple corky barriers at infection sites (Robinson and Morrison 2001). This species response to wounds
10622 and the thick bark that it generates also make it among the most resistant to fire damage, and a species
10623 more likely to persist and regenerate under increased fire frequency.

10624 Illustrating interactions between bark beetles and disease, a study in lodgepole pine forests of central
10625 Oregon showed that altered stand structure following an MPB epidemic increases dwarf mistletoe in
10626 lodgepole pine stands, thereby reducing stand growth and productivity and slowing stand recovery (Agne
10627 et al. 2014). The influence of dwarf mistletoe on stand structure heterogeneity could increase landscape

resistance and resilience to disturbances. Another example of complex interrelationships is the interaction between stem decay, bark beetles and fire frequency in central Oregon lodgepole pine. After fire damaged the roots of lodgepole pines, stem decay fungi infected these damaged roots and over time caused extensive heartwood decay in the boles of these trees. Data show these decay-infected trees grew at a slower rate than uninfected trees and trees with stem decay were preferentially attacked by mountain pine beetles years later (Littke and Gara 1986).

NONNATIVE PLANTS

Overview

Projecting how nonnative plants and climate change may interact to alter native plant communities, ecosystems, and the services they provide is challenging because of our limited ability to project how climate change will alter specific local abiotic conditions that define the fundamental niches of plants (Gurevitch et al. 2011; Thuiller et al. 2008). We start with knowledge of structure and function of current ecosystems, and then apply first principles of ecology to explore how climate change might alter these systems, their susceptibility to invasion, and invasiveness of introduced plants from a general perspective. We do not project changes in individual plant species, but define the parameters that bound potential community change based on climate projections and discuss how community invasibility might be affected across that range of potential conditions.

Effects of Climate Change on Nonnative Species

Hundreds of nonnative species have been introduced into the Northern Rockies (http://invader.dbs.umt.edu). Not all of these species are abundant, but recent surveys showed that nonnative plants comprise an average of 40 percent of species present (richness), and 25 percent of those nonnatives have significant effects on native grassland flora (Ortega and Pearson 2005; Pearson et al. in review). Invasive plant species represent a threat to ecosystem integrity, because they compete with native species in many plant communities and can alter ecological processes. These negative impacts can reduce biological diversity, forage for wildlife, and recreation opportunities. Most nonnative invasives are

herbaceous species (graminoids and forbs), but some are shrub and tree species that commonly occur in riparian areas (e.g., Russian olive [*Elaeagnus angustifolia*], tamarisk [*Tamarix ramosissima*]).

Although extensive work has been done to understand the biology of some of the most common nonnatives, such information is far from complete, and few studies have explored how changes in temperature and moisture related to climate change may affect nonnative plant populations in the Northern Rockies.

It has historically been assumed that climate change will favor nonnative plants over natives (Dukes and Mooney 1999; Thuiller et al. 2008; Vila et al. 2007; Walther et al. 2009), but this may be an overgeneralization (Bradley et al. 2009, 2010; Ortega et al. 2012). Numerous attributes associated with successful invaders suggest nonnatives could flourish under certain climate change scenarios. For example, many nonnatives are fast growing early seral species (ruderals) that tend to respond favorably to increased resource availability, including temperature, water, sunlight, and CO_2 (Milchunas and Lauenroth 1995; Smith et al. 2000; Walther et al. 2009). As a result, extensive work shows that nonnatives respond favorably to disturbance (Zouhar et al. 2008) which can increase resource availability (Davis et al. 2000). Nonnatives may also exploit the disturbances associated with postfire conditions better than many natives (Zouhar et al. 2008), despite native plant adaptations to fire. In bunchgrass communities, many nonnative plants recruit more strongly than do natives when native vegetation is disturbed, even under equal propagule availability (Maron et al. 2012). Successful invaders also commonly have strong dispersal strategies and shorter generation times, both of which can allow them to migrate more quickly than slow growing and slowly dispersed species (Clements and Ditommaso 2011). Greater plasticity of successful invaders could also favor their survival in place and ability to expand their populations (Clements and Ditommaso 2011). Collectively, these attributes suggest that many nonnatives would benefit if climate change results in increased disturbance.

Few studies have manipulated CO_2, moisture, or temperature to quantify the effects of climate change on nonnative versus native plants in the northern Rockies. Of the work that does exist, most has targeted grassland and sagebrush communities, presumably because these are among the most susceptible to

invasion (Forcella 1992, chapter 7). Experimentally increasing temperatures in a Colorado meadow system resulted in increases in native upland shrubs with big sagebrush (*Artemisia tridentata*) increasing in drier conditions and shrubby cinquefoil (*Dasiphora fruticosa*) in wetter conditions (Harte and Shaw 1995). These different responses indicate the importance of background moisture in driving species-specific responses to elevated temperatures.

Recent experimental work in western Montana showed that reduced precipitation can significantly impact spotted knapweed (*Centaurea melitensis*), whereas native bluebunch wheatgrass (*Pseudoroegneria spicata*) populations were unaffected by the same drought stress (Ortega et al. 2012; Pearson et al. unpublished data). This result is consistent with historic observations of spotted knapweed declines following drought conditions (Pearson and Fletcher 2008). In Wyoming sagebrush-steppe systems, bluebunch wheatgrass outperformed both cheatgrass and medusahead (*Taeniatherum caput-medusae*) in dry years, but the opposite was true in wet years (Mangla et al. 2011). Community-level studies in other grasslands have shown that drought periods can shift vegetation away from annual grasses and forbs and toward drought-tolerant native perennial grasses (Tilman 1992). Hence, heating and drying could favor drought-tolerant natives in dry grassland and sagebrush systems and reduce their susceptibility to nonnatives (see chapter 7). However, these same conditions might increase susceptibility of native vegetation to invasive species in wetter locations.

Xeric Grasslands and Shrublands

Of the many dominant cover types that occur in the Northern Rockies, the most vulnerable to weed invasion are typically those on warm, dry (xeric) sites, although riparian and wetland sites can be invaded by several invasive plant species. The most susceptible plant communities tend to have low vegetation cover, high bare ground, and unproductive soils; various nonnatives plant species exploit these more open sites. However, disturbances resulting from fire or vegetation management can provide opportunities for invasion in most kinds of dominant vegetation. Hundreds of nonnative plant species occur in the Northern Rockies, the most serious of which are described in table 8.8.

Xeric grasslands and shrublands are highly vulnerable to establishment of nonnative species (see chapter 7). Many of the native plants in Northern Rockies grasslands are perennials that tolerate environmental variability over long time scales versus the life history strategies of weedy invasive species (Grime 1977; MacArthur 1967). Whether natives or nonnatives benefit, or more specifically, which natives or nonnatives benefit, will likely depend on the specific ways in which climate change plays out.

If temperature increases but precipitation does not, this will likely reduce resource availability and increase stress, potentially favoring native species. Projections of the effects of climate change needs to consider how nonnative plants respond, as well as how recipient communities and their invasibility may change. Many successful nonnatives flower later and have different phenologies than natives, allowing nonnatives to potentially exploit an empty niche (Pearson et al. 2012). Therefore, nonnatives may increase if this niche expands with climate change, or decline if the niche is disrupted.

Invasive species primarily spread into disturbed areas with sufficient bare ground and sunlight for germination and establishment, although some species such as spotted knapweed, houndstongue (*Cynoglossum officinale*), yellow sweet clover (*Melilotus officinalis*), and yellow toadflax (*Linaria vulgaris*) can readily establish in undisturbed plant communities. Non-forested vegetation (e.g., shrublands, grasslands) has been invaded in many areas of the Northern Rockies and Northern Great Plains (see chapter 7). As fires and other disturbances increase in intensity and frequency, invasive species can occupy and potentially dominate native plant communities that were previously resistant to invasion, although numerous factors such as fire resistance of native species, propagule availability, and variation in burn severity can affect establishment (Zouhar et al. 2008). Native and domestic livestock grazing and browsing of native species can reduce plant vigor and open up sites for establishment of invasive species. Silvicultural prescriptions that decrease canopy cover also increase the likelihood that invasive species may establish and increase in both cover and density, although subsequent succession may suppress those species as canopy closure returns.

Climate change is likely to result in a range of responses among invasive species, due to differences in their ecological amplitude and life history strategies (table 8.9). Bioclimatic envelope modeling

indicates that climate change could result in both range expansion and contraction for five widespread and dominant invasive plants in the western U.S. Yellow starthistle (*Centaurea solstitialis*) and tamarisk are likely to expand, whereas leafy spurge (*Euphorbia esula*) is likely to contract, and cheatgrass and spotted knapweed are likely to shift in range, leading to both expansion and contraction (Bradley 2009; Bradley et al. 2009). Invasive species are generally inherently adaptable and capable of relatively rapid genetic change, which can enhance their ability to invade new areas in response to ecosystem modifications (Clements and Ditomaso 2011), including short-term disturbance (fire) or long-term stressors (e.g., prolonged drought, increased temperatures, chronic improper overgrazing). Increased concentrations of CO_2 in the atmosphere have been shown to increase the growth of weed species, which could have an influence on their invasiveness (Ziska 2003).

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Chapter 9: Climate Change and Wildlife in the Northern Rocky Mountains

Kevin S. McKelvey and Polly C. Buotte

HOW CLIMATE AFFECTS WILDLIFE

Temperature and moisture affect organisms through their operational environment and the thin boundary layer immediately above their tissues, and these effects are measured at short time scales (fig. 9.1). When a human (a mammal) wearing a dark insulative layer walks outdoors on a cold but sunny day, s/he feels warm because the sun energy is interacting with the dark clothing, creating a warm boundary layer to which his/her body reacts. Conditions beyond that thin boundary layer are physiologically irrelevant. Walk into the shade, and suddenly one is cold because the warm boundary layer has been replaced with one at the ambient temperature of the air. This example demonstrates a number of factors to consider when evaluating the degree to which a change in climate will affect an organism. Climate is defined as the long-term average of temperature, precipitation, and wind velocity. "Long term," when applied to climate, is a relative term and can refer to periods of weeks to centuries. In the context of climate models, results are generally reported as averages across 30-year intervals, which for many animal species represents multiple generations. Our ability to infer the biological effects of projected long-term changes in temperature and precipitation relies both on our abilities to directly relate these multi-year averages to biological responses, and the trophic distance between climate-induced ecological change and its effects on specific biological relationships.

As noted above, a human's response to change in radiant energy is fast, measured in seconds to minutes, so its relation to 30-year average temperature is obscure. Climate changes the frequency of weather events, which in turn change the frequency of nearly instantaneous shifts in boundary layer conditions around one's body. In aggregate, these changes in frequency either lead to conditions that you can navigate or tolerate or not. This is further complicated for endotherms (warm blooded animals) which maintain a constant body temperature. Cold or excessive heat affects endotherms by requiring them to

burn more calories to maintain the required core temperature. Thus, endotherms can function in a wide variety of environmental conditions if they have enough food to supply the necessary energy. Endotherm physiology responds directly to a change in temperature, whereas effectiveness and sustainability of the physiological response is related to the quality and quantity of available food. Fish, reptiles, and amphibians are ectotherms (cold blooded), which react to the cold not by feeling cold and metabolizing energy to maintain core temperature, but by having their metabolism slow until they are torpid.

Many of the species described here occupy terrestrial habitats. Terrestrial organisms can manipulate their operational environment in a myriad of ways, choosing to stand in the sun or shade, moving uphill or down, changing aspect, or seeking cooler or warmer environments by digging into a burrow in the ground or under the snow. Endothermic animals can change the thickness of the boundary layer by modifying their hair or feathers, both seasonally and on a short-term basis, thus responding to variable thermal conditions while minimizing energy expenditures. The ability of terrestrial organisms to manipulate their operational environment contrasts with aquatic organisms that have a harder time avoiding adverse temperatures because water is an excellent conductor of heat. In addition, aquatic ectotherms have no way to avoid overheating when water temperatures rise, so it is more straightforward to evaluate the effects of climate change for fish with known warm-water limits than it is for terrestrial endotherms (see chapter 5).

Due to the flexibility of terrestrial endotherms in dealing with changes in temperature, these species are more likely to experience effects associated with changes in precipitation amounts and types, because water produces physical features that serve as habitat. In the Northern Rockies, and in other areas with cold winters, snow provides physical habitat for which a number of organisms have specific adaptations. An obvious adaptation is seasonal color change in pelage: being white in a snowy landscape enhances the likelihood of escaping detection if you are prey, and approaching prey if you are a predator. Therefore, white pelage in winter confers specific fitness advantages if pelage change is properly timed to coincide with snow cover, but is a disadvantage if mistimed (see discussion of snowshoe hare [*Lepus americanus*] below) (fig. 9.2). Specific morphological features such as oversized feet, long legs, and light bone

structures also provide benefits in snow-covered landscapes but may be disadvantageous in environments without snow.

Deep snow provides a relatively warm, stable environment at the interface between snow and soil; soils in areas characterized by deep snow generally remain above freezing throughout the winter (Edwards et al. 2007), and the subnivean environment (beneath the snow surface) is used by many organisms to den or feed. For organisms that depend on a stable subnivean environment, or who have specific phenological adaptations to snow, reduced snowpack caused by a shift in precipitation from snow to rain represents a loss of critical habitat (see discussion of American pika [*Ochotona princeps*] below). Similarly, water bodies provid physi al habitats for a wide variety of animals, providing features such as safety from predation, temperature con ol, and sources of prey. In addition, open or flowing water can provide important microclim or ex mple, pika can be found in what appear to be hot, dry environments if water flow beneath he talu produ es cool microsites (Millar and Westfall 2010a).

Physical features associated with snow nd water int g te across longer time periods and are therefore closely associated with projected climate. F r e ample, depth of snowpack integrates seasonal moisture and temperature. Seeps, springs, bogs, and pe istent treams d pendent on continuous sources of groundwater can integrate longer climatic periods. In some areas, water fe tures are dependent on glaciers, which integrate seasonal weather and long-term climate. Therefor areas ith these features and the species that depend on them are vulnerable to climate change, rea ting at time scales reasonably consistent with the temporal projections of global climate models (GCM) and providing opportunities to project effects on habitats and species.

As noted above, terrestrial endotherms have many options for controlling both their operational environments and the physiological effects of these environments. Terrestrial plants are stationary ectotherms, and lacking the behavioral and physiological plasticity of endothermic animals, are more directly affected by climate changes (see chapter 6). Therefore, climate effects on wildlife will frequently occur due to changes in plant assemblages that comprise wildlife habitat (fig. 9.1). For predators, these effects may be either direct (e.g., changes in the number and locations of vegetation boundaries used by

predators) or indirect through changes in prey densities or prey availability to predators. Climate-induced changes in trophic structures are expected to be common, complex, and interactive, but are at least one step removed from climate (e.g., Post et al. 1999).

The effects of these changes on a specific animal are difficult to project and require specific understanding of the functional roles that ecological attributes play in the animal's life history, and the consequences associated with alternative life history strategies. These types of data are often lacking, and although current behaviors can be studied, they may not be informative relative to climate change effects, and responses may be novel and unanticipated. For example, polar bears (*Ursus maritimus*) are historically adapted to pack-ic hunti g for seals, but with recent reductions in pack ice, they have in some areas shifted to fe ing on the eg s of snow geese (*Chen caerulescens*) (Rockwell and Gormezano 2009), whose populations ha pted because of their ability to feed in agricultural fields (Fox et al. 2005).

In addition to changes in vegetation and prey, trophi e fects include the presence and abundance of disease and parasitic organisms. For example, for gr ter age-grouse (*Centrocercus urophasianus*), the potential spread of West Nile virus (*Flavivirus* spp.) as ociated with climate change may increase stress in grouse populations (Schrag et al. 2011), but the effect is difficult to project. F r many organisms, current ranges are often strongly limited by human activities. For example, greater age-gr use range is limited by conversion of native sagebrush (*Artemisia* spp.) habitat to agricult ral uses (Connelly et al. 2004; Miller and Eddleman 2001).

Climate change is likely to alter the nature and location of human activities that affect wildlife. In the western United States, changes in water availability and the amounts required for irrigation can be expected to have profound effects on human activity and settlement patterns (Barnett et al. 2005). In addition, societal effects associated with local changes will occur within the context of societal changes across much larger spatial domains. Changes in technology, standards of living, infrastructure, laws, and the relative effects of climate changes in other areas will all affect local human activities.

In summary, the ways that climate change affects endothermic terrestrial species are likely to be complex and difficult to project. In addition to the uncertainty of future climate itself (see chapter 3), effects on most species will be indirect through proxies such as ecological disturbance, habitat structure, prey availability, disease dynamics, and shifts in human activities.

THE IMPORTANCE OF COMMUNITY IN DEFINING HABITAT

Our understanding of wildlife ecology, particularly at broad spatial scales, is generally limited to the correlation of occurrence patterns rather than direct studies of those factors that limit species distributions. In some cases, patterns of occurrence are clear, consistent, and highly correlated with climate (see section on wolverine [*Gulo gulo*] belo), bu the causal relationships remain obscure. Many passerine birds, for example, nest only in sp cific habitats uch as Brewer's sparrow (*Spizella breweri*) (see section below), which is obligate to sagebrus Al hough the pattern is clear and invariant, the nature of the obligate links to sagebrush are unknown. Species such as ruffed grouse (*Bonasa umbellus*) (see section below) clearly have northern distributions, but the factors that define th southern limits of their current distributions are not well understood (Lowe et al. 2010).

This lack of causal understanding may be unimpor ant for current management of these species, because management occurs only in areas where they currently exist or wher they existed in the recent historical past. Based on observed patterns of use and distribution, enough nforma ion exists to identify and manage current habitat. However, it cannot be assumed that mea red correlations will persist in an altered climate. We typically characterize habitat elements that exist in assemblages of mostly unmeasured plants and animals. Assume that an organism's occurrence is strongly correlated with mature Douglas-fir (*Pseudotsuga menziesii*) forests. These forests contain other specific tree and understory species, animal communities, and successional trajectories (e.g., habitat types; Daubenmire [1952]). However, Douglas-fir projected onto a future landscape may be associated with different plant and animal communities. Due to the correlational nature of most of our habitat knowledge, it is difficult to know which of these community members are critical to habitat quality of a target species and thus the habitat quality of novel species assemblages.

11823 In addition, factors identified as important are restricted to those that currently limit behavior.
11824 Therefore, in correlation-based habitat relationships, changes in non-limiting but essential factors will not
11825 produce strong correlations with behaviors. For example, distance to water may be a strong habitat
11826 correlate in desert environments but may not be correlated with habitat quality in a rainforest. Water may
11827 be no less important in the rainforest, but it is currently not limiting. As climate change alters biophysical
11828 attributes of landscapes, limiting factors and definitions of what constitutes habitat may change.
11829 In addition to potentially changing vegetation communities and limiting factors, the effects of climate
11830 on future habitats are further complicated by altered disturbance regimes. Regeneration, growth, and
11831 disturbance patterns collective y crea landscapes that provide habitats. Changing disturbance dynamics
11832 (see chapter 8) alter the haracteristics f landscape mosaics and fundamentally alter habitats. As climate
11833 change causes shifts in plant d nimal distributions, a temporal mismatch between decrease of current
11834 habitat and increase of new habitat may occur, a mismatch that will be exacerbated by increased levels of
11835 disturbance. Wildfire can destroy current habitat in a day, but generation of new habitat may require
11836 centuries, depending on the time necessary to create critical elements through regeneration, growth, and
11837 succession. The fisher (*Martes pennanti*) provides an example of these uncertainties. In Idaho and
11838 Montana, fishers are currently limited to mature forests in the Inland Maritim climatic zone. However,
11839 GCMs indicate that this zone will move to the east, and mature forest may quire century or more to
11840 grow in this location, creating uncertainty about the future range of fi her (see discussion below).
11841 Given the uncertainty associated with determining likely trajectories of species and their habitats
11842 under climate change, assessments of general vulnerability and projected changes can be viewed as
11843 hypotheses to be tested. Therefore, it is desirable to develop a trajectory focused on proactive
11844 management strategies that maintain valued species and landscape attributes, including objectives such as
11845 creating resilience to disturbance. Prioritizing which things are measured can improve the connection
11846 between environmental change and management. A monitoring program designed to test specific
11847 hypotheses associated with specific organisms (Nichols and Williams 2006) can improve our

understanding of relationships between climate change and landscapes, providing data that inform science-based management.

EVALUATING SPECIES SENSITIVITY TO CLIMATE CHANGE

Evaluating the potential effects of climate change on animal species begins with determining which species are of interest, collecting biological information about them, and paying special attention to biological traits that might lead to changes in distribution and abundance in a warmer climate (e.g., Glick et al. 2011). Some species have received significant attention and have generated peer-reviewed articles that formally analyze the effects of climate change, although this is relatively uncommon.

Foden et al. (2013) identif three dimensions associated with climate change vulnerably—sensitivity, exposure, and adaptive pacity—and pply a framework based on assessing these attributes to nearly 17,000 species. Other expert t ms have been developed to evaluate the relative degree of climate sensitivity and vulnerability for various species including the Climate Sensitivity Database (http://climatechangesensitivity.org) and NatureServe Climate Change Vulnerability Index (http://www.natureserve.org/conservation-tools/climate change-vulnerability-index). These tools do not seek to understand specific responses of animals to climate, but rather to identify species that are likely to be vulnerable based on current habitat associations, life history traits, and distributions (Foden et al. 2013). Bagne et al. (2011) formalized this process in the System for Assessing Vulnerability of Species (SAVS) to climate change. In SAVS, species are assessed based on a large number of traits associated with habitat (7 traits), physiology (6 traits), phenology (4 traits), and biotic interactions (5 traits). For each of these 22 traits, a score of -1, 0, or 1 is assigned; positive scores indicate vulnerability, and negative scores indicate resilience. The raw scores are multiplied by correction factors associated with the number of traits in a category and possible scores across traits, to achieve a standardized score between -20 and 20 that indicates the relative vulnerability of the species.

Formalizing traits that can lead to vulnerability provides a framework for collecting biological data associated with a species and for considering the effects of climate change. However, existing expert systems cannot be used to infer that sensitivities for disparate topics such as habitat and phenology are

proportionally important or if estimated vulnerability has quantitative meaning (Bagne et al. 2011; Case et al. 2015). Even if these issues were considered unimportant, for most of the species evaluated below, accurately identifying vulnerability (Foden et al. 2013) would not be possible given current biological understanding. Since data on climate-species relationships are so sparse, this assessment focuses primarily on evaluation of each trait as it relates to the biology of animal species.

Below are assessments for animal species identified as high priority by Forest Service, U.S. Department of Agriculture Northern Region resource specialists, and for additional species identified by participants in five workshops convened by the Northern Rockies Adaptation Partnership (see chapter 1). Species were not necessarily c osen ased on their perceived level of vulnerability. In many cases, species are associated w h specific hab tats that were considered vulnerable; for example, some species are associated with sagebrush munities, others with snow depth and cover, et al. with dry forests that have large trees. The assessment summaries below contain projections of climate change effects based on interpretation of the pertinent literature. Level of detail differs considerably among species and is mostly driven by the degree to which the species have been evaluated in the context of climate change. Species are listed in alphabetical order within each taxonomic class.

American Beaver (*Castor canadensis*)

Since beavers tend to spend most of the winter in their lodges or swimming to retrieve food, climate may be more influential during spring through autumn than during winter (Jarema et al. 2009). However, body weights of juvenile European beavers were lighter when winters were colder (Campbell et al. 2013). The cost of thermodynamic regulation may be greater for juveniles because they have higher surface area-to-volume ratios than adults (on whom winter temperature had no effect) (Campbell et al. 2013).

In Quebec (Canada), beaver density was highest in areas with the highest maximum spring and summer temperatures (Jarema et al. 2009). Conversely, European beavers in Norway achieved heavier body weights when spring temperatures were lower, and the rate of vegetation green-up was slower (Campbell et al. 2013). This apparent contradiction may have been caused by the timing and measurement of climate and response variables. Although beavers create and require ponds, survival and

11900 body weight in European beavers has been linked to lower, and more consistent, April-September
11901 precipitation (Campbell et al. 2012, 2013). Higher water levels during high precipitation years were
11902 thought to lead to decreased riparian plant growth caused by waterlogging (Campbell et al. 2012).
11903 Climate can indirectly influence beavers through effects on vegetation. Climate change and climate-
11904 driven changes in streamflow are likely to reduce an abundance of dominant, early-successional tree
11905 species in riparian habitats (Perry et al. 2012), reducing food and building materials for beaver. Beavers
11906 can be used as a management tool to buffer riparian systems from drought (Lawler 2009) (fig. 9.3).
11907 Beaver ponds increase the amount of open water (Hood and Bayley 2008), and beaver management can
11908 be used as a surrogate for amp ibian onservation (Stevens et al. 2007).

11909 **Ame ican Pika (*Ochotona princeps*)**

11910 The American pika is a s ll (5-8 oz) lagomorph that often inhabits rocky alpine areas in western
11911 North America (Smith and Weston 1990) (fig. 9.4). The species has been extensively studied in the Great
11912 Basin where pika habitat typically occurs as small islands near mountaintops. Relatively little study of
11913 pikas had occurred in the Northern Rockies until recently, with the exception of research on occupancy
11914 and abundance in relation to microclimate, topography, and vegetation in the Bighorn Mountains and
11915 Wind River Range (Wyoming) (Yandow 2013). Currently, studies are in process in the Bridger-Teton
11916 National Forest and Greater Yellowstone Area (Beever, U.S. Geological Survey, Northern Rocky
11917 Mountain Science Center, personal communication).
11918 Pikas appear to depend on moist, cool summer conditions and winter snow (Beever et al. 2011), and
11919 on low water-balance stress and green vegetation (Beever et al. 2013). Across paleontological time scales
11920 (Grayson 2005) and during the 20th century, pikas across the Great Basin have reacted to increasing
11921 temperature by moving upslope or becoming locally extirpated when the climate becomes hot and dry
11922 (Beever et al. 2011). Results from field research in 2012-2014 in the Great Basin indicate that local
11923 extirpations and retractions are continuing (Beever, U.S. Geological Survey, Northern Rocky Mountain
11924 Science Center, personal communication). Local changes in pika distribution have also been recorded in

Utah, the southern Sierra Nevada, and southern and central Cascade Range (Beever et al. 2011 and references therein).

In the Great Basin, pika extirpation (1994-2008) occurred in microsites that were generally hotter in summer (more frequent acute heat, and hotter average temperature across the whole summer) and were more frequently very cold in winter than in locations where pikas persisted. In the latter case, warming reduced insulating snow, causing temperatures near-ground temperature to decrease (Beever et al. 2010). Furthermore, density of pikas in surveys during 2003-2008 was best predicted by maximum snow-water equivalent and growing-season precipitation (Beever et al. 2013). Some extirpations have occurred at sites with low annual precipit ion (B ever et al. 2011, 2013), reinforcing studies in the southern Rocky Mountains (mostly Colo ado), where s rveys indicated that four pika extirpations (among 69 total sites with historical records) occur d the driest sites (Erb et al. 2011).

Winter snowpack not only insulates pikas during cold periods, but also provides water during the summer, when plant senescence at drier sites occurs earlier in the year, eliminating available metabolic water for pikas. Surveys, mostly in the Sierra Nevada, found that pika extirpations were associated with sites with higher maximum temperatures and lower annual precipitation (Millar and Westfall 2010b). Chronic stresses (average temperature during summer, maximum snowpack, and growing-season precipitation), acute temperature stresses (hot and cold), and vegetation productivity appear to affect pika declines in the Great Basin (Beever et al. 2010, 2011, 2013).

Individual mountain ranges are believed to act as discrete areas without any pika migration between adjacent ranges across valley bottoms (Castillo et al. 2014), although disjunct metapopulations of pikas separated by short distances may exist. In a study of pika populations in ore dumps separated by tens to hundreds of yards, individual populations that were extirpated were recolonized, and abundance across all ore piles remained constant (Smith 1980). This process appears to occur only at very short distances because habitats isolated by more than 1150 ft were generally unoccupied, although populations in the southern group of ore piles subsequently collapsed. Connectivity of pika populations appears to be context dependent, with lower connectivity between sites that occur in hotter, drier landscapes (Castillo et

11951 al. 2014; Henry et al. 2012). Thus, recolonization may occur at distances less than 0.5 mi and in areas
11952 where between-population dispersal occurs within cool, moist landscapes, whereas recolonization at
11953 longer distances is rare. In the Great Basin, across 21 years of contemporary research, once pikas have
11954 been extirpated from a site, they have never been detected in subsequent surveys (Beever et al. 2011).
11955 At the broadest spatial scales, there is genetic evidence for historical isolation in which pikas across
11956 the Intermountain West separate into five distinct groups (Galbreath et al. 2010). At smaller scales, in
11957 British Columbia, inbreeding and high levels of genetic structure exist between high- and low-elevation
11958 populations, even when the populations are geographically proximal. Castillo et al. (2014) found that
11959 gene flow is restricted primaril by to ographic relief, water, and west-facing aspects, suggesting that
11960 physical restrictions rela ed to small bo y size and mode of locomotion, as well as exposure to relatively
11961 high temperatures, limited pik di persal.
11962 Studies in the Sierra Nevada (Millar and Westfall 2010a,b) and southern Rocky Mountains (Erb et al.
11963 2011), at sites in which pikas were common and not generally subject to extirpation across most of the
11964 landscape, indicated that physiological limits for this species had not been reached. This will probably be
11965 the case for most pika populations in the Northern Rockies in the near term. Although hot, dry climate
11966 may limit pika distributions, local moisture sources, rock-ice features, aspect, and the physical structure of
11967 talus fields may climatically buffer pikas from macroclimatic stresses (Millar and Westfall 2010a).
11968 Existence of pikas at Lava Beds National Monument, Craters of the Moon National Monument, and the
11969 Columbia River Gorge—all of which have warm, dry climate—underscore the importance of
11970 microclimate for species vulnerability assessments, and indicate that microclimate and macroclimate are
11971 decoupled in some locations (Rodhouse et al. 2010; Simpson 2009; Varner and Dearing 2014).
11972 Since pikas are sensitive to high temperature, we expect that pika populations will respond to climate
11973 change in the Northern Rockies. However, site-specific factors contribute to highly variable
11974 microclimates, so response to climate change will vary considerably over space and time. A large amount
11975 of data has been collected on this species over the past decade, and it should be possible to develop more
11976 accurate projections of population response as monitoring data continue to accrue.

Canada Lynx (*Lynx canadensis*)

The Canada lynx is a mid-sized cat with a number of specific adaptations that allow it to travel across soft snow. The most obvious adaptation is oversized feet: foot loading is 0.5 times that of the similar sized bobcat (*L. rufus*) (Buskirk et al. 2000). Canada lynx prey nearly obligately on snowshoe hares (*Lepus americanus*) (fig. 9.2). Not only do snowshoe hares constitute 33-100 percent of lynx diet (Mowat et al. 2000), but a low proportion of hares in the diet indicates scarcity of hares, not diet plasticity (Mowat et al. 2000). Studies of lynx winter diet in the Clearwater River watershed (western Montana) found 94-99 percent of the diet consisted of snowshoe hare (Squires and Ruggiero 2007). Snowshoe hares are also specially adapted to snowy en ronm nts. When compared to similar sized leporids, they have oversized feet. They also exhibit s asonal pelage hange from brown to white. Due to the close association between lynx and hares, and because b th pecies have specialized adaptations to allow survival in snowy environments, climate relationships for both species are explored in this section.

Canada lynx is found exclusively in North America, its distribution extending across the interior of Canada and Alaska and northward into tundra vegetation. In the conterminous United States, both current and likely historical populations are located in the extreme northern portions of this region: Maine, historically New York and New Hampshire, Minnesota north of Lake Superior, western Montana, and northern Washington (McKelvey et al. 2000). Periodically, in the years immediately following major population eruptions in the north, lynx distributions expand and lynx are found ephemerally in North Dakota, and populations temporarily increase in Montana (McKelvey et al. 2000). Since bobcats (*Lynx rufus*) and lynx were not well differentiated in the fur market (Novak et al. 1987), with large bobcats often recorded as "lynx," trapping records are typically untrustworthy (McKelvey et al. 2000). Recently, a population was translocated to Colorado, and appears to be persisting; after initial high mortality rates, annual survival has exceeded 90 percent (Devineau et al. 2010). However, the historical evidence for lynx in Colorado is weak, with most of the verified records occurring in years consistent with immigration from the north (McKelvey et al. 2000). Hare densities in Colorado are generally less than the 0.5 hare ac^{-1}

12002 threshold (Ivan et al. 2014) thought to be the minimum hare density associated with stable lynx
12003 populations (Mowat et al. 2000).

12004 When evaluating the potential distribution of lynx, it is important to note that large populations of
12005 lynx are located in the interior of the continent. Lynx are common in Alberta and Saskatchewan (Canada)
12006 where over 20,000 were trapped per year in recent eruptions (Novak et al. 1987), but were rare along both
12007 the Atlantic and Pacific coasts. Lynx are more common in areas with a northern continental climate,
12008 probably because soft powdery snow is more common there.

12009 Maintaining population connectivity is central to lynx conservation. However, maintaining
12010 connectivity may become incr asingly difficult as southern populations of boreal species become more
12011 isolated with climate ch nge (van Oort t al. 2011). This is of particular concern because disturbance
12012 processes that include wildfir i ects, and disease make some boreal forests vulnerable to climate
12013 change (Agee 2000; Carroll et al. 2004; Fishlin et al. 2007; Fleming et al. 2002; IPCC 2007a,b; Logan et
12014 al. 2003).

12015 In the Northern Rockies, lynx exist in only a few areas: the Clearwater River watershed, Bob
12016 Marshall Wilderness, and northwestern corner of Montana. Dens are located in boulder fields and spruce-
12017 fir forests with high horizontal cover and abundant coarse woody debris. Eighty percent of dens are in
12018 mature forest and 13 percent in mid-seral regenerating stands (Squires et al. 2008). For winter foraging,
12019 lynx preferentially forage in mature, multilayer spruce-fir forests composed of larger diameter trees with
12020 high horizontal cover, abundant snowshoe hares, and deep snow (Squires et al. 2010). During summer,
12021 lynx occupy young forests with high horizontal cover, abundant total shrubs, abundant small diameter
12022 trees, and dense spruce-fir saplings (Squires et al. 2010). Lynx select home ranges with vegetative
12023 conditions consistent with those identified for foraging and denning, primarily at mid elevations (Squires
12024 et al. 2013). Assuming that preferences for movement between home ranges are similar to those
12025 associated with moving within the home range, dispersal pathways consist of areas with similar properties
12026 to those used for foraging (Squires et al. 2013).

12027 The range of snowshoe hare (Hall and Kelson 1959) is more extensive than that of lynx, extending
12028 into the mid Sierra Nevada and areas such as the Olympic Peninsula where there are no records of lynx
12029 occurrence (McKelvey et al. 2000). The more extensive hare distribution, which includes areas with
12030 limited snow (e.g., the Pacific coast), is likely caused by greater genetic differentiation for snowshoe
12031 hares than for lynx. Across the continent, lynx exist in a single, largely panmictic (random mating)
12032 population (Schwartz et al. 2004), whereas hares are subdivided into six subspecies (Wilson and Reeder
12033 2005).

12034 Hares exhibit variation in timing of pelage change across western North America, but variation is low
12035 in any specific location, and timing appears to be genetically controlled and linked to photoperiod (e.g.,
12036 Hall and Kelson 1959; Z mova et al. 20 4). Timing of pelage change is critical for hare survival, because
12037 mismatches—a white hare on d k background and vice versa—cause most hares to die from predation
12038 (Hodges 2000) (fig. 9.2). Initiation of pelage change appears to be driven by photoperiod rather than
12039 background color, so the ability of hares to shift the timing of pelage change to match patterns of snow
12040 cover is limited (Mills et al. 2013). Given projections of snow cover by 2100 (see chapters 3 and 4),
12041 current patterns of pelage change in the Northern Rockies will be mismatched with the period of snow
12042 cover. Unless a significant change occurs in the population genetics of hares, they will be the wrong color
12043 for approximately two months per year (one month in spring, one month in autumn) in the Northern
12044 Rockies (Mills et al. 2013).

12045 Both lynx and hares require specific amounts and duration of winter snow. An example of this for
12046 lynx occurs in Minnesota where current and historical populations are limited to the “arrowhead” north of
12047 Lake Superior (McKelvey et al. 2000; Schwartz et al. 2004). This area is characterized by lake-effect
12048 snow, and outside of it, bobcats dominate and lynx are not found. Both lynx and hares require forests with
12049 dense understory canopies. In western Montana, lynx and hares use older spruce-fir forests. If climate
12050 change and associated disturbance reduce the abundance of these forest types, habitat loss could be
12051 significant, reducing populations of lynx and hares.

12052 **Fisher (*Martes pennanti*)**

12053 The fisher is a mid-sized, forest-dwelling mustelid whose range covers much of the boreal forest in
12054 Canada, a broad area of the northeastern United States extending from the Lake States to Maine, and a
12055 scattered distribution in the western United States. Males and females are similar in appearance but the
12056 males are larger. Males are 35-47 in long and weigh 8-13 lb; females are 30-37 long and weigh 4-6 lb
12057 (Powell 1993).

12058 Fishers are common and often associated with urban environments in the eastern United States, but
12059 are uncommon in the western United States and appear to have very specific habitat associations.
12060 Although the current distribution of fishers is reduced from its historical range, its populations have
12061 typically been disjunct. Geneti studi s have shown that fisher populations in California have been
12062 historically isolated from those in Was ington, and fishers in the southern Sierra Nevada have been
12063 isolated from those in the Kla h region (Tucker et al. 2012). Fisher in Montana contains unique
12064 haplotypes (DNA variations that tend to be inherited together) not found elsewhere (Schwartz 2007;
12065 Vinkey et al. 2006) and therefore were apparently isolated both from large populations in northern British
12066 Columbia and coastal populations in Washington. Common attributes for resting sites across eight studies
12067 of Western fishers were: steep slopes, cool microclimates, dense forest canopy cover, high volume of
12068 logs, and prevalence of large trees and snags (Aubry et al. 2013). Although these features are important
12069 for managing fisher habitat, they do not necessarily explain the fragmented historical distribution in the
12070 West (Tucker et al. 2012).

12071 Fishers have long been thought to have specific climatic associations. Krohn et al. (1995) compared
12072 fisher and marten (*Martes americana*) distributions in the Sierra Nevada, and found that areas occupied
12073 predominantly by marten were closely associated with forested areas with the deepest snow (>9 in per
12074 winter month), whereas areas occupied predominantly by fishers were forested areas with low monthly
12075 snowfall (<5 in). There is direct evidence that fishers avoid deep snowpack (Krohn et al. 1995, 2005;
12076 Raine 1983) and that deep snow can limit fisher dispersal (Carr et al. 2007). Fishers also avoid dry
12077 habitats (Jones and Garton 1994; Schwartz et al. 2013).

12078 Presence in warmer, wetter forests appears to be common in both macro and micro distributions of
12079 fishers in the western United States, although large populations in northern interior British Columbia and
12080 Alberta are not associated with these specific climates. Therefore, defining fisher habitat in climatic terms
12081 and projecting future habitat is more challenging than for animals with more obvious climatic associations
12082 (Copeland et al. 2010; McKelvey et al. 2011).

12083 In a recent modeling study of fisher habitat in an area consistent with its distribution in the Northern
12084 Rockies, Olson et al. (2014) built occurrence models for fisher populations in northern Idaho and western
12085 Montana that included variables such as canopy cover, climatic variables such as minimum winter
12086 temperature, and topographic ariabl such as slope. They found that most of the variability in the model
12087 was explained by mean nnual precipit tion (34 percent), topographic position index (29 percent), and
12088 mean temperature of the cold t onth (27 percent). Therefore, fisher habitat was projected to be best in
12089 areas with high annual precipitation, low relief, and mid-range values for mean temperature in the coldest
12090 month. Krohn et al. (1997) and Olson et al. (2014) both projected similar areas of fisher habitat and in
12091 similar places.

12092 Olson et al. (2014) used downscaled data from a single GCM (Collins et al. 2001; Hadley Centre
12093 Coupled Model, version 3; HCCM3) and two emission scenarios (A2-high, B2-low) (IPCC 2007b),
12094 projecting habitat for 2030, 2060, and 2090. At the macro scale, results for both scenarios are similar: in
12095 the near term, habitat currently occupied by fishers might improve, but by 2090, habitat in areas that are
12096 currently occupied (primarily central Idaho) decline sharply, and new habitat is created in to the east in
12097 northwestern Montana. The main difference between the scenarios at this level of detail is the rate at
12098 which changes occur. In the A2 scenario, the change is visibly apparent by 2060, but not for the B2
12099 scenario. As habitat shifts, it becomes increasingly fragmented, and the amount of usable habitat is
12100 strongly affected by how acceptable minimum patch size is defined (Olson et al. 2014).

12101 Olson et al. (2014) bracketed the emission scenarios, providing some measure of the potential range
12102 of results, but between-model variability exceeds variability between emission scenarios. In addition, the
12103 performance of specific GCMs varies considerably at the regional scale (Mote and Salathé 2010), and the

12104 Hadley family of GCMs is considered to be on the hot-dry side of climate projections for the Northern
12105 Rockies (Alder and Hostetler 2014). As a result, details within the model can influence patterns of
12106 projected habitat.

12107 Additional uncertainties exist about the ability of habitat components to track climate. Given that
12108 fishers are associated with mature forests, significant time lags may exist between the loss of current
12109 habitat and formation of new habitat in areas that currently are unsuitable. If large trees cannot survive the
12110 shift in climate, mature forests may become rare for many decades. In climatic zones suitable for fishers,
12111 forests may be dominated by young trees and shrubs whose suitability for fisher habitat is unknown.
12112 Therefore, projections in Olso et al. (2014) are an optimistic view of habitat availability under climate
12113 change, and it is uncerta n if fishers wo ld disperse into new habitat should it occur.

12114 **Moose (*Alces alces*)**

12115 A number of species fall into categories for which the effects of climate change are apparent, but
12116 difficult to assess, including species whose ranges are clearly northern but for which the southern range
12117 limitations are not linked either to physiological constraints or to specific vegetative communities. Some
12118 organisms with broad historical distributions are currently limited to northern distributions because of
12119 southern extirpation, such as gray wolves (*Canis lupus*) and brown bears (*Ursus arctos*). These species
12120 are considered to be climate limited, although human populations are low in boreal forests and tundra, and
12121 interaction with large carnivores is minimal. Were climates to warm, and people to relocate into these
12122 northern systems, this would obviously affect species such as wolves and brown bears.

12123 For other species whose northern ranges are not defined by human impacts, both direct and indirect
12124 climate limits may not have been identified. Moose provide an example of a well-studied animal that has
12125 a northern distribution but whose dependency on boreal environments is not immediately obvious. We
12126 suspect that other species with northern distributions may exhibit similar constraints that define the
12127 southern extents of their ranges.

12128 A limited amount of climate change research has been conducted on moose (Murray et al. 2006,
12129 2012). Several factors have been identified as influencing the biogeographical distribution of moose

including food supply, climate, and habitat. Based on metabolic research, moose are intolerant of heat but well adapted to cold, and summer temperatures may define their southerly distribution (Renecker and Hudson1986). When winter temperatures were >23 °F or summer temperatures were >57 °F, moose experienced an increase in metabolism and heart and respiration rates (Renecker and Hudson 1986, 1990), reduced feed intake (Belovsky and Jordan 1978; Renecker and Hudson 1986), and reduced body weight (Renecker and Hudson 1986). When ambient air temperatures exceeded 68 °F moose resorted to open-mouthed panting to regulate core body temperature (Renecker and Hudson 1986). Heat stress was particularly difficult in the spring when moose were still in their winter coats (Schwartz and Renecker 1997). These temperature thresholds represent physiological thresholds that, when exceeded, represent heat stress that increases the energy expenditure needed to stay cool.

However, it is unknown if moose are able to avoid being exposed to high mid-day summer temperatures. In Minnesota, Lenarz et al. (2009) found that temperature was highly correlated with moose survival, but winter temperature was more critical than summer heat. High temperatures in January were inversely correlated with subsequent survival and explained >78 percent of variability in spring, fall, and annual survival. In northern Minnesota, moose populations were not viable, largely because of disease and parasite related mortality (Murray et al. 2006). However, in nearby southern Ontario (Canada), moose populations appeared to be viable with favorable growth rates (Murray et al. 2012). Warming temperatures favor white-tailed deer (*Odocoileus virginianus*) expansion into moose range, and increased transmission of deer parasites to moose (Lankester 2010), although separating direct and indirect climate effects is difficult (Murray et al. 2012).

Northern Bog Lemming (*Synaptomys borealis*)

As the name implies, northern bog lemmings inhabit wet meadows, bogs, and fens within several overstory habitat types (Foresman 2012). Generally these places have extensive sphagnum (*Sphagnum* spp.), willow (*Salix* spp.), or sedge components. These mammals likely occupy places that retained high water levels after the last glacial retreat (Foresman 2012). Given their dependence on wet habitats, it follows that climate changes that decrease the amount of surface water will likely have negative impacts

12156 on northern bog lemmings. Management practices that maintain surface water may therefore be
12157 beneficial. However, documented studies of climate and management effects are lacking.

12158 **Pronghorn (*Antilocapra americana*)**

12159 The pronghorn (*Antilocapra americana*) is an ungulate native to the prairies, shrublands, and deserts
12160 of the western United States occupying a broad range of climatic conditions from southern Canada
12161 (Dirschl 1963) to Mexico (Buechner 1950). Although pronghorns occupy a broad climatic region and
12162 their diet is generalized, they are prone to epizootic diseases, notably bluetongue (a viral disease
12163 transmitted by midges [*Culicoides* spp.]) (Thorne et al. 1988). Bluetongue is thought to be cold weather
12164 limited, and recent extensions of bluetongue in Europe have been attributed to climatic warming (Purse et
12165 al. 2005). Given their current range and food habits, the emergence of new disease threats caused by a
12166 warmer climate probably poses the greatest risk to pronghorns.

12167 **Pygmy Rabbit (*Brachylagus idahoensis*)**

12168 The pygmy rabbit is one of the smallest leporids in the world and is endemic to big sagebrush
12169 (*Artemisia tridentata*) (Katzner and Parker 1997), which is critical for food and cover. In southeastern
12170 Idaho, areas selected by pygmy rabbits had a significantly higher woody cover and height than other
12171 areas, with lower quantities of grasses and higher quantities of forbs. Sagebrush was eaten throughout the
12172 year, comprising 51 percent of the diet in summer and 99 percent in winter (Green and Flinders 1980).
12173 These findings are similar to those reported for southern Wyoming (Katzner and Parker 1997) and Utah
12174 (Edgel et al. 2014). In addition, areas used by pygmy rabbits accumulate more snow than unused areas,
12175 and rabbits use the subnivean environment to access food and avoid predators (Katzner and Parker 1997).
12176 The presence of significant snow for thermal protection may be important for winter survival, because of
12177 small body size, lack of metabolic torpor, and lack of food caching (Katzner and Parker 1997).

12178 Structural characteristics of sagebrush are considered more important than food availability for
12179 pygmy rabbits (Green and Flinders 1980; Katzner and Parker 1997). Although large, dense sagebrush
12180 would seem to be associated with older stands, Edgel et al. (2014) found no difference in age between
12181 occupied and unoccupied sites; structure was important, but age was not. As a result, processes that

12182 reduce the size and density of sagebrush are likely to have negative effects on pygmy rabbits, and
12183 processes that fragment sagebrush stands may decrease habitat quality. For example, Pierce et al. (2011)
12184 found that burrows, observed rabbits, and fecal pellets decrease in density with proximity (<300 ft) to
12185 edges.

12186 Paleoecological studies show that both sagebrush and pygmy rabbits are sensitive to climate change.
12187 Both species decreased in the mid-Holocene, characterized in the Great Basin by extreme aridity
12188 (Grayson 2000). Big sagebrush is sensitive to fire, and 100 percent mortality and complete stand
12189 replacement after burning are common (Davies et al. 2011; see chapter 7). In addition, big sagebrush
12190 cannot resprout from the root crown after a fire, so recruitment of sagebrush relies on wind dispersal of
12191 seeds from adjacent seed sources, and on composition of the seed bank in the soil (Allen et al. 2008;
12192 Ziegenhagen and Miller 2009). Mountain big sagebrush (*A. tridentata* ssp. *vaseyana*) required 13-27
12193 years after spring prescribed burning to return to conditions suitable for pygmy rabbit habitat (Woods et
12194 al. 2013). In areas where fire has been suppressed for many decades, sagebrush habitat can be displaced
12195 by conifer incursion (Miller and Rose 1999).

12196 Pygmy rabbits are likely to be sensitive to climate change for several reasons. First, they depend on a
12197 single species (big sagebrush) and habitat condition (tall, dense stands). Climatic variability has affected
12198 sagebrush communities and pygmy rabbits in the past (Grayson 2000), and this could happen again in the
12199 future. Second, pygmy rabbit habitat is sensitive to altered disturbance. Increased fire frequency and area
12200 burned are projected as the climate continues to warm (see chapters 6, 7, and 8). Finally, changes in
12201 winter snow depth could affect overwinter survival by altering the protection provided by the subnivean
12202 environment.

12203 **Townsend's Big-Eared Bat (*Corynorhinus townsendii*)**

12204 Climate change can affect foraging ability, drinking water availability, and timing of hibernation in
12205 bats (Sherwin et al. 2013). Townsend's big-eared bats generally require cavern-like structures for diurnal,
12206 maternal, and hibernation roosting, although they also use large tree cavities, buildings, and bridges
12207 (Gruver and Keinath 2003). They forage for insects along riparian and forest edge habitats (Fellers and

12208 Pierson 2002). Their distribution appears to be limited by the availability of suitable roosting sites, as
12209 western populations have declined (O'Shea and Vaughan 1999) coincidental with the closure of mines
12210 (Gruver and Keinath 2003). Townsend's big-eared bats are not able to produce highly concentrated urine
12211 (Geluso 1978) and therefore require daily access to water sources for drinking (Gruver and Keinath
12212 2003). Man-made water holes and mining ponds may serve as water sources (Geluso 1978), metal
12213 contaminants in the latter have may cause some bat mortality (Pierson et al. 1999).

12214 Bioaccumulation of pesticides in fat tissue appears to be one cause of declines in Townsend's big-
12215 eared bat populations (Clark 1988). Human activities that reduce moth populations can also negatively
12216 affect bat populations because moths are a primary food source of Townsend's big-eared bats (Burford
12217 and Lacki 1998; Whitaker et al. 1977). Bats may be especially sensitive to human disturbance during
12218 hibernation (Thomas 1995).

12219 In Colorado, the reproductive success of *Myotis* spp. declined during warmer and drier conditions,
12220 which are projected to be typical of future climate conditions (Adams 2010). However, in other instances,
12221 warmer spring temperatures have led to earlier births, which promotes juvenile survival (Lucan et al.
12222 2013). Higher summer precipitation may reduce reproductive success (Lucan et al. 2013). Future
12223 warming may also reduce the effectiveness of some bat echolocation calls (Luo et al. 2014).

12224 **Ungulates (Elk, Mule Deer, White-tailed Deer)**

12225 Rocky Mountain elk (*Cervus canadensis*), Rocky Mountain mule deer (*Odocoileus hemionus*
12226 *hemionus*) and white-tailed deer (*O. virginianus*) provide the core of big game hunting in the Northern
12227 Rockies. All three have very broad ranges in North America. The current range for elk, which includes
12228 most of the Rocky Mountain West, also includes areas in the eastern and southwestern United States that
12229 were historically occupied by other sub-species. Rocky Mountain mule deer extends from the Yukon
12230 (Canada) to northern Arizona. White-tailed deer extend across most of North America and into northern
12231 South America, including 38 recognized sub-species (De la Rosa-Reyna 2012).

12232 Based on their broad ranges, it is clear that all three species exhibit a high degree of flexibility
12233 towards habitat. Habitat use by elk in forested areas is associated with edges (Grover and Thompson

1986; Irwin and Peek 1983; Thomas et al. 1979, 1988) in which areas containing high quality forage and areas with forest cover are in proximity. In open habitats, they select areas of high vegetative diversity with intermixed patches of shrubs and grasslands (Sawyer et al. 2007). Both patterns of habitat use appear to be maximized by a disturbance regime with spatial heterogeneity at relatively fine scales.

A study of Rocky Mountain mule deer found that home range size increased in areas with few large patches and was smallest in fine-grained vegetation mosaics (Kie et al. 2002). Mule deer depend on disturbance to create forage (e.g., Bergman et al. 2014), but the size and juxtaposition of patches are important. Fine-grained disturbance mosaics appear to be optimal for white-tailed deer, especially in areas where thermal cover is important. In the Northern Rockies, thermal cover prevents heat loss during winter, although in warmer climates, thermal cover reduces daytime heating. In Texas, male white-tailed deer chose areas with high cover and poor foraging opportunities during the mid-day, but chose areas with higher forage quantities during crepuscular and nocturnal periods (Wiemers et al. 2014).

Ungulates generally respond positively to disturbance (fig. 9.5), but the types of disturbance and the resulting landscape condition and species composition are equally important. Just as wildfire intensity affects patchiness in the postfire landscape, it also affects which plant species are likely to revegetate burned areas. For example, Emery et al. (2011) found that at lower temperatures several native plant species exhibited enhanced germination, whereas nonnative plant species did not. Vegetation growth after disturbance is important where nonnative species are common. For example, Bergman et al. (2014) found that treatments that removed trees and controlled weeds produced better mule deer habitat than treatments that removed only trees.

Climate change is expected to alter fire regimes, but for ungulates the exact nature of those changes will be critical. For example, in the Greater Yellowstone Area subregion, wildfires are infrequent, large, and intense. If climate change causes more frequent fires (Westerling et al. 2011), then the landscape will be patchier compared to the current condition, and the distribution and abundance of forest species could change. In the short term, novel fire-climate-vegetation relationships can be expected. In the long-term,

12259 the effects of altered vegetation on ungulate populations are uncertain, but it is unlikely that there will be
12260 highly negative consequences.

12261 **Wolverine (*Gulo gulo*)**

12262 The wolverine is the largest mustelid, occurring throughout the Arctic, as well as subarctic areas and
12263 boreal forests of western North America and Eurasia. At the southern extent of its distribution in North
12264 America, populations occupy peninsular extensions of temperate montane forests. Monitoring programs
12265 in Fennoscandia (Flagstad et al. 2004) and surveys in Canada (Lofroth and Krebs 2007) inform our
12266 understanding of wolverine occurrence in those regions, but the limits of wolverine distribution in other
12267 portions of its range are less understood.

12268 Wolverines are often considered to be generalists with respect to habitat, and their occurrence has
12269 been associated with remoteness from human development (Banci 1994; May et al. 2006; Rowland et al.
12270 2003). However, unlike brown bear and gray wolf, whose northern distributions are the result of recent
12271 human hunting and habitat alteration, there is no historical evidence for wolverine presence in areas not
12272 characterized by arctic or boreal conditions (Aubry et al. 2007). Fossil evidence is consistent with this
12273 understanding (Alvarez -Lao and Garcıa 2010), and it appears that wolverines have always been
12274 associated with cold northern climates.

12275 Wolverines den in snow, and deep snow throughout the denning period is thought to be essential
12276 (Magoun and Copeland 1998). The strong, perhaps obligate relationship between wolverine den selection
12277 and deep snow in the late spring has been reinforced by recent studies (Copeland et al. 2010; Dawson et
12278 al. 2010; Inman et al. 2012). A proxy for spring snowpack (areas where snow persisted through mid May)
12279 effectively describes den site selection, current range limits, and year-around habitat use at the southern
12280 periphery of their range (Copeland et al. 2010). These same areas are associated with successful dispersal
12281 (Schwartz et al. 2009) and historical range (Aubry et al. 2007). Although not all biological aspects of this
12282 association are understood, its universal nature in both space (it applies to populations in Alaska, Idaho,
12283 and Scandinavia) and time (it describes both historical and contemporary distributions) indicate that snow
12284 persistence will be associated with future distributions as well. Since wolverines apparently travel within

12285 these areas when dispersing and strongly minimize travel through low-elevation habitat, we can project
12286 both current and future travel routes based on altered snowpack.

12287 McKelvey et al. (2011) modeled future spring snowpack within the Columbia, Upper Missouri, and
12288 Colorado River basins, and projected changes in habitat and connectivity associated with future
12289 landscapes based on existing wolverine habitat relationships (Copeland et al. 2010) and dispersal
12290 preferences (Schwartz et al. 2009). A projection derived from an ensemble mean of 10 GCMs under an
12291 intermediate emission scenario (A1B) (Mote and Salathé 2010) was used to produce climate projections
12292 (Elsner et al. 2010; Littell et al. 2011). Historical data across the area were reconstructed following
12293 methods in Hamlet and Lettenmaier (2005), and changes from historical patterns were modeled using the
12294 "delta" method of downscaling, resulting in regionally averaged temperature and precipitation change for
12295 2030-2059 and 2070-2099. Downscaled climate data were input to the Variable Infiltration Capacity
12296 (VIC) model (Hamlet and Lettenmaier 2005; Liang et al. 1994), which was used to project snowpack.
12297 Historical modeled snowpack depth was fit to most closely match the persistent snow cover data from
12298 Copeland et al. (2010), and this fit was then used to identify areas of future habitat for wolverines.

12299 In the Columbia and Upper Missouri River Basins, where most of the Northern Rockies is located,
12300 snowpack projection indicated a loss of 35 percent and 24 percent, respectively, for spring snow by the
12301 mid 21st century, and 66 percent and 51 percent, respectively, by the end of the century. Central Idaho
12302 was projected to lose nearly all snow by the end of the century, whereas northern Montana, the southern
12303 Bitterroot Mountains, and the Greater Yellowstone Area retained significant spring snow (McKelvey et
12304 al. 2011). The ensemble mean model output was similar to results associated with the Parallel Climate
12305 Model (pcm1; a cool extreme; http://www.cgd.ucar.edu/pcm), but at the warm extreme, little spring snow
12306 was retained at the end of the century. A connectivity model (Schwartz et al. 2009) in conjunction with
12307 ensemble climate model projections indicated that all remaining habitat would be genetically isolated by
12308 the end of the 21st century (McKelvey et al. 2011).

12309 The threshold between rain and snow causes estimates of snowpack loss to differ greatly between
12310 GCMs, because timing of moisture and the temperature when it occurs affect model performance. Cool

12311 models (e.g., Goddard Institute for Space Studies model E; Schmidt et al. 2006) indicate increases in
12312 January snowpack at high elevation (e.g., Yellowstone Plateau, Colorado) through the mid-21st century,
12313 whereas warmer models (e.g., Model for Interdisciplinary Research on Climate; Watanabe et al. 2011)
12314 show large losses in snowpack across all regions (Alder and Hostetler 2014). All models, including the
12315 coolest and wettest, indicate a continuing reduction in spring snow, a pattern that has been ongoing since
12316 at least the 1950s (Mote et al. 2005).

12317 **Brewer's Sparrow (*Spizella breweri*)**

12318 Brewer's sparrow appears to be a sagebrush obligate during the nesting period when nest occupancy
12319 is positively related to tall, dense stands of sagebrush (Petersen and Best 1985; Reynolds 1981) (fig. 9.6).
12320 In areas where other sage obligate species exist (e.g., sage thrasher [*Oreoscoptes montanus*]), these
12321 sparrows may compete for nest locations (Reynolds 1981). In many areas, however, Brewer's sparrow is
12322 the most abundant bird species (Norvell et al. 2014). Some consider the closely related timberline sparrow
12323 (*Spizella breweri taverneri*) to be a species (i.e., *S. taverneri*) or sub-species, but in any case, no genetic
12324 mixing occurs between the alpine and sagebrush variants (Klicka et al. 1999).

12325 Reasons for the obligate relationship of Brewer's sparrow with sagebrush are obscure. Although this
12326 relationship appears to be robust, especially patterns of nest occupancy (Petersen and Best 1985),
12327 evidence for why Brewer's sparrow nests in sagebrush rather than in other brush species is lacking.
12328 Therefore, we rely on correlative associations to project climate change effects and cannot speculate as to
12329 the flexibility of this species to shift to alternative shrub species should sagebrush become scarce. Within
12330 sagebrush communities, Brewer's sparrows do exhibit flexibility in response to nest predation, shifting
12331 locations of sequential nests in response to previous predation (Chalfoun and Martin 2010)

12332 Brewer's sparrow populations appear to be reasonably stable range-wide, although they have been in
12333 decline in some areas in Colorado (USGS 2013). Although Brewer's sparrow selects for areas with tall,
12334 dense sagebrush, sparrow abundance was unaffected by treatments designed to modify sagebrush cover
12335 and improve habitat for greater sage-grouse (Norvell et al. 2014). Similarly, a study of the effects of
12336 (nonnative) smooth brome (*Bromus inermis*) found that nest success was higher in areas with brome

12337 establishment (Ruehmann et al. 2011). In general, the effects of climate change on Brewer's sparrow will
12338 probably depend to a great degree on changes in the distribution, abundance, composition, and structure
12339 of sagebrush communities. Increased wildfire will likely reduce the distribution, abundance, and age of
12340 sagebrush stands in a warmer climate.

12341 **Flammulated Owl (*Otus flammeolus*)**

12342 The flammulated owl is a small nocturnal owl, approximately 6 inches long with a 14-inch wingspan.
12343 It is migratory but breeds in montane areas across much of western North America, ranging from southern
12344 British Columbia to central Mexico (Ridgely et al. 2003). It is a cavity nester, associated with mature
12345 forests with large diameter trees. It is also associated with open forests, but does not appear to be specific
12346 to any particular tree species. In New Mexico, it is found in pinyon pine (*Pinus edulis*) (McCallum and
12347 Gehlbach 1988), pondersoa pine (*P. ponderosa*) (Bull et al. 1990; Linkhart et al. 1998) and Douglas-fir
12348 (Powers et al. 1996; Scholer et al. 2014) forest. In the Sierra Nevada, it has been associated with (from
12349 low to high elevation) black oak (*Quercus kelloggii*), mixed conifer, Jeffrey pine (*P. jeffreyi*), white fir
12350 (*Abies concolor*), and red fir (*A. magnifica*) forest (Stanek et al. 2011).

12351 Flammulated owls are thought to be obligate secondary cavity nesters, although it has been
12352 anecdotally observed to nest in the ground (Smucker and Marks 2013). Flammulated owls feed almost
12353 exclusively on insects, primarily Lepidoptera, which they gather from trees, on the ground, or in flight
12354 (Linkhart et al. 1998). During the nesting period, males are single-trip, central-place foragers, so the
12355 energetics of prey selection are important, with distance traveled and energy content of prey differing by
12356 forest type. Little information is available on the diet of flammulated owls and their relationships to forest
12357 habitat. Interactions with other owl species appear minimal (Hayward and Garton 1988).

12358 The extensive latitudinal range of flammulated owls, lack of specific forest associations, and
12359 generalized insect diet indicate that straightforward links to specific climatic regimes are unlikely. If
12360 climate change is to affect flammulated owls, then it will most likely be through disturbance processes
12361 that remove large diameter trees. Shifts to denser forest structure would be problematic for this species,
12362 but there is little evidence that this would occur, because drought and wildfire are projected to increase

12363 throughout the Northern Rockies (Alder and Hostetler 2014). Like other long-lived owl species (Linkhart
12364 and Reynolds 2004), flammulated owl populations will be very sensitive to adult survival (Noon and
12365 Biles 1990).

12366 **Greater Sage-Grouse (*Centrocercus urophasianus*)**

12367 Greater sage-grouse is the largest grouse in North America (Mezquida et al. 2006). Considered an
12368 obligate with sagebrush (Miller and Eddleman 2001), its distribution is currently about half of its pre-
12369 settlement range (Schroeder et al. 2004), and many populations have been steadily declining in recent
12370 decades (Braun 1998; Connelly and Braun 1997; Connelly et al. 2004). In some areas, land conversion
12371 that eliminated sagebrush appears to have caused the declines (Connelly et al. 2004; Miller and Eddleman
12372 2001). Extirpation of sage-grouse is more likely in areas with high human population densities, land
12373 conversion to cropland, severe droughts (Aldridge et al. 2008), sagebrush displacement by conifers, and
12374 corvid predation. It is also more likely in areas with <25 percent sagebrush cover proximal to the edge of
12375 the historical range.

12376 Declines in sage-grouse have also occurred in areas still dominated by sagebrush (Miller and
12377 Eddleman 2001). In addition to reduced sagebrush cover, declines have been attributed to nonnative
12378 plants (Connelly et al. 2004; Knick et al. 2003; Wisdom et al. 2002), energy exploration and extraction
12379 (Braun et al. 2002; Doherty et al. 2008; Holloran et al. 2005; Lyon and Anderson 2003; Walker et al.
12380 2007a), grazing (Beck and Mitchell 2000; Hayes and Holl 2003), altered fire regimes (Connelly et al.
12381 2000, 2004), and a warmer climate (Neilson et al. 2005). In recent years, West Nile virus has also been
12382 implicated (Naugle et al. 2004, 2005; Walker et al. 2007b).

12383 Assessing the effects of climate change is challenging, because so many factors potentially affect
12384 sage-grouse population dynamics, Nevertheless, Schrag et al. (2011) produced a detailed climate change
12385 assessment for greater sage-grouse that evaluated changes in distribution of sagebrush and transmission of
12386 West Nile virus. They first built bioclimatic models for sagebrush distribution, then West Nile spread was
12387 modeled based on temperature thresholds. They used six GCMs and one emission scenario (A1B), and
12388 GCM output was statistically downscaled to 7.5-mi pixels. Both the envelope model and temperature

thresholds were projected to 2030 based on the downscaled GCM output. Results varied greatly across models, but it was concluded that the cumulative effects of projected climate change on both sagebrush and West Nile virus transmission would reduce suitable sage-grouse habitat in the Northern Rockies and northern Great Plains (Schrag et al. 2011). Since sage-grouse require large areas of mature sagebrush, future increases in wildfire are expected to significantly reduce habitat.

Creutzburg et al. (2015) evaluated the likely trajectory of greater sage grouse habitat in southeastern Oregon. They simulated the effects of climate change, disturbance, and cheatgrass (*Bromus tectorum*) invasion by coupling a linked dynamic global vegetation model, climate envelope model, and state-and-transition simulation model, based on three climate models, chosen to cover a range of possible futures. In the near term, loss of sagebrush from wildfire and cheatgrass invasion leads to habitat deterioration. However, in all three climate projections, native shrub-steppe communities increased circa 2070 leading to habitat improvement. In this simulation, all projected climate futures had better long-range prospects for sage-grouse than was simulated based on current climate.

Harlequin Duck (*Histrionicus histrionicus*)

Harlequin ducks in the intermountain west breed and summer on fast-flowing mountain streams and winter on rocky coastal areas (Robertson and Goudie 2015). In Grand Teton National Park, breeding pairs used streams with dense shrubs along the banks (Wallen 1987). During summer they feed primarily on larval insects on stream bottoms and in winter on a variety of small food items including snails, small crabs, barnacles, and fish roe (Robertson and Goudie 2015). They are relatively rare in Montana, with a concentration in Upper McDonald Creek in Glacier National Park (Reichel 1996). Climate change may alter the timing, duration, and levels of streamflows. In Glacier National Park, harlequin duck reproductive success declined with higher and less predictable streamflows (Hansen 2014).

Mountain Quail (*Oreortyx pictus*)

The mountain quail (*Oreortyx pictus*) is a small ground-dwelling bird that occupies upland forest and woodland habitats in the western United States and northern Mexico (Brennan et al. 1987). In the Pacific Northwest, its range extends into deep canyons such as Hells Canyon of the Snake River (Pope and

12415 Crawford 2004) where their populations have been declining. Population augmentation through
12416 translocation is common. Population studies have focused on survival, but connections to climate-related
12417 change are minimal. Stephenson et al. (2011) found that climate-related variables were important to
12418 survival, with lower survival being linked both to hot, dry conditions and cold winter weather. Seasonal
12419 movements to avoid snowpack led to increased rates of movement, which were also important predictors
12420 of survival.

12421 **Pygmy Nuthatch (*Sitta pygmaea*)**

12422 The pygmy nuthatch, a small bird about 4 inches long, is found throughout montane coniferous
12423 forests in western North America and as far south as central Mexico (McEllin 1979; Ridgely et al. 2003).
12424 It is a cavity nester, often associated with ponderosa pine forests (McEllin 1979) but also found in other
12425 forest types such as quaking aspen (*Populus tremuloides*) (Li and Martin 1991). Pygmy nuthatches can
12426 exhibit a social structure of cooperative breeding in which "helpers" aid breeding birds by feeding the
12427 incubating female, feeding nestlings and fledglings, and defending nesting territory (Sydeman et al.
12428 1988).

12429 Pygmy nuthatches nest in cavities in both live and dead trees (Li and Martin 1991; study site in
12430 Arizona), and population responses to disturbance are modest. For example, Hurteau et al. (2008; study
12431 site in Arizona) found that population densities across a variety of thinning and fuel treatments remained
12432 constant except in thin-and-burn treatments, where densities increased by over 500 percent. Saab et al.
12433 (2007; information from interior western United States) found that nuthatches showed a negative response
12434 to fire the first year after wildfire, but a neutral response in subsequent years. Due to their apparent neutral
12435 response to disturbance, coupled with flexibility in habitat and wide latitudinal range, it is difficult to
12436 project whether pygmy nuthatch will respond positively or negatively to climate change. Other than the
12437 effects of conversion from forest to non-forest, extirpation of this organism from climate change appears
12438 unlikely.

12439 **Ruffed Grouse (*Bonasa umbellus*)**

Ruffed grouse are characterized by a boreal distribution that includes peninsular extensions into the Rocky Mountains and Appalachian Mountains (USGS 2014). Throughout much of their range, ruffed grouse occupy aspen forest (Kubisiak 1985; Stauffer and Peterson 1985; Svoboda and Gullion 1972), which provides important food sources (Jakubas and Gullion 1991). Although ruffed grouse exist in forests that contain no aspen (e.g., oak-dominated forest) (Haulton et al. 2003), they are mostly limited to aspen habitats in many areas of the West (e.g., Mehls et al. 2014). Since ruffed grouse were identified as a species of concern in the Northern Rockies in the context of aspen-dominated forest, we focus here on the use of aspen by ruffed grouse.

In central Wisconsin, ruffed grouse densities were highest in young (<25 years) aspen stands (Kubisiak 1985). Similarly, ruffed grouse preferred stand structures characteristic of early successional stages in Idaho (Stauffer and Peterson 1985) but also use aspen stands of all ages (Mehls et al. 2014). Thus, optimal grouse habitat consists of aspen forests with stands in a variety of age classes, including a large component of young stands.

Aspen may be sensitive to heat and drought in some locations (Anderegg et al. 2013; Huang and Anderegg 2011). Although higher temperature is expected to cause increased stress in aspen, differences in forest structure and age affect the relationship between aspen mortality and drought (Bell et al. 2014), and mortality can be reduced by controlling stand densities and ages and limiting competition from conifers. If climate change causes decreased extent of aspen in the Northern Rockies, reduced habitat would have detrimental effects on ruffed grouse populations. However, it appears that significant options exist to mitigate these changes through silviculture that favors aspen over conifers and through active manipulation of stand densities and ages.

Columbia Spotted Frog (*Rana luteiventris*)

The Columbia spotted frog (*Rana luteiventris*) breeds in montane ponds throughout western North America (Green et al. 1996, 1997) (fig. 9.7). Funk et al. (2008) built a phylogeny for this species based on samples across western North America. Populations separated into three distinct clades; within the analysis area, all samples were associated with the northern clade and were fairly closely related. The

12466 effects of climate change on Columbia spotted frogs are unclear. In Utah, they were more likely to occur
12467 in persistent, shady ponds that maintained constant temperatures (Welch and MacMahon 2005). In
12468 Yellowstone National Park, pond desiccation led to sharp declines in frog populations (McMenamina et
12469 al. 2008), and throughout their range, populations in large stable water bodies were doing well, whereas
12470 those in smaller more ephemeral ponds were subject to rapid declines (Hossack et al. 2013). In Montana,
12471 warmer winters were associated with improved reproduction and survival of Columbia spotted frogs
12472 (McCaffrey and Maxell 2010). This species does not appear to be sensitive to stand-replacing fires
12473 (Hossack and Corn 2007).

12474 Columbia spotted frog populations are stable in areas with stable water supplies, and are capable of
12475 rapid population expansion into restored wetlands (Hossack et al. 2013). However, the amphibian chytrid
12476 fungus (*Batrachochytrium dendrobatidis*, hereafter referred to as Bd), is prevalent in many populations
12477 (Pearl et al. 2009; Russell et al. 2010) and warming waters would, in most systems, favor Bd (see section
12478 on western toad below). Although the fungus is common, the population effects of infection are unclear.

12479 **Western Toad (*Anaxyrus boreas*)**

12480 Western toads (*Anaxyrus boreas*) are montane amphibians broadly distributed across the western
12481 United States (Muths et al. 2008); in the southern Rocky Mountains, the subspecies boreal toad (*A. b.*
12482 *boreas*) is recognized. The western toad appears to have suffered widespread declines, particularly at the
12483 southern extent of its range (Corn et al. 2005), a phenomenon well documented in Colorado (Carey 1993).
12484 This species suffers from the amphibian chytrid fungus, which is often fatal. Laboratory studies of Bd
12485 have found that it grows optimally at 63-77 °F, and colonies are killed at 86 °F (Piotrowski et al. 2004).
12486 Although Bd can grow in temperatures as cold as 39 °F, warming waters would increase its prevalence.

12487 In a study across Colorado, Wyoming, and Montana, Bd was consistently found in western toad
12488 tissues, and was more prevalent in warmer, lower elevation sites (Muths et al. 2008). A warmer climate
12489 may allow Bd to spread to higher elevations and become even more widespread, although there is some
12490 question about how susceptible the western toad is to the effects of Bd, because increased mortality is not

12491 always associated with high infection rates. Recent studies indicate that the skin of the toad contains
12492 bacterial colonies that inhibit Bd (Park et al. 2014).

12493 **ASSESSING SUBREGIONAL DIFFERENCES IN VULNERABILITY**

12494 When considering how climate change would affect wildlife populations in their subregion, Northern
12495 Rockies Adaptation Partners (NRAP) workshop participants tended to think in terms of pathways through
12496 which climate could exert an influence (fig. 9.1, black text and arrows). These pathways can interact with
12497 each other, and with population characteristics (fig. 9.1, blue text and arrows) to produce an effect on the
12498 population of interest (fig. 9.1, red text). However, a given pathway influences multiple species, and
12499 multiple pathways influence a given species. Below we summarize the subregional workshop discussions.

12500 Upper temperature thresholds for moose were discussed for the Greater Yellowstone Area subregion
12501 (GYA). This was the only species and subregion with a discussion of direct physiological sensitivities to
12502 climate. However, it was noted in all subregions that there is a general lack of understanding of direct
12503 physiological sensitivities to climate for most wildlife species. However, even when these sensitivities
12504 have been measured (e.g., the lower thermoneutral limits for wolverines (e.g., Iversen 1972) it is unclear
12505 how this laboratory-derived knowledge can be interpreted in the context of habitat use and demographic
12506 performance.

12507 Position within a species' niche can influence population vulnerability. Some species are at the
12508 climatological limits of their range in particular subregions. Exposure to climate change in these places
12509 has a strong effect on species ability to persist, whereas the same amount of change in the center of its
12510 range has less effect. The Western Rockies and Central Rockies subregions are at the junction of maritime
12511 and continental climates, and many species are at the edges of their ranges. For example, participants in
12512 the Central Rockies workshop discussed how future climate change is expected to increase habitat
12513 suitability for the fisher, such that this species may expand its range into the subregion.

12514 Some species had different habitat associations in different subregions. For example, in the GYA,
12515 ruffed grouse was linked to aspen habitat but was associated with a broader range of habitats in the

Central Rockies subregion. Therefore, ruffed grouse were seen as more sensitive to climate effects on aspen in the GYA than in the Central Rockies.

The importance of previous habitat loss, potentially caused by recent warming, differed across the subregions. In the Eastern Rockies subregion, extensive lodgepole pine (*Pinus contorta* var. *latifolia*) mortality has been caused by mountain pine beetles (*Dendroctonus ponderosae*), likely caused by warmer winters (Bentz et al. 2010). Cavity nesting birds were thought to be more sensitive to potential future habitat loss, because they have already lost a substantial portion of their habitat. Prior habitat loss was not discussed in the other subregions.

Another pathway for habitat loss, discussed in the Central Rockies workshop, was an increase in invasive species. For example, the flammulated owl feeds on insects that depend on understory plant composition, and that composition could be altered by increased abundance of invasive plants such as cheatgrass.

Negative effects on wildlife populations from an increase in disease occurrence and transmission caused by climate change (e.g., West Nile virus) was discussed in three of the five subregions. Participants also noted there was relatively little known about disease ecology and the future potential for disease to affect wildlife populations.

Connectivity was a primary concern in four of the five subregions. Participants considered different scales of connectivity to be important: the ability for individuals to move through the landscape to meet their daily needs, the ability to complete seasonal migrations, and the ability to track potentially shifting habitat. Numerous indirect influences on each of those scales of connectivity were discussed.

Indirect pathways that increase vulnerability to climate change can also arise when a changing climate influences landscape configurations such that species are then more at risk from other stressors. In the GYA and Central subregions, participants discussed the need to understand how potential shifts in residential development (e.g., into riparian habitats) could affect wildlife. Changing demands for energy sources and the influence of energy development on wildlife habitat were discussed in the Central and Grassland subregions.

Another source of regional variation was the importance of multiple collaboratives focused on conservation issues in the Central subregion. Forest Service participants stated that these collaboratives increased their range of achievable management tactics.

There were differences in the amount of climate change expected (exposure), the response of individuals and populations to that change (sensitivity), and the ability of organisms and organizations to adapt to that change (adaptive capacity) across Northern Rockies subregions. However, participants agreed there is a lack of understanding about mechanisms of climate influence. Identifying and contrasting the importance of *pathways* of climate influence across subregions can suggest potential *mechanisms* of climate influence. Hypotheses can be developed to account for these mechanisms, and management actions can be monitored to test those hypotheses. Based on the results of those tests, decisions can be made to continue with management actions, or develop new actions or hypotheses, creating an adaptive monitoring program (Lindenmayer and Likens 2009). Sensitivities listed in tables 9.2-9.9 provide a starting point for identifying potential hypotheses.

ADAPTING WILDLIFE MANAGEMENT TO THE EFFECTS OF CLIMATE CHANGE

Adaptation to climate change for wildlife resources in NRAP subregions was focused on maintaining adequate habitat and healthy wildlife populations, and increasing knowledge of species needs and climate sensitivities. Workshop participants identified the major habitats in their subregion and then developed adaptation strategies for species they regarded as important and for which they believed viable management options exist. For example, participants in the GYA workshop discussed climate sensitivities of American pika, but decided not to work through adaptation options because they did not see how management efforts could influence pika population viability. Participants tended to address species or habitats that had not been covered in prior workshops, even if some were important in their subregion. Adaptation options are summarized according to major habitats, (tables 9.2 through 9.7) which can then be associated with individual species (table 9.1).

Riparian habitats are important across the Northern Rockies. The primary strategy for improving riparian habitat resilience is maintaining healthy American beaver populations (table 9.2). Beaver

12568 complexes can buffer riparian systems against both low and high streamflows, and provide habitat
12569 structure and foraging opportunities for multiple species. Non-riparian wetlands were discussed as
12570 important habitats, but no adaptation strategies were developed.

12571 Quaking aspen habitats are common in the four western subregions and occur occasionally in the
12572 Grassland subregion. Aspen was identified as important because of its high productivity, role in structural
12573 diversity, and habitat for cavity-nesting birds. In the GYA, ruffed grouse were identified as strongly tied
12574 to aspen habitats. Reduction in the distribution and abundance of aspen is projected for some locations
12575 (especially lower elevation) in a warmer climate (see chapter 6). The most common tactics for promoting
12576 aspen resilience were allowing wildfire or using prescribed fire in older aspen stands, protection from
12577 grazing, and reducing conifer encroachment in any age stand (table 9.3).

12578 Dry ponderosa pine forests are common in the Central Rockies and Eastern Rockies subregions and
12579 provide habitat for cavity nesting birds such as the flamulated owl. These habitats have experienced
12580 encroachment by Douglas-fir as a result of fire exclusion, increasing vulnerability of pine to future fires.
12581 Tactics for promoting ponderosa pine resilience included reducing competition from Douglas fir through
12582 understory burning and cutting, protecting mature stands, and planting ponderosa pine were it has been
12583 lost (table 9.4).

12584 The Western Rockies and Central Rockies subregions support older, mesic forests because they
12585 experience a maritime climate influence (see chapter 3). These forests, which provide important habitat
12586 for fisher, may have younger age classes (caused by increased disturbance; see chapter 8) and different
12587 species composition in a warmer climate (see chapter 6). Adaptation strategies included restoring
12588 historical structure, conserving current structure, and promoting potential future mesic forest habitats
12589 (table 9.5).

12590 Mountain sagebrush-grassland habitat occurs in all regions except the Grassland. In the Western
12591 Rockies subregion, mountain sagebrush-grassland habitats are unique in that they have less of a sagebrush
12592 component, primarily occur in steep mountain canyons, and support populations of mountain quail;
12593 differences in aspect have a strong influence on climate in these canyons. In a warmer climate, these

habitats could lose some of their forb component, making them vulnerable to increased abundance of nonnative species (see chapter 7). Specific tactics for restoring historical habitat and maintaining current habitat included managing fire, controlling nonnative species, and restoring formerly cultivated lands (table 9.6).

Sagebrush habitats are common in the Eastern Rockies, GYA, and Grassland subregions, supporting gallinaceous birds (greater sage-grouse, Brewer's sparrow, greater prairie chicken [*Tympanuchus cupido*], sharp-tailed grouse [*T. phasianellus*) and pygmy rabbits, among other species. Tactics for maintaining adequate sagebrush habitat included managing fire, controlling nonnative species, preventing fragmentation, and restoring degraded habitat (table 9.7). Current focus on conservation of greater sage-grouse within sagebrush habitat in the western United States will benefit from including a climate-smart approach to management.

Developing on-the-ground management tactics requires understanding how climate change will influence species. In all subregions, and independent of habitat association, participants identified the need for better understanding of species requirements and the mechanisms of climate change impacts. In addition, connectivity and the potential for increases in disease were identified as important processes affecting multiple habitats and species in each subregion, although climate sensitivities of diseases are not well understood. Accordingly, several adaptation strategies were suggested to fill knowledge gaps (table 9.8). There is wide agreement on the need to better understand the mechanisms of climate sensitivities relative to the life histories of individual species. Examples of tactics to accomplish this objective include analyzing female Canada lynx home ranges to determine the necessary distribution and size of habitat patches, quantifying and monitoring pygmy rabbit distribution, and understanding sagebrush succession following fire. The influence of low-snow years on wolverine denning success is an example of a mechanistic relationship with climate that needs more data.

Connectivity, although not tied to a particular habitat type, is considered an important conservation strategy for most species in all Northern Rockies subregions, although climate influences on connectivity are uncertain. Several forms of connectivity were identified: daily, seasonal, dispersal, and range shift.

Connectivity can be affected by changes in water supply, habitat loss, habitat shifts, vegetation phenology shifts, human population expansion and redistribution, and snowpack dynamics. Specific tactics for increasing knowledge that would enable the maintenance of connectivity include monitoring connectivity with genetic, tracking, and remote-sensing tools; identifying dispersal habitats; and identifying and removing or mitigating barriers to connectivity (table 9.9).

Disease is also important in most subregions, not tied to a particular habitat, and not well understood. Specific tactics for addressing disease include monitoring the presence of white-nose syndrome (caused by the fungus *Pseudogymnoascus destructans*) in bat hibernacula (currently ongoing through collaboration of U.S. Forest Service, other agencies, and Northern Rocky Mountain Grotto), monitoring disease trends in moose and bighorn sheep, and coordinating with state agencies to monitor West Nile virus.

More specific details on adaptation strategies and tactics for each NRAP subregion are in Appendix 9A.

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Chapter 10: Effects of Climate Change on Recreation

Michael S. Hand and Megan Lawson

INTRODUCTION

Outdoor recreation is an important benefit provided by federal agencies and other public lands in the Northern Rockies. National forests in the Northern Region and Greater Yellowstone Area see an estimated 13.3 million visits per year; Yellowstone, Grand Teton and Glacier National Parks account for an additional 8 million visits per year. National forests and national parks provide recreation opportunities at sites that offer a wide variety of characteristics. Recreation on public lands in the Northern Rockies and Greater Yellowstone Area is inseparable from ecosystems and natural features. Whether skiing, hiking, hunting, or camping, visiting developed sites or the backcountry, or simply driving through a park or forest, natural and ecological conditions in large part determine the overall recreation experience.

Climatic conditions and environmental characteristics that depend on climate are key factors that determine the availability of and demand for different recreation opportunities (Shaw and Loomis 2008). Changing climate conditions may alter the supply of and demand for recreation opportunities, resulting in changes visitation patterns and the benefits derived from recreation in the future. Climate change is projected to increase outdoor recreation participation in general (Bowker et al. 2013). Benefits provided by recreation are expected to increase under climate change scenarios due to increases in summer and warm-weather activities outweighing losses in winter activities (Loomis and Crespi 2004; Mendelsohn and Markowski 2004).

Public lands managers will face a complex task of managing recreation opportunities under changing recreational preferences and ecological conditions. Investments in infrastructure, the provision and maintenance of facilities, and decisions about recreation development are important inputs that determine recreational setting and the type of recreational opportunities available to visitors. These inputs can be classified using the Recreation Opportunity Spectrum (ROS), which has been used for decades by public

lands managers for planning and allocation of recreation opportunities (Clark and Stankey 1979). Recreation visitation behavior and values can be mapped to the ROS, providing managers with information about the tradeoffs associated with different types of investments and development (Rosenthal and Walsh 1986; Swanson and Loomis 1996). A changing climate may alter types of recreation experiences desired and the opportunities that can be provided by public lands.

Although broad trends in recreation participation under climate change scenarios may be borne out at the regional scale, little is known about how recreation in the Northern Rockies will change. This chapter describes the broad categories of recreation activities that may be sensitive to climate-related changes in the Northern Rockies, and assesses the likely effects of projected climate changes on recreation participation.

RELATIONSHIPS BETWEEN CLIMATE CHANGE AND RECREATION

The supply of and demand for recreation opportunities are sensitive to climate through (1) a direct effect of changes in temperature and precipitation on the availability and quality of recreation sites, and (2) an indirect effect of climate on the characteristics and ecological condition of recreation sites (Loomis and Crespi 2004; Mendelsohn and Markowski 2004; Shaw and Loomis 2008) (fig. 10.1).

Direct effects of changes in temperature and precipitation patterns are likely to affect most outdoor recreation activities in some way. Direct effects are important for skiing and other snow-based winter activities that depend on seasonal temperatures and the amount, timing, and phase of precipitation (Englin and Moeltner 2004; Irland et al. 2001; Stratus Consulting 2009). Warm-weather activities are also sensitive to direct effects of climate change. Increases in minimum temperatures have been associated with increased national park visits in Canada, particularly during non-peak “shoulder” seasons (Scott et al. 2007). The number of projected warm-weather days is positively associated with expected visitation for a national park in the United States, although visitation is expected to be lower under extreme-heat scenarios (Bowker et al. 2012; Richardson and Loomis 2004). Temperature and precipitation may also directly affect the comfort and enjoyment that participants derive from engaging in an activity on a given day (Mendelsohn and Markowski 2004).

13418 Indirect climate effects tend to be important for recreation activities that depend on additional
13419 ecosystem inputs, such as wildlife, vegetation, and surface water. Cold-water fishing is expected to
13420 decline in the future due to climate effects on temperature and streamflow that threaten cold-water fish
13421 species habitat (Jones et al. 2013) (see chapter 5). Surface water area and streamflows are important for
13422 water-based recreation (e.g., boating), and forested area affects several outdoor activities (e.g., camping
13423 and hiking) (Loomis and Crespi 2004). Recreation visits to sites with highly valued natural
13424 characteristics, such as glaciers or popular wildlife species (see chapters 4 and 9) or scenic and aesthetic
13425 qualities, may be reduced in some future climate scenarios if the quality of those characteristics is
13426 threatened (Scott et al. 2007). The indirect climate effect on disturbances, and wildfire in particular (see
13427 chapter 8), may also play a role in recreation behavior, although the effect may be diverse and vary over
13428 time (Englin et al. 2001).

13429 **IDENTIFYING CLIMATE-SENSITIVE OUTDOOR RECREATION ACTIVITIES**

13430 People participate in a wide variety of outdoor recreation activities in the Northern Rockies. The
13431 National Visitor Use Monitoring (NVUM) survey, conducted by the Forest Service, U.S. Department of
13432 Agriculture (USFS) to monitor recreation visitation and activity on national forests, identifies 27 different
13433 recreation activities in which visitors may participate. These include a wide variety of activities and ways
13434 that people enjoy and use national forests and other public lands.

13435 NVUM surveys roughly one-quarter of forest units in each region every year, and each unit is re-
13436 surveyed every five years. For this analysis, we used the latest survey data available for each forest.
13437 Sample years for the units included in this analysis are as follows: 2008 – Bridger-Teton, Custer, Helena;
13438 2009 – Gallatin, Idaho Panhandle, Shoshone; 2010 – Beaverhead-Deerlodge, Caribou-Targhee, Flathead;
13439 2011 – Clearwater, Lolo, Nez Perce; 2012 – Bitterroot, Kootenai, Lewis and Clark. Visitors are sampled
13440 using a stratified random sampling technique designed for assessing use on national forests. Sampling
13441 sites are stratified according to type of recreation site and times of day and week. Visitors are asked about
13442 different categories of trip-related spending incurred within 50 miles of the site where they are

interviewed. Interviewees are selected at random, and interviewers conduct as many surveys as possible (English et al. 2001).

All outdoor recreation activities depend to some degree, directly or indirectly, on climate conditions or environmental conditions that are determined by climate. For example, skiing opportunities depend on the availability of areas with snow-covered terrain, which is determined by patterns of temperature and precipitation as snow. As climate change affects seasonal trends in temperature and precipitation, the availability of certain skiing sites may change in the future.

To assess how recreation patterns may change in the Northern Rockies, categories of outdoor recreation activities are identified that may be sensitive to climate changes (fig. 10.2). For the purposes of the recreation assessment, a recreation activity is sensitive to climate change if changes in climate or environmental conditions that depend on climate would be an important factor affecting the demand for or supply of that recreation activity within the study area. However, there is no hard rule on which activities satisfy this requirement, and other types of activities not explicitly covered in this chapter may be affected by climate changes.

The 27 recreation activities identified in the NVUM survey are grouped into five climate-sensitive categories of activities, plus an "other" category of activities that are less sensitive to climate changes. Each category includes activities that would likely be affected by changes to climate and environmental conditions in similar ways. Table 10.1 lists the activities that comprise the climate-sensitive categories and summarizes their sensitivity to climate changes. The categories were developed to capture the most common types of recreation that people engage in on public lands in the Northern Rockies that would be affected by climate changes. In total, 17 activities were identified as sensitive to climate changes.

These 17 activities account for the primary recreation activities for 83 percent of visits to national forests in the study area. Activities in the "Other" category were judged to be less sensitive to climate changes and tend to be less frequently listed as a primary recreation activity in the study area. Although participation in many of these activities is likely linked to climate in some way, other factors are likely to be more important determinants of participation (for example, maintenance of infrastructure for visiting

13469 interpretive sites). Warm-weather activities are the most popular, and include hiking/walking, viewing
13470 natural features, developed and primitive camping, bicycling, backpacking, horseback riding, picnicking,
13471 and other non-motorized uses. These were the main activity for 35.9 percent of national forest visitors
13472 (4.8 million visitors per year) (table 10.1). Of these, hiking/walking was the most popular, and is the
13473 primary reason for a visit for 16.9 percent of visitors (2.2 million people). Snow-based winter activities
13474 are also a large draw, and include downhill skiing, snowmobiling, and cross-country skiing. They were
13475 the primary activity for 25 percent of all visitors (3.3 million people). Wildlife-related activities, including
13476 hunting, fishing, and viewing wildlife, were the primary activity for 18.5 percent of visitors (2.5 million
13477 people). Of these, hunting was the most popular with 11 percent of visitors (1.5 million people).
13478 Gathering forest products such as berries and mushrooms was the primary activity for 2.4 percent of
13479 visitors (300,000 people). Motorized and non-motorized water activities (other than fishing) comprised
13480 0.7 percent of visitors (97,000 people) (table 10.1).

13481 Non-local visitors – those who report a home zipcode that is more than 30 miles from the forest
13482 boundary – spend $601 million (in 2014 dollars) per year within 50 miles of the forest boundaries. The
13483 non-local definition is applied based on reported home zipcode; some non-local respondents may have
13484 second homes near the forest boundary that would qualify as local had they reported the zipcode
13485 associated with the second home (Stynes and White 2005). Table 10.2 summarizes expenditures by
13486 visitors to national forests in the Northern Rockies and Greater Yellowstone Area. We focus on spending
13487 by non-local visitors because these individuals spend money in local communities that would not have
13488 occurred otherwise. Lodging expenses comprise nearly 31 percent of total expenditures, followed by
13489 restaurant (18 percent), gas and oil (17 percent), and groceries (12 percent). The remaining expenditure
13490 categories of other transportation, activities, admissions and fees, and souvenirs comprise 21 percent of
13491 all spending.

13492 **CLIMATE CHANGE VULNERABILITY ASSESSMENT**

13493 The overall effect of climate change on recreation activity is likely to be an increase in participation
13494 and increase in the benefits derived from recreation. This is due primarily to warmer temperatures and

increased season length appropriate for warm-weather activities, outweighing decreased winter activities that depend on snow and consistently cold temperatures (Mendelsohn and Markowsi 2004). However, these general findings mask potential variation in the effects of climate on recreation between types of activities and geographic locations (boxes 10.1, 10.2).

This section provides an assessment of the likely effects of climate on major climate-sensitive recreation activities in the region. Two sources of information are used to develop assessments for each category of recreation activity. First, reviews of existing studies of climate change effects on recreation and studies of how recreation behavior responds to climate-sensitive ecological characteristics are used to draw inferences about likely changes for each activity category. Second, projections of ecological changes specific to the Northern Rockies, as detailed in the other chapters contained in this volume, are paired with the recreation literature to link expected responses of recreation behavior to specific expected climate effects.

Current Conditions and Existing Stressors

Public lands in the Northern Rockies provide an abundance and variety of recreational options, offering opportunities for people of all interests and abilities. Opportunities range from high-use developed sites near urban areas and popular tourist destinations, to vast areas of remote wilderness and seldom-used sites off the beaten path. The facilities and services available also exhibit a wide range of conditions and characteristics. Some sites are developed with modern amenities and staffed by agency employees or volunteers. Others may exhibit scant evidence of human influence other than a trailhead.

Current conditions reflect wide variation in intra- and inter-annual (within and between years) weather and ecological conditions. Temperature, precipitation, water flows and levels, wildlife distributions, vegetative conditions, and wildfire activity may exhibit wide ranges of variation. Recreationists are likely already accustomed to some degree to making decisions with a significant degree of uncertainty about conditions at the time of participation.

Several existing challenges and stressors affect recreation in the Northern Rockies. Increased population, particularly in proximity to public lands, can strain visitor services and facilities due to

13521 increased use; projected population increases in the future may exacerbate these effects (Bowker et al.
13522 2012). Increased use due to population growth can also reduce site quality because of congestion at the
13523 most popular sites (Yen and Adamowicz 1994). Changes in land use may alter access to public lands,
13524 fragmentation of landscapes and habitat, and disturbance regimes that relate to recreation activities.

13525 The physical condition of recreation sites and natural resources are constantly changing due to human
13526 and natural forces. Recreation sites and physical assets need maintenance, and deferred or neglected
13527 maintenance may increase congestion at other sites that are less affected or increase hazards for visitors
13528 who continue to use degraded sites. Unmanaged recreation can create hazards and contribute to natural
13529 resource degradation (U.S. Department of Agriculture 2010). This stressor may interact with others, such
13530 as population growth and maintenance needs, if degraded site quality or congestion encourages users to
13531 engage in recreation that is not supported or appropriate at certain sites or at certain times of the year.
13532 Natural hazards and disturbances may create challenges for the provision of recreation opportunities. For
13533 example, wildfire affects recreation demand (due to site quality and characteristics), but may also damage
13534 physical assets or exacerbate other natural hazards such as erosion (see chapters 4 and 12).

13535 **Current Management**

13536 Recreation is an important component of public land management in the Northern Rockies. For lands
13537 managed by the USFS, sustainable recreation serves as a guiding principle for planning and management
13538 purposes (U.S. Department of Agriculture 2010, 2012b). Recreation is included among other major
13539 multiple uses of national forests, such as timber products and livestock grazing. Sustainable recreation
13540 seeks to "sustain and expand benefits to America that quality recreation opportunities provide," (U.S.
13541 Department of Agriculture 2010). At the heart of this principle is the desire to manage recreational
13542 resources to increasingly connect people with natural resources and cultural heritage, and adapt to
13543 changing social needs and environmental conditions. Recreation managers aim to provide diverse
13544 recreation opportunities that span the recreation opportunity spectrum, from modern and developed to
13545 primitive and undeveloped (Clark and Stankey 1979)

13546 **Warm-Weather Activities**

Warm-weather activities as a category are the most common recreation activities in national forests and national parks in the Northern Rockies. Slightly more than one-third of all visits involve one of these activities as the primary activity of visitors. Warm-weather recreation is sensitive to the length of appropriate season, depending on the availability of snow- and ice-free trails and sites, and the timing and number of days with temperatures within minimum and maximum comfortable range (which may vary with activity type and site). The number of warm-weather days has been shown to be a significant predictor of expected visitation behavior (Richardson and Loomis 2004), and studies of national park visitation show that minimum temperature is a strong predictor of monthly visitation patterns (Scott et al. 2007).

Participants are also sensitive to site quality and characteristics, such as the presence and abundance of wildflowers, conditions of trails, and vegetation and cover (e.g., cover for shade, wildfire effects). The condition of unique features that are sensitive to climate changes, such as glaciers, may affect the desirability of certain sites (Scott et al. 2007). Forested area is positively associated with warm-weather activities, such as camping, backpacking, hiking, and picnicking (Loomis and Crespi 2004), and is sensitive to future climate changes (U.S. Department of Agriculture 2012a).

Wildfire can also affect participation in warm-weather activities through changes to site quality and characteristics (fig. 10.3). Wildfires have a diverse and temporally nonlinear effect on recreation (Englin et al. 2001). The presence of recent wildfires has differential effects on the value of hiking trips (positive) and mountain biking (negative), although recent wildfire activity tends to decrease the number of visits (Hesseln et al. 2003, 2004; Loomis et al. 2001). The severity of fire may also matter; high-severity fires have been associated with decreased recreation visitation, whereas low-intensity fires are associated with slight increases in visitation (Starbuck et al. 2006). Recent fires are associated with initial losses of benefits for camping (Rausch et al. 2010) and backcountry recreation activities (Englin et al. 1996) that are attenuated over time. Visitation in Yellowstone National Park tends to be lower following months with high wildfire activity, although there is no discernable effect of previous-year fires (Duffield et al. 2013).

Overall demand for warm-weather activities is expected to increase due to a direct effect of climate change on season length. Temperatures are expected to increase 5 to 12 °F across the region by the year 2100 (see chapter 3), which is expected to result in earlier availability of snow- and ice-free sites and an increase in the number of warm-weather days in spring and autumn. For example, higher minimum temperatures are associated with increased number of hiking days (Bowker et al. 2012). More extreme summer temperatures can dampen participation during the hottest weeks of the year, and extreme-heat scenarios for climate change are expected to reduce visitation (Richardson and Loomis 2004), and higher maximum summer temperatures are associated with reduced participation in warm-weather activities (Bowker et al. 2012). The temperature that is considered "extreme" may vary between individuals and chosen activities. In Bowker et al. (2012), a linear effect of maximum summer temperature in the visitor's home county was included in participation models. Extreme heat may shift demand to cooler weeks at the beginning or end of the warm-weather season, or shift demand to alternative sites that are less exposed to extreme temperatures (e.g., at higher elevations).

Indirect effects of climate change on forested area may have a negative effect on warm-weather recreation if site availability and quality (e.g., scenic and aesthetic attributes) are compromised. However, the effect on warm-weather recreation in the Northern Rockies and its various subregions will depend on local effects of climate on forest resources.

Potential increases in the likelihood of extreme wildfire activity may reduce demand for warm-weather activities in certain years because of degraded site desirability, impaired air quality from smoke, and limited site access due to fire management activities. The Northern Rockies are expected to experience increased area burned by wildfire, average fire size, and fire severity (see chapter 8), which tend to have a negative impact on recreation visitation and benefits derived from recreation.

Adaptive capacity among recreationists is high because of the large number of potential alternative sites, ability to alter the timing of visits, and ability to alter capital investments (e.g., appropriate gear). However, benefits derived from recreation may decrease even if substitute activities or sites are available (Loomis and Crespi 2004). For example, some alternative sites may involve higher costs of access

(because of remoteness or difficulty of terrain) or congestion costs if demand is concentrated among fewer desirable sites. In addition, limits on ability to alter seasonality of visits may exist because of the timing of scheduled academic breaks. Although the ability of recreationists to substitute sites and activities is well established, there remains little understanding of how people substitute across time periods or between large geographic regions (e.g.., choosing a site in the Northern Rockies instead of the Southwest) (Shaw and Loomis 2008). In some cases, unique features or strong individual attachment to particular places may limit substitutability.

Projected climate scenarios are expected to result in a moderate increase warm-weather recreation activity and benefits derived from these activities. Longer warm-weather seasons will likely increase the number of days when warm-weather activities are viable and increase the number of sites available during shoulder seasons. The effects of a longer season may be offset somewhat by negative effects on warm-weather activities during extreme heat and increased wildfire activity. The likelihood of effects on warm-weather recreation is high; the primary driver of climate-related changes to warm-weather recreation is through direct effects of temperature changes on the demand for warm-weather recreation. Climate scenarios outlined in chapter 3 vary in their projection of the magnitude of warming, but overall project warmer temperatures. Indirect effects on recreation, primarily through wildfire effects, may be harder to project with certainty and precision (particularly at a fine-grained geospatial scale).

Cold-Weather Activities

The Northern Rockies boast a large number of winter recreation sites that in total exhibit a wide range of site characteristics and attract local, national, and international visitors. Several sites support developed downhill skiing and snowboarding operated by special permit on lands administered by the USFS. Sites for cross-country skiing, snowshoeing, and snowmobiling tend to be maintained directly by the Forest Service, although national parks also provide access for these activities.

Snow-based recreation is highly sensitive to variations in temperature and the amount and timing of precipitation as snow. Seasonal patterns of temperature and snowfall determine the likelihood of a given site having a viable season and the length of viable seasons (Scott et al. 2008). Lower temperatures and

13625 the presence of new snow are associated with increased demand for skiing and snowboarding (Englin and
13626 Moeltner 2004). Indirect effects of climate, such as changes in scenery and unique features (e.g., glaciers)
13627 may also affect winter recreation, although these effects are expected to be small relative to the effect of
13628 changes in amount and timing of snowfall.

13629 Climate change is expected to have a generally negative effect on snow-based winter activities,
13630 although a wide range of effects at local scales are possible because of variations across the region in site
13631 location and elevation. Warmer projected winter temperatures for the region are expected to reduce the
13632 proportion of precipitation as snow, even if the total amount of precipitation does not deviate significantly
13633 from historical norms (see chapter 4). The rain-snow transition zone (i.e., where precipitation is more
13634 likely to be snow rather than rain for a given time of year) is expected to move to higher elevations,
13635 particularly in late autumn and early spring (Klos et al. 2014). This effect places lower elevation sites at
13636 risk of shorter or non-existent winter recreation seasons (fig. 10.4). However, the highest elevation areas
13637 in the region remain snow-dominated for a longer portion of the season in future climate scenarios.

13638 Studies of the ski industry in North America uniformly project negative effects of climate change
13639 (Scott and McBoyle 2007). Overall warming is expected to reduce expected season length and the
13640 likelihood of reliable winter recreation seasons. Climatological projections for the Northern Rockies (see
13641 chapter 3) are consistent with studies of ski area vulnerability to climate change in other regions, where
13642 projected effects of climate change on skiing, snowboarding, and other snow-based recreation activities is
13643 negative (Dawson et al. 2009; Scott et al. 2008; Stratus Consulting 2009).

13644 Snow-based recreationists have moderate capacity to adapt to changing conditions given the
13645 relatively large number of winter recreation sites in the region. For undeveloped or minimally developed
13646 site activities (for example, cross-country skiing, backcountry skiing, snowmobiling, snowshoeing),
13647 recreationists may seek higher elevation sites with higher likelihoods of viable seasons. Although
13648 developed downhill skiing sites are fixed improvements, potential adaptations include snowmaking,
13649 higher elevation development, and new run development (Scott and McBoyle 2007). However, the ability
13650 of winter tourism sector businesses to adapt likely varies considerably. Warmer temperatures and

13651 increased precipitation as rain may increase availability of water for snowmaking in the near term during
13652 winter, but warmer temperatures may also reduce the number of days per season when snowmaking is
13653 viable.

13654 Changes in Northern Rockies sites relative to other regions may also be important. If other regions
13655 experience relatively large effects of climate on snow-based recreation, recreationists may view Northern
13656 Rockies sites as a substitute for sites in other regions (e.g., the Southwest), although inter-regional
13657 substitution patterns for recreation activities are poorly understood (Shaw and Loomis 2008). Further,
13658 increased inter-regional substitution combined with shorter seasons may result in concentrated demand at
13659 fewer sites on fewer days, creating potential congestion effects.

13660 The magnitude of climate effects on snow-based winter activities is expected to be high. Warmer
13661 temperatures are likely to shorten winter recreation seasons and reduce the likelihood of viable seasons at
13662 lower elevation sites. Developed sites may have limited ability to adapt to these changes unless additional
13663 adjacent area is available and feasible for expanded development. In comparison to other regions,
13664 Northern Rockies winter recreation sites may see fewer effects from climate change; inter-regional
13665 substitution could mitigate losses in some years if participants from other regions are more likely to visit
13666 Northern Rockies sites. The likelihood of effects is expected to be high for snow-based recreation,
13667 although variation across sites is possible because of differences in location and elevation. Climate
13668 models generally project warming temperatures and a higher-elevation rain-snow transition zone, which
13669 would leave additional sites exposed to the risk of shorter seasons.

13670 **Wildlife Activities**

13671 Wildlife recreation activities involve terrestrial or aquatic animals as a primary component of the
13672 recreation experience. Wildlife recreation can involve consumptive (e.g., hunting) or non-consumptive
13673 (e.g., wildlife viewing, birding, catch-and-release fishing) activities. Distinct from other types of
13674 recreation, wildlife activities depend on the distribution, abundance, and population health of desired
13675 target species. These factors influence activity "catch rates," that is, the likelihood of catching or seeing
13676 an individual of the target species. Sites with higher catch rates can reduce the costs associated with a

13677 wildlife activity (e.g., time and effort tracking targets) and enhance overall enjoyment of a recreation day
13678 for that activity (e.g., greater number of views of highly valued species).

13679 Participation in wildlife activities is sensitive primarily to climate-related changes that affect expected
13680 catch rates. Catch rates are important determinants of site selection and trip frequency for hunting
13681 (Loomis 1995, Miller and Hay 1981), substitution among hunting sites (Yen and Adamowicz 1994),
13682 participation and site selection for fishing (Morey et al. 2002), and participation in non-consumptive
13683 wildlife recreation (Hay and McConnell 1979). Changes to habitat, food sources, or streamflows and
13684 water temperature (for aquatic species) may alter wildlife abundance and distribution, which in turn
13685 influences expected catch rates and wildlife recreation behavior.

13686 Wildlife activities may also be sensitive to other direct and indirect effects of climate change. The
13687 availability of highly valued targets affects benefits derived from wildlife activities (e.g., cutthroat trout
13688 [*Oncorhynchus clarkii*] for cold-water anglers) (Pitts et al. 2012), as does species diversity for hunting
13689 (Milon and Clemmons 1991) and non-consumptive activities (Hay and McConnell 1979). Temperature
13690 and precipitation are related to general trends in participation for multiple wildlife activities (Bowker et
13691 al. 2012; Mendelsohn and Markowski 2004), although the precise relationship may be specific to the
13692 activity or species. Some activities such as big game hunting may be enhanced by cold temperatures and
13693 snowfall at particular times to aid in field dressing, packing out harvested animals, and tracking. Other
13694 activities may be sensitive to direct climate effects similar to warm-weather activities, in which moderate
13695 temperatures and snow- and ice-free sites are desirable.

13696 Warming temperatures projected for the Northern Rockies are expected to increase participation in
13697 terrestrial wildlife activities because of an increased number of days that are desirable for outdoor
13698 recreation. In general, warmer temperatures are associated with greater participation in and number of
13699 days spent hunting, bird watching, and viewing wildlife (Bowker et al. 2012). However, hunting that
13700 occurs during discrete seasons (e.g., elk and deer hunts managed by state seasons) may depend on
13701 weather conditions during a short period of time. The desirability of hunting during established seasons

may decline as warmer weather persists later into the fall and early winter and the likelihood of snow cover decreases, reducing harvest rates.

The effects of changes in habitat for target species are likely to be ambiguous because of complex relationships among species dynamics, vegetation, climate, and disturbances (primarily wildfire and invasive species) (see chapter 9), and are likely heterogeneous across species and habitat types. Overall vegetative productivity may decrease in the future, although this is likely to have a neutral effect on game species populations, depending on the size, composition, and spatial heterogeneity of forage opportunities in the future (see chapter 9). Similarly, the effects of disturbances on target species harvest rates are ambiguous because it is unknown exactly how habitat composition will change in the future.

Higher temperatures will likely decrease populations of native cold-water fish species as climate refugia retreat to higher elevations (see chapter 5). This change favors increased populations of fish species that can tolerate warmer temperatures. However, it is unclear whether shifting populations of species (e.g., substituting rainbow trout [*O. mykiss*] for cutthroat trout) will affect catch rates because relative abundance of fish may not necessarily change.

Total precipitation is not projected to change under future climate scenarios (see chapter 3), but increased interannual variability in precipitation, the possibility of extreme drought, and reduced snowpack could result in higher peakflows in winter and lower low flows in summer, creating stress for fish populations during different portions of their life histories. The largest patches of habitat for cold-water species will be at higher risk to shrink and fragment. Increased incidence and severity of wildfire may increase the likelihood of secondary erosion events that degrade waterways and game species habitat. These effects could degrade the quality of individual sites in a given year or decrease the desirability of angling as a recreation activity relative to other activities.

The magnitude of climate effects on activities involving terrestrial wildlife is expected to be low overall for terrestrial wildlife activities and moderate for fishing. Ambiguous effects of vegetative change on terrestrial wildlife populations and distribution suggest that conditions may improve in some areas and decline in others. Overall warming tends to increase participation, but may create timing conflicts for

activities with defined regulated seasons (e.g., big game hunting) unless the timing of seasons is changed. Anglers may experience moderate negative effects of climate change on benefits derived from fishing. Opportunities for cold-water species fishing are likely to be reduced as cold-water refugia retreat to higher elevations or are eliminated in some areas. Cold-water species tend to be the highest value targets, indicating that this habitat change will decrease benefits enjoyed by anglers. Warm-water tolerant species may increasingly provide targets for anglers, mitigating reduced benefits from fewer cold-water species. Warmer temperatures and longer seasons encourage additional participation, but indirect effects of climate on streamflows and reservoir levels could reduce opportunities in certain years. The likelihood of climate-related effects on wildlife activities is expected to be moderate for both terrestrial and aquatic wildlife activities. Uncertainties exist about the magnitude and direction of indirect effects of climate on terrestrial habitat and the degree to which changes in available target species affects participation.

Gathering Forest Products

Forest product gathering for recreational purposes accounts for a relatively small portion of primary visit activities in the Northern Rockies, although it is relatively more common as a secondary activity. Forest products are also important for cultural and spiritual uses, which is discussed in chapter 11. A small but avid population of enthusiasts for certain types of products supports a small but steady demand for gathering as a recreational activity. Small-scale commercial gathering likely competes with recreationists for popular and high-value products such as huckleberries (*Vaccinium* spp.), although resource constraints may not be binding at current participation levels.

Forest product gathering is sensitive primarily to climatic and vegetative conditions that support the distribution and abundance of target species. Participation in forest product gathering is also akin to warm-weather recreation activities, depending on moderate temperatures and the accessibility of sites where products are typically found. Vegetative change due to warming temperatures and increased inter-annual variation in precipitation may alter the geographic distribution and productivity of target species (see chapters 6 and 7). Increased incidence and severity of wildland fires may eliminate sources of forest products in some locations (e.g., for berries), but in some cases fires may encourage short- or medium-

term productivity for other products (e.g., mushrooms). Long-term changes in vegetation that reduces forest cover may reduce viability of forest product gathering in areas that have a high probability of vegetative transition to less productive vegetation types.

Recreationists engaged in forest product gathering may have the ability to select different gathering sites as the distribution and abundance of target species changes, although these sites may increase the costs of gathering. Those who engage in gathering as a secondary or tertiary activity may choose alternate activities to complement primary activities. Commercial products serve as an imperfect substitute for some forest products such as Christmas trees.

The magnitude of climate effects on forest product gathering is expected to be low. This activity is among the less-common primary recreation activities in the region, although it may be more often engaged in as a secondary or tertiary activity. Longer warm-weather seasons may expand opportunities for gathering in some locations, although these seasonal changes may not correspond with greater availability of target species. The likelihood of effects is expected to be moderate, although significant uncertainty exists regarding direct and indirect effects on forest product gathering. Vegetative changes caused by climate changes and disturbances may alter abundance and distribution of target species, although the magnitude and direction of these effects is unclear.

Water-Based Activities, Not Including Fishing

Separate from angling, water-based activities comprise a small portion of primary recreation activity participation on federal lands. Upper reaches of streams and rivers are generally not desirable for boating and floating. Lakes and reservoirs provide opportunities for both motorized and non-motorized boating and swimming, although boating may commonly be paired with fishing. Existing stressors include the occurrence of drought conditions that reduce water levels and site desirability in some years, and disturbances that can alter water quality (for example, erosion events following wildland fires).

Even if total precipitation does not change significantly under future climate scenarios (see chapter 3), the availability of suitable sites for non-angling, water-based recreation is sensitive to reductions in water levels caused by warming temperatures, increased variability in precipitation (including the possibility of

13780 severe droughts), and decreased precipitation as snow. Reduced water levels may also have an indirect
13781 effect on the aesthetic qualities of some water-based recreation sites (e.g., exposure of "bathtub rings" at
13782 reservoirs with low water levels). Reductions in surface-water area are associated with decreases in
13783 participation in boating and swimming activities (Bowker et al. 2012; Loomis and Crespi 2004;
13784 Mendelsohn and Markowski 2004), and streamflow is positively associated with number of days spent
13785 rafting, canoeing, and kayaking (Loomis and Crespi 2004). Demand for water-based recreation is also
13786 sensitive to temperature. Warmer temperatures are generally associated with higher participation in water-
13787 based activities (Loomis and Crespi 2004; Mendelsohn and Markowski 2004), although extreme heat may
13788 dampen participation for some activities (Bowker et al. 2012).

13789 Increasing temperatures, reduced storage of water as snowpack, and increased variability of
13790 precipitation are expected to increase the likelihood of reduced water levels and greater variation in water
13791 levels in lakes and reservoirs on federal lands (see chapter 4), which is associated with reduced site
13792 quality and suitability for certain activities (fig. 10.5). Increased demand for surface water by downstream
13793 users may exacerbate water levels in drought years. Warmer temperatures are expected to increase the
13794 demand for water-based recreation as the viable season lengthens. Extreme heat encourages some people
13795 to seek water-based activities as a climate refuge, although extreme heat also discourages participation in
13796 outdoor recreation in general (Bowker et al. 2012). Overall, projections of water-based activities in
13797 response to climate change tend to be small compared to broad population and economic shifts (Bowker
13798 et al. 2012).

13799 Climate change is expected to have a moderate effect on water-based activities. Increasing
13800 temperatures and longer warm-weather seasons are likely to increase demand, although the incidence of
13801 extreme temperatures may dampen this effect in certain years. A higher likelihood of lower streamflows
13802 and reservoir levels and potential reductions to site aesthetic quality may also offset increased demand to
13803 some extent. Climate change effects are expected to occur with moderate likelihood. Climate model
13804 projections tend to agree on a range of warming temperatures and longer seasons, although changes in
13805 precipitation are uncertain. Changes in the timing of snowmelt may increase the likelihood of negative

effects to water-based activities (through lower summer flows and reservoir levels) that offset increases due to warmer temperatures.

Summary

Several recreation activities are considered highly sensitive to changes to climate and ecosystem characteristics. However, recreation in the Northern Rockies is diverse, and the effects of climate are likely to vary widely between different categories of activities and across geographic areas within the region. Overall, participation in climate-sensitive recreation activities is expected to increase in the region, primarily because longer warm-weather seasons will make more recreation sites available for longer periods of time.

Increased participation in warm-weather activities is likely to be offset somewhat by decreased snow-based winter activities. Receding snow-dominated areas and shorter seasons in the future are likely to reduce the opportunities (in terms of available days and sites) for winter recreation.

Beyond these general conclusions, the details of changes to recreation patterns in response to climate changes are complex. Recreation demand is governed by several economic decisions with multiple interacting dependencies on climate. For example, decisions whether to engage in winter recreation, activity type (e.g., downhill or cross-country skiing), location, frequency of participation, and duration of stay per trip depend somewhat on climate and ecological characteristics. On the supply side, site availability and quality depend on climate, but the effect may differ greatly from one location to another. Thus, climate effects on recreation depend on spatial and temporal relationships between sites, climate and ecological characteristics, and human decisions.

Uncertainty derives from unknown effects of climate on site quality and characteristics that are important for some recreation decisions (e.g., indirect effects of climate on vegetation, wildlife habitat, and species abundance and distribution). The precise effect of climate on target species or other quality characteristics may be difficult to predict or diverse across the region, yet these characteristics play a large role in recreation decisions for some activities. Another source of uncertainty is how people will adapt to changes when making recreation decisions. Inter-regional and inter-temporal substitution

13832 behavior is not yet well understood (Shaw and Loomis 2008). This may be important for the Northern
13833 Rockies if in the future some sites exhibit relatively little effect from climate change compared with sites
13834 in other regions. For example, winter recreation sites in the Northern Rockies may experience shorter or
13835 lower-quality seasons in the future but see increased demand if the quality of sites in other regions
13836 becomes relatively worse in the future.

13837 Substitution is likely to be an important adaptation mechanism for recreationists. Many recreation
13838 activities that are popular in the region may have several alternate sites, or timing of visits can be altered
13839 to respond to climate changes. However, substitution may represent a loss in benefits derived from
13840 recreation even if it appears that participation changes little (Loomis and Crespi 2004); the new substitute
13841 site may be slightly more costly to access, or slightly lower quality than the preferred visit prior to climate
13842 change. This represents a decrease in benefits to the person engaging in recreation.

13843 ## ADAPTING RECREATION TO THE EFFECTS OF CLIMATE CHANGE

13844 Adapting recreation management to climate change in the Northern Rockies will be critical to ensure
13845 that recreation opportunities exist in the future.

13846 ### Adaptation by Recreation Participants

13847 Increasing temperatures with changing climate will have significant negative effects on snow-based
13848 recreation, because the snow-based recreation season will likely decrease in length, and the quality of the
13849 snow during the season may also decrease (be wetter).

13850 Water-based recreationists may adapt to climate change by choosing different sites that are less
13851 susceptible to changes in water levels (e.g., by seeking higher-elevation natural lakes) and changing the
13852 type of water-based recreation activity they engage in (e.g., from motorized boating on reservoirs to non-
13853 motorized boating on natural lakes).

13854 Hunters may need to adapt by altering the timing and location of hunts. However, state rules on
13855 hunting season dates impose a constraint on this behavior unless states change hunting seasons based on
13856 expected climate changes. Hunters may also target different species if the abundance or distribution of
13857 preferred species changes in the future.

Like hunters, wildlife viewers may change the timing and location of viewing experiences and target different species. Since viewing is not typically governed by state-regulated seasons, wildlife viewers may have more flexibility to shift timing to coincide with appropriate weather conditions or species movements into accessible areas. However, adaptation options may be more limited if the abundance or distribution of highly valued species significantly decreases the likelihood of viewing, and limited high-quality substitute species are available.

Anglers may adapt by choosing different species to target (for example, shifting from cold-water to warm-water tolerant species) and choosing sites that are relatively less affected by climate change (for example, higher-elevation secondary-stem reaches of streams). The former is less costly than the latter, although some anglers may place a high value on certain target species and have a lower willingness to target warm-water species that may thrive in place of cold-water species.

Adaptation by Public Land Managers

Managers may need to reconsider how infrastructure investments and the provision and maintenance of facilities align with changing ecological conditions and demands for recreation settings. The Recreation Opportunity Spectrum (ROS) can be used to match changing conditions and preferences to the allocation of available recreation opportunities. Adaptation by managers may take the form of responding to changing recreation patterns, but also helping to shape the settings and experiences that are available to recreation users on public lands in the future.

For winter recreation, a general adaptation strategy may be to transition recreation management to address shorter winter recreation seasons and changing recreation use patterns (table 10.4). Specifically, opportunities may exist to expand facilities where concentrated use increases, and options for snow-based recreation can be diversified to include more snow-making, additional ski lifts, and higher-elevation runs. However, in some cases adaptations related to the supply and quality of winter recreation opportunities could result in tradeoffs with other activities, e.g. undeveloped warm-weather access to higher elevation sites or winter vs. summer streamflow effects of snowmaking.

With higher temperatures and earlier snowmelt, warm-weather activity seasons will likely lengthen. Recreation managers have options for responding to changing patterns in warm-season recreation demand in order to provide sustainable recreation opportunities. A first step will be to conduct assessments to understand the changing patterns of use (table 10.4). Then, adjustments can be made to increase the capacity of recreation sites that are showing increased use (e.g., campgrounds can be enlarged, and more fences, signs, and gates can be installed where necessary). The potential for congestion and resource damages due to increases in use for some sites may, in part, drive such adjustments. However, there may be some limitations to increasing the capacity of some recreations sites (e.g., limitations for developed recreation sites under the U.S. Fish and Wildlife Service Northern Continental Divide Ecosystem Grizzly Bear Conservation Strategy; USFWS 2013). The timing of some actions such as trail closures, food storage orders, and special use permits may also need to be adjusted within the context of providing sustainable recreation. For example, the season for whitewater rafting permits may need to be modified to adjust to shifts in timing of peakflows (table 10.4).

Increased frequency of disturbances, such as fire and flooding, will likely cause increased damage to infrastructure associated with multiple types of recreation activities. Recreation sites can be managed to decrease risks to public safety and infrastructure (table 10.4). Assessments can be used to determine which sites and infrastructure are most at risk from disturbance, and strategic investments can be made in those facilities that will likely be viable in the future and accommodate changing use patterns.

More specific details on adaptation strategies and tactics for each Northern Rockies Adaptation Partners (NRAP) subregion are in Appendix 10A.

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Chapter 11: Effects of Climate Change on Ecosystem Services

Travis Warziniack, Megan Lawson, and S. Karen Dante-Wood

INTRODUCTION

In this chapter, we focus on the ecosystem services provided to people who visit, live adjacent to, or otherwise benefit from natural resources on public lands. Communities in the region are highly dependent on ecosystem services from water, soil, and air that will be impacted by climate change in a variety of ways. Every community in the region will feel these impacts. We link biophysical effects associated with climate change, as described in previous chapters, with potential effects on the well-being of humans and communities, and identify strategies for adapting to climate-induced changes and prioritizing among competing interests. First, we introduce ecosystem services and how to describe and measure them. Second, we describe how people and communities currently use and benefit from public lands in the Northern Rockies, as well as existing stressors that may affect the ability of communities to adapt to a changing climate. Third, we discuss climate change effects on specific ecosystem services. Finally, we identify adaptation strategies that can help reduce negative effects on ecosystem services, and discuss the ability of public agencies and communities to respond to climate change (adaptive capacity).

Ecosystem services are benefits to people from the natural environment. These include timber for wood products, clean drinking water for downstream users, recreation opportunities, and spiritual and cultural connection to the environment and natural resources. As stated by Collins and Larry (2007), "An ecosystem services perspective encourages natural resource managers to extend the classification of multiple uses to include a broader array of services or values."

Ecosystem services are commonly placed in the following four categories (Millenium Ecosystem Assessment 2005):

- Provisioning services—products obtained from ecosystems, including timber, fresh water, wild foods, and wild game.

- Regulating services—benefits from the regulation of ecosystem processes, including the purification of water and air, carbon sequestration, and climate regulation.
- Cultural services—nonmaterial benefits from ecosystems, including spiritual and religious values, recreation, aesthetic values, and traditional knowledge systems.
- Supporting services—long-term processes that underlie the production of all other ecosystem services, including soil formation, photosynthesis, water cycling, and nutrient cycling.

Categorizing ecosystem services in this manner helps identify the ways in which natural resources and processes benefit humans, and how changes in the natural environment will affect these benefits. Climate change will affect the quality and quantity of ecosystem services provided by public lands. Establishing the link among natural processes, ecosystem services, and human benefits helps clarify the communities or types of people most vulnerable to a changing climate.

Although ecosystem service categories help organize our understanding of the relationship between natural resources and human benefits, this simple approach may obscure complex relationships between natural and human systems. Three important caveats are relevant to discussions of ecosystem services and anticipated climate change effects. First, these categories are not exclusive, and many natural resources fall under multiple categories, depending on the context. For example, the consumption of fresh water can be considered a provisioning service, the process of purifying water a regulating service, the use of fresh water for recreation a cultural service, and the role of fresh water in the life cycle of organisms a supporting service. Second, these categories are interdependent, such that individual services would not exist without the functioning of a broad set of ecosystem services.

To address the challenges of ecosystem services falling into multiple, interdependent categories, Boyd and Krupnick (2009) use ecological production theory to describe ecosystems as "collections of commodities linked by a range of biophysical processes, delineating biophysical inputs and outputs, ecological endpoints, and processes that transform them from one to another." In this framework, fresh water is an output from a filtration process, an ecological endpoint in itself as drinking water, and then an input for the endpoints of recreation and plant and animal populations. This framework facilitates

assessment of ecosystem service vulnerability by allowing analysts to identify ecosystem service endpoints and connect changes in inputs and processes caused by climate change to changes in ecosystem service provision.

Ecological production theory and the subsequent distinction between natural resources that are endpoints, inputs, and outputs, provides a helpful framework for measuring ecosystem services. Later in this chapter, we identify the most significant ecosystem services in the Northern Rockies and describe how they are expected to change.

ECOSYSTEM SERVICES AND PUBLIC LANDS

The evaluation of ecosystem services in this assessment is consistent with federal agency management requirements. Under the Forest Planning Rule of 2012, the Forest Service, U.S. Department of Agriculture is required to formally address ecosystem services in land management plans for national forests (Federal Register 2012). The National Park Service does not have specific mandates concerning ecosystem services, but they have incorporated ecosystem service considerations into management planning and made ecosystem services a key part of their 2014 Call to Action (NPS 2014). The Bureau of Land Management has also identified nonmarket environment values, synonymous with ecosystem services, as an increasingly important consideration for land management (Winthrop n.d.).

Although all natural systems provide some type of ecosystem services, managing for ecosystem services on public lands involves specific considerations that make it especially important to identify the endpoints, how they are used, and which ones are most susceptible to disruption from a changing climate. There are many beneficiaries from ecosystem services provided by public lands, including neighboring communities, non-local visitors, and people who may never visit or directly use the lands but gain satisfaction from knowing a resource exists and will be there for future generations (Kline and Mazzotta 2012). This is particularly true for iconic landscapes and rivers in the study area such as Yellowstone National Park, Glacier National Park, the Salmon River, and the Selway River (Borrie et al. 2002; Chouinard and Yoder 2004; Mansfield et al. 2008; O'Laughlin 2005; Pederson et al. 2006).

Mandates to manage for multiple use of natural resources can create situations in which some ecosystem services conflict with others. For example, managing lands for non-motorized recreation may conflict with managing for motorized recreation, timber, and mining, but it could complement management for biodiversity and some wildlife species. Ecosystem services from public lands are critical for neighboring communities, particularly in rural areas of the Northern Rockies where people rely on these lands for fuel, food, water, recreation, and cultural connection. Decreased quantity and quality of ecosystem services produced by public lands will affect human systems that rely on them, requiring neighboring communities to seek alternative means of providing these services or to change local economies and lifeways.

Management decisions for public lands can substantially affect ecosystem service flows, with cascading effects on numerous users. This chapter is intended to highlight potential climate change effects on ecosystem service flows, for which management decisions can help users mitigate or adapt to these effects and illustrate the tradeoffs in the decision-making process. Since the concept of ecosystem services is somewhat new, data on ecosystem services are scarce. In this chapter, we use quantitative data when possible, but we often rely on qualitative descriptions or proxy measures. Demographic and economic factors often have a significant effect on ecosystem services, providing an important context for understanding the effects of climate change.

ECOSYSTEM SERVICES IN THE NORTHERN ROCKIES

The U.S. Forest Service Northern Region Resource Information Management Board identified ecosystem services that are used by a large number of people and can also be affected by management decisions. Using the standard categories discussed above, we focused on provisioning, regulating, and cultural ecosystem services. Supporting services were not included because, although important, they are largely indirect services that are inputs to other biophysical processes, and are unlikely to be directly affected by management decisions. Note, while we have grouped ecosystem services into provisioning, regulating, and cultural services below, these categories are not definitive; many could have been

included in an alternative category. Although the Forest Service designated these ecosystem services, many of these services are also important for other public agencies in the Northern Rockies:

Provisioning ecosystem services

- Abundant fresh water for human (e.g., municipal and agricultural water supplies) and environmental (e.g., maintaining streamflows) uses
- Building materials and wood products
- Mining materials
- Forage for livestock
- Fuel from firewood and biofuels
- High air quality and scenic views
- Genetic diversity and biodiversity

Regulating ecosystem services

- Water filtration and maintenance of water quality associated with drinking, recreation, and aesthetics
- Protection from wildfire and floods
- Protection from erosion
- Carbon sequestration

Cultural ecosystem services

- Recreation opportunities
- Aesthetic values from scenery
- Protection and use of cultural sites
- Native American treaty rights

The amount of detail below for these ecosystem services varies as a function of how much information is available and can be interpreted in the context of climate change. Many of the ecosystem services are also discussed in other chapters of this assessment, including recreation (chapter 10), genetic

diversity and biodiversity (chapter 6), and protection from wildfire and floods (chapter 9). Most of the others are covered to some extent in this chapter. Ecosystem services are combined in a single section if all of them are likely to be affected by the same changes in natural resource conditions.

SOCIAL VULNERABILITY AND ADAPTIVE CAPACITY

Communities that have the social structure and resources to adapt to one environmental impact generally have the capacity to adapt to others. A growing literature on social vulnerability seeks to identify which institutions, resources, and characteristics make communities more or less resilient to environmental hazards. The sections below address the first part of social vulnerability – exposure to negative changes related to specific ecosystem services and possible adaptation strategies. The capacity to adapt to those changes often depends on factors that transcend specific resources, and are so addressed more broadly here.

The most widely used measure of social vulnerability is the Social Vulnerability Index (SoVI), managed and updated by the Hazards and Vulnerability Research Institute at the University of South Carolina (Cutter et al. 2003). The SoVI is based on 11 underlying factors identified to affect social vulnerability: personal wealth, age, density of the built environment, single-sector economic dependence, housing stock and tenancy, race, ethnicity, occupation, and infrastructure dependence. For each county in the U.S., scores based on these 11 factors are summed to form a composite vulnerability score. To highlight counties with the most "extreme" scores, composite scores are then converted to standard deviations and mapped (fig. 11.1).

Figure 11.1 shows that most counties in the region fall in the high to medium vulnerability range. A large factor in the region's vulnerability is its rural character. Among the region's counties, the average percentage of county populations living in rural areas is 75.3 percent, compared to a national average of 19.3 percent (all demographic data in this section is based on the 2012 Census American Community Survey). Rural counties tend to be reliant on a single industry, have older populations, and have fewer social resources (hospitals, for example) than urban areas. Loss of youth is also a primary concern among ranching communities, where the younger generation is often reluctant to take over the ranching business

and more likely to move outside the region. The oldest mean average age in the region is found in Prairie County, Montana, where the mean age is 56. The average median age among the counties is 43.4, and the low is 22 in Madison County, Idaho. Figure 11.2f shows the proportion of each county over the age of 65. An aging population and decline in youth in rural counties worries many because of the potential loss of a traditional culture in many Western communities.

The median household income of Region 1 counties is $45,235, which is considerably lower than the national average of $53,046. The high-income counties tend to be in the eastern part of the region, with ties to the oil and gas industry, and areas with high concentrations of recreation-based industries. Income is lowest in the counties dependent on grazing and timber.

Figures 11.2a and 11.2b show relatively widespread unemployment and poverty in the region. Theodossiou (1998) found employment is more important than income in predicting life satisfaction. The region on average had an average unemployment rate in 2012 of 5.4 percent, which was lower than the national average of 9.3. Spatially, unemployment follows median incomes closely, with counties in the east having low unemployment and counties in the west having high unemployment. A few counties have very high unemployment, particularly in the timber-dependent counties where jobs are concentrated among a few large employers.

The service industry typically pays low wages, maintains part time positions, and does not pay benefits like retirement and health insurance. Employment fluctuates with overall economic conditions. For these reasons, workers in the service industry can be vulnerable to economic fluctuations. The mean percent employed in the region's service industry is 17.8. Some counties have more than 30 percent of their labor force employed in the service industry.

Many of the factors that make individuals more vulnerable are compounded among migrants and minorities. They tend to have fewer economic resources, lack political power and sometimes struggle with communication (Aguirre 1998; Blaikie et al. 1994; Fothergill and Peek 2004; Morrow 1999; Phillips 1993; Phillips and Ephraim 1992). Such factors make minorities less likely to participate in disaster planning, be familiar with support services, and have basic resources like a vehicle for use during an

14232 evacuation or to transport the injured and sick to hospitals (fig. 11.2c). On average, the region has very
14233 few foreign born residents, 2.7 percent compared to a national average of 12.9 percent. A few counties,
14234 however, have large concentrations of migrant agricultural workers (fig. 11.2d). Clark County, Idaho,
14235 though it only had 982 people in the 2010 Census, was home to over 350 immigrants. Minorities are also
14236 concentrated among a few counties. Between 39 and 56 percent of the populations in the Idaho counties
14237 in the region are minorities, compared to a regional average of only 15.9 percent. In comparison, many
14238 counties in eastern Montana and North Dakota have less than 5 percent minorities. The predominant
14239 minority group in the region is Native American, located in counties with more than 56 percent of their
14240 population from minorities.

14241 Some of the regional trends in vulnerability and demographics are tied to traditional uses of the land
14242 and major industries in the counties. Table 11.1 shows mean SoVI scores by industry. Grazing
14243 communities, because they tend to be older, poorer, and more rural, score significantly higher on the SoVI
14244 than communities without grazing. Communities dependent on timber, oil and gas, and recreation have
14245 significant score significantly lower on the SoVI than other counties. Counties in the national forest
14246 economic impact zones of Region 1 have higher SoVI scores, though the difference is not significant
14247 (table 11.1).

14248 Table 11.2 shows the number of counties significantly below or above the regional mean SoVI, by
14249 industry. Each row shows data for counties that are in the top half of counties sorted by share of
14250 employment in that industry. For example, the "Grazing" row shows results for counties for which
14251 grazing represents a larger share of total employment than half the other counties in the region. Among
14252 grazing counties, 54 counties have unemployment rates significantly below the regional average of 5.4
14253 percent and 18 counties have unemployment rates significantly above the regional average (based on 95
14254 percent confidence intervals). Grazing counties tend to have the lowest median incomes, the oldest
14255 populations, and the highest percentage of people living in rural settings. Timber counties tend to have the
14256 highest unemployment rates and the highest percentages of foreign-born residents and minorities.
14257 Counties with a lot of recreation-based employment are among the least vulnerable, though they do have

a lot of service industry employment. Counties with oil and gas tend to have lower unemployment rates and higher wages than most places in the U.S., much less the region.

ECOSYSTEM SERVICE: WATER QUANTITY

Water use can be broadly classified as consumptive or non-consumptive. Water allocated to a consumptive use is not available for other uses, whereas water allocated to a non-consumptive use is available for other uses. Most economic uses of water have components of both consumptive and non-consumptive uses. For example, a portion of water applied to croplands is taken up by plants and does not return to the waterways; this portion represents consumptive use of water by the crop. The portion of water applied to cropland that returns to the waterways via runoff is the non-consumptive portion. Major consumptive uses of water in the Northern Rockies include domestic and municipal water supply, industrial use of water, and water for oil and gas development (drilling and hydraulic fracturing). Non-consumptive uses of water in the region include recreational uses (e.g., boating, maintaining fish habitat) and hydroelectric power production. Most water in the Northern Rockies is already appropriated, and many uses are tied to junior water rights. Junior water rights can be exercised only during high-flow years, so they are unreliable from season to season or year to year. Any new uses of water require a transfer of water rights, increased water supply through reservoir storage, or mining of ground water.

A recent draft of the Montana State Water Plan (Montana DNRC 2014) details water use in Montana (tables 11.3, 11.4) and is representative of most of the Northern Rockies. Hydroelectric power generation (hydropower) accounts for 86 percent of total water demand in Montana, although hydropower is considered a non-consumptive use because it does not affect in-stream flow or total water available downstream. However, reservoirs needed for hydropower experience high rates of water loss to evaporation. Fort Peck Reservoir, in the Lower Missouri River Basin, annually loses 611,400 acre-feet of water to evaporation.

The largest consumptive use of water in Montana is irrigated agriculture, which accounts for 96 percent of all water diversions and 67 percent of all consumptive use (accounting for return flows). In the Yellowstone River basin, irrigation accounts for 83 percent of consumptive use.

Due to the downstream location of fish and wildlife habitat, preserving in-stream water for habitat often requires explicit water rights. Montana Fish, Wildlife, and Parks maintains 3.6 million acre-feet of in-stream flow rights downstream of Fort Peck and below the Milk River confluence with the Missouri River. They maintain 5.5 million acre-feet of in-stream flow rights for the Yellowstone River at Sidney. Although population is increasing in the Western Rockies and Greater Yellowstone Area subregions, water demand for urban uses has not increased significantly; even in the most populated regions, consumptive use by households is below 4 percent.

The share of any particular water use does not imply anything about relative values of water among uses. The marginal value of water in agriculture is routinely an order of magnitude lower than the marginal value of water for municipal uses, particularly in areas of recent population growth. Prices for municipal uses are $290 to $3,145 per acre-foot, whereas prices for leased agricultural water diverted for in-stream conservation are $42 to $3,614 per acre-foot (Montana DNRC 2014). In general, prices increase for more senior water rights and when few other options for obtaining water exist in the area. Current rates paid by agricultural users of water from Bureau of Reclamation and Montana Department of Natural Resources and Conservation facilities are $2.32 to $7.50 per acre-foot per year, or a capitalized value of $76 to $244 per acre-foot. Accounting for delivery and operating costs, the capitalized costs of agricultural water range from $189 to $615 per acre-foot.

Effects of Climate Change

A warming climate is expected to cause a transition in the form of precipitation from snow to rain (see chapter 3), which will affect the timing of water availability (see chapter 4). Warmer temperatures will make drought more frequent, despite small increases in precipitation shown in some climate models, increasing overall competition for water. This will amplify many of the effects of population growth and demographic changes already occurring. Agricultural and municipal users will experience major impacts, making it more difficult to allocate in-stream flows for recreation and wildlife.

Agriculture

Timing of snowmelt is a chief concern in the Columbia and Missouri Basin headwaters (see chapter 4). Earlier runoff may be out of sync with many of the water rights currently held by agriculture, even as warmer months extend the growing season. Future water quantities in North Dakota and the eastern plains of Montana are likely to be more variable.

North Dakota has already seen an increase in regional temperatures that has brought a mixture of impacts to agriculture, the largest industry in the state. Wheat production alone generates $4.5 billion annually in economic activity (North Dakota Wheat Commission 2007). Warmer temperatures and higher commodity prices have pushed wheat and corn production into areas of the state where either they were not previously grown or where shorter-season varieties dominated.

Higher temperatures increase plant demand for water, contributing to droughts even though the Grassland subregion is expected to see a slight increase in precipitation (see chapter 3). Drier soils and more intense precipitation events may increase flood frequency, leading to increased dependence on tile drainage. In 2002, drought cost North Dakota $223 million, and heavy rains in 2005 ruined over 1 million acres of cropland and prevented another 1 million from being planted. These heavy rains caused $425 million in damage to North Dakota crops, and the state's livestock industry lost $32 million, largely from the increased price of feed which was in short supply (Karetinkov et al. 2008). More droughts and intense temperatures may also make plants more susceptible to insect pests (Rosenzweig et al. 2000).

Domestic and Municipal Uses

If the frequency of drought and heavy rain events increases, they will stress municipal water supply systems and built infrastructure. Decreased permeability of soils associated with drought conditions will also lead to more flash floods, endangering lives and affecting water supply systems and infrastructure. In regions with clay soils, increased frequency of drought is already causing sidewalks, driveways, and streets to crack, and while the cost of fixing one sidewalk one time is relatively small, these persistent costs add up and have been shown to cause large financial burdens on communities.

Warmer months and growing populations will increase demand for both air conditioning and lawn watering. There will be a slight decrease in demand for heat, but net household demand for electricity is

expected to rise. Therefore, demands for water for power generation and other municipal uses are expected to increase.

Recreation and Wildlife

The effects of climate change on skiing, boating, and fishing are summarized in chapter 10, and the effects of wildfire are described in chapter 8. Beyond effects mentioned in those chapters, it may become harder to preserve in-stream flows even though demographic changes will increase demand for such preservation. Particularly vulnerable habitats include small streams in the mountains and highly valued fisheries throughout the Northern Rockies.

Climate models suggest a drier climate will shift some of the most productive waterfowl breeding grounds of the northern prairie wetlands and pothole region (which produces 50 to 80 percent of North America's ducks) to the wetter eastern and northern fringes of the Northern Rockies, an area where many wetlands have been drained. Unless these wetlands are restored, bird populations will be significantly affected (Johnson et al. 2005). Some estimates show that the north-central duck population in the United States could be reduced by 50 percent (Sorenson et al. 1998).

Adaptive Capacity

As noted above, adaptive capacity refers to institutional capability to modify management, decision-making, and policy to ensure sustainable production of ecosystem services. Objectively assessing the region's capacity to respond to changes in ecosystem services is difficult, with little guidance in general from science and no guidance specific to the region. This section, therefore, mostly focuses on adaptation strategies.

Transfer of water rights from one use to another is legally possible within the Northern Rockies but realistically constrained by the ability to transport water. Transfers between agricultural and municipal uses, for example, can only occur between users in the same watershed. Since municipal values of water are usually higher than those of agriculture, these transfers are likely to occur should the need be dire enough.

Reuse of effluent and other conservation methods will be important tools for adaptation. Ground water pumping is also available as a short-term solution, but is not sustainable in the long run. These methods are expensive and will be cost prohibitive for most rural communities in the Northern Rockies. New municipal demands are more likely to be met by purchasing or leasing reliable senior water rights (Montana DNRC 2014). Water rights are still available in some water basins, but these new appropriations are junior in priority and not likely to be reliable enough for municipal uses.

A drier climate in the central and western prairie pothole habitats of the Grassland subregion will diminish the benefits of preserving waterfowl habitat in that area and increase the importance of restoring wetlands along the wetter fringes (Johnson et al. 2005).

Risk Assessment

Compared to more arid regions of the western United States, changes in water yield in the northern Rockies are expected to be modest, although they may be disproportionately large for local residents who experience them (Foti et al. 2012). Changes in timing of runoff will be significant. Climate and hydrological models consistently project changes in temperature and timing of runoff, making the likelihood of these effects high.

ECOSYSTEM SERVICE: WATER QUALITY, AQUATIC HABITATS, AND FISH FOR FOOD

Compared to many areas of the United States, the Northern Rockies have excellent water quality. The headwater streams of the region generally provide safe, clean drinking water to downstream communities (fig. 11.3) and provide habitat for some of the country's premier recreational and commercial fisheries (see chapter 10). Fresh water is important to the cultural practices of area tribes, including ability to exercise their indigenous fishing rights. Nonetheless, many of the region's streams and lakes are already threatened or impaired according to U.S. Environmental Protection Agency standards (tables 11.5, 11.6, 11.7). In all Northern Rockies states, agriculture is the primary source of impairment in rivers and streams, caused by grazing in riparian and shoreline zones and by fertilizer sediment in runoff. In Montana, grazing leads to loss of streamside vegetation and increased sedimentation. Idaho sees similar disturbances, but with increased water temperatures as the primary reason for impairment. In North

Dakota, animal feeding operations add to riparian grazing, causing unsafe levels of fecal coliform and habitat alterations.

Major causes of impairment for lakes, reservoirs, and ponds differ between states. Runoff from roads and bridges are a problem in Idaho, leading to high levels of phosphorous and mercury. In Montana, abandoned mines can cause accumulation of mercury and lead. In North Dakota, grazing and animal feeding operations can produce levels of fecal coliform that can contaminate water bodies.

For municipal water supplies, disturbances such as wildfires and mudslides are a major concern (see chapter 8) (fig. 11.4). Due to the generally high water quality in the region, water treatment plants are able to operate with lower capital investments. When there are sudden increases in sediment or other pollutants, such as often occurs after a wildfire, treatment plants need to shut down or incur high costs to treat the water and remove sediment from reservoirs.

Some Northern Rockies residents worry about the effects of increased oil and gas extraction activities on watershed health. Groundwater contamination in northeastern Montana near the Fort Peck Indian Reservation has been linked to development of the East Poplar oil field (Thamke and Smith 2014). Groundwater is the only source of drinking water in the area, and contamination has affected drinking water quality. Oil spills in the Yellowstone River (2011, 2015), a pipeline leak near Tioga, North Dakota (2014), and train derailments in Lac Megantic, Canada (2013) and near Lynchburg, Virginia (2014) highlight the dangers to watersheds surrounding oil and gas fields, even if the activity that caused contamination does not occur in the watershed.

Effects of Climate Change

Climate change will impact water quality in ways that affect fishing, water-based recreation, and drinking water. Climate change will amplify the effects of development on water quality already occurring in the region. Increased number and severity of wildfires will deposit more sediment in streams, lakes, and reservoirs. Increased air temperature and loss of vegetation along stream banks will raise the temperature of streams, and altered vegetation may affect water filtration and flow rate. Lower water

quality may affect municipal water supplies, water-based recreation, and ecosystem services tied to the health of fish and wildlife and associated aquatic systems.

Warming air temperature due to climate change and loss of streamside vegetation due to development, grazing, and agriculture in the riparian zone will cause water temperatures to increase. Since most aquatic organisms are ectothermic, temperature is a significant abiotic factor influencing physiology, bioenergetics, behavior, and biogeography (Rahel 2002; Sweeney et al. 1992). Some native fish species, such as bull trout (*Salvelinus confluentus*), are extremely sensitive to warm water, whereas some nonnative species can tolerate higher temperatures (see chapter 5). Fish habitats at lower elevations are likely to experience the biggest and soonest temperature increases, making them the most vulnerable to shifts in species composition and distribution. The response of microbial and aquatic invertebrate communities to a warming climate and altered hydrologic patterns is poorly understood. Native fish species with high ecological plasticity will be able to withstand some environmental change by altering life history timing or distribution patterns, but the magnitude and rate of change will overwhelm species with narrow ecological niches or limited ability to withstand competition from nonnatives. In the Northern Rockies, this includes bull trout and cutthroat trout (*Oncorhynchus clarkii*).

Effects of climate change on fish are summarized in chapter 5, and effects on recreational fishing are summarized in chapter 10. Additional effects are likely to occur to culturally important fisheries. For example, the Nez Perce tribe maintains fishing rights within the boundaries of their reservation and traditional fishing grounds, which include the mainstem of the Columbia River. Hydropower and stream modification have already significantly affected salmon and steelhead (*O. mykiss*) fisheries (Smith et al. 2002; Wagner et al. 2004; Williams et al. 2001). Climate change is expected to amplify these impacts, leading to decreased fish abundance and increased emphasis on conservation programs.

Threats to municipal watersheds from wildfire and insects are expected to increase considerably (see chapter 8). Climate models project higher precipitation for the region and more frequent occurrence of storm events (see chapter 3). These changes will potentially increase sedimentation in rivers and

reservoirs, increase water treatment costs, and require expensive dredging in reservoirs to maintain water storage.

Warming has already led to expansion of agriculture in some areas of the western United Stated, including the Northern Rockies. Higher precipitation could lead to increased dependence on tile drainage and increased levels of pollutants in waterways. Increased occurrence of drought would have the exact opposite effect. Expansion of agriculture would generally cause reduced water quality, but the net effects of both more flooding and more drought are uncertain (Warziniack 2014).

Many of the effects on water quality will be magnified if water quantity also falls substantially. Lower flows have been linked to increases in water temperature, eutrophication, and increases in nutrients and metals. Lower flows imply less water to dissipate solar radiation and dilute pollutants already in the water (Allan and Castillo 2007; Murdoch et al. 2000; Poole and Berman 2001; van Vliet et al. 2011). Low flows also increase the likelihood of eutrophication in nutrient-rich bodies of water (Conley et al. 2009; Schindler et al. 2008; Vollenweider 1968).

Adaptive Capacity

Restoration of streams, wetlands, and riparian areas may help stabilize temperatures in some locations, but in the long term, investments in water treatment infrastructure will be needed if sediment increases substantially or if large disturbances become more frequent. Enhancing fish populations through hatcheries is already occurring, and such human intervention may become more important in the face of climate change. Other adaptation strategies for aquatic species and water-based recreation are described in chapters 5 and 10.

Risk Assessment

The effects of increased fire frequency on municipal water supplies will be large, and are likely to be amplified by an increasing population reliant on surface water. Altered timing of precipitation and frequency of flooding may affect erosion rates (Sham et al. 2013). Given current knowledge gaps regarding species response to climate change, it is difficult to provide a quantitative risk assessment. For example, 20-90 percent of currently suitable habitat for native trout species could disappear in the

Northern Rockies by 2100 (Isaak 2012). This would be an example of a high magnitude effect for ecosystem services and aquatic species.

The likelihood of effects on municipal water supplies is high, and is already occurring in some regions of the western United States. Sedimentation from severe wildfires in areas where fire has been excluded for many decades may cause more impacts than climate change. Nonetheless, climate change is expected to exacerbate these effects. Given the high levels of diversity and variability in how aquatic habitats will respond to a changing climate, it is difficult to quantify the likelihood of effects for these ecosystem services. Low-elevation habitats are expected to be affected the most and soonest, resulting in a high likelihood for a shift in ecosystem services in aquatic systems. High-elevation aquatic environments may be buffered by the influence of altitude on temperature, resulting in a lower likelihood of effects, at least in the near term.

ECOSYSTEM SERVICE: BUILDING MATERIALS AND WOODS PRODUCTS

Timber used for wood products is a provisioning ecosystem service. Since much of the timber is exported from the region, the most important aspect of timber is its ability to provide jobs, particularly in rural communities. The timber industry also helps maintain a labor force capable of doing forest restoration work.

A timber processing area for the U.S. Forest Service Northern Region is defined by counties with processing facilities that receive timber from counties containing non-reserve timberland in the region (primarily located in Idaho north of the Salmon River and in Montana) (McIver et al. 2013). Timber processing spans 12 Idaho counties, 26 Montana counties, and four Washington counties (fig. 11.5). Over 95 percent of timber harvested from regional forests is processed by mills in northern Idaho and Montana. In 2011, Idaho and Montana contained 160 timber processing facilities including saw mills (73), house log/log home facilities (42), manufacturers of log furniture (18), post and small pole producers (18), cedar products producers (4), plywood and veneer plants (4), and a utility pole producer. Over 97 percent of timber is processed in sawmills, and 91 percent of timber processed is from trees with diameters greater

than 10 inches. The percent of timber processed in sawmills is up from 80 percent reported in Keegan et al. (2005).

Timber and forest products are dominant economic forces in the Northern Rockies, with forest products (as defined by U.S. Department of Labor, Bureau of Labor Statistics) comprising 23 percent of direct manufacturing employment in Montana (McIver et al. 2013) (table 11.8). Historically, much of the timber harvested in the area has come from national forests, although that share has decreased greatly. In 1979, 46 percent of timber harvested in Idaho came from national forests, declining to only 7 percent by 2006 (Brandt et al. 2012). Table 11.8 shows the sold volume for the Northern Rockies for the past two decades. Timber removal has varied over time in response to changing market and policy conditions, but the past decade has been particularly difficult for the timber industry.

Timber harvests have decreased since the late 1980's on national forests throughout the nation due to changing economic conditions, environmental policies, and litigation against public agencies. The easily accessible larger tree stock has mostly been cut, increasing timber costs and decreasing profits. Increased housing starts spurred a slight recovery in 2003-2005, but the recession that followed led to the worst wood products markets since the Great Depression (Keegan et al. 2012). Between 2005 and 2009, employment in the wood products industry declined 29 and 24 percent in Idaho and Montana, respectively. Most of these losses were in the forestry and logging industries, for which employment declined 33 and 37 percent in Idaho and Montana, respectively (Bureau of Economic Analysis data, from Keegan et al. 2012).

Mills in the region are the major employer for some small communities, making the effects particularly pronounced in a few places. At the height of the downturn in 2008, initial unemployment claims in the woods products industry were over 3,400 in 39 mass layoffs. Across the West, there were 30 percent fewer mills operating in 2009-2010 than in 2004-2005, a 27 percent decrease in timber-processing capacity (Keegan et al. 2012).

Timber jobs have generally been declining in the Northern Rockies, whereas non-timber jobs have generally been increasing (fig. 11.6). These data include jobs in growing and harvesting, sawmills and

paper mills, and wood products manufacturing. In 1998, there were 17,076 jobs in the timber industry, but in 2012, there were only 9,531 jobs, a 44.2 percent decrease. At the same time, non-timber employment increased from 287,163 to 350,929 jobs, a 22.2 percent increase. Since the absolute number of timber jobs has declined while the number of non-timber jobs has increased, the proportion of employment in timber has decreased substantially, from 5.6 percent in 1998 to 2.6 percent in 2012.

However, regional trends in timber employment differ within the Northern Rockies (table 11.9). The Western Rockies subregion, which includes the Idaho Panhandle, Kootenai, and Nez Perce-Clearwater National Forests, has the highest proportion of employment in the timber industry, accounting for 5.2 percent of private employment in 2012. Benewah County, Idaho has 31.8 percent of private employment in timber, the highest in the subregion. Employment in the timber industry has decreased most in the Western Rockies subregion, with 7 of 15 counties (Asotin, WA; Bonner, ID; Clearwater, ID; Kootenai, ID; Lincoln, MT; Pend Oreille, WA; and Sanders, MT) losing over half of their timber-related jobs between 1998 and 2012. Only one county in the subregion (Idaho County, ID) increased employment in the timber industry (18 percent). Some counties in the Central Rockies and Eastern Rockies subregions have increased employment, but these are counties with a low proportion of jobs in the timber sector, so a small number of new jobs have a disproportionate effect.

Effects of Climate Change

Although temperature and precipitation may affect vegetation in the Northern Rockies, the direct effect of climate on timber production is expected to be small. More important to the timber industry are the economic and policy changes that affect demand for forest products and timber quotas for national forests. The primary effects of climate change on timber will occur through the effects of temperature on disturbance and to a lesser extent on growth and productivity (see chapters 7 and 8).

The primary sensitivities of timber resources associated with climate change are wildfire, insects, and disease. Forest growth is expected to be lower in areas that experience higher temperature and decreased precipitation (Ryan et al. 2008) (see chapter 7). In addition, warmer winters and associated freezing and thawing may increase forest road erosion and landslides, making winter harvest more difficult and

14539 expensive, and potentially reducing the timber supply (Karl et al. 2009). Reduced snowpack may promote
14540 insect or disease outbreaks, although harvests could increase in the short term through salvage of dead
14541 and dying trees. Climate change will result in larger, more frequent fires and a longer fire season.
14542 Increased fires may increase demand for fuel treatments, either through timber harvests or through
14543 mechanical and manual thinning that uses the timber labor force and infrastructure. Although this may
14544 affect the availability of harvestable wood products, the overall effect on timber-related jobs would be
14545 relatively small.

14546 **Forest Products (Commercial Use)**

14547 The provision of commercial timber from national forests could be affected by altered temperature
14548 and precipitation. Effects on the distribution and abundance of vegetation are expected to vary widely by
14549 species and location (see chapter 6). Although overall wood production is projected to increase, the
14550 proportion of saw timber (combining both softwoods and hardwoods) is somewhat larger with climate
14551 change in all scenarios, species, and regions. This shift in product mix reflects the effects of accelerated
14552 growth on rotation age, which is lengthened in the long term for all regions and species. With longer
14553 rotations come larger volumes of saw timber relative to pulpwood (Irland et al. 2001).

14554 Although direct effects of elevated temperature on tree growth rates can be positive (e.g., through
14555 lengthening the growing season), associated soil water deficits will probably occur in most locations
14556 except in the high elevations. Tree responses to soil water deficits vary among species as a result of
14557 differences in tree physiology and morphology. Within species, drought sensitivity of trees is usually
14558 largest in seedlings. Mortality can result directly from water stress or indirectly from insects and
14559 pathogens, and vulnerability of trees to increase outbreaks may increase during periods of water deficit
14560 (Kardol et al. 2010). Climate-driven changes in in-stream flow are likely to reduce abundance of early-
14561 successional tree species, favor herbaceous species and drought-tolerant and late-successional woody
14562 species (including introduced species) reduce habitat quality for some riparian animals, and slow litter
14563 decomposition and nutrient cycling (Perry et al. 2012).

Although direct effects on tree growth will vary by species and climate change scenario, one study observed that productivity and timber inventories will increase while timber prices decrease (Irland et al. 2001), the result of an adaptive timber market. Adaptation in U.S. timber and wood product markets are expected to offset some potentially negative effects of climate change. In the United States, lumber and plywood production increases under all scenarios, and pulpwood production decreases under some scenarios. Overall, consumers and mill owners would benefit from climate change, whereas landowners may have reduced economic benefits (Irland et al. 2001).

Markets generally adapt to short-term increases in mortality by reducing prices, salvaging dead and dying timber, and replanting new species that are favorably adapted to the new climate. Salvage during dieback ranges from 50 to 75 percent, depending on management intensity. Total benefits to producers plus consumers rise in all scenarios considered. Market adaptation can reduce or reverse potential forest carbon fluxes in the United States (Irland et al. 2001). New technologies represent another method of adapting to climate change. For example, new adhesives have led to new classes of wood panels and composites, which have displaced older products. These new products often enable the industry to draw on more abundant species of trees that are also closer to end-use markets. New technologies have also helped mills produce more product value from a given tree. If this trend continues, the forest-based economy will be more resilient if forest dieback occurs in the future (Irland et al. 2001).

Adaptive Capacity

Adaptive capacity will depend on the ability to manage both the natural resources (maintaining healthy forests) and adapting to economic forces. Management actions may be able to mitigate drought stress and soil water deficits, mitigating some of the effects of climate change. Land managers also have the option to conduct fuel treatments, which help decrease the probability of large, severe wildfires and to salvage burned or insect-killed timber before it loses market value. Timber management can improve forest resistance and resilience to stressors in areas identified for treatment, usually in the portions of the forest that contain roads. Timber management is a relatively slow process, requiring 50 or more years from regeneration to harvest. Therefore, timber management cannot respond quickly to potential threats,

serving more as a long-term modification of forest composition and structure by helping the landscape gradually become more resistant and resilient. The wood products industry may also be able to adapt to changing conditions by using alternative species, changing the nature or location of capital and machinery, changing reliance on imports or exports, and adopting new technologies (Irland et al. 2001). Developing capacity within the industry to take advantage of emerging products will be important, though the most resilient communities will be those that diversify their economic bases, effectively reducing their exposure to adverse impacts to the timber industry.

Risk Assessment

In summary, the magnitude of effects for wood products is expected to be large, but mostly from non-climate forces. The likelihood of effects is moderate, again from non-climate forces, but it is uncertain how climate will affect forest disturbances that could have a more dominant influence on timber supply.

ECOSYSTEM SERVICE: MINING MATERIALS

Minerals are provisioning ecosystem services, but their primary role in the region is as an economic driver, providing jobs and incomes. Mineral development is important throughout the Northern Rockies, but particularly in northeastern Montana and northwestern North Dakota. In some counties, oil and gas development represents a third of total income to residents. According to 2012 IMPLAN data (MIG 2012), the percentage of total county income directly from the oil and gas sector are: Fallon County, MT (33 percent), Williams County, ND (32 percent), Slope County, ND (29 percent), Dunn County, ND (26 percent), Stark County, ND (23 percent), Mountrail, ND (22 percent), McKenzie, ND (21 percent). Most of this income comes from the Bakken Formation, which lies under parts of North Dakota, Montana, and Saskatchewan. At full development (about four wells per square mile), the formation is expected to be the nation's largest oil field (Mason 2012).

The main stressors from oil and gas development are effects on other ecosystem services, such as water quality (discussed above). Traffic from trucks and heavy machinery also increase the risk of introducing nonnative species to surrounding rangelands (see chapter 7).

Effects of Climate Change

Climate is not likely to directly affect minerals, but it is included in this assessment due to its prominence in the region and because of its potential to conflict with other ecosystem services. Power generation, oil and gas development, and mineral extraction are major users of water. Increased mudslides and fires may threaten oil and gas infrastructure, which would in turn threaten the ecosystem services that are co-located with mineral development.

Regional centers of oil and gas draw people from all over the country looking for high-paying jobs. Competition for workers in the oil fields causes wages in all other sectors of regional economics, including traditionally low-wage jobs in the service industry, to rise. If climate adversely affects other economic sectors, job opportunities in mining and energy will become more important. Climate change could affect the oil and gas infrastructure, but non-climatic drivers will be more important, including international prices for oil and gas, national climate policy, and regional concerns about threats to watersheds.

Adaptive Capacity

Global economic forces primarily drive the oil and gas industry. Oil and gas development potential determines where drilling activity takes place, and regional growth occurs so quickly that communities respond to rather than plan for such development. Adaptive capacity is either not applicable to this ecosystem service or limited from an economic development perspective. The most successful mineral-based economies are those that are able to collect some of the resource rents from drilling and invest them back into the community, extending prospects for long-term economic growth (Kunce and Shogren 2005). Oil and gas development is subject to booms and busts, and the most resilient communities are those that invest resource rents into efforts to diversify the economy.

Risk Assessment

Climate change is not expected to have significant effects on industries based on extraction of minerals and energy. The magnitude of effects is expected to be large from non-climate forces, and the likelihood of effects is expected to be moderate from non-climate forces.

ECOSYSTEM SERVICE: FORAGE FOR LIVESTOCK

The area contained within the Northern Rockies Adaptation Partnership contains 158 million acres of rangeland. Over 85 percent of these rangelands are privately held; 43 percent of rangeland in the Northern Region economic impact area is in Montana, which ranks third in the nation, behind Texas and New Mexico, in non-federal rangeland area. Of the federal rangeland, 8.5 million acres are Bureau of Land Management lands, of which 8 million acres are in Montana (USDI BLM n.d.). A variety of economic uses for rangeland exist in the Northern Rockies, but grazing cattle is by far the largest. Almost all counties in the region have shares of total income derived from cattle above the national average, with some counties in Montana and the Dakotas having more than 100 times the national average (MIG 2012 IMPLAN data).

Cheatgrass (*Bromus tectorum*), and other nonnative plants have become a major nuisance throughout Western rangelands, significantly reducing usable forage. The Nez Perce-Clearwater National Forest assessment (June 2014 review draft) states that forage has decreased in some places from 250 pounds per acre to as low as 25 pounds per acre (table 11.10). Human modification has also converted rangeland to other uses (Reeves and Mitchell 2012). Between 1982 and 2007, Montana lost about 900 acres of rangeland, 3100 acres of Conservation Reserve Program land, and 30 acres of cropland. This pattern of loss is consistent across the region, with the exception of small gains in pasture in Montana and Idaho (table 11.11). Historic rangeland losses in the West have been caused by agricultural development (17 percent), resource extraction (7.4 percent), and residential development (5.8 percent) with much smaller losses to mixed use, recreation, and transportation (Reeves and Mitchell 2012).

Rates of land conversion exceed population growth. Nationally, between 1945 and 1992, one additional person led to about half an acre converted to urban use; between 1992 and 1997, the rate reached 1.2 acres per additional person (DeCoster 2000). Human modification and fragmentation of rangelands have potential consequences for the socio-economic sustainability of rural communities, including loss of rural character, loss of biodiversity, difficulty in managing interconnected lands for

grazing, threats to watershed health, limited outdoor opportunities, compromised viewscapes, loss of native species, changes in disturbance regimes, and increased spread of nonnative species.

Effects of Climate Change

Warmer temperatures and increased precipitation are expected to increase productivity of rangelands (Reeves and Mitchell 2012) (see chapter 7), and increased regional population will lead to fragmentation of rangelands. Arid grasslands are likely to experience short-term response in species richness to altered precipitation due to the prevalence of annual species (Cleland et al. 2013). Carbon dioxide (CO_2) enrichment may alter the relative abundance of grassland plant species by increasing the production of one or more species without affecting biomass of other dominant and co-dominant species. This favored-species pathway to species change is the most frequently reported mechanism by which CO_2 affects grassland communities (Polley et al. 2012).

Cattle stocking rates in the Northern Rockies remain at or below current capacity of the land to support livestock (Reeves and Mitchell 2012), with few counties experiencing forage demand above current forage supply. In the long term, longer and wetter growing seasons would likely make rangeland more productive. The greatest threat to grazing from climate change may be increasing rates of spread of nonnative weeds and changes in fire regime (Maher 2007). Fire, itself, makes ranch planning difficult. Loss of access to grazing areas, on both private and public lands, requires emergency measures like the use of hay, which can devastate ranchers already operating with thin margins. Across all rangelands, increased fire in the future has the general effect of converting more lands to invasive mono-cultures (*B. rubens, B. tectorum*, etc.). Fire also kills shrubs, increasing the prevalence of grasses and herbs, which can reduce structural and floristic diversity. The net effect is a narrowing of options for ranch income diversification (e.g., loss of quail habitat and loss of mule deer winter range).

Adaptive Capacity

Human modification of rangelands and associated fragmentation are driven by opportunities for economic growth, as land is converted to higher-value uses. Rangeland conversion to residential development has brought new populations, higher incomes, and higher tax bases to rural communities,

creating what has been called the "New West" (Riebsame et al. 1997). During the 1990s, 67 percent of counties in the Rocky Mountains grew faster than the national average (Beyers and Nelson 2000). Natural amenities in the Northern Rockies are often touted as an economic asset (Power 1998; Rasker 1993). Economic growth without preservation of these assets is not likely to be sustainable.

Risk Assessment

The magnitude of effects on rangeland reflected in potentially large increases in productivity will be high, but given that forage supply exceeds demand, the effect on grazing will be small. Effects of invasive species and development may be large. The likelihood of effects is high, given that change is already being observed and that these trends are likely to persist. Loss of rural character is a concern, but it is not likely that the region will become heavily urbanized in the foreseeable future.

ECOSYSTEM SERVICE: VIEWSHEDS AND CLEAN AIR

Air quality is an important ecosystem service that can be altered by changes in vegetation composition and tree responses to climate change. For example, tropospheric ozone (O_3), air pollution episodes, plant sensitivity to air pollutants, and release of pollen all affect the provision of air quality by forests.

The Northern Rockies generally have exceptional air quality, although a few counties in the region regularly have days with poor air quality (American Lung Association 2015), and some areas are subject to wintertime inversions that trap air pollutants. During these inversions, wood-burning stoves used to heat homes become a major source of air pollution. In the summer, smoke from wildfires settles in valleys, leading to poor air quality. Counties in Idaho are often affected by burning of crop residues, and smoke can get trapped or settle into valleys where it persists until strong winds clear the air. Major sources of air pollution in North Dakota include coal-fired power plants, oil-field emissions, and vehicle traffic in the mineral-rich areas of the state. However, the North Dakota topography does not contain any features that would trap pollutants, so air quality is generally good throughout the state.

A large percentage of Northern Rockies residents are in demographic groups (e.g., elderly, poor) that are sensitive to poor air quality. Almost 1 in 10 adults in the region have asthma (Center for Disease

Control 2009). As more and more young people leave rural communities for more urban settings, sensitive populations are left isolated in rural areas that often lack the health facilities needed to accommodate an aging, ailing population.

Effects of Climate Change

Air quality can decline rapidly during a wildfire, and increased frequency of wildfires will affect viewsheds and air quality. Extended fire seasons will affect both scenery and air quality, with detrimental effects to human health. Analyses of the effects of climate change on air pollution in general have shown that climate change will increase the severity and duration of air pollution episodes (Bedsworth 2011). Climate change may affect distribution patterns and mixtures of air pollutants through altered wind patterns and amount and intensity of precipitation. The intensity of precipitation determines atmospheric concentration and deposition of acidifying compounds, potentially altering frequency and extent of pollution episodes (e.g., O_3) (Bytnerowicz et al. 2007). By 2050, summertime organic aerosol concentration over the western United States is projected to increase by 40 percent and elemental carbon by 20 percent. Higher temperatures accelerate chemical reactions that synthesize O_3 and secondary particle formation. Higher temperatures, and perhaps elevated CO_2 concentrations, also lead to increased emissions by vegetation of volatile organic compound precursors to O_3 (Kinney 2008). In addition to earlier onset of the pollen season and possibly enhanced seasonal pollen loads in response to higher temperatures and longer growing seasons, elevated CO_2 itself may increase pollen levels in some plant species (Kinney 2008).

Adaptive Capacity

A number of systems are already in place to alert residents when air quality deteriorates. These systems may become more common, as will days with poor air quality and associated alerts. Adaptation options include limiting physical activity outdoors, using air conditioning, and taking medications to mitigate health impacts. Tighter restrictions on use of wood for heating homes and on agricultural burning can reduce pollutants, and fuels treatments can reduce wildfire risk and smoke intensity. These strategies reduce exposure and mitigate damages. Many may be possible in the long run, but the geographic

diversity and rural character of the region makes quick adaptation unlikely. Unfortunately, the effects of poor air quality also fall heaviest on the most vulnerable populations like the elderly, young, and poor – groups that make up much of the rural populations of the region where shortages of health care already exist. These groups have little capacity to adapt.

Risk Assessment

The magnitude of effects is expected to be high, since a large percentage of the population (rural poor and elderly) is at risk for health impacts from poor air quality. This percentage will increase as the population ages, and young people move to urban areas. The likelihood of effects is expected to be high because many areas are alread seein diminished air quality from increased fires and longer pollen seasons.

ECOSYSTEM SERVICE SOIL EROSION REGULATION

A U.S. Forest Service soil man gement irecti e (USDA FS 2009) identifies six soil functions: soil biology, soil hydrology, nutrient cycling, c bon storage o l stability and support, and filtering and buffering. Steep slopes are the key element associated wi h erosion and landslides in mountain landscapes, and open rangeland is susceptible to topso loss. E osion and landslides threaten infrastructure, water quality, and important cultural sites.

General resource management practices are designed to limit erosion a d soil impaction, but landslides and erosion are still a common problem. Roads and other h man activities are the largest source of sediment in most watersheds. Landslide-prone areas are generally on slopes greater than 60 percent with geomorphology and surficial geology sensitive to earth movement. Individual management units in public lands may experience hundreds of landslides each year.

Loss of soil from farm fields is a problem in the eastern part of the Northern Rockies (Kellogg et al. 1997) (fig. 11.7), but best practices in agriculture and range management have begun to slow the loss. Soil loss rates still exceed natural regeneration of soil in much of the eastern part of the Northern Rockies, and recent expansion of agriculture is likely to make the problem worse.

Effects of Climate Change

Soil erosion is tied to many forces on the landscape that are affected by climate change. In mountainous areas, wildfire and precipitation interact to affect erosion rates. Frequency of wildfire, precipitation in the form of rain rather than snow, and intense precipitation events are expected to increase (see chapters 3, 4, and 8), a combination that will lead to greater erosion and more landslides.

In the eastern rangelands, increased precipitation and warmer temperatures may benefit grass productivity and limit erosion. However, the same changes that make rangelands more productive also make land more valuable for agriculture. Expansion of agriculture is already occurring and will increase soil erosion in some areas. A combination of increased drought and increased flooding will add to already high erosion rates. Erosion rat on r ngelands are also likely to increase with increased fire prevalence and spread of nonnative pecies.

Erosion is a significant c n for c tural sites, and is discussed in more detail in chapter 12.

Adapt e Capacity

One of the key impacts of soil erosion i mountains i i effect on water quality and drinking water treatment costs. Without expensive dredging, the usa le l e of dams and reservoirs will shorten, and capital investments will be necessary to remove added ediment from drinking water sources (Sham et al. 2013). Limiting erosion on rangelands can be done with best management practices for agriculture, including the use of buffers and limiting activity in sensitive riparian areas. In all areas, more resilient vegetation can be used to stabilize soils and support soil formation and nutrient cycling.

Risk Assessment

Landslides and flooding in mountainous areas have the potential for large, sudden damages to homes, infrastructure, and watersheds. Costs of soil erosion on the plains are high, but occur over extended periods of time. The likelihood of increased erosion in the mountains is high, because it depends on natural processes (e.g., fire, flooding) that are already changing. If agricultural practices do not change, erosion on the plains is also fairly certain. Likelihood of effects on the plains could be low if best practices become more common in agriculture.

ECOSYSTEM SERVICE: CARBON SEQUESTRATION

Forests provide an important ecosystem service in the form of carbon sequestration, or the uptake and storage of carbon in forests and wood products. Carbon sequestration is often referred to as a regulating ecosystem services because it mitigates greenhouse gas emissions by offsetting losses through removal and storage of carbon. As such, carbon storage in forests is "...becoming more valuable as the impacts of greenhouse gas emissions are becoming more fully understood and experienced" (USDA FS 2015).

The National Forest System (NFS) constitutes one-fifth (22 percent) of the Nation's total forestland area and contains one-fourth (24 percent) of the total carbon stored in all U.S. forests, excluding interior Alaska. The management of these lands and disturbances such as fire, insect, and disease influence carbon sequestration rates. Rates of sequestration may be enhanced through management strategies that retain and protect forest land from conversion t nonfo st uses, restore and maintain resilient forests that are better adapted to a changing climat and oth r stre ors, and reforest lands disturbed by catastrophic wildfires and other natural events (e.g., mo ality following windthrow).

The Forest Service champions the principles of considering carbon and other benefits together, integrating climate adaptation and mitigation, and balancing carbon uptake and storage in a wide range of ecosystem services, some of which have tradeoffs. The goal is to maintain and enhance net sequestration on federal forests across all pools and age classes through protection of existing stocks and building resilience in stocks through adaptation, restoration and reforestation. Carbon stewardship is an aspect of sustainable land management. It is also important to consider that carbon estimates are most useful at larger spatial scales; typically, baseline carbon estimates at the forest scale are not useful for project-specific applications.

Forests are highly dynamic systems that are continuously repeating the natural progression of establishment, growth, death, and recovery, while cycling carbon throughout the ecosystem and the atmosphere. This cycle, which drives overall forest carbon dynamics, varies geographically and by forest type, but also depends on the frequency, magnitude, and type of disturbance events. Natural and anthropogenic disturbances can cause both immediate and gradual changes in forest structure, which in

14821 turn affect forest carbon dynamics. For instance, a severe wildfire may initially release carbon dioxide to
14822 the atmosphere and cause tree mortality, shifting carbon from living trees to dead wood and the soil.
14823 However, as the forest recovers, new trees establish and grow, absorbing carbon dioxide from the
14824 atmosphere. While disturbances may be the predominant drivers of forest carbon dynamics (Pan et al.
14825 2011), environmental factors, such as the availability of key forest nutrients like CO_2 and nitrogen, as
14826 well as climatic variability, influence forest growth rates and consequently the cycling of carbon through
14827 a forest ecosystem (Pan et al. 2009).

14828 Changes in carbon stocks and resulting net emissions may be influenced through vegetation
14829 management strategies. Land management and restoration strategies, plans, and actions, such as fire and
14830 fuels management, timber harvesting, reforestation, and other forest stand treatments, can be designed to
14831 integrate carbon sequestration capacity across broad landscapes and over the long-term, while meeting
14832 other resource management objectives.

14833 Wood uses for products can also complement land management by extending the storage of carbon in
14834 useful products and reducing emissions as wood products substitute for those that emit more carbon
14835 dioxide and other greenhouse gasses. Harvested wood products (HWP), such as lumber, panels, and
14836 paper, can account for a significant amount of off-site carbon storage and estimates of this addition are
14837 important for both national level accounting and regional reporting (Skog 2008). Products derived from
14838 the harvest of timber from the national forests extend the storage of carbon and/or substitute for fossil fuel
14839 use, which is part of the overall carbon cycle.

14840 **Baseline Estimates**

14841 The Forest Service's 2012 Planning Rule and Climate Change Performance Scorecard Element 9
14842 (Carbon Assessment and Stewardship) both require NFS units to identify baseline carbon stocks and to
14843 consider that information in planning and management. The Climate Change Advisor's Office (now the
14844 Office of Sustainability and Climate Change) facilitated work by Forest Service Research & Development
14845 to develop a nationally-consistent carbon assessment framework and to deliver forest information for
14846 every NFS unit. Estimates of total ecosystem carbon and stock change (flux) have been produced at the

forest level across the entire country, relying on consistent methodology and plot-level data from the Forest Inventory and Analysis (FIA) program (USDA FS 2015).

Carbon stocks reflect the amount of carbon stored in seven ecosystem carbon pools – above-ground live tree, below-ground live tree, understory, standing dead trees, down dead wood, forest floor, and soil organic carbon – for the period 1990 to 2013. Carbon stock change (flux) reflects the year-to-year balance of carbon going into or being pulled from the atmosphere (Woodall et al. 2013). Carbon stock change measures the inter-annual change in carbon stock caused by tree growth, disturbance, management, etc. Negative stock change values indicate that carbon is being pulled from the atmosphere (i.e., net carbon sink), while positive values mean carbon is being released (i.e., net carbon source).

Figure 11.8 displays carbon stock trends for each of the national forests in the Northern Region between the years 1990 and 2013, where the Idaho Panhandle National Forest stored the largest amount of carbon in the region, approximately 207 million short tons in 1990 and 202 million short tons in 2013. During this period, the Beaverhead-Deerlodge, Kootenai, Nez Perce, Flathead, Lolo, Clearwater, Gallatin and Custer national forests all increased in ecosystem forest carbon stocks, while the Lewis and Clark, Helena, Bitterroot national forests and Dakota Prairie Grassland decreased.

The cumulative carbon stored in the Northern Region HWP experienced a jump in 1955 and began to continually increase at a steady rate, peaking in 1995 with approximately 37 million short tons in storage (fig. 11.9). The HWP pool since then has decreased to 35 million short tons. This illustrates the influence of timber harvest on the HWP pool. Since the amount of HWP carbon entering that pool is less than the amount of carbon exiting it through various pathways, HWP stocks are decreasing.

Effects of Climate Change

Many factors affect the sensitivity of forests to sequester carbon, and the net effect of climate change on carbon storage in forests is uncertain. The greatest vulnerability to forest distribution and health as a result of climate change is increased risk of fire, insects, and disease (mostly fungal pathogens). Preliminary results from the Forest Carbon Management Framework (Healey et al. 2014; Raymond et al. 2015), show for example, that fire had the largest impact of carbon storage on the Flathead National

Forest between 1990 and 2012, followed by harvest. The largest impact on carbon storage on the Idaho Panhandle National Forest was disease, followed by harvest.

Since nitrogen often is a limiting nutrient in forests, nitrogen deposition may increase wood production and accumulation of soil organic matter, thus increasing carbon sequestration. When carbon uptake is caused by increased growth, it is likely a transitory phenomenon. When soil accumulation is the main cause, forests could be a long-term carbon sink, because belowground carbon has longer turnover times than aboveground carbon (Bytnerowicz et al. 2007).

Tropospheric O_3 damage in sensitive plant species may offset some productivity gains from elevated atmospheric CO_2, thus reducing carbon storage on land and possibly contributing further to climate change. Increasing O_3 will negatively affect plant productivity, reducing the ability of ecosystems to sequester carbon, indirectly providing feedback to atmospheric CO_2 (Sitch et al. 2007). Over the course of the 21st century, net carbon uptake by terrestrial ecosystems is likely to peak before mid-century and then weaken or even reverse, thus amplifying climate change (IPCC 2007).

Fungal pathogens, especially various types of root rot, are another key concern for forests and may affect the ability of forests to sequester carbon (Hicke et al. 2012). Increased temperature and humidity coupled with decreased snow and cold weather facilitate the spread of root rot. As more trees die and decompose, forests could switch from carbon sinks to carbon sources.

Adaptive Capacity

Adaptive capacity for sequestering carbon depends on the spatial and temporal scales at which an ecosystem service is defined. Carbon storage in any particular forest location may go up or down over time, but analysis of storage should occur at very large spatial scales. Adaptive capacity for this particular ecosystem service is likely low, since most of the factors affecting carbon sequestration are external, including development pressures and wildfire. The Climate Change Scorecard and Carbon Management Principles highlight the role National Forests can play in managing forest carbon.

Risk Assessment

Although increased temperature and drought will reduce forest growth, the most detrimental effects to carbon sequestration will be indirect, through increased risk and frequency of wildfires and insect outbreaks. Some deterioration in forest health is highly likely, so some change in the ability of forests to sequester carbon is also likely. However, the net effects on forest health and carbon sequestration are difficult to project, primarily due to the uncertainty in the magnitude of future occurrence of wildfire and insect outbreaks.

ECOSYSTEM SERVICE: CULTURAL AND HERITAGE VALUES

The goods and services that ecosystems provide have spiritual, cultural, and historical value to many people. The effects of climate change will affect the provision of these services for individual locations, plant and animal species, and landscape characteristics. The majority of research on this topic pertains to forest resource values realized by Native American tribes and the effect of climate change on sense of place (see Adger et al. 2013 for a review).

Availability of resources (e.g., for food) and adequate habitat limit traditional lifeways, especially if the distribution and abundance of plants and animals change in response to increased temperature and disturbance (especially wildfire). In general, cultural and heritage values are high in the Northern Rockies, and mostly threatened by changes in culture and the way humans interact with the landscape. Tribal values face ongoing stresses as Native American people attempt to preserve both culture and places on the land, including legal struggles with federal agencies (for example, the ongoing disagreement between the Blackfeet and Glacier National Park regarding access to resources on the park) and effects of recreation on sacred places. Educational programs and law enforcement on federal lands protect many cultural sites, but funding is insufficient to protect all of them (see chapter 12).

A large part of one's culture is his or her connection with physical places, often including an image of "home." Such senses of place may be at risk by climate change if those connections and images change. People may identify with livelihoods and activities that are no longer sustainable in a changing climate (Adger et al. 2011; Agyeman et al. 2009; Igor 2005). People that are tied to their communities are more

reluctant to leave during economic and social hard times, which makes them more vulnerable to the effects of climate change (Field and Burch 1988).

Effects of Climate Change

Increased frequency of wildfire, floods, nonnative species establishment, and erosion all put cultural values, cultural sites, and historic sites at risk. Changes in climate that affect ranges of species that are traditionally harvested by Native Americans affect the ability of tribes to exercise their treaty rights. Impacts can be amplified or mitigated by management decisions and societal forces.

The economies of resource-dependent communities and indigenous communities in the region are particularly sensitive to climate change, with likely winners and losers controlled by effects on important local resources (Maldonado et al. 2013). Residents of high-elevation and northern-latitude communities are likely to experience the most disruptive impacts of climate change, including shifts in the range or abundance of wild species crucial to the livelihoods and well-being of indigenous people (Field et al. 2007). As traditional foods are affected by climate change through habitat alterations and changes in the abundance and distribution of species, traditional practices and knowledge tend to erode (Cordalis and Suagee 2008; Lynn et al. 2013). Tribal rights to harvest culturally important plants, animals, and fish are based on historic harvest areas, so tribes may lose their ability to exercise these rights if species leave their historic ranges.

Adaptive Capacity

Since this ecosystem service relates to preserving the past and maintaining access to current sites, adaptive capacity is low. Increased resources for law enforcement and preservation of cultural sites can mitigate some of the expected damages, and Traditional Ecological Knowledge has helped Tribes adapt to past social and ecological periods of change. Fish hatcheries and other human assistance to survival of plant and animal species will become more important. Vegetation management can potentially be implemented near high-risk cultural and historic sites that are prone to fire, floods, nonnative species establishment, and erosion.

Risk Assessment

Loss of sacred places and heritage is largely irreversible, and many argue that the damage associated with such losses cannot be quantified. The overall magnitude of climate-induced changes may be moderate to high. Increased rates of erosion are already being observed at some cultural sites, and vandalism rates are increasing as human population increases. Culturally important fish populations are declining and in some cases rely on human assistance for migration and survival. Therefore, the likelihood of climate change effects is high.

SUMMARY

Ecosystem services are the benefits people derive from landscapes and encompass the values that motivate people to live in the Northern Rockies. Ecosystem services are the core of our sense of place and are important to protect in the face of a growing number of threats. Some of these threats are social (demographic changes, economics, policy) and some are environmental (e.g., climate change). In many cases, social and environmental forces will act to amplify the effects of the other, but opportunities exist for adaptation in some cases. Below are key findings from the ecosystem services vulnerability assessment.

- Total annual **water yield** is not expected to change significantly. However, timing of water availability will likely shift, and summer flows may decline. These changes may result in some communities experiencing summer water shortages, although reservoir storage can provide some capacity. Snowmelt is already occurring earlier, and both floods and drought may become more common. Agriculture is currently the largest consumer of water and one of the largest economic forces in the region, and rural agricultural communities will be disproportionately affected by climate change.
    - **Water quality** is closely tied to water yield. Increased occurrence of wildfires and floods will add sediment to rivers and reservoirs, affecting in-stream water quality and making water treatment more expensive. Agriculture is currently the major source of impairment, leading to loss in streamside vegetation, loss of aquatic habitat, increased water temperatures, and high levels of fecal coliform. Climate change is expected to amplify these effects.

- **Wood products** provide jobs in the region. Climate changes will lead to more wildfires and insect outbreaks, but in general effects will be small. The largest effects on wood products are likely to be from economic forces and policies. Timber production has been in steady decline, and that trend is likely to continue. Timber is a major employer in some small towns that have already seen an economic downturn, a trend that may continue as a function of economic factors at the national to local levels.
- The Northern Rockies contain one of the largest oil fields in the United States. Near the Bakken formation, about a third of regional income comes directly from oil and gas. **Minerals** and mineral extraction are not likely to be affected by climate change, making mining and energy development important economic drivers. The greatest effect on mineral and energy extraction is likely to be how it connects to other ecosystem services, particularly water quality. Wildfires, floods, and mudslides all put mineral extraction infrastructure in danger, which in turn increases risk to watersheds.
- Climate change is expected to increase the potential of rangeland to provide **forage for livestock**. Ranching and grazing, all else equal, may benefit from climate change. Major threats to grazing are human induced, including loss of rural population, spread of nonnative grasses, and fragmentation of rangelands.
- **Viewsheds** and **air quality** will be affected by increasing wildfires and longer pollen seasons. A growing percentage of the region's population will be in at-risk demographic groups who will suffer respiratory and other medical problems on days with poor air quality.
- The ability to **regulate soil erosion** will be diminished by both agricultural expansion, spread of invasive plants, and increased frequency of wildfire and floods. Increased capital investments may be needed for water treatment plants if water quality degrades significantly. Best practices in agriculture and construction of roads can mitigate some of these effects.

- The ability of forests to **sequester carbon** may be affected by wildfires, insect outbreaks, and plant disease, and carbon sequestration in the western part of the Northern Rockies, will be affected by more frequent disturbance and stress. Managing forests for carbon sequestration is likely to become more important in response to national climate policies.
- Disturbances such as wildfires, floods, and soil erosion place **cultural and heritage values** at risk. Damage to cultural and historic sites are irreversible, making protection a key management focus. Climate-induced changes in terrestrial habitats and human modification of streamflow affect abundance of culturally plants and animals (especially native fish), affecting the ability of Native American tribes to exercise their treaty rights. Effects on this ecosystem service are amplified by social forces that include a growing regional population, vandalism, and loss of traditional practices in a globalizing culture.

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Chapter 12: Effects of Climate Change on Cultural Resources

Carl M. Davis

BACKGROUND AND CULTURAL CONTEXT IN THE NORTHERN ROCKIES

People have inhabited the Northern Rocky Mountains of the United States since the close of the last Pleistocene glacial period, some 14,000 B.P. (Fagan 1990; Meltzer 2009). Across this region (15 national forests, 3 national parks; northern Idaho, Montana, northwest Wyoming, North Dakota, and northern South Dakota), evidence of this distant and more recent human occupation is found throughout all of the subregions within the Northern Rockies Adaptation Partnership area. Each of these subregions, and the public and private lands they now encompass, contain thousands of years of human history.

The Northern Rockies are the ancestral homeland or aboriginal territory of the Arikara, Assiniboine, Bannock, Blackfeet, Chippewa-Cree, Coeur d'Alene, Crow, Hidatsa, Kiowa, Kutenai, Mandan, Nez Perce, Northern Cheyenne, Pend d 'Oreille, Salish, Shoshone, Sioux and other Plains, Intermountain, and Columbia Plateau American Indian tribes (DeMallie 2001; Schleiser 1994; Walker 1988). Beginning in the 18th century, the region was explored and then settled by people of French, British, Irish, Scottish, Chinese, German, Scandinavian and other ancestries (White 1993). The region then, as today, was a diverse blend of cultural backgrounds and lifeways.

The archaeological and historical evidence of these past cultural groups, interactions, and events—collectively called "cultural resources"—is extensive and varied across the Northern Rockies. Cultural resources here include (1) ancient Indian camps and villages, rock art, tool stone quarries, and travel routes, (2) historic military forts and battlefields, mining and logging ruins, and homesteads, and (3) ranger stations, fire lookouts, and recreation sites built by the Civilian Conservation Corps. Currently, some 20,000 cultural resources have been documented, which represents a small fraction of what likely exist in the Northern Rockies.

Protection of cultural resources has been formally recognized since 1906 when the Antiquities Act was signed into law. This law requires federal land management agencies to preserve historic, scientific, commemorative, and cultural values of archaeological and historic sites and structures of public lands for present and future generations (NPS 2015a), and gives the President of the United States authority to designate national monuments as a means to protect landmarks, structures, and objects of historical or scientific significance. The importance of cultural resources has been reaffirmed through the Historic Sites Act of 1935, the National Historic Preservation Act of 1966, the Archaeological Resources Protection Act of 1979 and the Native American Graves Protection and Repatriation Act of 1990. Although the focus of these laws differs, together they mandate the protection and management of cultural resources in federal lands. The National Park Service has a particularly strong emphasis on protection of cultural resources (box 12.1).

Beyond physical sites, structures, and artifacts associated with past human use or events, protection of cultural resources involves the ongoing use of resources and associated activities relevant to the continuation of specified extant cultures. Many cultural resources are currently vulnerable to natural biophysical phenomena and human activities. Wildfire and biological processes degrade and destroy cultural resources, particularly those made of wood or located in erosion-prone environments. Vandalism, illegal artifact digging, arson, and other depreciative human behaviors also damage cultural resources. Agency land management actions can affect cultural sites and landscapes, and although federal land managers protect and mitigate adverse effects to cultural resources, the enormity of this task often outstrips agency resources and capacity.

BROAD-SCALE CLIMATE CHANGE EFFECTS ON CULTURAL RESOURCES

This assessment of the potential effects of climate change on cultural resources in the Northern Rockies is fairly general, because so little information has been generated on this topic, compared to the effects of climate change on natural resources. A broad diversity of cultural resources and locations where they are found make it difficult to infer the spatial extent and timing of specific effects. Therefore, we have synthesized the relevant literature from diverse disciplines to cautiously

project how an altered climate, both directly and indirectly (through increased disturbance) will create conditions that modify the condition of and access to cultural resource sites and their contents.

Climate change has the potential to exacerbate and accelerate existing effects to cultural resources (table 12.1). A warmer climate will alter the scale of wildfires across western North America (Schoennagel et al. 2004; Westerling et al. 2006) (see chapter 8), thus having at least three general effects on cultural resources. First, wildfires readily burn cultural resources made of wood and combustible materials, such as ancient aboriginal wood shelters and game drives, or historic homesteads, mining ruins, and buildings. Second, emergency wildfire suppression tactics, including fireline construction using heavy equipment, affect both standing structures and archaeological sites buried in forest soils. Third, post-wildfire flooding and debris flows threaten cultural resources exposed atop fire-charred landforms and soils. Alternatively, fire can expose cultural sites that might not have been otherwise visible (fig. 12.1).

Currently, federal agencies implement various actions to reduce the effects of wildfire on cultural resources, such as encasing historic structures in fireproof wrap, routing of fireline away from sites, and armoring cultural resources vulnerable to postfire flooding events. However, these actions are often not commensurate with the scale of large wildfires or the ensuing cultural resource loss. Thus, damage is expected to continue as climate change amplifies amount of area burned, if not severity, across the Northern Rockies.

Seasonal aridity and prolonged drought accelerate soil deflation and erosion, and thus expose archaeological sites once buried in plains and mountain soils. Wind and water roil across archaeological sites, blowing or washing away ground cover, revealing ancient artifacts and features such as cooking hearths and tool-making areas (fig. 12.2). This new ground exposure leaves artifacts vulnerable to artifact collecting and illegal digging, effects that are intensified in areas where livestock grazing, recreation, and mining occur and the ground is already impacted. For example, livestock in grazing allotments typically converge around creeks and natural springs where ancient hunter-gatherer archaeological sites are commonly located.

15418 Periods of dry climate and drought have occurred throughout the Holocene in the intermountain
15419 West, with corresponding episodes of soil deflation, erosion, and down cutting (Meltzer 1990;
15420 Ruddiman 2007). However, increasing temperatures outside of the Holocene norm (IPCC 2014;
15421 Mayewski and White 2002) (see chapter 3) will create additional potential for cultural resource loss
15422 through drought and erosion, particularly in drier areas such as southeastern Montana.
15423 In addition, if winter precipitation increases (see chapter 3) and reduced snowpack leads to higher
15424 winter streamflows (see chapter 4), archaeological and historic sites will be increasingly vulnerable to
15425 flooding, debris flows, down cutting, and mass wasting of underlying landforms. This scenario is now
15426 common in the aftermath of large-scale wildfires, especially in the dry mountain ranges of central and
15427 eastern Montana (fig. 12.3). These severe events are likely to accelerate hydrological impacts to
15428 cultural resources (National Research Council 2002).
15429 Perennial, high-elevation snowfields contain ancient artifacts, the result of hunting and gathering
15430 excursions to mountain environments (Lee 2012) (fig. 12.4). Melting ice caused by a warmer climate
15431 poses a risk to previously ice-encased and well-preserved cultural resources. For example, melting ice
15432 patches in the Beartooth Mountains of south-central Montana have yielded ancient bone, wood, and
15433 fiber artifacts. Although melting ice patches provide research opportunities, the rapid rate of melting
15434 ice may preclude timely inspection of by archaeologists, and newly exposed artifacts may decay or be
15435 stolen without adequate archaeological documentation.
15436 Climate change also affects larger cultural landscapes whose integrity is derived from both
15437 cultural resources and environmental context (NPS 1994). Historical sites from the 1800s (e.g., Euro-
15438 American settlements, battlefields) are also valued historical resources, especially in some National
15439 Park Service units. Major shifts in dominant vegetation could potentially affect the physical and
15440 visual integrity of these landscapes (Melnick 2009). For example, whitebark pine (*Pinus albicaulis*) is
15441 an important historical component of the Alice Creek-Lewis and Clark Pass cultural landscape on the
15442 Continental Divide near Helena, Montana (fig. 12.5). Whitebark pine is currently in decline, because
15443 warmer winter temperatures have accelerated the rate of mountain pine beetle outbreaks

15444 (*Dendroctonus ponderosae*) in addition to the effects of white pine blister rust (*Cronartium ribicola*),
15445 a nonnative fungal pathogen (Tomback and Kendall 2001) (see chapter 8).

15446 Cultural sites and landscapes are also recognized for their traditional importance to descendant
15447 communities, particularly American Indian tribes in the intermountain West. Some traditional use
15448 areas provide foods, medicinal and sacred plants, paints, and other resources, as well as ceremonial-
15449 religious places. Significant climate-induced effects in these landscapes, particularly altered
15450 distribution and abundance of vegetation, may curtail and even sever the continuous cultural
15451 connectivity and traditional use of these areas by indigenous peoples and local communities.

15452 Climate change also poses risks to historic buildings and structures, including wildfire, flooding,
15453 debris flow, and extreme weather events (fig. 12.6). In addition to these direct threats, period
15454 furniture, interpretive media, and artifact collections inside historic (and non-historic) buildings may
15455 likewise be affected by those events. More nuanced stressors include increased heat, moisture,
15456 humidity, freeze-thaw events, insect infestation, and micro-organisms (mold), all of which accelerate
15457 weathering, deterioration, corrosion, and decay of buildings, structures and ruins made of wood,
15458 stone, and other organic materials (UNESCO 2007).

15459 Finally, climate change may diminish the appeal of cultural sites and landscapes for public
15460 visitation and interpretation. Extensive outbreaks of mountain pine beetle and other insects, which
15461 have been facilitated by higher temperature, have turned some historic landscapes in southwestern
15462 Montana from green to brown to gray (e.g., Logan and Powell 2001). In addition to visual impacts,
15463 dead and dying forests present hazards to hikers, sightseers, and other forest users (see chapter 10).
15464 Over time, altered ecological conditions in cultural landscapes of the Northern Rockies may reduce
15465 their attractiveness and value for tourism, recreation and other purposes, thus affecting local
15466 communities and economies (see chapters 10, 11).

15467 **Likelihood and Magnitude of Climate Change Effects**

15468 Climate change effects on cultural resources are likely to be highly variable across the Northern
15469 Rockies by the end of the 21st century, depending on the particular stressor and geographic location.

Wildfire is expected to create the highest risk for cultural resources and is expected to broadly, though unevenly, affect cultural resources and on all national forests, national grasslands, and national parks, including locations that have already burned since the 1990s.

The prospect of prolonged aridity and drought caused by projected temperature increase may be partly offset if winter precipitation increases in the future (see chapter 3). Thus, it is difficult to quantify the long-term effects of drought, floods, and extreme weather events on cultural resources. In general, these natural processes, enhanced by climate change, are likely to pose a significant risk to cultural resources. Resource loss will be greatest in those areas prone to major hydrological events, such as at canyon mouths and in river bottoms where cultural sites are often concentrated. Cultural sites located here are difficult to armor and protect in the face of significant flooding and debris flows. Furthermore, artifact collectors may eventually target these areas because newly exposed cultural materials are often strewn over a wide area in the aftermath of a flood or debris flow, invoking the need for active law enforcement.

Other potential climate change-related effects on cultural resources will be more subtle and moderate. Shifting or changing vegetation regimes are likely to affect the visual integrity of some cultural landscapes. Climate change effects to historic buildings or structures will be both gradual and cumulative (i.e., decay and degradation) and sudden and direct (i.e., structural collapse caused by moisture and snow loading). Certain natural resources associated with traditional cultural landscapes, which continue to be used by tribal peoples today, may be diminished or entirely disappear. However, increased wildfire may increase the abundance of some culturally valuable species, such as huckleberry (*Vaccinium* spp.) common camas (*Camassia quamash*), and nodding onion (*Allium cernuum*).

Agency proposals and efforts to control, abate, or mitigate the projected effects of climate change may also affect cultural resources. For example, in anticipation of significant flooding events in the future, historical culverts and bridge abutments made of stone may be replaced with larger metal ones. Although project design and mitigation measures would reduce many adverse effects to cultural

resources, landscape restoration projects designed to increase resilience to climate stressors could diminish the cultural resource base in some locations.

The effects of climate change on cultural resource tourism are difficult to estimate because this is contingent on social and economic factors. Visiting historical sites is popular throughout the Northern Rockies (Nickerson 2014), and tourism is an important economic contributor to many local communities (see chapter 10). Hot, dry summer weather could reduce public interest in visiting cultural resources, cultural landscapes, and interpretive sites located in federal lands, particularly in areas recently affected by severe wildfires or floods. This potential effect on forest tourism could, in turn, affect local communities to some extent.

ADAPTING TO THE EFFECTS OF CLIMATE CHANGE

Federal agencies in the Northern Rockies have the capacity to address some of the projected effects of climate change on cultural resources. Fuels reduction around significant cultural resources is already in place in some locations, thus reducing the intensity and severity of future wildfires. Forest Service, U.S. Department of Agriculture heritage personnel are engaged in all aspects of wildfire suppression and recovery, which facilitates protection of cultural resources threatened by wildfires. However, fire vulnerability assessment and abatement programs for cultural resources may need further emphasis to address a potential for more wildfires in the future.

Less progress has been made in completing vulnerability assessments or implementing protection strategies for cultural resources located in areas prone to large-scale hydrological events, and the full scope of this risk is unknown in the Northern Rockies. Hydrological events are unpredictable, and protection measures such as stabilization and armoring are expensive. Viable protection measures often require hydrological, engineering, and other resource expertise. Nonetheless, federal agencies have a strong mandate to implement measures to protect cultural sites threatened by such natural processes and emergency events.

Survey and evaluation in areas where cultural resources are concentrated or likely is ongoing, although intermittent, in the Northern Rockies. It will be possible to locate and monitor cultural

resources potentially only if these efforts are significantly expanded. High-elevation melting ice patches are a particular priority, but surveys are critical in other locations where cultural resources are likely to be affected by flooding and debris flows in mountain canyon and foothills areas. Correlating areas where cultural resources are common with areas where flooding and ice melt are expected will help to focus attention in landscapes at greatest risk.

Some climate-induced vegetation shifts in designated cultural landscapes could be partly mitigated through silvicultural treatments and prescribed burning, although the effectiveness of proposed treatments relative to the scope and scale of the cultural landscape is difficult to evaluate. Careful monitoring and tracking of vegetation stability and change in cultural landscapes will become increasingly important in future decades.

To date, the potential effects of climate change on the historic built environment in the Northern Rockies has received relatively little attention. However, a variety of actions may eventually be necessary to abate or mitigate the projected effects of climate change on historic buildings and structures. Vulnerability assessments by qualified experts are necessary precursors to initiating any remediation work such as stabilization, armoring, and other interventions. In this context, historic preservation teams, volunteers, and partners will be important contributors to climate-related preservation work in the future.

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Chapter 13: Conclusions

S. Karen Dante-Wood and Linh Hoang

The Northern Rockies Adaptation Partnership (NRAP) provided significant contributions to assist climate change response in national forests and national parks of the region. The effort synthesized the best available scientific information to assess climate change vulnerability, develop adaptation options, and catalyze a collaboration of land management agencies and stakeholders seeking to address climate change in the Northern Rockies. The vulnerability assessment and corresponding adaptation options provided information to support national forests and national parks in implementing respective agency climate change strategies described in the National Roadmap for Responding to Climate Change (USDA FS 2010), Climate Change Performance Scorecard (USDA FS 2012) (see chapter 1), and National Park Service Climate Change Response Strategy (USDI NPS 2010). The NRAP process allowed all forests in the USFS Northern Region to respond with "yes" to scorecard questions in the organizational capacity, engagement, and adaptation dimensions. Also, the NRAP process enabled participating national parks to make progress towards implementing several components (communication, science, and adaptation goals) of the National Park Service (NPS) Climate Change Response Strategy (USDI NPS 2010).

RELEVANCE TO AGENCY CLIMATE CHANGE RESPONSE STRATEGIES

In this section, we summarize the relevance of the NRAP process to the climate change strategy of federal agencies and the accomplishments of participating national forests, national grasslands and national parks. Information presented in this report is also relevant for other land management agencies and stakeholders in the Northern Rockies. This process can be replicated and implemented by any organization, and the adaptation options are applicable in the Northern Rockies and beyond. Like previous adaptation efforts (e.g., Halofsky et al. 2011; Raymond et al. 2014), a science-management partnership was critical to the success of the NRAP. For others interested in emulating this approach, we

encourage them to pursue this type of partnership as the foundation for increasing climate change awareness, assessing vulnerability, and developing adaptation plans.

Communication, Education, and Organizational Capacity

Organizational capacity to address climate change, as outlined in the Forest Service, U.S. Department of Agriculture (USFS) Climate Change Performance Scorecard requires building institutional capacity in management units through training and education for employees. Training and education were built into the NRAP process through workshops and webinars that provided information about the effects of climate change on water resources, fisheries, forested vegetation, non-forested vegetation, disturbance, wildlife, recreation, ecosystem services, and cultural resources). The workshops introduced climate tools and processes for assessing vulnerability and planning for adaptation.

The NPS Climate Change Response Strategy challenges NPS staff to increase climate change knowledge among employees and to communicate this information to the public, in addition to the actions taken by the agency to respond to climate change. Although communication about climate change with the public was beyond the scope of the NRAP, knowledge generated through this process can be used for outreach and interpretive materials.

Partnerships and Engagement

The NRAP science-management partnership and process were as important as the products that were developed, because these partnerships are the cornerstone for successful agency responses to climate change. We built a partnership that included several federal agencies as well as other organizations (e.g., EcoAdapt, Headwater Economics) and universities (Oregon State University, University of Washington).

Elements 4 and 5 of the USFS Climate Change Performance Scorecard require units to engage with scientists and scientific organizations to respond to climate change (element 4) and work with partners at various scales across all boundaries (element 5). Similarly, the NPS Climate Change Response Strategy emphasizes the importance of collaboration and building relationships, in addition to products that support decision-making and a shared vision. The NRAP process therefore allowed both agencies to achieve unit-level compliance in their agency-specific climate responses.

15681 The NRAP process encouraged collaboration between Forest Service, U.S. Department of Agriculture
15682 (USFS) and NPS, supporting a foundation for a coordinated regional response to climate change. By
15683 working with partners (federal and non-governmental), we increased our capability to respond to climate
15684 change. Responding to such a challenge requires using an all lands approach, which this partnership
15685 fostered.

15686 **Assessing Vulnerability and Adaptation**

15687 Elements 6 and 7 of the USFS Climate Change Performance Scorecard require units to assess the
15688 expected effects of climate change and which resources as a result will be most vulnerable, and identify
15689 management strategies to improve the adaptive capacity of the national forest lands. The NRAP
15690 vulnerability assessment used the best available science to identify sensitivity and vulnerability of
15691 multiple resources in the Northern Rockies (table 13.1). Adaptation options were then developed for each
15692 of the resource areas that can be incorporated into resource specific programs and plans.

15693 The science-management dialogue identified management practices that are useful for increasing
15694 resilience and reducing stressors and threats. Although implementing all options developed in the NRAP
15695 process may not be feasible, resource managers can still draw from the menu of options as needed. Some
15696 adaptation strategies and tactics can be implemented on the ground now, whereas others may require
15697 changes in policies and practices or can be implemented when management plans are revised or as threats
15698 become more apparent.

15699 The NRAP process used many of the principles and goals for assessing vulnerability and planning for
15700 adaptation, as identified in the NPS Climate Change Response Strategy, which calls for units to
15701 implement adaptation in all levels of planning to promote ecosystem resilience and enhance restoration,
15702 conservation, and preservation of resources (USDI NPS 2010). It specifically requires developing and
15703 implementing adaptation to increase the sustainability of facilities and infrastructure, and preserve
15704 cultural resources.

15705 **Science and Monitoring**

Monitoring is addressed in Element 8 of the USFS Climate Change Performance Scorecard and in the NPS Climate Change Response Strategy. Where applicable, the NRAP products identified information gaps or uncertainties important to understanding climate change vulnerabilities to resources and management influences on vulnerabilities. These identified information gaps could drive where important monitoring and research would decrease uncertainties inherent to management decisions. In addition, current monitoring programs that provide information for detecting climate change effects, and new indicators, species and ecosystems that require additional monitoring, were identified for some resource chapters. Working across multiple jurisdictions and boundaries will allow NRAP participants to increase collaborative monitoring and research of climate change effects and effectiveness of implementing adaptation strategies and tactics that increase resilience or reduce stressors and threats.

Throughout the NRAP process, the best available science was used to understand projected changes in climate and effects on natural resources. This science can be incorporated into large landscape assessments such as forest/grassland planning assessments, environmental analysis for National Environmental Policy Act (NEPA) projects, or project design and mitigations.

NEXT STEPS

The NRAP built on previous science-management partnerships by creating an inclusive forum for local and regional stakeholders to address issues related to climate change vulnerability and adaptation. Although this partnership was conducted at the regional scale, more work is needed to truly achieve an "all lands" approach to adaptation. The federal agencies involved have different missions and goals, and are at different stages in integrating climate change in resource management and planning. Although the differences allowed agencies to share approaches and experiences, it presented challenges in terms of creating a collaborative adaptation plan.

In the future, it may be valuable to develop partnerships around specific resource issues and implement adaptation options accordingly. Similarly, working at sub-regional scales would enable the assessment to target specific management concerns. Finally, engaging managers early through a query

15731 regarding priority information needs to support adaptation planning would help to generate "buy in" and
15732 ensure that products target important management needs.

15733 The goal of this vulnerability assessment was to cover a range of natural resources that are critical to
15734 the region. By exploring several resources in detail, participants identified species and ecosystems that are
15735 sensitive to climate change. More detailed quantitative and spatially-explicit vulnerability assessments
15736 would improve the scientific basis for detecting the effects of climate change and developing site-specific
15737 management responses and plans. It would also allow resource managers to prioritize locations for
15738 implementation. The vulnerability assessment could also be expanded to include other systems and issues
15739 such as social and economic effects.

15740 **Implementing Adaptation Strategies and Tactics**

15741 Implementing adaptation strategies and tactics is the most challenging next step. This will gradually
15742 occur with time, changes in policies, plan and program revisions, and major disturbances or extreme
15743 weather events. As previously noted, collaboration among landowners and management agencies will
15744 produce more successful adaptation outcomes than operating independently.

15745 With the formation of the science-management partnership, two products were produced through the
15746 NRAP partnership: the vulnerability assessment and the adaptation strategies and tactics. Prior to
15747 applying any of the adaptation strategies or tactics, land managers require a process to consider which
15748 actions are most important and the locations that are most important to implement those actions.
15749 Landscape management strategies provide context for decision making in which managers can be
15750 transparent in decisions to apply any given strategy or tactic. Determinations of which adaptation options
15751 are most appropriate must consider the condition and context of the resource, social and ecological
15752 values, time scales for management, and feasible goals for treatment given changing climate (Peterson et
15753 al. 2011). Depending on the context and conditions, landscape management strategies can have various
15754 objectives, such as increasing resilience, resisting climate influences, facilitating transitions, or
15755 realigning/restoring systems to be more resilient (Peterson et al. 2011).

Developing critical questions based on the vulnerability assessment, other factors important for resources, and site-specific ecological and social situations in the context of larger landscapes would assist land managers in making reasoned and transparent decisions in applying adaptation strategies and tactics. Workshops with large and small planning teams to develop resource specific critical questions and their response to those questions could result in the development of broadly applicable management strategies (see fig. 13.1 for general framework and fig. 13.2 for example). A process similar to the Climate Project Screening Tool (Morelli et al. 2012) could be adapted to landscape management.

In many cases, similar adaptation options were identified for more than one resource sector, suggesting a need to integrate adaptation planning across multiple disciplines. Adaptation options that yield benefits to more than one resource are likely to have the greatest benefit (Halofsky et al. 2011; Peterson et al. 2011; Raymond et al. 2014). However, some adaptation options involve tradeoffs and uncertainties that need further exploration. Assembling an interdisciplinary team to tackle this issue will be critical for assessing risks and developing risk management options.

Applications

The climate change vulnerability assessment and adaptation approach developed by the NRAP can be used by the USFS, NPS, and other organizations in many ways (fig. 13.3, table 13.2). From the perspective of federal land management, this information can integrate within the following aspects of agency operations:

- *Landscape management assessments/planning*: The vulnerability assessment provides information on departure from desired conditions and best science on effects of climate change on resources for inclusion in planning assessments. The adaptation strategies and tactics provide desired forest/grassland conditions, objectives, standards, and guidelines for land management plans and general management assessments.
- *Resource management strategies:* The vulnerability assessment and adaptation strategies and tactics can be used to incorporate NRAP best science into conservation strategies, fire management plans, infrastructure planning, and State Wildlife Action Plans.

- *Project NEPA analysis:* The vulnerability assessment provides best available science for documentation of resource conditions, effects analysis, and alternatives development. Adaptation strategies and tactics provide mitigation and design tactics at specific locations.
- *Monitoring plans:* The vulnerability assessment can help identify knowledge gaps that can be addressed by monitoring in broad-scale strategies, plan-level programs, and project-level data collection.

We are optimistic that climate change awareness, climate-smart management and planning, and implementation of adaptation in the Northern Rockies will continue to evolve. We anticipate that by the end of the decade:

- Climate change will become an integral component of business operations.
- The effects of climate change will be continually assessed on natural and human systems.
- Monitoring activities will include indicators to detect the effects of climate change on species and ecosystems.
- Agency planning processes will provide opportunities to manage across boundaries.
- Restoration activities will be implemented in the context of the influence of a changing climate.
- Management of carbon will be included in adaptation planning.
- Institutional capacity to manage for climate change will increase within federal agencies and local stakeholders.
- Managers will implement climate-informed practices in long-term planning and management.

This assessment provides the foundation for implementing adaptation options that help reduce the negative effects of climate change and transition resources to a warmer climate. We hope that building on existing partnerships, the assessment will foster collaborative climate change adaptation in resource management and planning throughout the Northern Rockies.

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Tables

Table 1.1—U.S. Forest Service policies related to climate change.

Policy	Description
Forest Service Strategic Framework for Responding to Climate Change (USDA FS 2008)	Developed in 2008, the *Strategic Framework* is based on seven strategic goals in three broad categories: foundational, structural, and action. The seven goals are science, education, policy, alliances, adaptation, mitigation, and sustainable operations. Like the challenges themselves, the goals are interconnected; actions that achieve one goal tend to help meet other goals. The key is to coordinate approaches to each goal as complementary parts of a coherent response to climate change. All seven goals are ultimately designed to achieve the same end (the USFS mission): to ensure that Americans continue to benefit from ecosystem services from national forests and grasslands.
USDA 2010-2015 Strategic Plan (USDA FS 2010d)	In June 2010, the U.S. Department of Agriculture released the *Strategic Plan* that guides its agencies toward achieving several goals including Strategic Goal 2—Ensure our national forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing our water resources. This goal has several objectives. Objective 2.2 is to lead efforts to mitigate and adapt to climate change. The performance measures under this objective seek to reduce greenhouse gas emissions by the U.S. agricultural sector, increase the amount of carbon sequestered on U.S. lands, and bring all national forests into compliance with a climate change adaptation and mitigation strategy. The USFS response to this goal includes the *National Roadmap for Responding to Climate Change* and *Performance Scorecard*.
National Roadmap for Responding to Climate Change (USDA FS 2010c)	Developed in 2011, the *Roadmap* integrates land management, outreach, and sustainable operations accounting. It focuses on three kinds of activities: assessing current risks, vulnerabilities, policies, and gaps in knowledge; engaging partners in seeking solutions and learning from as well as educating the public and employees on climate change issues; and managing for resilience in ecosystems and human communities through adaptation, mitigation, and sustainable consumption strategies.
Climate Change Performance Scorecard (USDA FS 2010a)	To implement the *Roadmap*, starting in 2011, each national forest and grassland began using a 10-point scorecard to report accomplishments and plans for improvement on 10 questions in four dimensions: organizational capacity, engagement, adaptation, and mitigation. By 2015, each is expected to answer “yes” to at least seven of the scorecard questions, with at least one “yes” in each dimension. The goal is to create a balanced approach to climate change that includes managing forests and grasslands to adapt to changing conditions, mitigating climate change, building partnerships across boundaries, and preparing employees to understand and apply emerging science.
2012 Planning Rule (USDA FS 2012)	The *2012 Planning Rule* is based on a planning framework that will facilitate adaptation to changing conditions and improvement in management based on new information and monitoring. There are specific requirements for addressing climate change in each phase of the planning framework, including in the assessment and monitoring phases, and in developing, revising, or amending plans. The *2012 Planning Rule* emphasizes restoring the function, structure, composition, and connectivity of ecosystems and watersheds to adapt to the effects of a changing climate and other ecosystem drivers and stressors, such as wildfire and insect outbreaks. A baseline assessment of carbon stocks required in assessment and monitoring will check for measureable changes in the plan area related to climate change and other stressors.Requirements of the *Roadmap* and *Scorecard* and requirements of the *2012 Planning Rule* are mutually supportive and provide a framework for responding to changing conditions over time.

Table 1.2—National Park Service policies related to climate change.

Policy	Description
National Park Service Climate Change Response Strategy (NPS 2010)	Developed in 2010, the *Climate Change Response Strategy* is designed to guide management actions and collaboration, from the national to park levels, to address the effects of climate change. The *Response Strategy* is based on four components: science, mitigation, adaptation, and communication. These components provide a framework for consistent, legal, and appropriate management decisions. The *Response Strategy* calls for a scientific approach to updating interpretations of previous policy and mandates in order to uphold the mission of the NPS in the face of new conditions created by climate change.
A Call to Action: Preparing for a Second Century of Stewardship and Engagement (NPS 2011)	The *Call to Action* outlines themes and goals for the second century of stewardship and engagement of the NPS. The plan provides actions for the achievement of each goal before the NPS centennial in 2016. Under the theme of preserving America's special places, the plan sets the goal for management of resources to increase resilience to climate change stressors. Specific actions include revised management objectives, increases in sustainability, and changes in investments.
Green Parks Plan (NPS 2012b)	The *Green Parks Plan* (GPP) outlines how the NPS will achieve the commitment set in *A Call to Action,* to "Go Green." An overarching vision and strategy for sustainable management in the future, the GPP is based on nine strategic goals that focus on the effects of park operations on the environment and human welfare. The goals are to continually improve environmental performance; be climate friendly and climate ready; be energy smart; be water wise; develop a green NPS transportation system, buy green and reduce, reuse, and recycle; preserve outdoor values; adopt best practices; and foster sustainability beyond NPS boundaries.
Revisiting Leopold: Resource Stewardship in the National Parks (NPS 2012c)	In August 2012, the NPS released the *Revisiting Leopold*, intended as a updated interpretation of the guiding document *The Leopold Report* (Leopold et al. 1963). Members of the current NPS Science Committee were tasked with revisiting three questions: (1) What should be the goals of resource management in the National Parks? (2) Which policies for resource management are necessary to achieve these goals? (3) Which actions are required to implement these policies? The interpretation presents general principles and guidance for the enlarged scope of all natural and cultural resources of the NPS. The committee stresses that the NPS needs to act quickly on structural changes and long-term investments in management in order to preserve resources through the uncertainties of environmental change.
Climate Change Action Plan 2012—2014 (NPS 2012a)	The 2012 *Climate Change Action Plan* builds on the 2010 *NPS Climate Change Response Strategy* to communicate how the NPS can respond to climate change at different geographic scales. The plan outlines parameters for introducing science, adaptation, mitigation, and communication actions to address climate change. The plan also identifies high-priority actions for addressing climate change in NPS operations, and describes how to anticipate and prepare for future changes.

Table 3.1—CMIP5 climate projections for RCP 4.5 and RCP 8.5 scenarios were obtained for these models using the Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections" archive at: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections. The first model run was selected for this analysis.

Institution	Climate model	RCP 4.5	RCP 8.5
Commonwealth Scientific and Industrial Research Organization and Bureau of Meteorology, Australia	ACCESS1-0	X	X
	ACCESS1-3	X	X
Beijing Climate Center, China Meteorological Administration	bcc-csm1-1	X	X
Beijing Climate Center, China Meteorological Administration	bcc-csm1-1-m	X	X
Canadian Centre for Climate Modelling and Analysis	CanESM2	X	X
National Center for Atmospheric Research	CCSM4	X	X
Community Earth System Model Contributors	CESM1-BGC	X	X
	CESM1-CAM5	X	X
Centro Euro-Mediterraneo per I Cambiamenti Climatici	CMCC-CM	X	X
Centre National de Recherches Météorologiques/ Centre Européen de Recherche et Formation Avancée en Calcul Scientifique	CNRM-CM5	X	X
Commonwealth Scientific and Industrial Research Organization, Queensland Climate Change Centre of Excellence	CSIRO-Mk3-6-0	X	X
EC-EARTH consortium	EC-EARTH	X	X
Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, and Center for Earth System Science, Tsinghua University	FGOALS-g2	X	X
Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, and Center for Earth System Science, Tsinghua University	FGOALS-s2	X	X
The First Institute of Oceanography, State Oceanic Administration, China	FIO-ESM	X	X
NOAA Geophysical Fluid Dynamics Laboratory	GFDL-CM3	X	X
	GFDL-ESM2G	X	X
	GFDL-ESM2M	X	X
NASA Goddard Institute for Space Studies	GISS-E2-H-CC	X	
	GISS-E2-R	X	X
	GISS-E2-R-CC	X	
Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	HADGEM2-AO	X	X
Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	HADGEM2-CC	X	X
Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	HADGEM2-ES	X	X
Institute for Numerical Mathematics	INM-CM4	X	X
Institut Pierre-Simon Laplace	IPSL-CM5A-LR	X	X
	IPSL-CM5A-MR	X	X
	IPSL-CM5B-LR	X	X
Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	MIROC-ESM	X	X
	MIROC-ESM-CHEM	X	X
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC5	X	X
Max Planck Institute for Meteorology (MPI-M)	MPI-ESM-LR	X	X
Max Planck Institute for Meteorology (MPI-M)	MPI-ESM-MR	X	X
Meteorological Research Institute	MRI-CGCM3	X	X
Norwegian Climate Centre	NorESM1-M	X	X
Norwegian Climate Centre	MorESM1-ME	X	X

Table 3.2—The CMIP3 models used by Littell et al. (2011). Two individual models were chosen as bracketing members: pcm1 and miroc_3.2, as well as an ensemble of 10 models from the AlB emission scenario (Nakićenović et al. 2000).

Model or ensemble	Reason for selection
Pcm1	Wetter summers: +10% by 2040s, +4% by 2080s; less temperature increase: +2.9 °F by 2040s, +5.2 °F by 2080s
Miroc_3.2	Drier summers: -12% by 2040s, -28% by 2080s; more temperature increase: +5.6 °F by 2040s, +10.4 °F by 2080s.
Ensemble A1B (comprised of models: bccr, cnrm_cm3, csiro_3_5, echam5, echo_g, hadcm, hadgem1, miroc_3.2, miroc3_2_hi, pcm1)	The suite of models reflects those models that best represented the historical Pacific Northwest climate.

Table 4.1—Adaptation options that address climate change effects on water resources in the Northern Rockies.

Sensitivity to climatic variability and change:
Increased flooding will increase damage to roads and infrastructure.

Adaption Strategy / Approach:
Identify and proactively decrease vulnerability of infrastructure to flooding.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Increase resilience of stream resources by identifying and restoring degraded riparian areas to reduce flooding and increase natural storage; add large woody debris, improve floodplain connectivity, increase riparian roughness, restore beavers.	Conduct a basin-wide risk assessment of hydrologic interactions with roads and other infrastructure where vulnerability of infrastructure is highest.	Increase resilience of infrastructure: culvert sizing, hardened fords, road drainage, etc.; remove or relocate infrastructure (e.g., roads, campgrounds).
Where can tactics be applied?	All lands	Federal and private lands	Mostly federal lands

Sensitivity to climatic variability and change:
Increased occurrence of disturbances such as drought and flooding will reduce water quality.

Adaption Strategy / Approach:
Build an information base for a timely response to disturbance, thus ensuring that data are available to inform decision making.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Prioritize data collection based on projections of future drought.	Collect pre-disturbance data on stream and riparian conditions, including high-quality values and habitat in need of protection.	Develop a clearinghouse for available funding and programs related to fire and other disturbances.
Where can tactics be applied?	Mostly federal lands	Mostly federal lands	Mostly federal lands

Table 4.1 (cont.)—Adaptation options that address climate change effects on water resources in the Northern Rockies.

Sensitivity to climatic variability and change: Reduced base flows will cause smaller riparian habitats and morphological changes, affecting groundwater, storage, and shallow alluvial aquifers.			
Adaption Strategy / Approach: Increase knowledge about the groundwater resource.			
Tactic	**Specific Tactic – A** Map aquifers and alluvial deposits	**Specific Tactic – B** Determine legal availability and better understanding of physical availability of water for aquifer recharge	**Specific Tactic – C** Improve monitoring of streamflow and groundwater to improve understanding of surface water-groundwater interactions; obtain real-time data
Where can tactics be applied?	All lands	All lands	All lands
Sensitivity to climatic variability and change: Reduced base flows will cause smaller riparian habitats and morphological changes, affecting groundwater, storage, and shallow alluvial aquifers.			
Adaption Strategy / Approach: Increase natural storage and build storage.			
Tactic	**Specific Tactic – A** Increase natural water storage (mirroring natural processes) with constructed wetlands, beavers, and road obliteration.	**Specific Tactic – B** Promote distributed small-scale water storage in small dams, retention ponds, and swales in stream channels and uplands.	**Specific Tactic – C** Improve streamflow and groundwater monitoring to improve understanding of surface water-groundwater interactions and obtain real-time data.
Where can tactics be applied?	Multiple land ownerships	Agricultural lands, headwaters without native fish species	All lands

Table 4.1 (cont.)—Adaptation options that address climate change effects on water resources in the Northern Rockies.

Sensitivity to climatic variability and change: Reduced snowpack will reduce the quantity and quality of municipal water supplies.			
Adaption Strategy / Approach: Reduce erosion potential to protect municipal water supplies; prioritize municipal systems for protection.			
Tactic	**Specific Tactic – A** Reduce hazardous fuels.	**Specific Tactic – B** Reduce disturbances (off-road vehicles, grazing, etc.).	**Specific Tactic – C** Use road management practices that reduce erosion.
Where can tactics be applied?	High-value locations	High value-locations on public and private lands	High value locations on public lands
Sensitivity to climatic variability and change: Higher temperatures and decreased snowpack will reduce water availability.			
Adaption Strategy / Approach: Reduce water use and increase efficiency, demonstrate leadership in water efficiency, and create outreach opportunities.			
Tactic	**Specific Tactic – A** Communicate water saving tactics and benefits.	**Specific Tactic – B** Research successful water saving tactics and apply tactics where appropriate.	**Specific Tactic – C** Install low -low appliances at administrative sites; replace landscaping with drought tolerant plants.
Where can tactics be applied?	All lands, where appropriate	All lands, including administrative locations (campgrounds, visitor centers, etc.)	All lands, including administrative locations (campgrounds, visitor centers, etc.); use Internet, press releases, interpretive signing, etc.

Table 5.1—Projected changes in mean August air temperature, stream temperature, and streamflow for major river basins in the Northern Rockies.

	2040s (2030–2059)			2080s (2070–2099)		
NorWeST unit[a]	Air temperature[b] change	Streamflow[b,c] change	Stream temperature[d] change	Air temperature change	Streamflow change	Stream temperature change
	°F	*Percent*	*°F*	*°F*	*Percent*	*°F*
Yellowstone	5.06	- 4.1	1.82	9.14	- 5.4	3.26
Clearwater	5.71	-23.9	2.92	9.81	-34.2	5.00
Spokane-Kootenai	5.49	-20.1	2.29	9.59	-31.5	3.94
Upper Missouri	5.85	-14.9	2.11	9.85	-21.3	3.49
Marias-Missouri	5.24	-10.0	1.35	9.54	-18.7	2.47

[a] For boundaries of NorWeST production units, see the NorWeST website (http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html).

[b] Changes in air temperature and streamflow are expressed relative to the 1980s (1970–1999) baseline climate period. Projections are based on the A1B emission scenario represented by an ensemble of 10 global climate models that best projected historical climate conditions during the 20th century in the northwestern United States (Hamlet et al. 2013, Mote and Salathé 2010). Additional details about the scenarios are provided elsewhere (Hamlet et al. 2013, Wenger et al. 2010).

[c] For more information on streamflow, see the western United States flow metrics website (http://www.fs.fed.us/rm/boise/AWAE/projects/modeled_stream_flow_metrics.shtml) and the Pacific Northwest Hydroclimate Scenarios Project website (http://warm.atmos.washington.edu/2860).

[d] Changes in stream temperatures account for differential sensitivity to climate forcing within and among river basins as described in Luce et al. (2014) and at the NorWeST website. For more information on stream temperatures, see Isaak et al. (2010), Luce et al. (2014) and the NorWeST website.

Table 5.2—Length of streams in the Northern Rockies, categorized by mean August stream temperature during the baseline climate period and by land administrative status. Values in parentheses are percentages of the total in the last row.

Land status [a, b]	<46 °F	46-52 °F	52–57 °F	57–63 °F	63–68 °F	>68 °F	Total
				Miles (percent of total)			
Private	274 (3.2)	5,494 (15.8)	16,524 (47.2)	14,465 (64.4)	8,178 (73)	1,067 (66.1)	46,002 (40.4)
The Nature Conservancy	1 (0)	191 (0.5)	99 (0.3)	9 (0)	1 (0)	0 (0)	301 (0.3)
Tribal	170 (2.0)	769 (2.2)	3,371 (9.6)	4,181 (18.6)	1,593 (14.2)	380 (23.5)	10,464 (9.2)
State/City	137 (1.6)	1,578 (4.5)	2,529 (7.2)	1,156 (5.1)	723 (6.5)	62 (3.8)	6,185 (5.4)
Bureau of Land Management	49 (0.6)	826 (2.4)	838 (2.5)	268 (1.2)	207 (1.8)	55 (3.4)	2,243 (2.0)
National Park Service	537 (6.2)	1,689 (4.9)	654 (1.9)	296 (1.3)	70 (0.6)	1 (0.1)	3,247 (2.9)
Forest Service Wilderness	2,269 (26.2)	3,516 (10.1)	1,174 (3.4)	175 (0.8)	39 (0.3)	1 (0)	7,174 (6.3)
Forest Service Non-Wilderness	4,825 (55.8)	19,299 (55.5)	8,168 (23.3)	1,041 (4.6)	206 (1.8)	16 (1)	33,555 (29.5)
Other	386 (4.5)	1,438 (4.1)	1,596 (4.6)	876 (3.9)	193 (1.7)	33 (2.1)	4,522 (4.0)
Total	8,648	34,800	34,953	22,467	11,210	1,615	113,693

[a] Stream reaches with slope less than 15 percent and summer flows greater than 0.20 $ft^3 s^{-1}$, based on the Variability Infiltration Capacity model (see text).

[b] Other category includes U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, and lands with undesignated status.

Table 5.3—Length of streams in the Northern Rockies, categorized by mean August stream temperature during the baseline and two future climate periods and by land administrative status (Forest Service [FS] and non-Forest Service [Non-FS]). Values in parentheses are percentages of the total in the last column.

Land status [a]	<46 °F	46-52 °F	52–57 °F	57–63 °F	63–68 °F	>68 °F	Total
				Miles (percent of total) [b]			
FS lands							
1980s	7,094 (17.4)	22,815 (56.0)	9,342 (22.9)	1,216 (3.0)	244 (0.6)	17 (0)	40,728
2040s	2,504 (6.3)	17,858 (44.7)	15,911 (39.8)	3,092 (7.7)	445 (1.1)	121 (0.3)	39,931
2080s	961 (2.4)	12,701 (32.3)	19,051 (48.5)	5,525 (14.1)	836 (2.1)	237 (0.6)	39,311
Non-FS lands							
1980s	1,554 (2.1)	11,986 (16.4)	25,645 (35.1)	21,260 (29.1)	10,963 (15.0)	1,597 (2.2)	73,005
2040s	569 (0.8)	5,960 (8.4)	20,980 (29.5)	24,422 (34.3)	15,434 (21.7)	3,820 (5.4)	71,185
2080s	253 (0.4)	3,448 (4.9)	16,401 (23.3)	25,128 (35.7)	18,410 (26.1)	6,798 (9.7)	70,438

[a] Stream reaches with slope less than 15 percent and summer flows greater than 0.20 $ft^3 s^{-1}$, based on the Variability Infiltration Capacity model (see text).

[b] Reductions in network extent result from projected decreases in summer flows as described in table 5.1.

Table 5.4—Number and length of cold-water habitats for juvenile cutthroat trout by probability of occurrence for three climate periods and two brook trout invasion scenarios across the Northern Rockies.

		Probability of occurrence (percent)					
		<25	**25–50**	**50–75**	**75–90**	**>90**	**Total**
Cold-water habitat number							
0% brook trout prevalence	1980s	71	392	1,140	1,817	1,739	5,159
	2040s	41	328	1,405	1,505	1,148	4,427
	2080s	86	659	949	977	770	3,441
50% brook trout prevalence	1980s	73	501	2,790	1,384	581	5,329
	2040s	41	382	2,571	1,065	367	4,426
	2080s	86	684	1,837	673	161	3,441
Cold-water habitat length				*Miles*			
0% brook trout prevalence	1980s	268	794	4,068	7,730	32,646	45,506
	2040s	78	558	3,832	6,034	17,964	28,466
	2080s	142	1,031	2,938	4,151	10,459	18,721
50% brook trout prevalence	1980s	387	1,456	6,413	8,203	12,023	28,482
	2040s	126	855	5,079	5,451	6,404	17,915
	2080s	228	1,238	3,931	3,908	2,857	12,162

Table 5.5—Number and length of cold-water habitats for juvenile bull trout by probability of occurrence during three climate periods and two brook trout invasion scenarios in the Northern Rockies.

		Probability of occurrence (percent)					
		<25	25–50	50–75	75–90	>90	Total
Cold-water habitat number							
0% brook trout prevalence	1980s	875	534	248	92	106	1,855
	2040s	664	314	98	41	32	1,149
	2080s	474	274	81	24	13	866
50% brook trout prevalence	1980s	995	484	181	65	28	1,753
	2040s	697	270	63	17	5	1,052
	2080s	535	260	49	5	3	852
Cold-water habitat length				*Miles*			
0% brook trout prevalence	1980s	2,906	3,168	2,565	1,616	4,657	14,912
	2040s	2,222	1,934	1,129	769	1,340	7,394
	2080s	1,310	1,324	773	386	579	4,372
50% brook trout prevalence	1980s	3,920	3,762	2,712	1,891	2,351	14,636
	2040s	2,728	2,208	1,191	589	408	7,124
	2080s	1,569	1,645	704	153	266	4,337

Table 5.6—Adaptation options that address climate change effects on fisheries in the Northern Rockies.

Sensitivity to climatic variability and change: Reduced snowpack will decrease summer streamflows.			
Adaption Strategy / Approach: Increase streamflows and moderate changes in instream flows.			
Tactic	**Specific Tactic – A** Pulse flows from regulated streams during critical times (high temperatures)	**Specific Tactic – B** Reduce water withdrawals and improve efficiency for agriculture (especially irrigation), municipal, and industrial uses	**Specific Tactic – C** Secure water rights for instream flows
Where can tactics be applied?	All regulated streams	Where water demands overlap with current and future suitable habitat	Where fish and suitable habitat overlap
Sensitivity to climatic variability and change: Reduced snowpack will increase stream temperatures and alter flow regimes.			
Adaption Strategy / Approach: Increase habitat resilience for cold-water aquatic organisms by restoring structure and function of streams.			
Tactic	**Specific Tactic – A** Restore natural channel and floodplain form and function (e.g., restore areas with human-caused bank and bed instability)	**Specific Tactic – B** Restore aquatic organism passage structures through design and placement of appropriate structures.	**Specific Tactic – C** Maintain functional stream channel morphology with adequate width:depth ratios, pool frequency, and healthy riparian vegetation
Where can tactics be applied?	Areas with ongoing restoration activities and where habitat is a primary limiting factor (especially where roads are present)	Drainages with frequent high peakflows, areas with sensitive geology, areas with important rearing streams	Areas with ongoing restoration activities and where habitat is a primary limiting factor (especially where roads are present)

Table 5.6 (cont.)—Adaptation options that address climate change effects on fisheries in the Northern Rockies.

Sensitivity to climatic variability and change:
Reduced snowpack will increase stream temperatures and alter flow regimes.

Adaption Strategy / Approach:
Increase habitat resilience for cold-water aquatic organisms by restoring structure and function of streams.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Restore riparian areas to increase hydrologic function and retain cold water	Reintroduce beaver where beaver and management of westslope cutthroat trout are compatible	Remove or relocate roads adjacent to riparian areas, channels, and floodplains where they inhibit complexity; minimize cumulative effect of road network on surface and subsurface flow
Where can tactics be applied?	Where riparian areas limit the availability of cold-water habitat	Where beaver will not affect barriers; in stream reaches >1 mile; in larger population conservation networks; where brook trout are absent	Where roads currently cause problems or may do so in the future, especially where roads occupy lengthy portions of the riparian zone

Sensitivity to climatic variability and change:
Reduced snowpack will increase stream temperatures, affecting native species and interactions between natives and nonnatives.

Adaption Strategy / Approach:
Provide opportunities for native fish to move and find suitable stream temperatures.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Increase the patch size of favorable habitat to enhance viable populations and allow migratory life histories	Modify or remove barriers to increase connectivity between areas of cold-water habitat	Identify and map where groundwater inputs provide cold water
Where can tactics be applied?	Where native fish currently exist; where suitable habitat is nearby; where nonnatives are not present or can be effectively managed; where populations are fragmented and need greater connectivity	Where barriers prevent movement to suitable habitat, and where removal will not increase invasion of nonnatives	All locations

Table 5.6 (cont.)—Adaptation options that address climate change effects on fisheries in the Northern Rockies.

Sensitivity to climatic variability and change: Warmer temperatures will increase stream temperature and risk of invasion by nonnative fish species.			
Adaption Strategy / Approach: Manage nonnative fish populations to eliminate or reduce their impact on native fish.			
Tactic	**Specific Tactic – A** Encourage increased take/harvest of nonnatives, especially near long-term strongholds for natives	**Specific Tactic – B** Remove nonnatives with manual or chemical techniques	**Specific Tactic – C** Exclude nonnatives with physical or electrical barriers
Where can tactics be applied?	Areas with heavy recreation and sport fishing; most effective at the front of invasions	Where long-term suitable habitat for natives is available and nonnatives are present	Where long-term suitable habitat for natives is available and nonnatives are present
Sensitivity to climatic variability and change: Continued livestock grazing will compound stress caused by increased stream temperatures.			
Adaption Strategy / Approach: Manage livestock grazing to restore ecological function of riparian vegetation and channels.			
Tactic	**Specific Tactic – A** Comply with all existing standards and guidelines for maintaining water quality in streams and riparian areas; facilitate compliance through monitoring	**Specific Tactic – B** Use innovative techniques to fund and maintain and implement improvements (e.g., riparian fencing, rest-rotation systems, off-channel water, exclosures)	**Specific Tactic – C** Identify and prioritize vacant allotments for retirement
Where can tactics be applied?	All locations, with emphasis on areas that are important in terms of ecological value and large financial investment	All locations, with emphasis on areas that are important in terms of ecological value and prior financial investment; prioritize areas with core conservation fish populations that are under imminent threat	All locations where vacant allotments exist and opportunities allow

Table 5.6 (cont.) —Adaptation options that address climate change effects on fisheries in the Northern Rockies.

Sensitivity to climatic variability and change:
Higher temperatures will increase wildfire occurrence that can lead to erosion and mass wasting.

Adaption Strategy / Approach:
Increase resilience to fire-related disturbance.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Implement fuel treatments (thinning, prescribed burning) to reduce wildfire severity and size	Disconnect roads from stream networks to reduce erosion and sediment delivery to streams	Install erosion control structures following wildfires
Where can tactics be applied?	Areas where canopy and surface fuels are high, adjacent to known native fish populations and habitat	Areas adjacent to known native fish populations and habitat	Where wildfire has occurred and erosion would affect known native fish populations and habitat

Table 6.1—Comparison of attributes characterizing a species' adaptive strategy.[1]

	Adaptive strategy	
Attributes	**Specialist**	**Generalist**
Factor controlling phenotypic expression of adaptive traits	Genotype	Environment
Mechanisms for accommodating environmental heterogeneity	Genetic variation	Phenotypic plasticity
Range of environments where physiological processes function optimally	Small	Large
Slope of clines for adaptive traits	Steep	Flat
Partitioning of genetic variation in adaptive traits	Largely among populations	Largely within populations

[1] Modified after Rehfeldt (1994).

Table 6.2—Assessment for soils to apply to vegetation concerns in the Northern Rockies (NR).

Broad-scale climate change effect	Ecosystem function	Current condition, existing stressors	Sensitivity to climatic variability and change	Expected effects of climate change	Risk assessment	
					Magnitude of effects	Likelihood of effects
Mainly changes in summer precipitation Higher summer temperatures	Available water (for vegetation)	Relative effective annual precipitation has been mapped for MT. Current condition has not been assessed for ID and ND. Existing stressors: extremes in water year (more frequent droughts), high stand densities.	Variable, depending on species, subregion and slope position.	In western Northern Rockies, decreased precipitation is projected at low elevations; increased summer drought may result. High elevations may have increased precipitation. In eastern Northern Rockies, the higher interannual variation of precipitation would lead to years of increased drought. No trend projected for annual or seasonal precipitation.	High	High
Increased atmospheric CO_2	Nutrient cycling for vegetation production	Variable. Nitrogen is the most common nutrient deficiency, but other nutrients (phosphorus, potassium, boron) are also limiting. Existing stressors: severe fires, erosion.	Unknown. Potassium is easily lost on some metasediments, during whole-tree yarding.	Nitrogen, phosphorus, potassium and boron will become less available if soils become more acidic. Increased acidity of leachate would contribute to faster parent material decomposition, which would release inherent mineral nutrients in soil.	Unknown	High
Soil temperature, moisture, and CO_2 levels	Soil biota	Most soils have healthy soil biota. Exceptions occur on abandoned roads and landings. Some stands have reduced biotic health from past management. Existing stressors: Severe fires, erosion	Moderate	Alteration of soil biota (fungi, microbes, nematodes) as well as the communities.	Variable	Very high

Table 6.2(cont.)—Assessment for soils to apply to vegetation concerns in the Northern Rockies (NR).

Broad-scale climate change effect	Ecosystem function	Current condition, existing stressors	Sensitivity to climatic variability and change	Expected effects of climate change	Risk assessment	
					Magnitude of effects	Likelihood of effects
Everything that contributes to increased fire and flood (e.g., more frequent high-intensity storms)	Soil stability	Little surface erosion occurs in the Northern Rockies Existing stressors: Most erosion occurs after severe wildfires or floods. Small amounts may occur in conjunction with roads, timber sales, grazing, and other land management activities.	High—existing stressors will become more prevalent.	Areas with decreased ground cover will be susceptible to increased surface erosion from wind and water.	Moderate	Very high
Changes in spring and autumn precipitation (rain rather than snow, period of saturation longer)	Slope stability	Landslide prone areas have been mapped. Existing stressor: long period of saturation in some years.	Variable	Size and frequency of landslides will increase.	Broad	Very high
Temperature, precipitation and CO_2 concentrations	Soil carbon storage and dynamics	Soil is currently a major carbon storage pool and will continue to be a carbon sink as long as young stands continue to mature. Current stressors: periodic wildfires and insect outbreaks.	High in areas where disturbances become more prevalent.	If wildfire increases in frequency and extent as much as projected, this will maintain forests in younger age classes with less potential for carbon storage but higher carbon uptake.	Potentially high in drier forests	High in dry forests

Table 6.3—Summary of tree characteristics that indicate possible responses to future climate change. All fields are rated on a scale from one to five, with 1 generally indicating low levels and five generally indicating high levels of the variable (see specific notes below).

		Tolerances[2]			Genetics					
Species	Distribution[1]	Shade	Drought	Fire	Diversity[3]	Geographic Differentiation[4]	Strategy[5]	Mycorrhizal dependence[6]	Insect and disease exposure[7]	Seed dissemination strategy[8]
Limber pine	1	1	5	2	3	3	I	4	4	5,4
Ponderosa pine–var. *scopulorum*	3	2	4	4	3	2	I	3	2	3,4
Ponderosa pine-var. *ponderosa*	3	2	4	5	3	2	I,S	3	4	3,4
Douglas-fir	4	4	4	4	2	2	S,G	3	3	3
Western larch	2	2	2	5	3	2	I	2	2	3
Western white pine	1	2	2	5	3	3	G	2	4	3,4
Aspen	2	1	4	1	5	2	G	2	3	3,2
Grand fir	2	4	2	2	2	2	G	2	4	3
Western redcedar	2	5	5	2	1	2	S	1	2	3
Western hemlock	2	5	5	2	2	2	S	2	2	3
Lodgepole pine	4	2	3	3	4	2	S	3	4	6
Whitebark pine	3	3	2	3	4	3	G	3	4	5
Subalpine fir	4	4	4	1	3	2	I	2	3	3
Engelmann spruce	3	4	4	2	3	2	I	2	2	3
Mountain hemlock	1	4	5	1	2	2	S	2	2	3
Alpine larch	1	1	5	1	2	3	S	3	1	3
Green ash	2	1	2	1	2	3	G	4	1	3
Cottonwood	2	1	4	3	3	3	G	3	2	1

[1]Distribution of 1 indicates narrow distribution in the Northern Rockies, while distribution of 5 indicates wide distribution.
[2]Shade, drought, and fire tolerance of 1 indicates high intolerance, while 5 indicates high tolerance.
[3]Genetic diversity of 1 indicates low diversity and 5 indicates high diversity.
[4]Geographic differentiation of 1 indicates low genetic differentiation (narrow seed zones) and 5 indicates wide differentiation (large seed zones).
[5]Genetic adaptive strategy of G indicates a generalist species (grows under wide range of conditions), I indicates an intermediate species (grows over a moderate range of conditions), and S indicates a specialist species (grows under a narrow range of conditions) (from Scott et al. 2013).
[6]Mycorrhizal dependence of 1 indicates that the species is not dependent on mycorrhizae, while 5 indicates that the species is highly dependent on mycorrhizae.
[7]Insect/disease exposure of 1 indicates that the species is not susceptible to many damaging agents, while 5 indicates that the species is highly susceptible to insects and disease.
[8]Seed dissemination is the primary means of seed dispersal where 1-water, 2-sprouts, 3-wind/gravity, 4-rodent, 5-bird, 6-serotinous.

Table 6.4—Categories used to assess the vulnerability of species, vegetation types, and resource concerns in this chapter.

Evaluation category	Description	Example
Habitat, ecosystem function, or species	Specific biophysical or social entity of interest	Whitebark pine
Broad-scale climate change effect	Overarching change in climate that is expected to affect a resource	Warming temperatures
Current condition, existing stressors	Current status of resource relative to desired conditions, including factors that are reducing the quality or quantity of the resource	Reduced abundance, wildland fire, mountain pine beetle, white-pine blister rust
Sensitivity to climatic variability and change	Specific sensitivity of a habitat, species, or ecosystem function that responds to climate	Low ability to compete with encroaching conifers
Expected effects of climate change	How specific habitat, species, or ecosystem function is expected to respond to climate change (develop inferences from model projections and known responses to climatic variability)	Regeneration may be reduced by combination of warming and low seed availability
Adaptive capacity	Ability to adjust to climate change, to moderate potential damages, or to cope with the consequences; usually more appropriate for species than for systems and processes	Variable: unable to compete with other tree species, but bird-mediated seed dispersal allows quick colonization of burned over areas
Exposure	The extent to which each species' physical environment will change expressed as low, moderate or high	High
Risk assessment, magnitude of effects	Estimate of the magnitude of climate change effects expressed as low, moderate, or high by time period	Moderate
Risk assessment, likelihood of effects	Estimate of the likelihood that climate change effects will occur expressed as low, moderate, or high by time period	High

Table 6.5—Final tree species ratings for the entire Northern Rockies (NR), and the five sub-regions of the NR. The table from lowest to highest vulnerability in the NR. Also included are ratings from the Pacific Northwest in Devine et al. (2012) report and from the northern Rocky Mountains in Hansen and Phillips (2015).

Tree species	NR	West	Central	East	GYA	Grass	Devine et al. (2012)	Hansen and Phillips (2015)
Alpine larch	1	2	1	NA[1]	NA	NA	4	NRT[2]
Whitebark pine	2	1	2	1	1	NA	1	1
Western white pine	3	5	3	NA	NA	NA	13	NRT
Western larch	4	6	4	NA	NA	NA	12	8
Douglas-fir	5	8	8	2	2	1	11	9
Western redcedar	6	4	5	NA	NA	NA	15	7
Western hemlock	7	3	6	NA	NA	NA	10	6
Grand fir	8	7	7	NA	NA	NA	5	11
Engelmann spruce	9	9	11	3	4	5	3	5
Subalpine fir	10	10	12	4	5	6	2	4
Lodgepole pine	11	11	10	5	6	7	8	3
Mountain hemlock	12	3	9	NA	NA	NA	7	2
Cottonwood	13	12	13	6	3	2	17	NRT
Aspen	14	13	14	8	7	3	6	NRT
Limber pine	15	NA	15	7	8	4	18	NRT
Ponderosa pine-west	16	14	16	NA	NA	NA	14	10
Ponderosa pine-east	17	NA	NA	8	9	8	NRT	10
Green ash	18	NA	NA	9	10	9	19	NRT

[1]NA = Not applicable
[2]NRT = Not rated

Table 6.6—Adaptation options that address climate change effects on forested vegetation in the Northern Rockies.

Sensitivity to climatic variability and change: The frequency and scale of disturbance will likely increase with climate change.			
Adaption Strategy / Approach: Promote disturbance-resilient species, including western larch and western white pine on moist sites, ponderosa pine on dry sites, Douglas-fir on extremely dry sites, and lodgepole pine on harsh sites that are difficult to regenerate.			
Tactic	**Specific Tactic – A** Thin to favor disturbance-resilient species.	**Specific Tactic – B** Plant disturbance-resilient species.	**Specific Tactic – C** Promote disturbance-resilient species with prescribed fire and/or natural fire use.
Where can tactics be applied?	On sites most likely to be affected by wildfire	On sites most likely to be affected by wildfire	On sites most likely to be affected by wildfire
Sensitivity to climatic variability and change: Increasing temperatures with climate change will lead to increased moisture stress and fire.			
Adaption Strategy / Approach: Reduce forest density and maintain low densities.			
Tactic	**Specific Tactic – A** Conduct thinning treatments (pre-commercial and commercial).	**Specific Tactic – B** Use prescribed fire to maintain structure and promote fire-tolerant conifer species.	**Specific Tactic – C** Use regeneration and planting to influence forest structure.
Where can tactics be applied?	On overstocked sites with low risk of root disease problems	On overstocked sites	Where there are no opportunities for thinning because of species or stand condition.
Sensitivity to climatic variability and change: Areas with limited species and genetic diversity will likely be more susceptible to climate change stressors.			
Adaption Strategy / Approach: Promote species and genetic diversity.			
Tactic	**Specific Tactic – A** Plant potential microsites with mix of species (hedge your bets).	**Specific Tactic – B** Maintain species diversity during thinning.	**Specific Tactic – C** Interplant to supplement natural regeneration and genetic diversity.
Where can tactics be applied?	In sufficiently large openings on sites most at risk for drought stress	In dense or overstocked stands on sites more at risk for drought stress and where sufficient diversity exists for thinning.	In sufficiently large openings on sites most at risk for drought stress.

Table 6.6 (cont.)—Adaptation options that address climate change effects on forested vegetation in the Northern Rockies.

Sensitivity to climatic variability and change: Increasing temperatures with climate change will lead to longer growing seasons, increased drought stress, and increased fire.			
Adaption Strategy / Approach: Promote ecosystem resilience.			
Tactic	**Specific Tactic – A** Promote legacy trees of western larch, Douglas-fir, western white pine, Engelmann spruce, whitebark pine, and subalpine larch for regeneration and wildlife habitat.	**Specific Tactic – B** Collect seed for post-wildfire reforestation and other planting needs, especially for subalpine larch, whitebark pine, and high-elevation western larch.	**Specific Tactic – C** Promote landscape heterogeneity and create connectivity at multiple scales.
Where can tactics be applied?	On dense spruce, fir, and lodgepole pine sites	Where species of interest occur	At the landscape scale
Sensitivity to climatic variability and change: Climate change will likely lead to increased disturbance, increased moisture deficits, and species distribution shifts.			
Adaption Strategy / Approach: Increase knowledge for agency land managers and stakeholders.			
Tactic	**Specific Tactic – A** Determine what connectivity means for different species and guilds.	**Specific Tactic – B** Track tree species regeneration and distribution.	**Specific Tactic – C** Improve integration between wildlife managers and forest ecologists, and between research and management.
Where can tactics be applied?	All lands	All lands	All lands
Tactic	**Specific Tactic – D** Monitor blister rust resistance within planted white pine stands, and try to understand the relationship between infection rates and climatic drivers (e.g., fog).	**Specific Tactic – E** Identify other resource management goals (not directly related to stand structure and composition) that may modify management strategies for forest vegetation, such as water yield, snow retention, and wildlife habitat.	**Specific Tactic – F** Support the adaptive management research framework; develop consistent monitoring framework that can capture long-term change.
Where can tactics be applied?	On sites planted with white pine	Federal lands	Federal lands

Table 6.6 (cont.)—Adaptation options that address climate change effects on forested vegetation in the Northern Rockies.

Sensitivity to climatic variability and change: Climate change will likely lead to increased whitebark pine mortality through increased mountain pine beetle activity, fire and white-pine blister rust. There will also likely be a loss of site conditions that support whitebark pine.			
Adaption Strategy / Approach: Promote resilient whitebark pine communities.			
Tactic	**Specific Tactic – A** Identify sites that are less likely to be affected by climate change (refugia), and focus on those sites for restoration.	**Specific Tactic – B** Implement a variety of management strategies and options to promote whitebark pine, including fire management, planting at lower elevations, and removing other dominant species (e.g., lodgepole pine, spruce and fir)	**Specific Tactic – C** Plant genetically-selected seedlings to promote blister rust resistance
Where can tactics be applied?	Federal lands	Federal lands	Federal lands
Sensitivity to climatic variability and change: Climate change will lead to increased risk of stand-replacing wildfire, mortality from drought, and loss of large ponderosa pine individuals in ponderosa pine forests.			
Adaption Strategy / Approach: Decrease density within stands, and increase structural diversity across the landscape.			
Tactic	**Specific Tactic – A** Reduce density by thinning, prescribed fire, and wildfire use, with density and structural goals based on past and predicted future conditions.	**Specific Tactic – B** Promote age class and structural diversity across the landscape, through regeneration harvest, thinning, prescribed fire and wildfire use.	**Specific Tactic – C** Monitor establishment, survival and development of ponderosa by age class and in different topoedaphic conditions using Forest Inventory and Analysis data and project-level stocking exams.
Where can tactics be applied?	Ponderosa pine, Douglas-fir forests	In locations where activities are allowed	Ponderosa pine, Douglas-fir forests
Sensitivity to climatic variability and change: Climate change stressors cross boundaries, forcing agencies to coordinate and work across boundaries.			
Adaption Strategy / Approach: Work across jurisdictions at a larger scales.			
Tactic	**Specific Tactic – A** Align budgets and priorities for program of work with neighboring lands	**Specific Tactic – B** Communicate about projects adjacent to other lands, and coordinate on the ground	**Specific Tactic – C** Work across boundaries to preserve roads, trails, and access with increasing fire and flood events
Where can tactics be applied?	All lands	All lands	All lands

Table 6.6 (cont.)—Adaptation options that address climate change effects on forested vegetation in the Northern Rockies.

Sensitivity to climatic variability and change: The vigor and extent of aspen may be reduced with increased frequency of disturbance and drought under changing climate.			
Adaption Strategy / Approach: Restore and promote the health and vigor of aspen clones.			
Tactic	**Specific Tactic – A** Manage ungulates during the regeneration phase (e.g., with slash barriers, increased hunting pressure, grazing management, and salt block placement)	**Specific Tactic – B** Remove conifers around aspen, at multiple scales and using multiple tools (i.e., hand and commercial treatments)	**Specific Tactic – C** Monitor the extent and condition of aspen clones to determine the effect of disturbance frequency on aspen survival, effects of sudden aspen decline, and incidence of new clones; this may lead to strategic protection measures for specific clones
Where can tactics be applied?	Wherever aspen regeneration prescriptions are applied	Wherever aspen occurs outside of protected areas	Wherever aspen occurs
Sensitivity to climatic variability and change: The distribution of subalpine forests is likely to shift as a result of increasing temperatures with climate change.			
Adaption Strategy / Approach: Monitor and detect change in seedling survival, species composition, and mortality of mature trees in subalpine forests.			
Tactic	**Specific Tactic – A** Install and analyze additional plots to gather trend information over time, targeting areas where changes are expected.	**Specific Tactic – B** Use Forest Inventory and Analysis plot information to determine trends in subalpine forests.	**Specific Tactic – C** Expand reforestation monitoring and post-treatment monitoring.
Where can tactics be applied?	Federal lands	All lands	In reforestation or treatment locations

Table 6.7—Management recommendations for each of the evaluated species, vegetation types, and resource concerns.

Habitat, ecosystem function, or species	Primary adaptive tactics	Restoration potential	Further management recommendations
Species			
Limber pine	Promote rust-resistance while preserving genetic diversity; monitor mortality rates and distributions; Evaluate which stands need treatment to ensure conservation of species; determine impact of fire exclusion era	Low to moderate – the main drawback is the exotic disease white-pine blister rust. Most management actions should be to increase rust resistance in native populations	Initiate rust-resistant programs; identify plus trees; collect cones and determine rust resistance; map limber pine populations and identify those stands that have become established before and after the fire exclusion era
Ponderosa pine	Restore fire to historically fire-dominated stands; reduce fuel loadings to mitigate uncharacteristic fire severities; use HRV as guide to design and conduct restoration treatments	Moderate to high – reintroducing fire or fire surrogates into fire-excluded stands is the first step; addressing where to plant in the future is the next	Reduce or eliminate Douglas-fir in fire-excluded stands; remove competition through thinnings and prescribed burns; monitor lower treeline in SW Montana and central Idaho to evaluate potential ponderosa pine increases
Douglas-fir	Reduce competition and increase vigor; keep stand density down; replace Douglas-fir with ponderosa pine, western white pine, and western larch in areas where root disease is a concern; emphasize ponderosa pine on lower elevation dry forests	Moderate to high – mitigating effects of the fire exclusion era is the first step; might be more difficult in cool, dry environs	Keep stocking low; change species composition on sites where root disease and soil moisture deficits will be increasing; concentrate planting on the higher elevation, mesic sites and avoid planting in the lower treeline
Western larch	Restore declining larch stands from adverse fire exclusion effects; Prioritize northerly aspects and ash cap soils for treatment; reduce competition; manage larch more intensively on more xeric sites where larch may not be the species to plant on south slopes even though current climate may be suitable Reduce forest density in all successional stages to provide larch with better chance to utilize soil moisture	Moderate to high in west region; moderate in central region	Cut to remove more shade-tolerant species using group selections and thinnings; consider planting options on north slopes where long term persistence will have highest potential; consider genetic stock with best adaptive traits for drought and moisture stress compatibility; Maintain stocking and structure diversity to favor moisture regime for larch in all successional stages and to be more able to cope with fire; Consider most intensive management for larch on sites with least moisture deficits
Western white pine	Promote rust-resistance	Moderate in west region; low to moderate in central region, mainly due to the devastating effects of rust mortality	Increased planting of blister rust resistant material; thinning dense stands to increase young pine vigor
Grand fir	Foster landscape heterogeneity; ensure age class structure is near HRV	High in the west and central regions	Low priority for restoration; no real need to spend valuable restoration dollars restoring this forest unless it is locally declining
Western redcedar	Ensure high landscape heterogeneity; multiple age classes	High in west and central NR regions	Low priority for restoration; no real need to spend valuable restoration dollars restoring this forest unless it is locally declining

Table 6.7(cont.)—Management recommendations for each of the evaluated species, vegetation types, and resource concerns.

Habitat, ecosystem function, or species	Primary adaptive tactics	Restoration potential	Further management recommendations
Species (cont.)			
Western hemlock	Maintain diversity of age classes and high landscape diversity	High in west and central NR regions	Low priority for restoration; no real need to spend valuable restoration dollars restoring this forest unless it is locally declining
Aspen	Restore quasi-historical fire regimes; prioritize areas were aspen already exist albeit at lower than historical levels	Moderate for all NR	Plant aspen where it is now absent but once flourished; manage aspen at the landscape level by ensuring mix of age classes and successional stages
Lodgepole pine	Perhaps the most important subalpine species to manage for mixed age classes and successional stages that approximate HRV	Moderate to high in most if its NR range	Allow WFU fires to burn in moderate years
Subalpine fir	Populations can best be modified by wildfire suppression efforts at local scales	High in most of the NR	Low priority for climate impact mitigation; no real need to spend valuable restoration dollars restoring this forest unless it is locally declining
Engelmann spruce	Populations can best be modified by wildfire suppression efforts at local scales; planting may be warranted in areas with declining populations	High in most of the NR; moderate in those low elevation wetland stands	Low priority for climate change adaptation actions; no real need to spend valuable restoration dollars conserving this forest unless it is declining locally
Mountain hemlock	Increased fire suppression efforts will increase populations if needed	Moderate to High in west and central regions of NR	While this species may have low priority for mitigating adverse climate change effects it is important to monitor the species so it does not go locally extinct
Whitebark pine	Most climate change adaptation strategies are detailed in Keane et al. (2015)[in press]: promote rust resistance; conserve genetic diversity; implement treatments on the higher stands in project areas; plant rust-resistant seedlings in old or recent burns	Low to moderate in most of its range primarily due to the devastating effects of WPBR	Follow Keane et al. (2010) rangewide strategy: protect rust-resistant plus trees; promote rust resistance; implement prescribed burn and mechanical cuttings to reduce competition; plant and direct-seed blister rust resistant seedlings on burn and treated areas; cold hardy and drought tolerant material
Alpine larch	Preserve genetic diversity by collecting and storing seed;	Low to moderate across most of its range	Monitor changes in alpine larch populations; document
Green ash	Reduce grazing; increasing fire suppression and grazing can be used to modify ash populations along with planting in those areas where populations are critically low	High in the eastern NR	Plant in recently burned areas where it last existed
Cottonwood	Foster high variability in river flows to increase seedling establishment potential; eliminate competition	Moderate to high	Prioritize the most mesic sites first; allow fire to burn in areas that are not too dense; conduct cuttings to remove conifer competition

Table 6.7(cont.)—Management recommendations for each of the evaluated species, vegetation types, and resource concerns.

Vegetation types			
Dry ponderosa pine and Douglas-fir forests	Create less dense forests with composition related to moisture deficit tolerance	High all over the Region with in dry settings	Manage density and appropriate composition related to projected moisture limited sites
Western larch mixed conifer forests	Create a greater landscape heterogeneity forest pattern that may limit the extent of large uncharacteristically severe disturbances using mechanical and prescribed fire as tools; Greater moisture deficits, less available moisture for trees will require consideration of appropriate species distribution and forest density in the future; Create within stand structure diversity and more open conditions to allow larch to maintain dominance	High in western portion of the region	Manage pattern of the forest to increase the diversity of successional stages and arrangement; tools in areas suitable for timber production will include timber harvest and prescribed burning, while areas in Roadless areas will be restored with wildfire for resource benefit with some planting where seed source is absent due to large fires; maintain stocking levels to favor larch moisture relationship in all successional stages and to be able to better cope with fire; Mange species composition less susceptible to root disease especially in northern Idaho; manage larch in lynx habitat knowing that larch needs more open conditions to maintain dominance over the long term in a stand
Lodgepole pine and aspen mixed conifer forests		High in most of the NR	Again, manage pattern to increase the diversity of successional stages and arrangement; Roadless areas need wildfire for resource benefit; planting to lodgepole may be needed where seed source is absent due to large fires; Mange species composition in lynx habitat knowing that returning natural fire regimes will reduce subalpine fir populations
Mixed mesic white pine, cedar, hemlock grand fir forests	Attempt to emphasize the restoration of western white pine while also maintaining landscape heterogeneities similar to historical conditions; promote rust resistance and plan treated and burned areas with pine seedlings	Moderate in most of the NR because of the exotic rust	Be careful to monitor local conditions to evaluate losses or gains in the four species so management options can be adjusted
Whitebark pine-spruce-fir forests	Most climate change adaptation strategies are detailed in Keane et al. (2015)[in press]: most important – create landscape heterogeneity in composition and size classes; also promote rust resistance; conserve genetic diversity; implement treatments on the higher stands in project areas; plant rust-resistant seedlings in old or recent burns	Low to moderate in most of its range primarily due to the devastating effects of WPBR	Follow Keane et al. (2010) rangewide strategy: protect rust-resistant plus trees; promote rust resistance; implement prescribed burn and mechanical cuttings to reduce competition; plant and direct-seed blister rust resistant seedlings on burn and treated areas; cold hardy and drought tolerant material

Table 6.7(cont.)—Management recommendations for each of the evaluated species, vegetation types, and resource concerns.

Resource concerns			
Landscape heterogeneity	Design restoration and climate change treatments at multiple scales, especially the landscape scale; allow wildfires to burn	Moderate	Landscape heterogeneity should be evaluated periodically to determine trends and magnitudes
Timber production	Thinning and planting western larch, ponderosa pine and western white pine on appropriate habitats will be im rtant to long term timber production o ena le the forest to better cope wit disturbanc such as fire and root dis se, manage density within dry fores settings	High in western portion of region for larch and western white pine. High for ponderosa pine throughout the Region. See appendix for acres of potential larch restoration and other tree species restoration within the suitable for timber production areas a d on-suitable for timber produ ion areas; High on all dry forest se ngs for density reduction	Manage landscapes for species composition, structure and pattern best able to cope with moisture deficits and disturbance, especially root disease, bark beetles and fire. Mange dry forest settings to be more open grown ponderosa pine compared to current dense mixed Douglas-fir forests. Increase percent of ponderosa pine, western larch and western white pine on mixed mesic settings to cope with increase in fire and root disease. Manage for a diversity of lodgepole pine, spruce, subalpine fir, larch and whitebark pine in higher elevations considering increasing soil moisture deficits. Manage for a diversity of successional stages (landscape heterogeneity) in a pattern that will better cope with disturbance agents
Carbon sequestration	Carbon can be best sequestered by embracing ecosystem management and restoring landscapes and ecosystems; Carbon sequestration is a side-effect of an ecosystem treatment, not the objective	/A	The best management approach for managing carbon sequestration is to foster a timber management program that emphasizes an ecosystem approach

Table 7.1—Approximate area of U.S. Ecological Systems identified as rangelands within the NRAP assessment region. Sagebrush systems were further subdivided into mountain, low, and big or sprouters. These distinct species were grouped into the "big or sprouters" category only for developing map legends because, using the mid-level Ecological Systems mapping approach, without external data, it would be difficult to differentiate each unique cover type dominated by the various *Artemisia* spp. across the landscape.

Rangeland vegetation types	Ecological system	Area	Sagebrush grouping
		Acres	
Northern Great Plains (C3/C4 mix)	Central Tallgrass Prairie	479,899	NA
	Northwestern Great Plains Mixedgrass Prairie	37,818,629	NA
	Western Great Plains Sand Prairie	2,285,234	NA
	Western Great Plains Shortgrass Prairie	39,543	NA
	Western Great Plains Tallgrass Prairie	7,763	NA
	North entral Interior Sand and Gravel Tallgrass Prai e	209,599	NA
	N thern Ta grass Prairie	367,864	NA
	Great Plains rairie Pothole	262,813	NA
Total		41,471,344	NA
Montane shrubs	Northern R cky Mountain Montane-Foothill ecidu s Shrubland	1,257,671	NA
	Inter-Mountain Basins Curl-leaf Mountain Mahogany Woodland and Shrubland	175,887	NA
	Rocky Mountain Lower Montane-Foothill Shrubland	4,602	NA
Total		1,438,160	NA
			NA
Montane grasslands (C3)	Columbia Plateau Steppe and Grassland	1,257,642	NA
	Columbia Basin Palouse Prairie	2,692,161	NA
	Columbia Basin Foothill and Canyon Dry Grassland	58,773	NA
	Inter-Mountain Basins Semi-Desert Grassland	42,311	NA
	Northern Rocky Mountain Lower Montane-Foothill-Valley Grassland	14,419	NA
	Northern Rocky Mountain Subalpine-Upper Montane Grassland	5,957	NA
Total		4,071,263	NA
Sagebrush systems	*Artemisia tridentata* ssp. *vaseyana* Shrubland Alliance	2,931,640	Mountain
	Inter-Mountain Basins Big Sagebrush Steppe	9,656,339	Big or sprouter
	Inter-Mountain Basins Big Sagebrush Shrubland	2,451,624	Big or sprouter
	Inter-Mountain Basins Montane Sagebrush Steppe	1,993,178	Big or sprouter
	Columbia Plateau Low Sagebrush Steppe	156,012	Low
	Wyoming Basins Dwarf Sagebrush Shrubland and Steppe	49,723	Low
	Inter-Mountain Basins Semi-Desert Shrub-Steppe	41,572	Big or sprouter
	Great Basin Xeric Mixed Sagebrush Shrubland	17,970	Low
	Columbia Plateau Scabland Shrubland	14,529	Big or sprouter
Total		17,312,587	
All rangelands total		64,293,354	

Table 7.2—Area of rangeland vegetation classes evaluated in each NRAP subregion.

Subregion	Rangeland vegetation classes	Area	Proportion
		Acres	*Percent*
Western Rockies	Montane grasslands	596,837	34.4
	Montane shrubs	298,153	35.7
	Sagebrush systems	358,086	29.9
Total		1,253,076	
Central Rockies	Montane grasslands	845,539	43.6
	Montane shrubs	173,980	18.6
	Sagebrush systems	507,391	37.8
Total		1,526,909	
Eastern Rockies	Montane grasslands	735,758	13.5
	Montane shrubs	328,306	12.5
	Northern Great Plains (C3/C4 mix)	221,193	5.9
	Sagebrush systems	2,572,138	68.2
Total		3,857,395	
Grassland	Montane grasslands	1,343,858	1.8
	Monta e shrubs	266,233	0.7
	Nor ern Great Plai (C3/C4 mix)	41,204,297	80.6
	Sageb ush system	8,586,897	16.8
Total		51,401,285	
Greater Yellowstone Area	Montane grasslands	549,271	6.1
	Montane shrubs	371,488	8.5
	Northern Great Plains (C3/C4 mix)	45,848	0.7
	Sagebrush systems	5,288,075	84.7
Total		6,254,682	
All subregions total		128,586,695	

Table 7.3—Adaptation options that address climate change effects on rangelands in the Northern Rockies.

Sensitivity to climatic variability and change: Increased susceptibility of vegetation communities (e.g., grasslands) to invasive species.			
Adaption Strategy / Approach: Increase proactive management actions in order to prevent invasive species			
Tactic	**Specific Tactic – A** Conduct ecologically based invasive plant management; implement prescriptive grazing, fire, he bicide and re-seeding.	**Specific Tactic – B** Develop weed management areas and coordinate with multiple agencies, non-governmental organizations, and the public.	**Specific Tactic – C** Apply early detection rapid response (EDRR) and inventory and mapping.
Where can tactics be applied?	Prioritize small/new vasions by most critical species; w k back to road corridors and deve ped areas	Recreation high use areas (roads); administrative areas	All lands
Tactic	**Specific Tactic – D** Use best invasive management practices to address vectors; emphasize invasive species education (e.g., teach people how to clean their equipment, boots).	**Specific Tactic – E** Remove conifers with mechanical treatments, prescribed fire, and harvest.	**Specific Tactic – F** Conduct integrated weed management (i.e., spraying, chemical, biological, mechanical, manual control, targeted grazing).
Where can tactics be applied?	Forest/grassland/region level	Encroached communities	Recreation high use areas (roads), administrative areas

Table 7.3(cont.)—Adaptation options that address climate change effects on rangelands in the Northern Rockies.

Sensitivity to climatic variability and change: Increased temperature and drought will cause more and larger wildfires, leading to mortality of sagebrush and grasslands and increased dominance of fire-adapted herbaceous and non-native species. **Adaption Strategy / Approach:** Maintain intact ecosystems, and increase resilience and resistance of native sagebrush-grass ecosystems**.**			
Tactic	**Specific Tactic – A** Inventory intact areas with high native cover (i.e., weed free areas).	**Specific Tactic – B** Employ preventative measures to reduce the spread and introduction of invasive species into intact/weed free plant communities.	**Specific Tactic – C** Manage priority invasive species on priority acres.
Where can tactics be applied?	On all land	Areas that are currently weed free	In priority areas
Tactic	**Specific Tactic – D** Restore to minimize or reverse adverse effects.	**Specific Tactic – E** Manage fire for resource benefits.	**Specific Tactic – F** Promote the occurrence and growth of native species.
Where can tactics be applied?	Degraded non-forest vegetation communities	Priority areas based on current condition and potential response to fire	Sagebrush-dominated areas where native species have significant populations and non-natives are not dominant
Tactic	**Specific Tactic – G** Determine and implement proper grazing; conduct adaptive management that recognizes climate changes will lead to different availability of range; use rest and rotation practices; reduce grazing in July and August to encourage perennial growth.	**Specific Tactic – H** Manage livestock grazing through planning efforts that serve as livestock movement guides (within-season triggers) and allow for the maintenance and/or enhancement of plant health (end-point indicators).	**Specific Tactic – I** Use targeted grazing to address contemporary vegetation management challenges (e.g., control invasive exotic and noxious weeds and undesirable species, and reduce fire risk).
Where can tactics be applied?	On all grazed lands	On all grazed lands	Priority areas based on current condition and potential response to treatment

Table 7.3(cont.)—Adaptation options that address climate change effects on rangelands in the Northern Rockies.

Sensitivity to climatic variability and change: Phenological mismatch between pollinators and host plants.			
Adaption Strategy / Approach: Maintain and restore natural grassland habitat to ensure pollination.			
	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Encourage native pollinators; provide other habitats for pollinators (nesting cover, feeding cover, brooding cover).	Restore and enhance habitat (using tools such as grazing, fire, herbicide application, reseeding).	Implement long term monitoring of pollinators (e.g., research, tech transfer, education, citizen science projects, and monitor existing populations).
Where can tactics be applied?	Throughout current range of grasslands	Use ecological site descriptions to identify priority areas for restoration or enhancement	Look at native and non-native ecosystems, overlap in these ecosystems and the types of pollinators present
Sensitivity to climatic variability and change: Loss of topsoil and invasion of weeds in montane shrublands.			
Adaption Strategy / Approach: Maintain and increase montane shrublands.			
	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Educate fuels specialists, forest ecologists, wildlife biologists and silviculturists on ecology and disturbances affecting shrublands; effects of repeated burns; shifting mosaics (creating a balance of types across landscapes); and weeds (identification, awareness, reporting).	Maintain adequate shrub cover, vigor, and species richness, and avoid bare ground; create different age classes and compositions of shrubfields (shifting mosaic); no action is a viable alternative dependent on system; tools include removal of timber products, targeted grazing, prescribed burning, and mastication/slashing.	Apply early detection rapid response (EDRR), and use ecologically based invasive plant management (EBIPM); tools include biocontrol, herbicides, timing burning prescriptions (to avoid annual brome expansion), and targeted grazing.
Where can tactics be applied?	Throughout and across jurisdictional boundaries	Throughout and across jurisdictional boundaries	Throughout and across jurisdictional boundaries

Table 8.1—Characteristics used to describe disturbance regimes.[a]

Disturbance characteristic	Description	Example
Agent	Factor causing the disturbance	Mountain pine beetle is the agent that kills trees
Source, cause	Origin of the agent	Lightning is a source for wildland fire
Frequency	How often the disturbance occurs or its return time	Years since last fire or beetle outbreak (scale dependent)
Intensity	A description of the magnitude of the disturbance agent	Mountain pine beetle population levels; wildland fire heat output
Severity	The level of impact of the disturbance on the environment	Percent mountain pine beetle tree mortality; fuel consumption in wildland fires
Size	Spatial extent of the disturbance	Mountain pine beetles can kill trees in small patches or across entire landscapes
Pattern	Patch size distribution of disturbance effects; spatial heterogeneity of disturbance effects	Fire can burn large regions but weather and fuels can influence fire intensity and therefore the patchwork of tree mortality
Seasonality	Time of year at which a disturbance occurs	Species phenology can influence wildland fires effects; spring burns can be more damaging to growing plants than fall burns on dormant plants
Duration	Length of time of that disturbances occur	Mountain pine beetle outbreaks usually last for 3-8 years; fires can burn for a day or for an entire summer
Interactions	Disturbance interact with each other, climate, vegetation and other landscape characteristics	Mountain pine beetles can create fuel complexes that facilitate or exclude wildland fire
Variability	The spatial and temporal variability of the above factors	Highly variable weather and mountain pine beetle mortality can cause highly variable burn conditions resulting in patchy burns of small to large sizes

[a]From Keane (2013).

Table 8.2— Risk assessment for fire regime changes.[a]

Fire regime component	Predicted direction of change	Main driver(s) of change	Projected duration of change	Likelihood of change
Ignitions	Unknown	Changes in lightning frequency and anthropogenic ignitions	Unknown	Unknown
Area burned	Increase	Increased fire season length, decreased fuel moistures, increased extreme fire conditions	Until a sufficient proportion of the landscape has been exposed to fire, thus decreasing fuel loads and increasing structural and species heterogeneity	High
Fire frequency	Increase	Increased ignitions, increased fuel loads, decreased fuel moistures, increased fire season length	In forested systems until a sufficient proportion of the landscape has been exposed to fire, reducing fuel loads and continuity; in grass- and shrubland systems, until global climate stabilizes	Moderate
Average fire size	Increase	Increased fire season length, decreased fuel moistures, increased extreme fire conditions	Until a sufficient proportion of the landscape has been exposed to fire, thus increasing the likelihood that previous fires will restrict growth of current year fires	High
Fire season length	Increase	Increased temperatures, decreased precipitation, decreased winter snowpack, decreased runoff	Until the global climate system stabilizes; predicted to increase as climate changes become more severe	High
Fire severity	Increase	Decreased fuel moistures, increased extreme fire conditions	In dry forest types, until fires decrease surface fuel loads; in mesic forests, if increased fire frequency decreases fuel loads	Moderate

[a] Developed using expert opinion and information from literature as summarized in this chapter.

Table 8.3—Bark beetle species that cause economic impacts in the Northern Rockies.

Bark beetle species		
Common name	**Scientific name**	**Host tree species**
Western pine beetle	*Dendroctonus brevicomis*	Ponderosa pine
Mountain pine beetle	*D. ponderosae*	Limber pine, lodgepole pine, ponderosa pine, western white pine, whitebark pine
Douglas-fir beetle	*D. pseudotsugae*	Douglas-fir
Spruce beetle	*D. rufipennis*	Engelmann spruce
Pine engraver beetle	*Ips* spp.	Lodgepole pine, ponderosa pine, western white pine
Fir engraver	*Scolytus ventralis*	Grand fir

Table 8.4—Risk assessment for mountain pine beetle outbreaks.[a]

Elevation	Direction of change	Main driver(s) of change	Projected duration of change	Likelihood of change
<3,300 ft	Increase if host trees available	Temperature–caused shift to bivoltinism[i]	Increasing risk through 2100	High
3,300-6600 ft	Decrease	Temperature-caused disruption of seasonality	Decreasing risk through 2100	High
6,600-10,000 ft	Increase initially, then decrease	Initially temperature-caused shift from semivoltine[ii] to unvioltine[iii], then disruption of seasonality	Decreasing risk through 2100	High
>10,000 ft	Increase	Temperature-caused shift from semivoltine to univoltine	Increasing risk through 2100	High

[a] Developed using model simulations and expert opinion and information from literature as summarized in this chapter.
[i] Two generations in one year.
[ii] One generation in two years.
[iii] One generation in one year.

Table 8.5—Pine and mountain pine beetle (MPB) metrics by elevation category. Pine forests <6600 ft have relatively low current hazard for MPB and low univoltine growth potential, although bivoltine potential is moderate. Pine forests >6600 ft have relatively high current stand hazard conditions for MPB and relatively high univoltine growth potential, although bivoltine potential is zero.

	<3,300 ft	3,300-6,600 ft	6,600-10,000 ft	>10,000 ft
Current stand density pine (trees per acre [standard deviation])[a]	46.4 (58.7)	142 (206)	471 (434)	223 (223)
Proportion of area (percent)[b] rated as:				
Low hazard	97	69	30	18
Moderate hazard	2	13	14	13
High hazard	1	18	56	68
MPB potential for population success (2015-2025), based on simulation with CanEMS2 GCM, emission scenario RCP-45				
Univoltine population growth rate (R)	0.00	0.44	1.62	0.65
Bivoltine (percent of points within elevation category projected to have a thermal regime supporting bivoltinism for >50 percent of years between 2015 and 2025)	24	5	0	0
MPB potential for population success (2015-2025), based on simulation with CanEMS2 GCM, emission scenario RCP-85				
Univoltine population growth rate (R)	0.04	0.86	2.0	1.05
Bivoltine (as above)	35	7	0	0

[a] From Blackard et al. (2009).

[b] Current MPB hazard based on host stand conditions (from Krist et al. 2014).

Table 8.6—Risk assessment for white pine blister rust.[a]

	Direction of change	Main driver(s) of change	Predicted duration of change	Likelihood of change
Infection frequency and severity	Little to moderate Increase	Possibility of increased wave years in high elevation ecosystems	Until a sufficient proportion of the landscape has populations of rust-resistant pine trees, there will always be high infections regardless of climate	Low

[a] Developed using expert opinion and information from literature as summarized in this chapter.

Table 8.7—Risk assessment for forest diseases.[a]

Pathogen component	Direction of change	Main driver(s) of change	Projected duration of change	Likelihood of change
Needle disease	Significant increase if appropriate precipitation timing occurs	Increased precipitation in spring and early summer	May occur sporadically in association with weather events	High
Root disease	Little change	Host stress	While hosts are maladapted	Moderate
Dwarf mistletoe	Could decrease mistletoe populations	Temperature could influence flowering and seed production/dispersal	Unknown	Low
Abiotic disease	Significant increase	Temperature and decreased precipitation	Unknown	High

[a] Developed using expert opinion and information from literature as summarized in this chapter.

Table 8.8—Prominent nonnative species in the Northern Rockies and their primary habitats.

Species	Habitat
Cheatgrass (*Bromus tectorum*)	Xeric shrublands and grasslands
Spotted knapweed (*Centaurea maculosa*)	Xeric shrublands and grasslands, dry forest openings
Rush skeletonweed (*Chondrilla juncea*)	Xeric shrublands and grasslands
Canada thistle (*Cirsium arvense*)	Wetland/riparian areas, disturbed sites in moist grasslands
Houndstongue (*Cynoglossum officinale*)	Highly disturbed mesic and xeric grasslands, roadsides
Leafy spurge (*Euphorbia esula*)	Riparian areas, mesic and xeric grasslands
Orange hawkweed (*Hieracium aurantiacum*)	Forest openings, moist meadows, roadsides
Yellow hawkweed complex (*Hieracium* spp.)	Forest openings, roadsides
St. Johnswort (*Hypericum perforatum*)	Xeric grasslands and shrublands
Dalmatian toadflax (*Linaria dalmatica*)	Xeric grasslands and shrublands
Yellow toadflax (*Linaria vulgaris*)	Mesic to xeric grasslands and shrublands, burned areas
Sulfur cinquefoil (*Potentilla recta*)	Xeric grasslands and shrublands
Common tansy (*Tanacetum vulgare*)	Riparian areas

Table 8.9—Risk assessment for nonnative plant species.[a]

Invasive species component	Direction of change	Main driver(s) of change	Likelihood of change
Area infested	Variable by species, from low to high	Altered temperature and precipitation patterns; increased atmospheric CO_2; altered fire regimes	High
Species response to habitat disturbance	High	Increased fire frequency and severity, which can increase the amount of habitat vulnerable to nonnative invasion	High
Altered fire regimes	High	Increased fire frequency in areas with fire-tolerant and flammable invasive species (e.g., cheatgrass-fire cycle)	High

[a] Developed using expert opinion and information from literature as summarized in this chapter.

Table 9.1—Species included in the Northern Rockies Adaptation Partnership vulnerability assessment, including species discussed at subregional workshops.

Habitat / Species	Western Rockies	Central Rockies	Eastern Rockies	Greater Yellowstone Area	Grassland
Dry forest					
Flammulated owl		X		X	
Pygmy nuthatch		X	X	X	
Riparian/wetland					
American beaver		X	X	X	
Moose				X	
Northern bog lemming				X	
Townsend's big-eared bat		X	X	X	
Harlequin duck		X		X	
Columbia spotted frog		X		X	
Western toad		X		X	
Quaking aspen					
Avian cavity nesters		X	X	X	
Ruffed grouse				X	
Sagebrush grasslands					
Pronghorn				X	
Pygmy rabbit			X		
Brewer's sparrow				X	
Greater sage-grouse				X	X
Mountain grasslands					
Mountain quail	X				
Mesic old-growth forest					
Fisher		X		X	
Snow-dependent species					
American pika				X	
Canada lynx		X		X	
Wolverine		X		X	

Table 9.2—Adaptation options that address climate change effects on riparian habitat and associated wildlife species in the Northern Rockies.

Sensitivity to climatic variability and change: Decreased streamflow reduces riparian vegetation, affecting food supply and habitat structure for multiple species.

Adaption Strategy / Approach: Improve riparian habitat by maintaining healthy beaver populations on the landscape.

Tactic	**Specific Tactic – A** Inventory current and potential habitat (include multiple factors)	**Specific Tactic – B** Restore riparian habitat e.g. plant willows, manage grazers, raise water level	**Specific Tactic – C** Translocation, manage trapping
Where can tactics be applied? (geographic)	Range-wide	Suitable habitat range-wide	Suitable habitats range-wide

Table 9.3—Adaptation options that address climate change effects on aspen habitat and associated wildlife species in the Northern Rockies.

Sensitivity to climatic variability and change: A warmer climate will lower water tables, leading to loss of quaking aspen.

Adaption Strategy / Approach: Promote aspen resilience.

Tactic	**Specific Tactic – A** Promote disturbance (fire, cutting) in older aspen stands	**Specific Tactic – B** Protect from grazing (fencing, manage grazing)	**Specific Tactic – C** Reduce conifer competition (fire, cutting) in any age aspen stand
Where can tactics be applied? (geographic)	Range-wide	Range-wide	Range-wide

Table 9.4—Adaptation options that address climate change effects on dry forest (ponderosa pine) habitat and associated wildlife species in the Northern Rockies.

Sensitivity to climatic variability and change: A warmer climate will potentially convert drier ponderosa pine to grassland; in addition, many ponderosa stands have converted to Douglas-fir because of fire exclusion and are susceptible to projected increases in fire frequency.

Adaption Strategy / Approach: Promote ponderosa pine resilience

Tactic	**Specific Tactic – A** Reduce competition from Douglas-fir and grand fir (thin, burn) in current mature ponderosa pine stands	**Specific Tactic – B** Frequent understory burning	**Specific Tactic – C** Retain current mature and older ponderosa pine stands	**Specific Tactic – D** Plant ponderosa pine where it has been lost
Where can tactics be applied? (geographic)	Range-wide	Range-wide	Range-wide	Range-wide

Table 9.5—Adaptation options that address climate change effects on old-growth, mesic forest habitat and associated wildlife species in the Northern Rockies.

Sensitivity to climatic variability and change: A warmer climate will create drier conditions and cause more wildfire, potentially eliminating old forest structure and mesic habitat.

Adaption Strategy / Approach: Maintain current habitat, restore historical habitat, and promote potential future inland maritime forest habitat.

Tactic	**Specific Tactic – A** Conserve current old-growth cedar and larch, but reduce density to increase resilience to drought	**Specific Tactic – B** Restore white pine with a cedar understory to create future habitat	**Specific Tactic – C** Maintain or create necessary structure in modeled future fisher habitat	**Specific Tactic – D** Conserve current old-growth cedar and larch, but reduce density to increase resilience to drought
Where can tactics be applied? (geographic)	Northern Idaho, Kootenai, Bitterroot divide Where risk of loss is greatest (edge of range) Need redundancy across landscape to buffer against future fire or drought mortality	Northern Idaho, Kootenai, Bitterroot divide. Need redundancy across landscape to buffer against future fire or drought mortality	Mission side of Swan Range. Need redundancy across landscape to buffer against future fire or drought mortality	Northern Idaho, Kootenai, Bitterroot divide Where risk of loss is greatest (edge of range) Need redundancy across landscape to buffer against future fire or drought mortality

Table 9.6—Adaptation options that address climate change effects on mountain sagebrush-grassland habitat and associated wildlife species in the Northern Rockies.

Sensitivity to climatic variability and change: A warmer climate will dry soils, reducing the forb component of mountain sagebrush-grassland habitat.

Adaption Strategy / Approach: Maintain current and restore historical habitat.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Manage fire to maintain desired habitat	Control invasive vegetation	Restore formerly cultivated land
Where can tactics be applied? (geographic)	Range-wide	Range-wide	Range-wide

Table 9.7—Adaptation options that address climate change effects on sagebrush habitat and associated wildlife species in the Northern Rockies.

Sensitivity to climatic variability and change: A warmer climate and increased wildfire will reduce the distribution and abundance of sagebrush habitat.

Adaption Strategy / Approach: Maintain adequate sagebrush habitat.

Tactic	**Specific Tactic – A** Manage fire to maintain desired habitat	**Specific Tactic – B** Control invasive vegetation	**Specific Tactic – C** Restore formerly cultivated land	**Specific Tactic – D** Prevent fragmentation of sagebrush habitat (roads, energy development lines)
Where can tactics be applied? (geographic)	Range-wide	Range-wide	Range-wide	Range-wide

Table 9.8—Adaptation options that address knowledge gaps in climate change effects on wildlife populations in the Northern Rockies.

Sensitivity to climatic variability and change: Species requirements and/or climate sensitivities are largely unknown for many species.				
Adaption Strategy / Approach: Increase knowledge of species needs and climate sensitivities				
Tactic	**Specific Tactic – A** Analyze female lynx home ranges to determine necessary mix of habitat patches: distribution and size	**Specific Tactic – B** Update and expand knowledge of existing pygmy distribution	**Specific Tactic – C** Understand climate influences on pygmy rabbits	**Specific Tactic – D** Understand succession after fire in sagebrush
Where can tactics be applied? (geographic)	Range-wide	Range-wide	Range-wide	Range-wide
Sensitivity to climatic variability and change: Loss of connectivity can be caused by changes in water supply and snowpack dynamics, habitat loss, habitat shifts, vegetation phenology shifts, and human population expansion and redistribution.				
Adaption Strategy / Approach: Maintain multiple levels of connectivity (daily, seasonal, dispersal range shift).				
Tactic	**Specific Tactic – A** Monitor connectivity using genetics, tracking, remote sensing tools (e.g., multi-carnivore genetic monitoring across the Northern Continental Divide Ecosystem with multiple partners	**Specific Tactic – B** Compile table of connectivity vulnerability by species (daily through range shift)	**Specific Tactic – C** Identify dispersal habitat requirements for selected species (e.g., wolverine)	**Specific Tactic – D** Identify and remove or mitigate barriers
Sensitivity to climatic variability and change: Disease transmission may increase with warmer temperatures.				
Adaption Strategy / Approach: Increase knowledge of disease-climate relationships.				
Tactic	**Specific Tactic – A** Monitor environmental conditions at bat hibernacula to understand environmental conditions that promote white-nose syndrome	**Specific Tactic – B** Monitor moose and bighorn sheep disease trends to determine if there are climatic drivers	**Specific Tactic – C** Work with the state wildlife departments to monitor West Nile virus	
Where can tactics be applied? (geographic)	Region-wide	Region-wide	Region-wide	

Table 9.9—Adaptation options that address climate change effects on connectivity for wildlife populations in the Northern Rockies.

Sensitivity to climatic variability and change: Connectivity depends multiple factors, including water supply, habitat shifts, vegetation phenology, snow pack dynamics, and human population expansion and redistribution.

Adaption Strategy / Approach: Maintain connectivity

Tactic	**Specific Tactic – A** Monitor connectivity through genetics, tracking, and remote sensing	**Specific Tactic – B** Compile table of known connectivity vulnerabilities by species	**Specific Tactic – C** Identify and remove barriers
Where can tactics be applied? (geographic)	Region-wide	Region-wide	Region-wide

Table 10.1–Participation in different recreational activities in national forests in the Northern Region and Greater Yellowstone Area.

Activity	Relationship to climate and environmental conditions	National Forest visitors who participated in this activity as their main activity[a]	
		Percent of total NF visits	*Number*
Warm-weather activities	Participation typically occurs during warm weather; dependent on the availability of snow- and ice-free sites, dry weather with moderate daytime temperatures, and the availability of sites where air quality is not impaired by smoke from wildfires.	***35.9***	***4,770,616***
Hiking/walking		16.9	2,248,171
Viewing natural features		8.6	1,136,245
Developed camping		2.8	375,174
Bicycling		2.2	286,707
Other non-motorized		2.0	265,476
Horseback riding		1.3	168,175
Picnicking		1.2	164,638
Primitive camping		0.6	74,876
Backpacking		0.4	51,154
Winter activities	Participation depends on the timing and amount of precipitation as snow and cold temperatures to support consistent snow coverage. Inherently sensitive to climate variability and inter-annual weather patterns.	**25.0**	**3,318,426**
Downhill skiing		12.8	1,695,621
Snowmobiling		6.4	843,778
Cross-country skiing		5.9	779,027
Wildlife activities	Wildlife is a significant input for these activities. Temperature and precipitation are related to habitat suitability through effects on vegetation, productivity of food sources, species interactions, and water quantity and temperature (for aquatic species). Disturbances (wildland fire, invasive species, insect and disease outbreaks) may affect amount, distribution, and spatial heterogeneity of suitable habitat.	**18.5**	**2,452,053**
Hunting		11.3	1,503,520
Fishing		5.3	708,589
Viewing wildlife		1.8	240,944
Gathering forest products	Depends on availability and abundance of target species (e.g., berries, mushrooms), which are related to patterns of temperature, precipitation, and snowpack. Disturbances may alter availability and productivity of target species in current locations and affect opportunities for species dispersal.	2.4	313,475
Water-based activities, not including fishing	Participation requires sufficient water flows (in streams and rivers) or levels (in lakes and reservoirs). Typically considered a warm-weather activity, and depends on moderate temperatures and snow- and ice-free sites. Some participants may seek water-based activities as a heat refuge during periods of extreme heat.	0.7	96,643

[a] Source: USDA FS (n.d.). Total estimated National Forest visits is 13,273,685. Percentage calculations are based on the percent of total visits accounted for by each activity and category

Table 10.2—Total annual expenditures by non-local and local visitors to Northern Rockies and Greater Yellowstone Area national forests, by spending category.

Spending category	Non-local spending[a,b]		Local spending	
	Total annual expenditures	Spending for each category	Total annual expenditures	Spending for each category
	Thousands of $ (2014)	*%*	*Thousands of $ (2014)*	*%*
Lodging	185,355	31	14,743	6
Restaurant	109,743	18	29,618	13
Groceries	74,003	12	44,886	19
Gasoline, oil	104,319	17	78,880	34
Other transportation	3,013	1	1,059	0
Activities	36,376	6	14,195	6
Admissions, fees	39,482	7	19,103	8
Souvenirs	48,839	8	28,075	12
Total	601,128		230,562	

[a] Non-local refers to trips that required traveling more than 50 miles.
[b] Source: USDA FS (n.d.).

Table 10.3—Summary of climate change assessment ratings for recreation by activity category.

Activity category	Magnitude of climate effect	Likelihood of climate effect	Direct effects	Indirect effects
Warm-weather activities	Moderate (+)	High	Warmer temperature (+) Higher likelihood of extreme temperatures (-)	Increased incidence, area, and severity of wildfire (+/-) Increased smoke from wildfire (-)
Snow-based winter activities	High (-)	High	Warmer temperature (-) Reduced precipitation as snow (-)	
Wildlife activities	Terrestrial wildlife: low (+) Fishing: moderate (-)	Moderate	Warmer temperature (+) Higher incidence of low streamflow (fishing -) Reduced snowpack (hunting -)	Increased incidence, area, and severity of wildfire (terrestrial wildlife +/-) Reduced cold-water habitat, incursion of warm-water tolerant species (fishing -)
Gathering forest products	Low (+/-)	Moderate	Warmer temperature (+)	More frequent wildfires (+/-) Higher severity wildfires (-)
Water-based activities, not including fishing	Moderate (+)	Moderate	Warming temperatures (+) Higher likelihood of extreme temperatures (-)	Lower streamflows and reservoir levels (-)

Note: Positive (+) and negative (-) signs indicate expected direction of effect on overall benefits derived from recreation activity

Table 10.4—Adaptation options that address climate change effects on recreation in the Northern Rockies.

Sensitivity to climatic variability and change: Ice- and snow-based recreation is highly sensitive to variations in temperature and the amount and timing of precipitation as snow.			
Adaption Strategy / Approach: Transition to address shorter average winter recreation seasons and changing use patterns.			
Tactic	**Specific Tactic – A** Maintain current infrastructure and expand facilities in areas where concentrated use increases.	**Specific Tactic – B** Develop options for diversifying snow-based recreation, such as cat-skiing, helicopter skiing, additional ski lifts, additional higher elevation runs, toboggan runs, snow making, and back country yurts	**Specific Tactic – C** Conduct safety education to make the public aware of increased risk of avalanche and thin ice
Where can tactics be applied?	Snow recreation areas and major lakes	In and around existing permitted areas; within driving distance of population centers	Snow recreation areas and major lakes
Sensitivity to climatic variability and change: The warm weather recreation season will increase in length with increasing temperatures and earlier snowmelt.			
Adaption Strategy / Approach: Provide sustainable recreation opportunities in response to changing demand.			
Tactic	**Specific Tactic – A** Assess to understand changes in use patterns and identify demand shifts	**Specific Tactic – B** Adjust capacity of recreation sites (e.g., enlarge campgrounds, collect additional fees, and install infrastructure such as fences, signs and gates)	**Specific Tactic – C** Adjust timing of actions such as road and trail closures, food storage orders, and special use permits
Where can tactics be applied?	At multiple levels (national, regional, forest-level, and local)	Where demand increases on federal lands, as appropriate	Federal lands

Table 10.4(cont.)—Adaptation options that address climate change effects on recreation in the Northern Rockies.

Sensitivity to climatic variability and change:
The seasonality of whitewater rafting will shift with increasing temperatures and shifts in the timing of peak streamflows.

Adaption Strategy / Approach:
Increase management flexibility and facilitate transitions to meet user demand and expectation.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Vary permit season to adapt to changes in peakflow and duration	Educate the public about changing river conditions	n/a
Where can tactics be applied?	Permitted rivers	Permitted rivers	n/a

Sensitivity to climatic variability and change:
Increases in flooding, fire, and other natural disturbances will cause damage to infrastructure.

Adaption Strategy / Approach:
Manage recreation sites to mitigate risks to public safety and infrastructure and to continue to provide recreation opportunities.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Assess to determine what recreation sites and infrastructure are at risk from increased flooding and other natural hazards	Prioritize post-disturbance treatments, including relocation, arming, and other mitigation measures	Invest strategically in developed recreation facilities, prioritizing those that will be viable in the future and accommodate changing use patterns
Where can tactics be applied?	Federal lands	Federal lands	Federal lands

Table 10.B1—National Forest visits by NRAP subregion and activity category.

Activity category	Subregion[a]				
	Western Rockies	Central Rockies	Eastern Rockies	Grassland	Greater Yellowstone Area
	Percent of annual visitors reporting main activity				
Warm-weather activities[b,c]	36.7	36.9	33.3	60.8	36.2
Snow-based winter activities	7.4	26.0	27.2	1.6	31.3
Wildlife activities	23.3	19.6	18.8	30.5	15.1
Forest product gathering	6.5	1.9	2.1	0.0	1.1
Water-based activities, not including fishing	0.5	0.8	1.6	0.2	0.1

[a] To estimate activity participation, subregions are defined by groups of national forests: Western Rockies (Idaho Panhandle, Kootenai, Nez Perce-Clearwater), Central Rockies (Bitterroot, Flathead, Lolo), Eastern Rockies (Beaverhead-Deerlodge, Custer, Gallatin, Helena, Lewis and Clark), Grassland (Dakota Prairie Grasslands), Greater Yellowstone Area (Bridger-Teton, Caribou-Targhee, Shoshone). Geospatial definitions of the subregions include parts of several forests divided between two subregions—for example, parts of Custer, Beaverhead-Deerlodge, and Gallatin National Forests are divided between the Eastern Rockies and Greater Yellowstone Area subregions, but tabulated as part of the Eastern Rockies subregion; these forests are also summarized in table 10.B2 separately from the other Greater Yellowstone Area forests.

[b] Source: USDA FS (n.d.).

[c] Percentages do not sum to 100 because not all visitors report activities, and not all activities are included in climate-sensitive categories (e.g., nature center activities, visiting historic sites).

Table 10.B2—Recreation visits to Greater Yellowstone Area units and Glacier National Park.

Unit	Total annual visits	Most frequent activity	Year
Yellowstone National Park[a,b]	3,390,000	Viewing wildlife (93% of visitors)	2010-2014 annual average
Grand Teton National Park[a,b]	2,650,000	Viewing scenery (88% of visitors)	2010-2014 annual average
Red Rock Lakes National Wildlife Reserve[c]	12,000	Viewing wildlife (45% of visitors)	2014
National Elk Refuge[a,d]	900,000	Viewing wildlife (53% of visitors)	2008, 2004
Gallatin National Forest[e]	2,010,000	Hiking/walking (29% of visitors)	2009
Beaverhead-Deerlodge National Forest[e]	583,000	Hunting (32% of visitors)	2010
Caribou-Targhee National Forest[e]	1,850,000	Hiking/walking (18% of visitors)	2010
Shoshone National Forest[e]	646,000	Viewing natural features (25% of visitors)	2009
Bridger-Teton National Forest[e]	2,180,000	Downhill skiing (31% of visitors)	2008
Custer National Forest[e]	314,000	Downhill skiing (26% of visitors)	2008
Glacier National Park[b,f]	2,149,000	Sightseeing (97% of visitors)	2010-2014 annual average 1990 (visitor activities)

[a] Source: NPS (2006).
[b] Source: NPS (2014).
[c] Source: USDI (2014).
[d] Source: Sexton et al. (2012).
[e] Source: USDA FS (n.d.); most frequent activity is the reported main activity (visitors may engage in other secondary or tertiary activities).
[f] Source: Littlejohn (1991).
Note: Visitor data are not available for John D. Rockefeller Parkway.

Table 11.1—Mean Social Vulnerability Index scores across industries. Counties were ranked by industry shares for each industry and separated into quartiles. Scores are first (on the left) compared scores for the lower and upper quartiles, then (on the right) the lower and upper half of counties, sorted by shares of employment in that industry. Significance levels are shown by the test statistics for comparison of the means and the associated p-values.

	Lower quartile	Upper quartile	Test statistic	p-value	Lower half	Upper half	Test statistic	p-value
Timber	2.93	0.94	4.32	0.00	2.90	0.76	5.44	0.00
Grazing	-0.20	3.69	-8.03	0.00	0.61	3.04	-6.37	0.00
Recreation	2.56	0.63	3.56	0.00	2.39	1.28	2.67	0.01
Oil & gas	2.45	1.68	1.38	0.17	1.94	1.74	0.47	0.64

	No	Yes	Test Statistic	p-value
Counties in National Forest Impact Zones	1.75	2.13	0.923	0.34

Table 11.10—Unsuitable land area in the Christie Creek and Sherwin Creek allotments in the Nez Perce-Clearwater National Forest, including forage production reduced from conversion of desirable vegetation to "weedy" species.[a]

Allotment	Pasture	Unsuitable land area	Forage reduced
		Acres	*Animal unit months*
Christie Creek	Rhett	83	11
	Christie Creek	106	11
	Deer Creek	151	20
Sherwin Creek	Lower Center Ridge	238	32
Total		578	74

[a] Source: Nez Perce–Clearwater National Forest assessment (June 2014 review draft).

Table 11.11—Changes in non-federal rangeland area, 1982-2007.[a]

	Net change						
	Rangeland	Pasture	CRP land	Crop land	Historic rangeland	Change from historic rangeland	Rangeland threatened by residential development
		Acres			*Thousands of acres*	*Percent*	*Thousands of acres*
Montana	-897.8	671.6	-3,084	-28.8	67,604	-24	28
South Dakota	-784.8	-556.2	-245	1.6	45,924	-52	46
North Dakota	-507.4	-5.8	-3,034	85.1	43,214	-71	29
Idaho	-177.6	103.4	-1,154	94.6	29,763	-20	77
Wyoming	221.0	-178.0	-458	10.0	49,306	-8	13

[a] Source: Reeves and Mitchell (2012).

Table 11.2—Number of counties significantly below and above regional means.

	Unemployment rate (5.4%)		Percent employed in service industry (17.8%)		Median household income ($45,235)		Median age (43.4)		Percent foreign born (2.7%)		Percent population minority (15.9%)		Percent population in rural areas (75.3%)	
	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above	Below	Above
Grazing	54	18	44	21	49	24	16	57	57	12	62	15	13	66
Timber	27	40	19	43	43	34	34	39	25	32	57	23	45	29
Recreation	37	36	18	44	41	32	37	36	31	26	59	21	47	31
Oil and gas	54	21	31	34	33	43	32	39	38	25	65	12	37	41

Table 11.3—Total water use in Montana[a].

Planning basin	Hydropower (non-consumptive)	Irrigation	Reservoir evaporation	Municipal, industrial, livestock	In-stream flow (non-consumptive)
			Percent		
Statewide	86.0	12.4	1.2	0.5	0
Clark Fork / Kootenai River	94.4	4.7	0.5	0.4	0
Upper Missouri	88.0	11.2	0.5	0.3	0
Lower Missouri	39.4	19.5	6.0	0.3	35.0
Yellowstone River	24.5	23.0	0.4	1.4	50.7

[a] Data from Montana DNRC (2014).

Table 11.4—Consumptive water use in Montana.[a]

Planning basin	Irrigation	Reservoir evaporation	Domestic & municipal	Livestock	Industrial	Thermo-electric
			Percent			
Statewide	67.3	28.0	2.4	1.2	0.3	0.8
Clark Fork / Kootenai River	67.0	27.0	3.9	0.5	1.2	0
Upper Missouri	82.2	13.7	3.0	0.9	<0.1	0
Lower Missouri	42.0	56.3	0.4	1.4	<0.1	0
Yellowstone River	83.3	7.2	2.8	2.1	0.3	4.2

[a] Data from Montana DNRC (2014).

Table 11.5—Threatened and impaired waterways in Montana.[a]

	Rivers and streams	Lakes, reservoirs, and ponds
Use	*Percent*	
Agriculture	14.3	22.1
Aquatic life	83.6	76.7
Drinking water	29.3	65.5
Primary contact recreation	38.7	13.5
Causes of impairment		
Rivers and streams	*Miles*	
Alteration in streamside or littoral vegetation	8,352	
Sedimentation, siltation	7,456	
Phosphorus	5,091	
Low flow alterations	4,936	
Nitrogen total	4,846	
Lakes, reservoirs, and ponds	*Acres*	
Mercury	311,192	
Lead	246,950	
Phosphorous, total	73,324	
Sedimentation, siltation	69,411	
Nitrogen, total	68,354	
Sources of impairment		
Rivers and streams	*Miles*	
Agriculture	6,000	
Grazing in riparian or shoreline zones	5,862	
Irrigated crop production	4,570	
Natural sources	4,518	
Source unknown	4,223	
Lakes, reservoirs, and ponds	*Acres*	
Impacts from abandoned mine lands	279,490	
Atmospheric deposition – toxics	250,570	
Historic bottom sediments (not sediment)	237,654	
Municipal point source discharges	97,542	
Source unknown	86,868	

[a] Data from U.S. Environmental Protection Agency Watershed Assessment, Tracking and Environmental Results System database (http://water.epa.gov/scitech/datait/tools/waters/index.cfm).

Table 11.6—Threatened and impaired waterways in Idaho.[a]

	Rivers and streams	Lakes, reservoirs, and ponds
Use	*Percent*	
Cold water aquatic life	52.5	91.3
Primary contact recreation	18.3	2.6
Salmonid spawning	45.9	86.0
Warm water aquatic life	68.0	99.4
Domestic water supply	3.2	0
Seasonal cold water aquatic life	0	100
Secondary contact recreation	15.3	97.0
Causes of impairment		
Rivers and streams	*Miles*	
Temperature, water	18,494	
Sedimentation, siltation	14,988	
Phosphorus	6,017	
Escherichia coli	4,480	
Combined benthic, fish bioassessments	4,306	
Other flow regime alterations	3,877	
Lakes, reservoirs, and ponds	*Acres*	
Phosphorus	146,576	
Mercury	121,329	
Other flow regime alterations	84,682	
Sediment, siltation	80,169	
Dissolved oxygen	77,473	
Sources of impairment		
Streams and rivers	*Miles*	
Grazing in riparian or shoreline zones	2,230	
Rangeland grazing	1,782	
Livestock (grazing, feeding)	1,152	
Flow alterations from water diversions	643	
Loss of riparian habitat	608	
Managed pasture grazing	561	
Lakes, reservoirs, and ponds	*Acres*	
Highways, roads, bridges, infrastructure	340	
Post-development erosion and sedimentation	340	
Natural sources	340	
Agriculture	340	
Loss of riparian habitat	340	

[a] Data from U.S. Environmental Protection Agency Watershed Assessment, Tracking and Environmental Results System database (http://water.epa.gov/scitech/datait/tools/waters/index.cfm).

Table 11.7—Threatened and impaired waterways in North Dakota.[a]

	Rivers and streams	Lakes, reservoirs, and ponds
Use	*Percent*	
Agriculture	0	0
Fish and other aquatic biota	16.6	0.1
Fish consumption	80.8	81.3
Industrial	0	0
Municipal and domestic	0	0
Recreation	27.2	0.9
Causes of impairment		
Rivers and streams	*Miles*	
Fecal coliform bacteria	3,820	
Physical substrate habitat alterations	2,423	
Escherichia coli	1,882	
Sedimentation, siltation	1,783	
Combined benthic, fish bioassessments	604	
Lakes, reservoirs, and ponds	*Acres*	
Fecal coliform bacteria	3,820	
Physical substrate habitat alterations	2,423	
Escherichia coli	1,882	
Sedimentation, siltation	1,783	
Combined benthic, fish bioassessments	604	
Sources of impairment		
Rivers and streams	*Miles*	
Grazing in Riparian or shoreline zones	5,797	
Animal feeding operations	3,909	
Crop production (crop land or dry land)	2,549	
Loss of riparian habitat	2,415	
Source unknown	1,148	
Lakes, reservoirs, and ponds	*Acres*	
Grazing in Riparian or shoreline zones	5,797	
Animal feeding operations	3,909	
Crop production (crop land or dry land)	2,549	
Loss of riparian habitat	2,415	
Source unknown	1,148	

[a] Data from U.S. Environmental Protection Agency Watershed Assessment, Tracking and Environmental Results System database (http://water.epa.gov/scitech/datait/tools/waters/index.cfm)

Table 11.8—Sold timber volumes from national forests in the U.S. Forest Service Northern Region and Greater Yellowstone Area subregion over the last two decades.[a]

	1980			2013			Difference		
National Forest	Number of sales	Sold volume	Inflation adjusted sold value	Sales	Sold volume	Inflation adjusted sold value	Sales	Sold volume	Inflation adjusted sold value
		ft^3	*Dollars*		*ft^3*	*Dollars*		*Percent*	
Beaverhead-Deerlodge	630	47,137	1,971,012	845	8,176	59,067	34	-83	-97
Bitterroot	268	42,751	3,883,685	266	8,123	459,684	-1	-81	-88
Bridger-Teton	425	20,141	885,087	627	9,641	150,834	48	-52	-83
Caribou-Targhee	7,347	98,301	7,726,627	743	7,234	93,922	-90	-93	-99
Custer	127	1,653	81,794	292	1,573	18,088	130	-5	-78
Flathead	289	194,340	22,504,836	334	14,797	963,163	16	-92	-96
Gallatin	310	23,575	628,518	551	4,480	44,820	78	-81	-93
Helena	113	21,916	1,451,979	393	3,431	34,000	248	-84	-98
Idaho Panhandle	669	317,157	64,207,103	866	40,180	3,562,340	29	-87	-94
Kootenai	616	175,803	36,705,744	820	35,589	1,820,020	33	-80	-95
Lewis and Clark	277	12,423	134,615	387	2,152	21,160	40	-83	-84
Lolo	367	40,744	2,281,829	597	6,402	298,537	63	-84	-87
Nez Perce-Clearwater	414	255,741	18,881,743	699	44,402	6,567,655	69	-83	-65
Shoshone	307	11,883	198,089	415	7,667	225,075	35	-35	14

[a] Source: U.S. Forest Service, accessed via Headwaters Economics (http://headwaterseconomics.org/interactive/national-forests-timber-cut-sold)

Table 11.9—Employment in the timber industry, by county and region, 2012.[a]

County	Total private employment	Timber employment	Employment in timber (%)	Change in timber employment, 1998-2012 (%)
All subregions	365,255	9,531	2.6	-44
Western Rockies subregion	112,143	6,511	5.8	
Asotin County, WA	4,605	9	0.2	-95
Benewah County, ID	2,130	677	31.8	-25
Bonner County, ID	10,972	401	3.7	-70
Boundary County, ID	2,239	410	18.3	-3
Clearwater County, ID	1,896	358	18.9	-59
Idaho County, ID	3,165	386	12.2	18
Kootenai County, ID	44,080	913	2.1	-52
Latah County, ID	8,398	349	4.2	-11
Lewis County, ID	717	132	18.4	-47
Lincoln County, MT	3,771	191	5.1	-79
Nez Perce County, ID	16,061	1,693	10.5	-13
Pend Oreille County, WA	1,403	83	5.9	-67
Sanders County, MT	1,910	122	6.4	-55
Shoshone County, ID	4,183	94	2.2	-28
Stevens County, WA	6,613	693	10.5	-30
Central Rockies subregion	110,451	2,374	2.1	
Flathead County, MT	31,316	977	3.1	-45
Glacier County, MT	2,205	1	0.0	0
Lake County, MT	5,121	119	2.3	-51
Mineral County, MT	895	231	25.8	175
Missoula County, MT	47,885	574	1.2	-69
Powell County, MT	1,024	243	23.7	37
Ravalli County, MT	8,522	220	2.6	-69
Silver Bow County, MT	13,483	9	0.1	125
Eastern Rockies subregion	114,783	595	0.5	
Beaverhead County, MT	2,234	9	0.4	-40
Broadwater County, MT	790	178	22.5	78
Carbon County, MT	2,169	3	0.1	50
Cascade County, MT	29,168	25	0.1	19
Chouteau County, MT	723	4	0.6	0
Fergus County, MT	3,291	9	0.3	-89
Gallatin County, MT	37,409	103	0.3	-59
Granite County, MT	481	47	9.8	-69
Jefferson County, MT	1,679	34	2.0	89
Lewis and Clark County, MT	23,623	48	0.2	129
Madison County, MT	1,943	10	0.5	67
Meagher County, MT	268	4	1.5	-73
Park County, MT	4,394	86	2.0	-28
Powder River County, MT	329	0	0.0	-100
Rosebud County, MT	2,562	0	0.0	-100

Stillwater County, MT	2,683	35	1.3	-58
Sweet Grass County, MT	1,037	0	0.0	-100
Greater Yellowstone Area subregion	26,609	50	0.2	
Fremont County, ID	1,429	19	1.3	-75
Park County, WY	9,876	25	0.3	-36
Teton County, WY	15,304	6	0.0	100
Grassland subregion	1,269	1	0.1	
Carter County, MT	184	0	0.0	-100
Harding County, SD	402	1	0.2	0
McHenry County, ND	683	0	0.0	0

[a] Source: U.S. Department of Commerce (2014).

Table 12.1—Summary of climate change stressors and potential effects on cultural resources in the Northern Rockies (see also Rockman 2014, UNESCO 2007). Human activities can exacerbate some of the expected effects of climate change (see text).

Climate change stressor	Biophysical effects	Effects on cultural sites and landscapes
Temperature increase	• Wildfire	• Combustion, damage, destruction
	• Drought, erosion	• Exposed artifacts and cultural features
	• Vegetation changes	• Altered physical appearance, integrity
	• Spread of invasive species	• Altered physical appearance, integrity
	• Ice patch melt	• Artifact decay and theft
	• Altered freeze-thaw cycles	• Saturation, desiccation, warping, biochemical changes
Altered precipitation	• Earlier seasonal runoff, flooding	• Removal, damage, degradation
	• Debris flows, slumping	• Burial, removal, degradation
	• Down-cutting, mass wasting	• Removal, damage, degradation
	• Increased moisture and humidity	• Decay, oxidation, exfoliation, corrosion, biochemical changes
	• Extreme precipitation events	• Removal, damage, degradation, collapse, exposure

Table 13.1—Risk assessment for resources in the vulnerability assessment for the Northern Rockies. The qualitative and quantitative approach for estimating magnitude and likelihood of climate change effects varies by resource and availability of information (see individual chapters for more detail).

Resource	Habitat, ecosystem function or species	Magnitude of effects	Likelihood of effects
Water resources	Snowpack and glaciers	High to low, depending on elevation and winter temperatures	High
	Streamflow	High to low across the region, depending on local climate	High to low across the region, depending on local climate
Fisheries	Bull trout	Moderate for 2040s, high by 2080s	High for 2040s, moderate for 2080s
	Westslope cutthroat trout and Yellowstone cutthroat trout	Low for 2040s, moderate for 2080s	High for 2040s, moderate for 2080s
Vegetation – general types	Dry ponderosa pine and Douglas-fir	High	High
	Lodgepole pine and aspen mixed conifer	Moderate	High
	Mixed mesic white pine, western redcedar, western hemlock grand fir	Moderate	Low
	Western larch mixed conifer	High	Very high
	Whitebark pine/spruce-fir	High	High
	Big sagebrush	Highly variable	Moderate
	Mountain big sagebrush and basin big sagebrush	Mountain big sagebrush – moderate; basin big sagebrush – high	High
	Threetip sagebrush and silver sagebrush	Moderate	High
	Western grasslands	High	High
Vegetation – tree species	Alpine larch	High	High
	Cottonwood	Moderate	Moderate
	Douglas-fir	High	High
	Engelmann spruce	Moderate	Moderate
	Grand fir	Moderate	Moderate
	Green ash	Moderate	High
	Limber pine	Low	Low
	Lodgepole pine	Moderate	High
	Mountain hemlock	High	High
	Ponderosa pine - var. *ponderosa*	Moderate	Moderate
	Ponderosa pine – var. *scopulorum*	Moderate	Moderate
	Quaking aspen	Moderate	High
	Subalpine fir	High	High
	Western hemlock	Moderate	Moderate
	Western larch	High	Very high
	Western redcedar	Moderate	Moderate
	Western white pine	Moderate	Moderate
	Whitebark pine	Moderate	Moderate
Vegetation – resource concerns	Carbon sequestration	High	Moderate
	Landscape heterogeneity	Moderate	High
	Timber production	Moderate to high in northern Idaho	High in north Idaho
	Bark beetle disturbances	Moderate	Varies
	Invasive plant species	High	High
	Wildfire regimes	Low-moderate	Moderate-high

Table 13.1(cont.)—Risk assessment for resources in the vulnerability assessment for the Northern Rockies.

Wildlife	American beaver	Moderate by 2100	Moderate by 2100
	American pika	Low in 2030, 2050; moderate by 2100	Varies
	Canada lynx	Moderate by 2030, high by 2050, extreme by 2100	High
	Fisher	Low by 2030, moderate by 2050, probably high by 2100	High
	Moose	Moderate by 2100	Moderate by 2100
	Northern bog lemming	Moderate by 2050; high by 2100	High by 2050
	Pronghorn	Moderate by 2100	Moderate by 2100
	Pygmy rabbit	Moderate by 2050; could be high by 2100	High by 2050
	Townsend's big-eared bat	Moderate by 2100	Moderate by 2100
	Ungulates (elk, mule deer, white-tailed deer)	Uncertain, but probably low to moderate by 2100	Low to moderate in all time periods
	Wolverine	Low by 2030, moderate by 2050, high to very high by 2100	High in all time periods
	Brewer's sparrow	Low to moderate by 2050; moderate to high by 2100	Moderate, depending on sagebrush habitat
	Flammulated owl	Largely unknown across all time periods	Largely unknown across all time periods
	Greater sage-grouse	Largely unknown across all time periods	Largely unknown across all time periods
	Harlequin duck	Moderate across all time periods	Moderate across all time periods
	Mountain quail	Low to moderate across all time periods	Low to moderate across all time periods
	Pygmy nuthatch	Largely unknown across all time periods	Largely unknown across all time periods
	Ruffed grouse	Low to moderate across all time periods	Low to moderate across all time periods
	Columbia spotted frog	Moderate across all time periods, depending on fungal infections	Moderate across all time periods
	Western toad	Moderate across all time periods	Moderate across all time periods
Recreation	Warm-weather activities	Moderate	High
	Snow-based recreation activities	High	High
	Wildlife-based activities	Hunting, wildlife viewing–low; fishing–moderate to high	Hunting, wildlife viewing–moderate; fishing–high
	Gathering forest products	Low	Moderate
	Water-based activities	Low to moderate	Moderate
Ecosystem services	Building materials/wood products	Large from non-climate forces	Likely from non-climate forces
	Cultural and heritage values	Highly variable	Highly variable
	Erosion regulation	Landslides and flooding have the potential for large sudden damages; costs of soil erosion are high.	High
	Fuel (firewood/biofuels)	Firewood – low; biofuels – uncertain	High
	Mining, minerals	Large from non-climate forces	High
	Viewsheds/clean air	High	High
	Water quality	High	High
	Water quantity	Moderate	High

Table 13.2—Example of how information on climate change vulnerability and adaptation can be used in land management applications for dry forests.

Vulnerability and adaptation information	Land management application
Sensitivity to climatic variability and change • Potential conversion to grassland • Many ponderosa pine forests have converted to Douglas-fir types due to fire exclusion and are therefore more susceptible to future fires	• Forest/grassland planning: assessment phase • Project National Environmental Policy Act (NEPA) analysis: existing condition and best science on effects of climate change on resource
Adaption strategy • Restore fire-adapted ponderosa pine stand conditions in order to facilitate transition	• Forest/grassland planning: desired conditions • Project NEPA analysis: purpose and needs
Tactics • Reduce competition from Douglas-fir and grand fir (thin, burn) in current mature pine stands • Conduce frequent understory burning • Retain current mature and older ponderosa pine stands • Plant ponderosa pine where it has been lost	• Forest/grassland planning: objectives • Project NEPA analysis: project design features and other mitigation

Figures

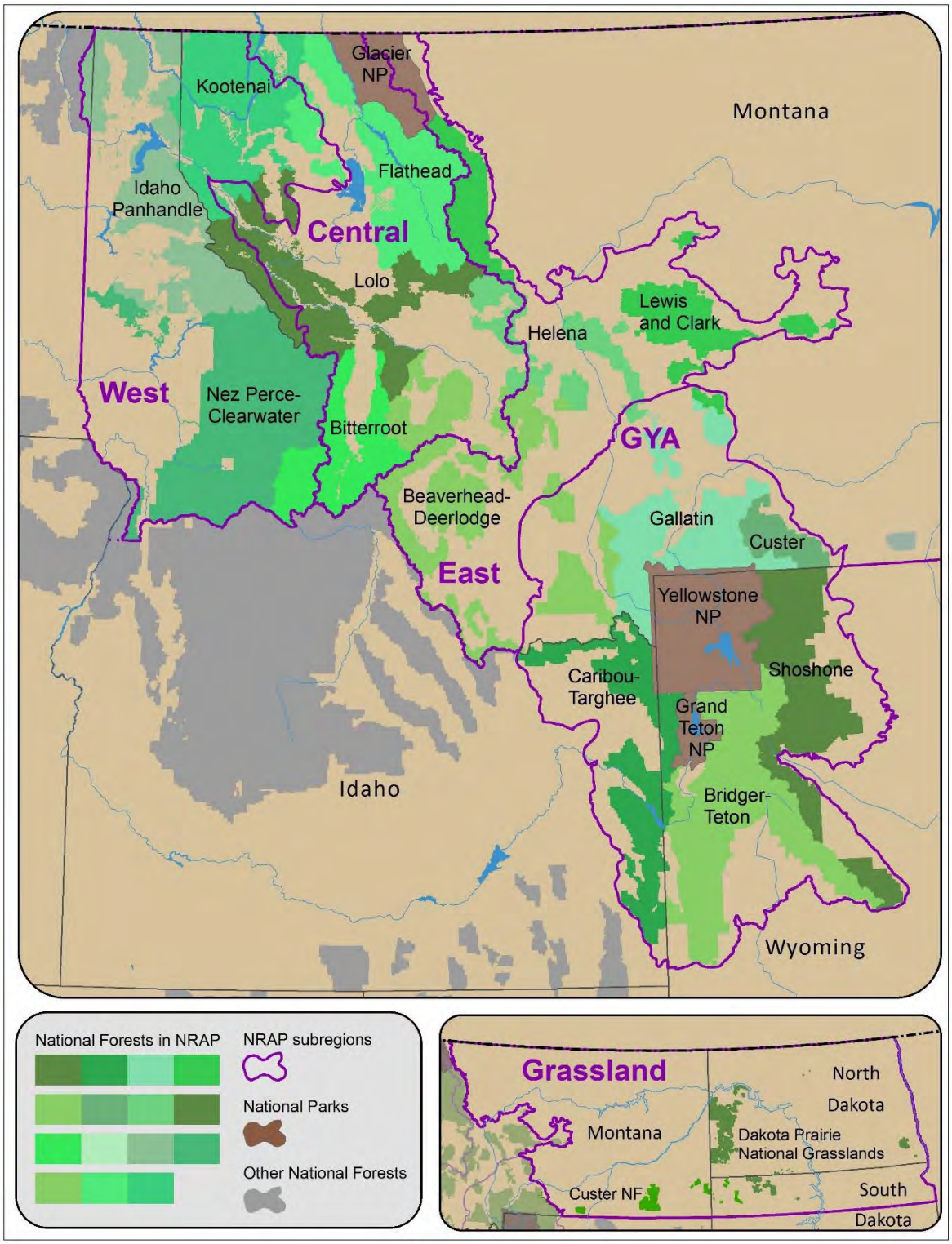


Figure 1.1—Project area for the Northern Rockies Adaptation Partnership (NRAP). Map by Robert Norheim.

Figure 2.1—Highly dissected watersheds with mixed conifer forest adjacent to streams are common in the Western Rockies subregion. (Photo by U.S. Forest Service).

Figure 2.2—Glacially carved landscapes, dense coniferous forest, and deep lakes are common in the Central Rockies subregion. (Photo by National Park Service)

Figure 2.3—The expedition of Lewis and Clark has created a historical legacy in the Eastern Rockies subregion. This painting by Alfred Russell depicts Sacajawea guiding the expedition from Mandan through the Rocky Mountains. (Photo by Bettmann/CORBIS)

Figure 2.4—Populations of the grizzly bear, an iconic species in the Greater Yellowstone Area subregion, have increased over the past several decades as a result of successful conservation efforts. (Photo by U.S. Fish and Wildlife Service)

Figure 2.5—A rich diversity of grasses and forbs, often mixed with ponds and lakes provide excellent habitat for waterfowl in the Grassland subregion. (Photo by Jim Ringelman, Ducks Unlimited).

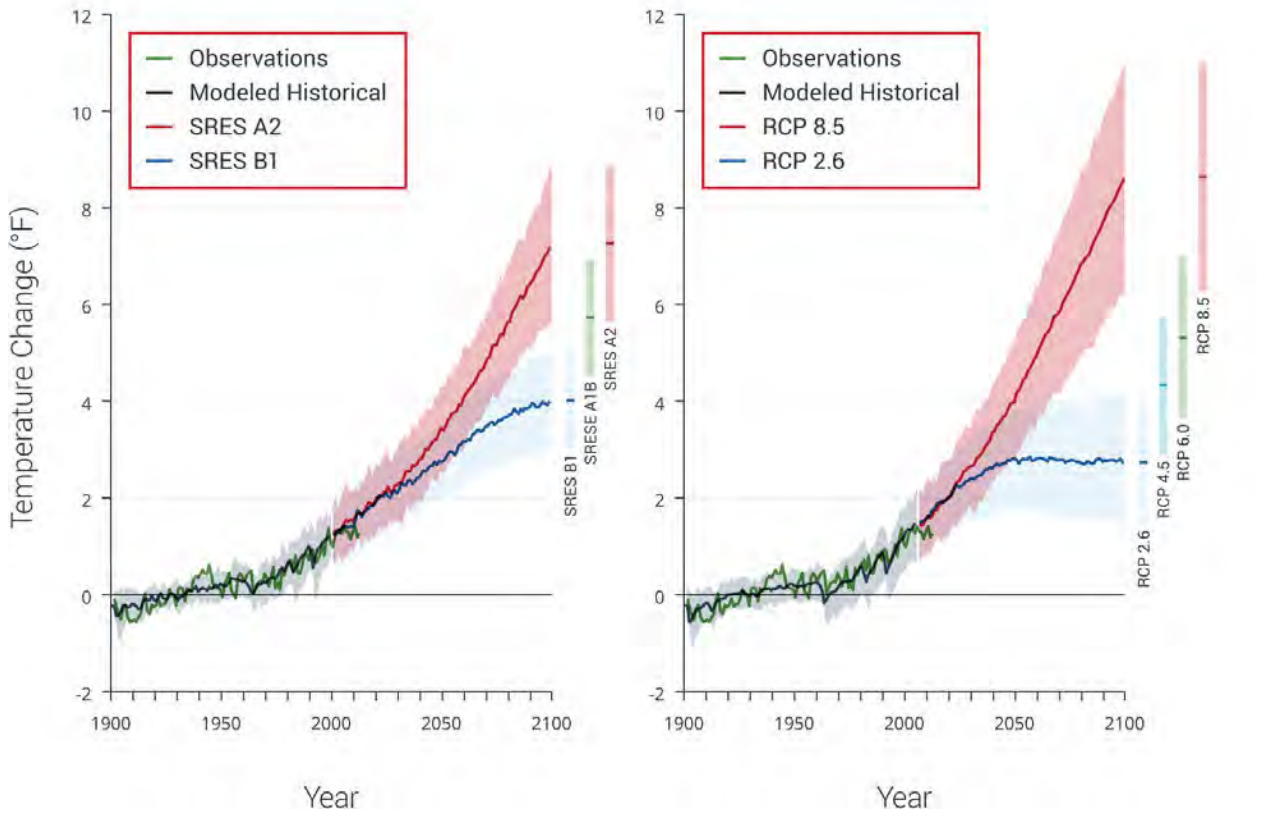


Figure 3.1—Comparison of global temperatures projected with emission levels from CMIP3 (left panel) and with emission levels from CMIP5 (right panel) (figure 2.4 from Walsh et al. 2014). Different amounts of heat-trapping gases released into the atmosphere by human activities produce different projected increases in Earth's temperature. In the figure, the red and blue lines represent a central estimate of global average temperature rise (relative to the 1901-1960 average) for a specific emissions pathway. The shaded areas for a given color indicate the range (5th to 95th percentile) of results from a suite of climate models. The bars to the right of each panel indicate projections in 2099 for additional emissions pathways are indicated. In all cases, temperatures are expected to rise, although the difference between lower and higher emissions pathways is substantial. (Left) The panel shows the two main scenarios (SRES – Special Report on Emissions Scenarios): A2 assumes continued increases in emissions throughout this century, and B1 assumes much slower increases in emissions beginning now and significant emissions reductions beginning around 2050, though not due explicitly to climate change policies. (Right) The panel shows results from the most recent generation of climate models (CMIP5) using the most recent emissions pathways (RCPs – Representative Concentration Pathways). The newest set includes both lower and higher pathways than did the previous set. The lowest emissions pathway shown here, RCP 2.6, assumes immediate and rapid reductions in emissions and would result in about 2.5 °F of warming in this century. The highest pathway, RCP 8.5, roughly similar to a continuation of the current path of global emissions increases, is projected to lead to more than 8 °F warming by 2100, with a high-end possibility of more than 11 °F. (Data from CMIP3, CMIP5, and NOAA NCDC). These results draw on raw GCM data summarized for the entire Earth rather than bias corrected to spatially downscaled GCM models for our regions depicted in all other graphics.

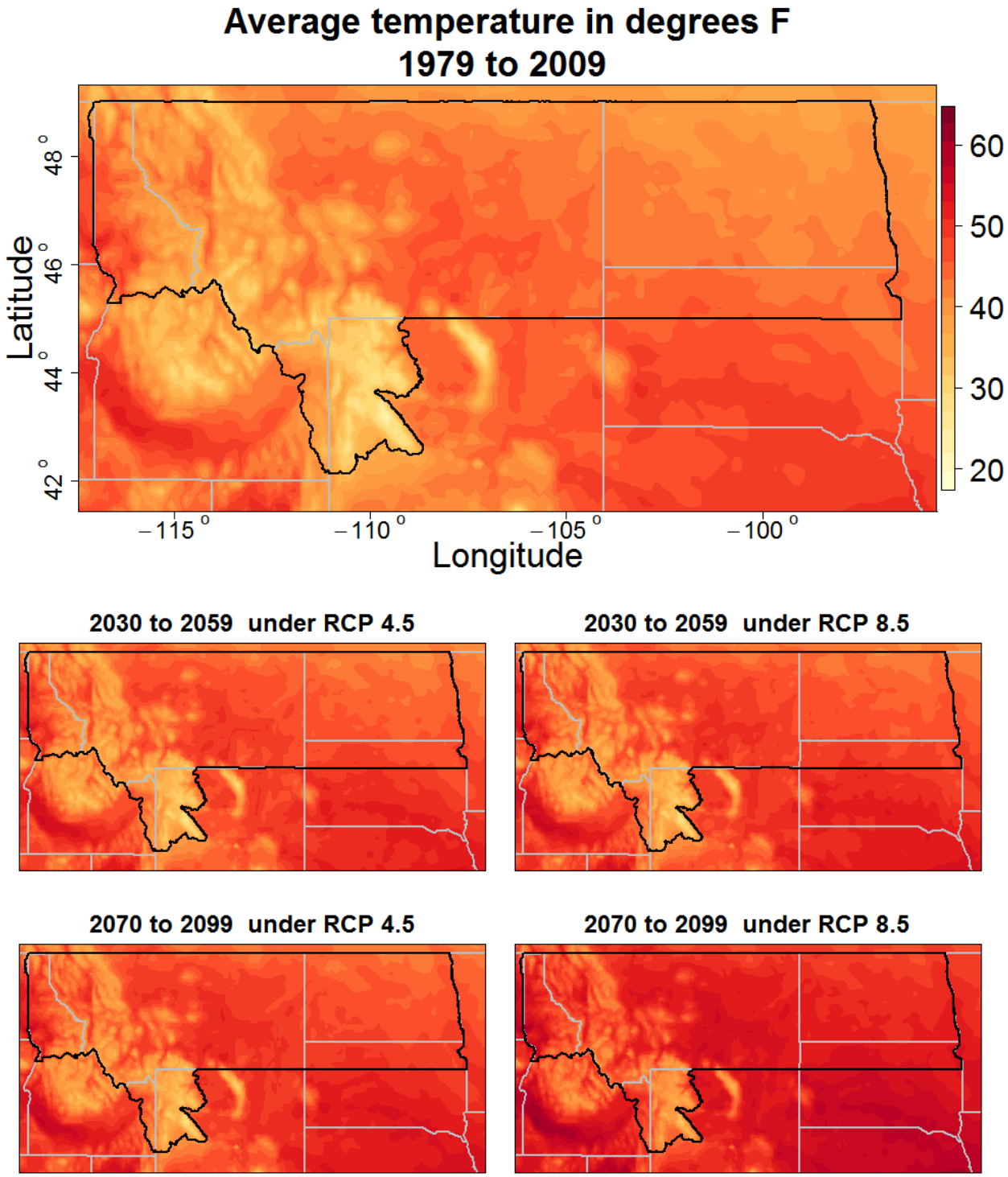


Figure 3.2—Historical (1970-2009) and projected (2030-2059 and 2070-2099) mean annual monthly temperature (°F) for Northern Rockies Adaptation Partnership Region (NRAP) under RCP 4.5 and RCP 8.5 scenarios. Projected climate results are the mean of 36 models for RCP 4.5 and 34 models for RCP 8.5 (see table 3.1). Spatial resolution of the data is 1/8-degree latitude-longitude.

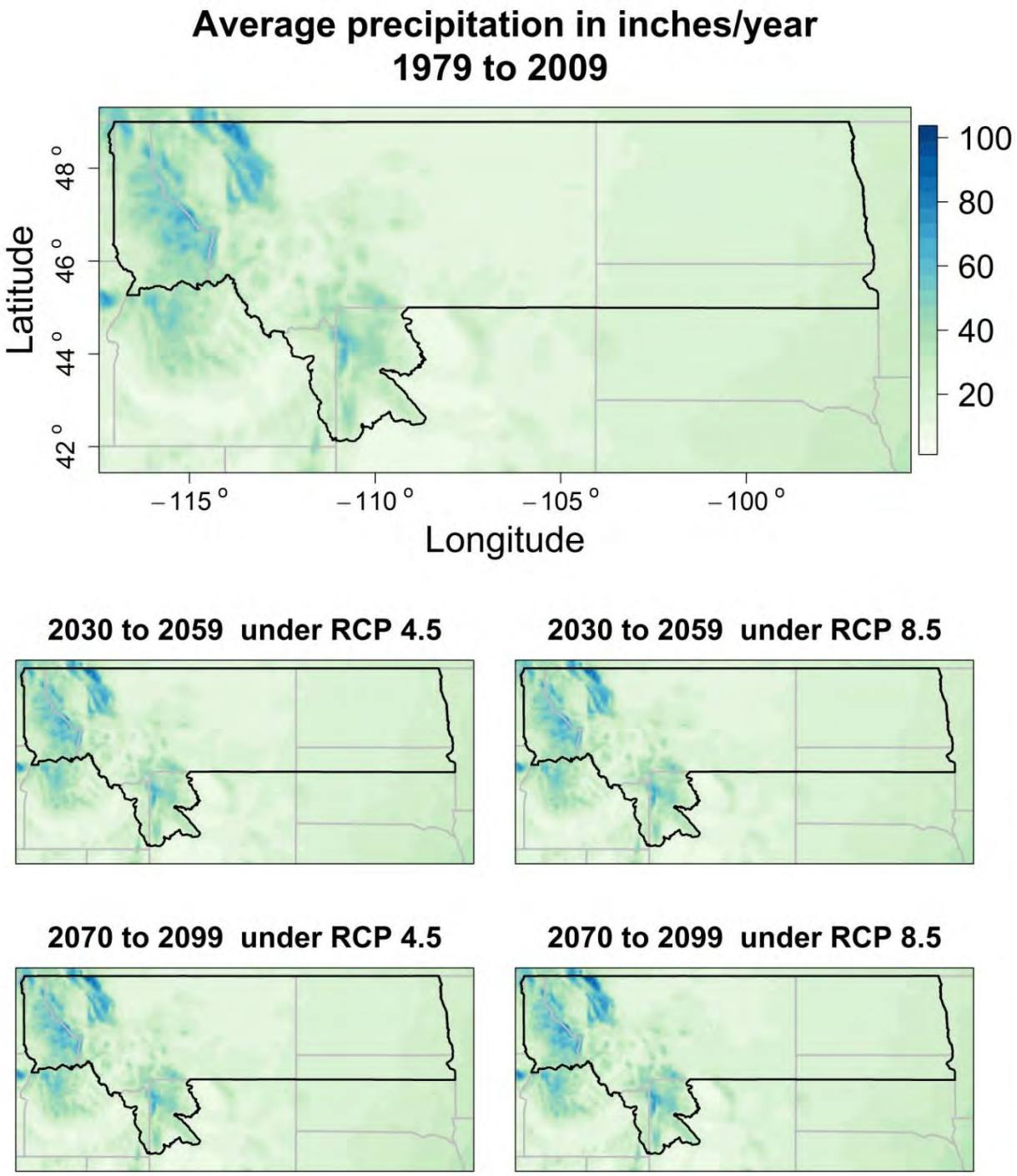


Figure 3.3—Historical (1970-2009) and projected (2030-2059 and 2070-2099) total annual precipitation (inches) under RCP 4.5 and RCP 8.5. Projected climate results are the mean of 36 models for RCP 4.5 and 34 models for RCP 8.5 (see Table 3.1). Spatial resolution of the data is 1/8 degree latitude-longitude.

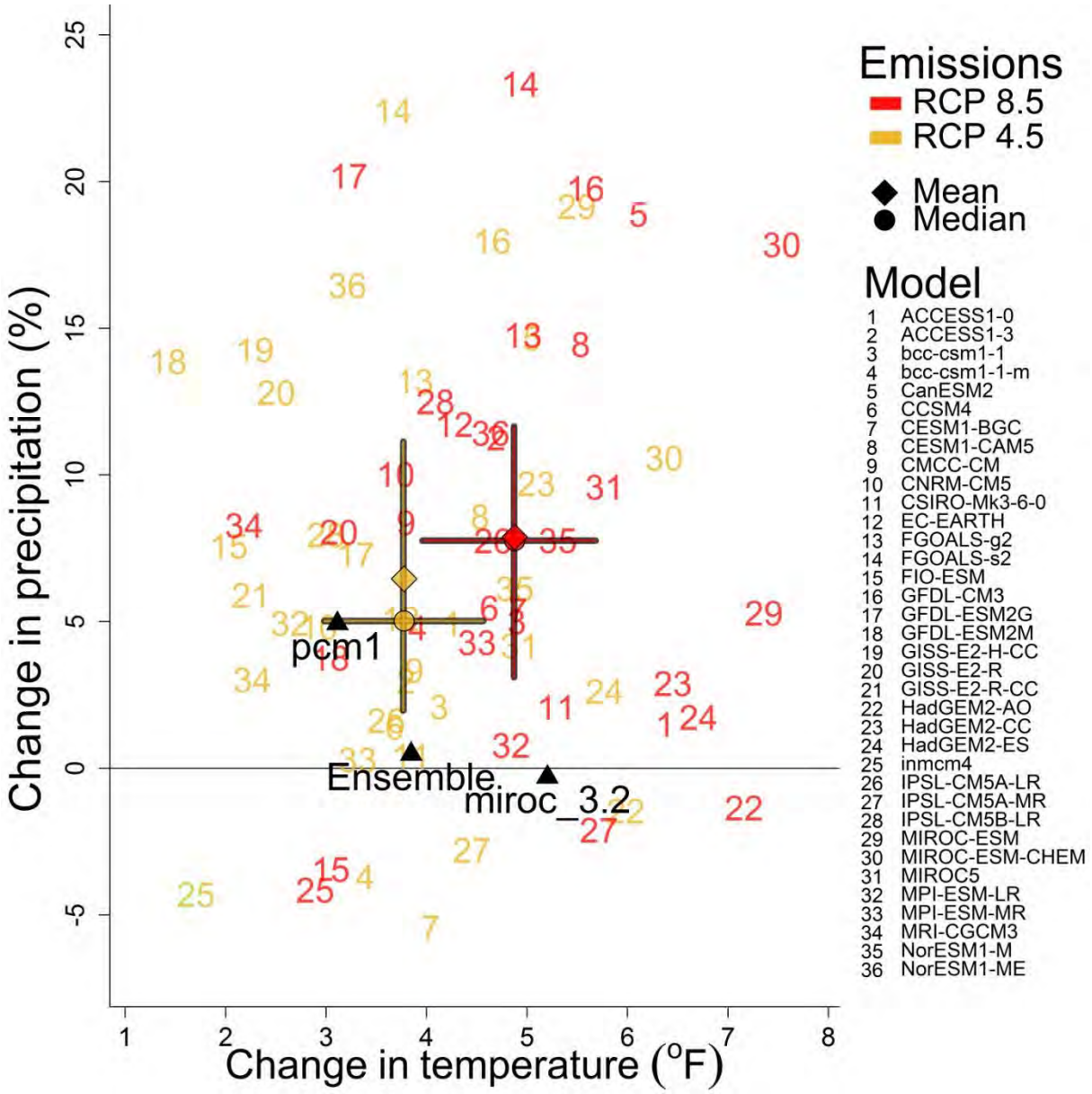


Figure 3.4—For the entire NRAP region, percent change in total annual precipitation (%) and change in mean annual temperature (°F) from the simulated historical climate (1979-2009) and the projected climate (2040-2060) using the CMIP5 RCP 4.5 and RCP 8.5 scenarios and the CMIP3 A1B scenario. Each CMIP5 model result is labeled by a number with a key in the legend (e.g., 29 is MIROC-ESM) in colors to indicate RCP 4.5 (yellow) and RCP 8.5 (red) (see table 3.1). The crosses in the middle represent the median and 25-75% of the RCP 4.5 and the RCP 8.5 projections used in this study. The mean values for the CMIP5 changes are shown on the figure as colored diamonds. The CMIP3 results are labeled in black triangles (see table 3.2 and Littell et al. 2011).

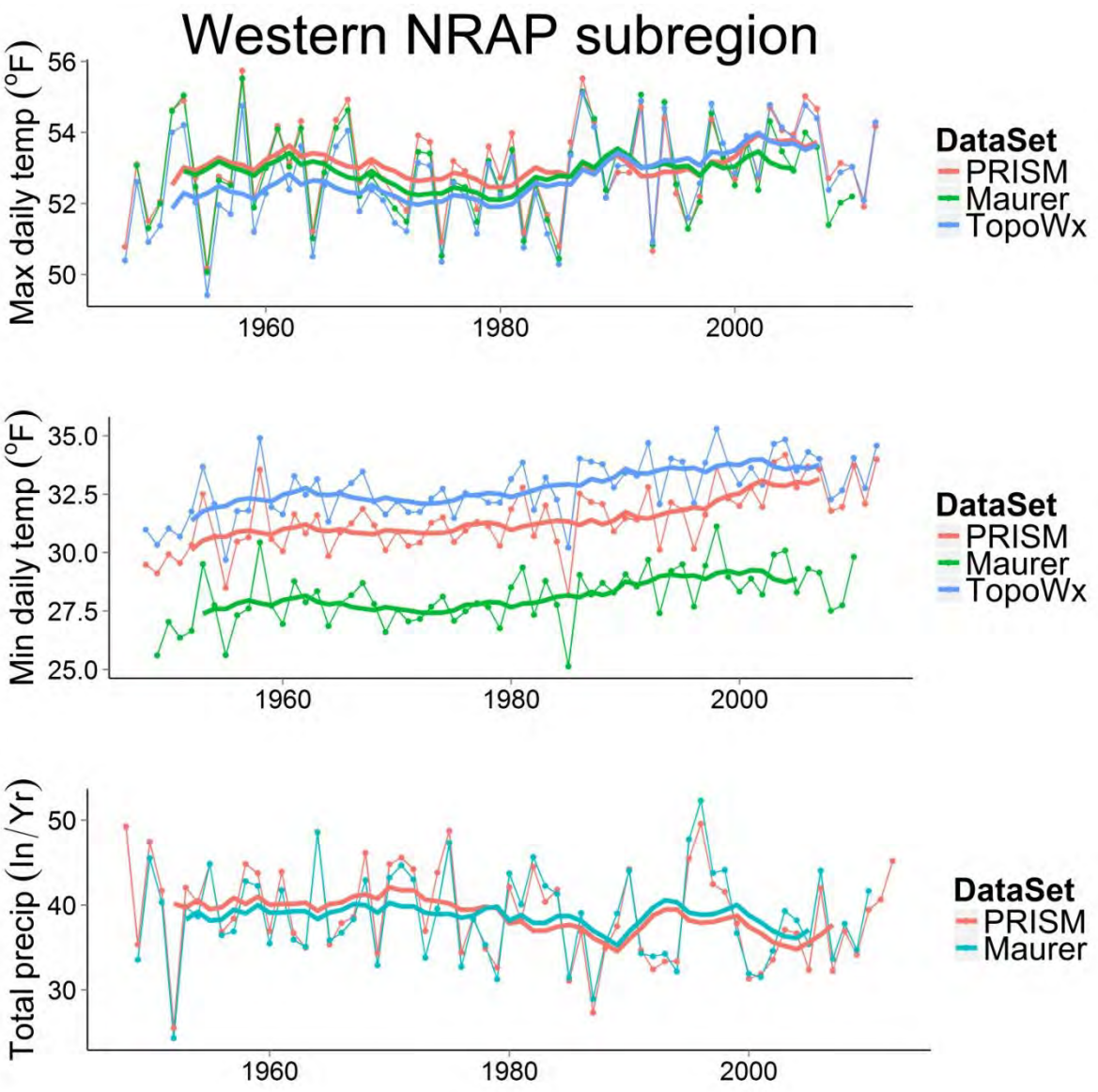


Figure 3.5—Annual historical mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation from monthly gridded PRISM, Maurer and TopoWx for 1949 to 2010 for the NRAP Western subregion. The heavy lines are the 10-year rolling average to show short-term trends.

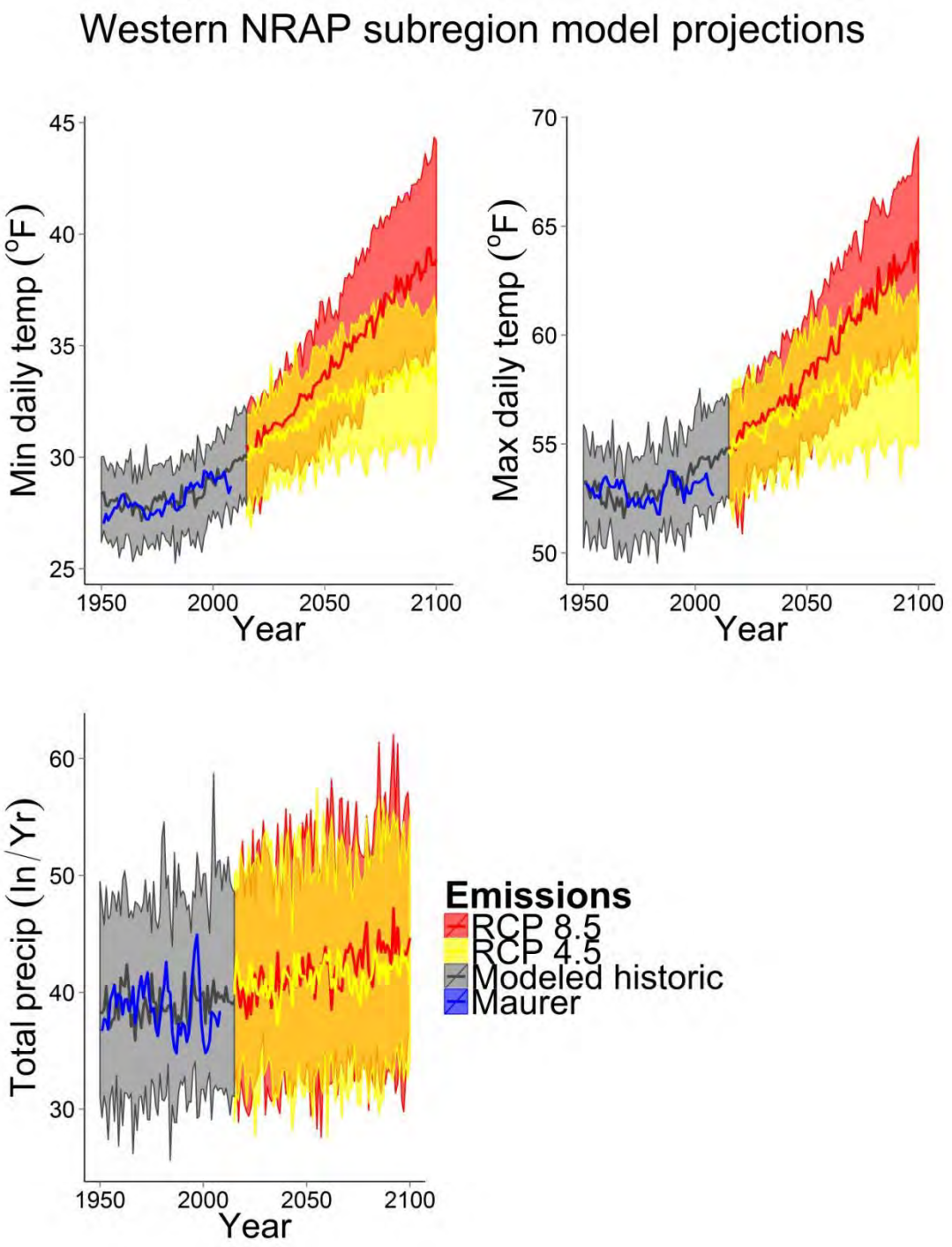


Figure 3.6—Historical modeled and projected annual mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation for the RCP 4.5 and RCP 8.5 emission scenarios based on CMIP5 data for the NRAP Western subregion. Historic modeled results are indicated in gray, projections in colors. The shaded area shows the 5th and 95th percent quantiles for all models. The grey, red, or yellow heavy line illustrate ensemble median; the heavy blue line is the gridded historical observed data from Maurer et al. (2002).

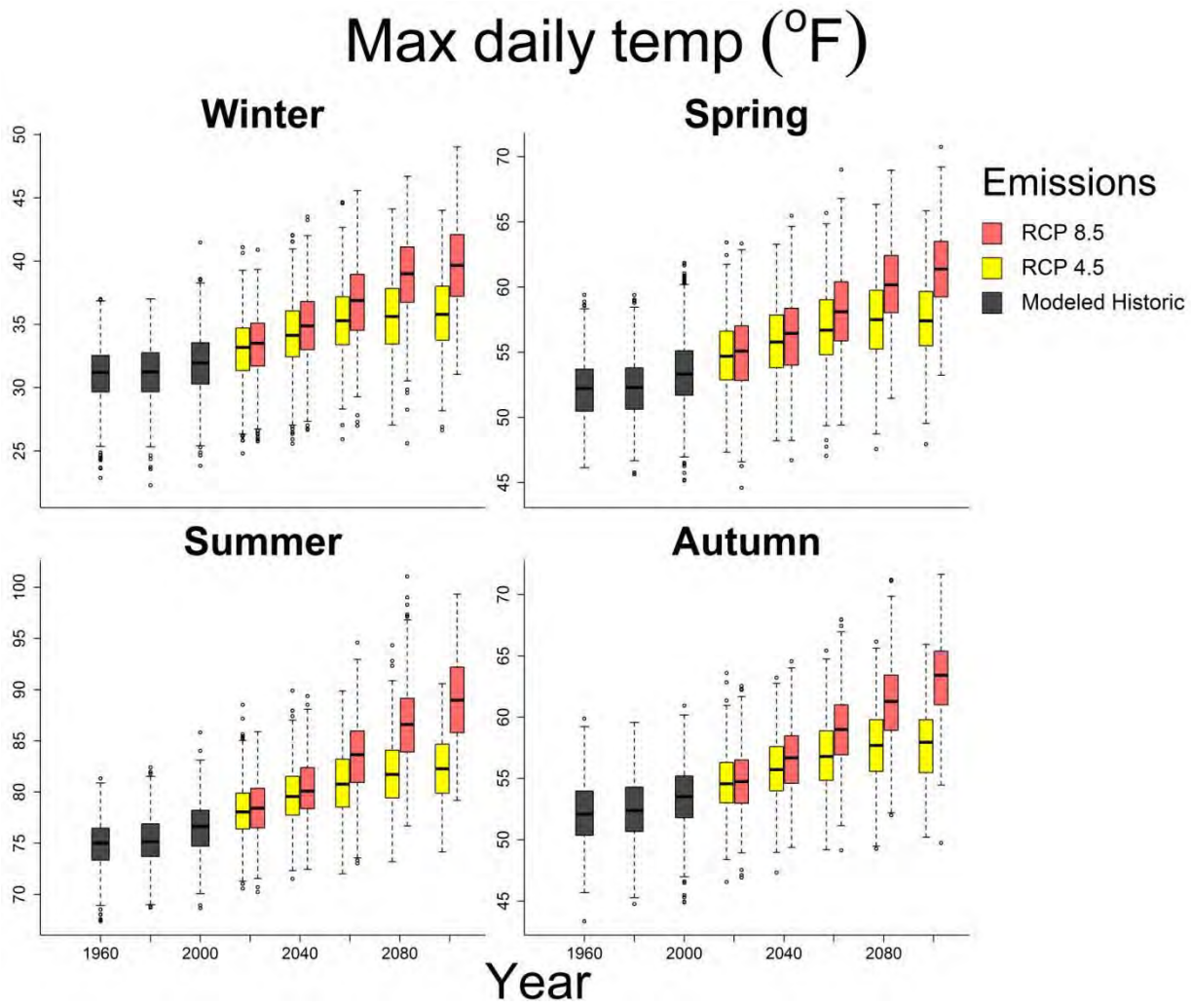


Figure 3.7—Seasonal mean monthly maximum temperature for 1950-2100 for the NRAP Western subregion. Each box is an aggregation of 20 years of modeled historical or projected seasonal data centered on the year listed (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.

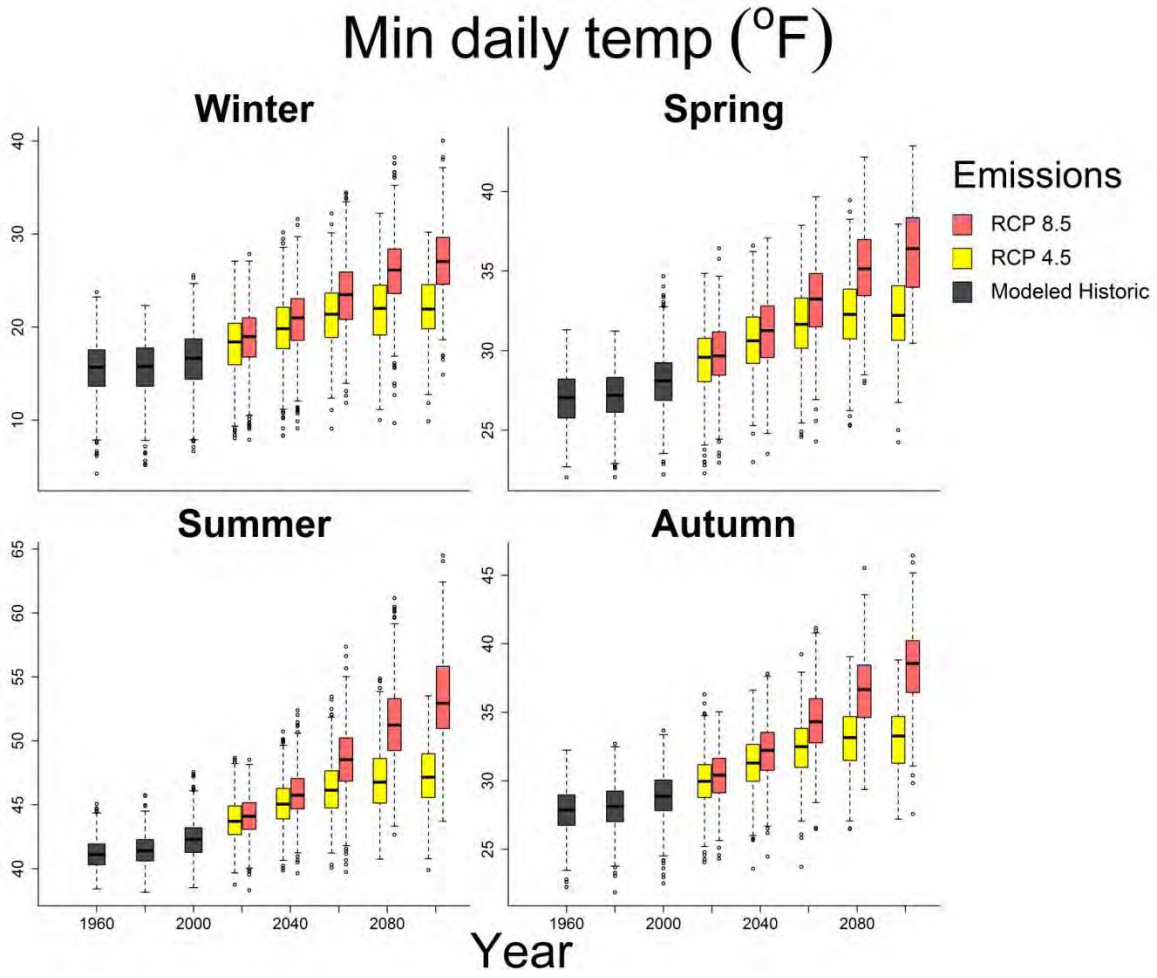


Figure 3.8—Seasonal mean monthly minimum temperature for 1950-2100 for the NRAP Western region. Each box is an aggregation of 20 years of modeled historical or projected seasonal data (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.

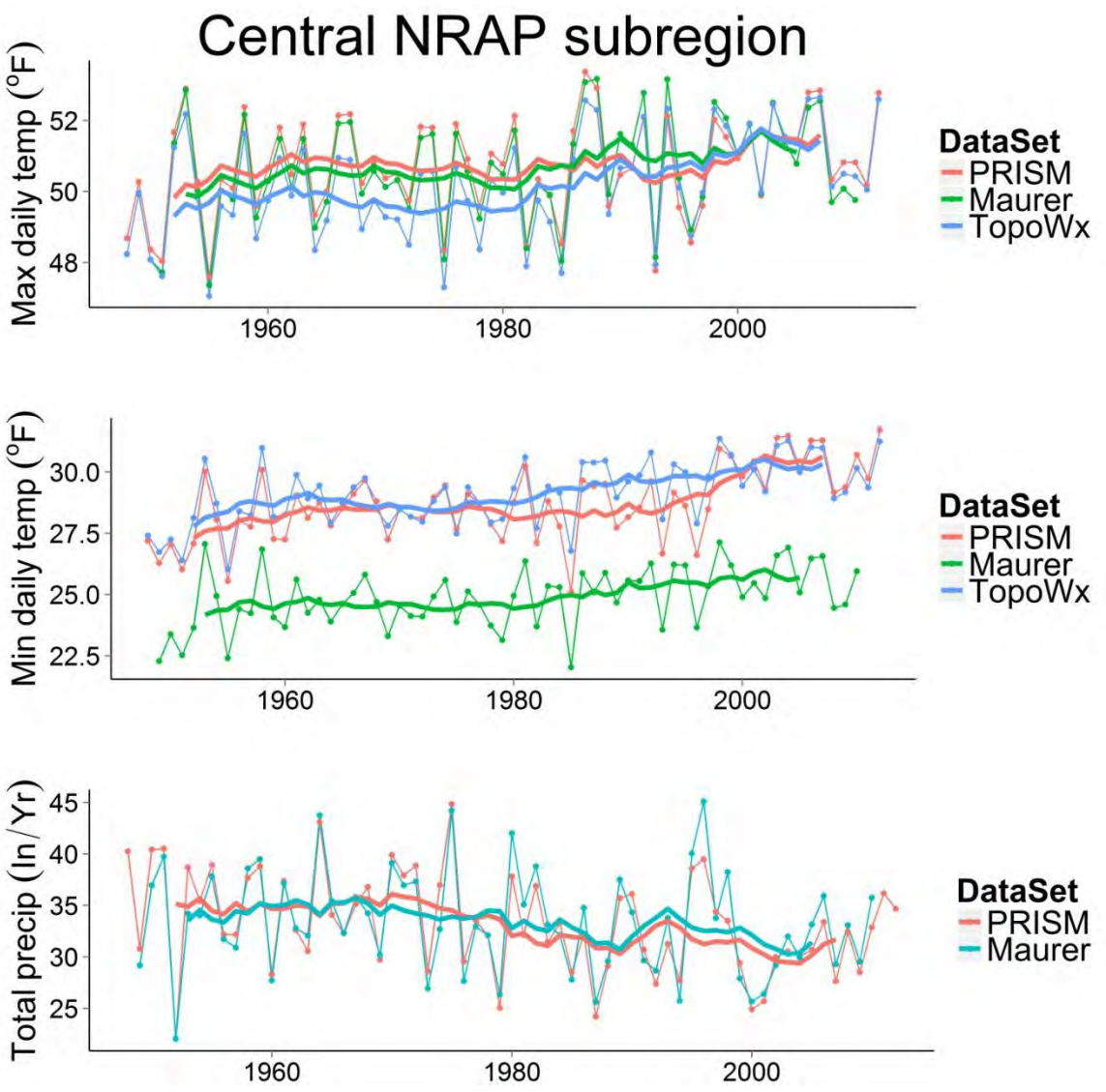


Figure 3.9—Annual historical mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation from monthly gridded PRISM, Maurer and TopoWx for 1949 to 2010 for the NRAP Central subregion. The heavy lines are the 10-year rolling average which show short-term trends.

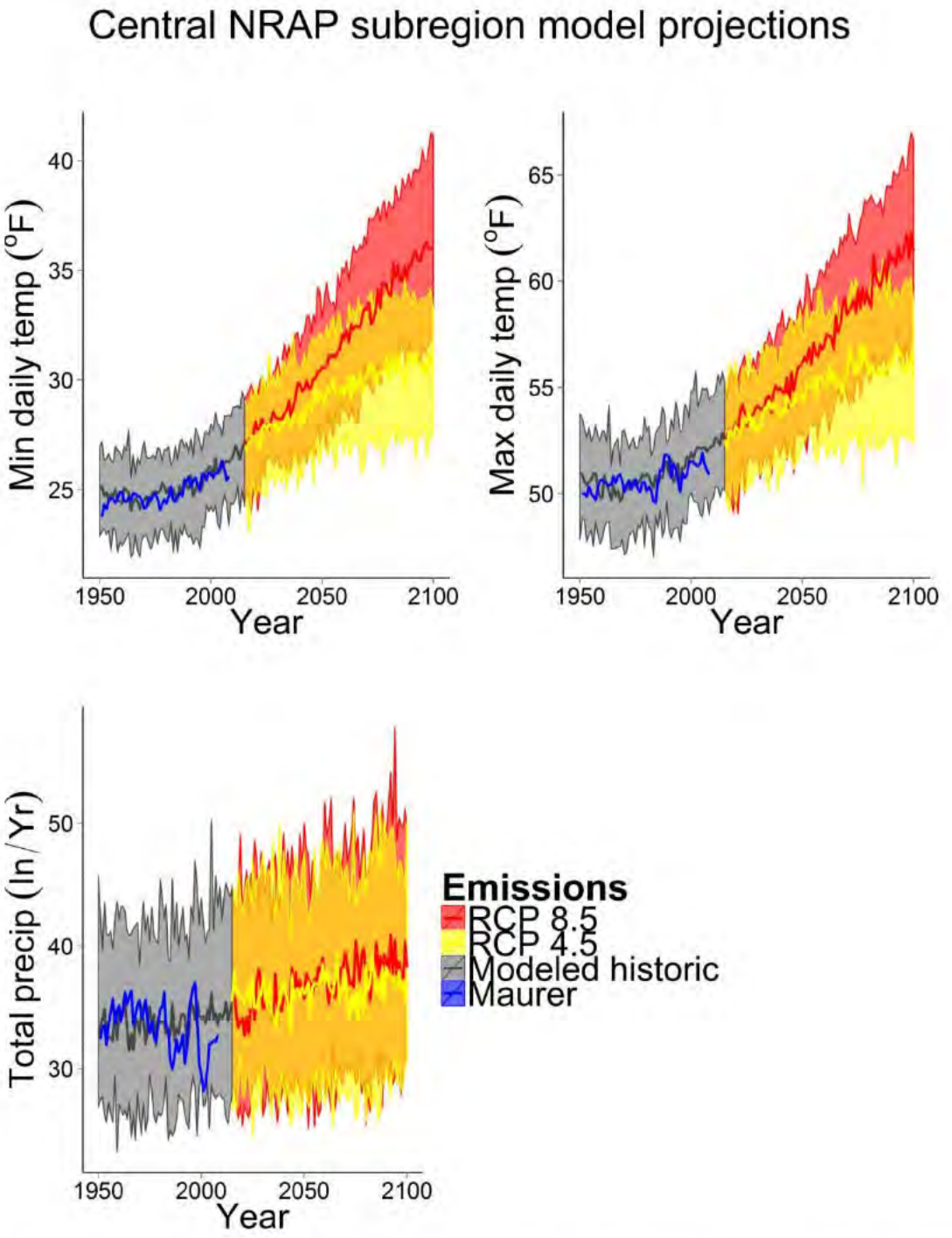


Figure 3.10—Historical modeled and projected annual mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation for the RCP 4.5 and RCP 8.5 emission scenarios based on CMIP5 data for the NRAP Central subregion. Historic modeled results are indicated in gray, projections in colors. The shaded area shows the 5th and 95th percent quantiles for all models. The grey, red, or yellow heavy line illustrate ensemble median; the heavy blue line is the gridded historical observed data from Maurer et al. (2002).

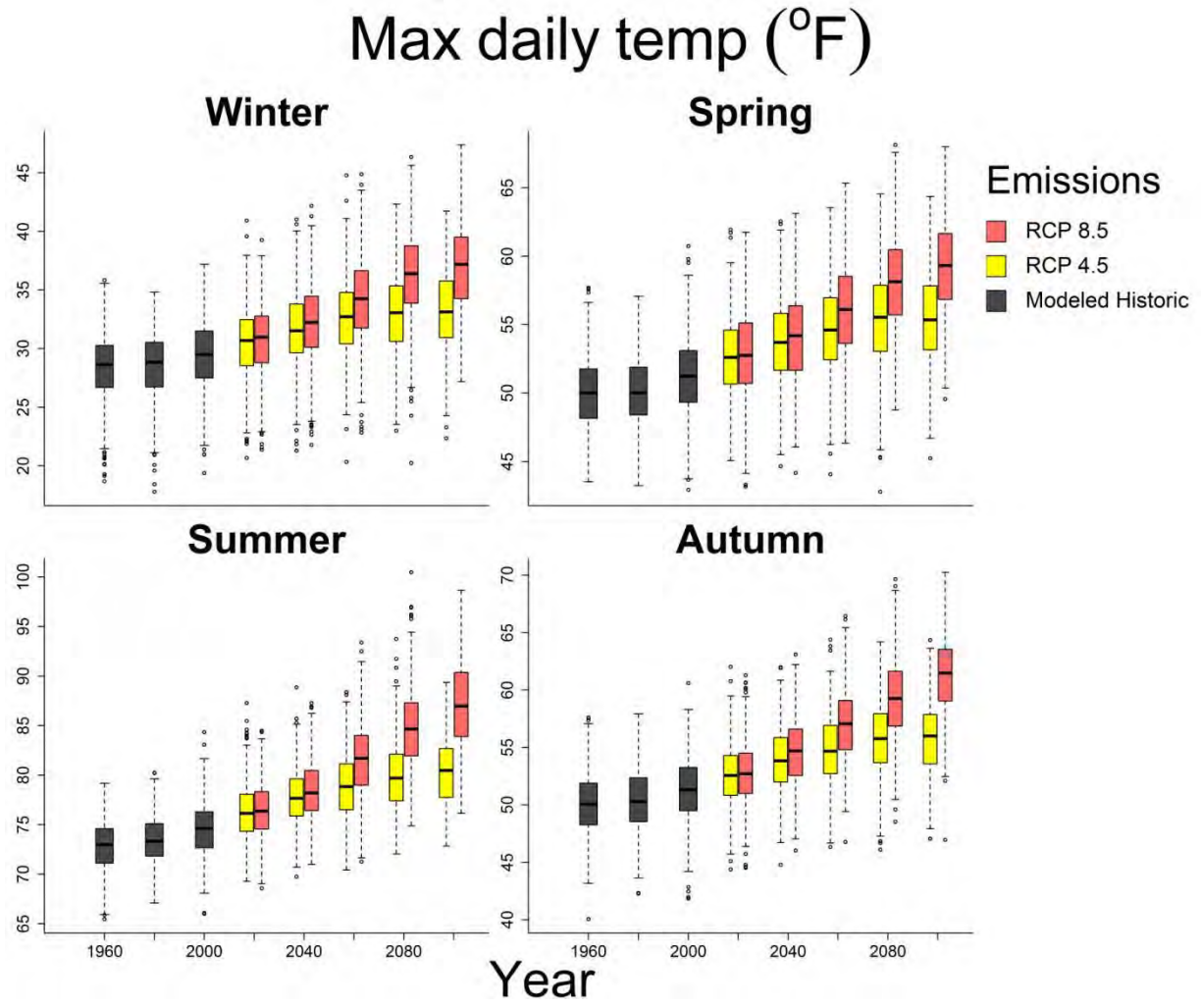


Figure 3.11—Seasonal mean monthly maximum temperature for 1950-2100 for the NRAP Central subregion. Each box is an aggregation of 20 years of modeled historical or projected seasonal data (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.

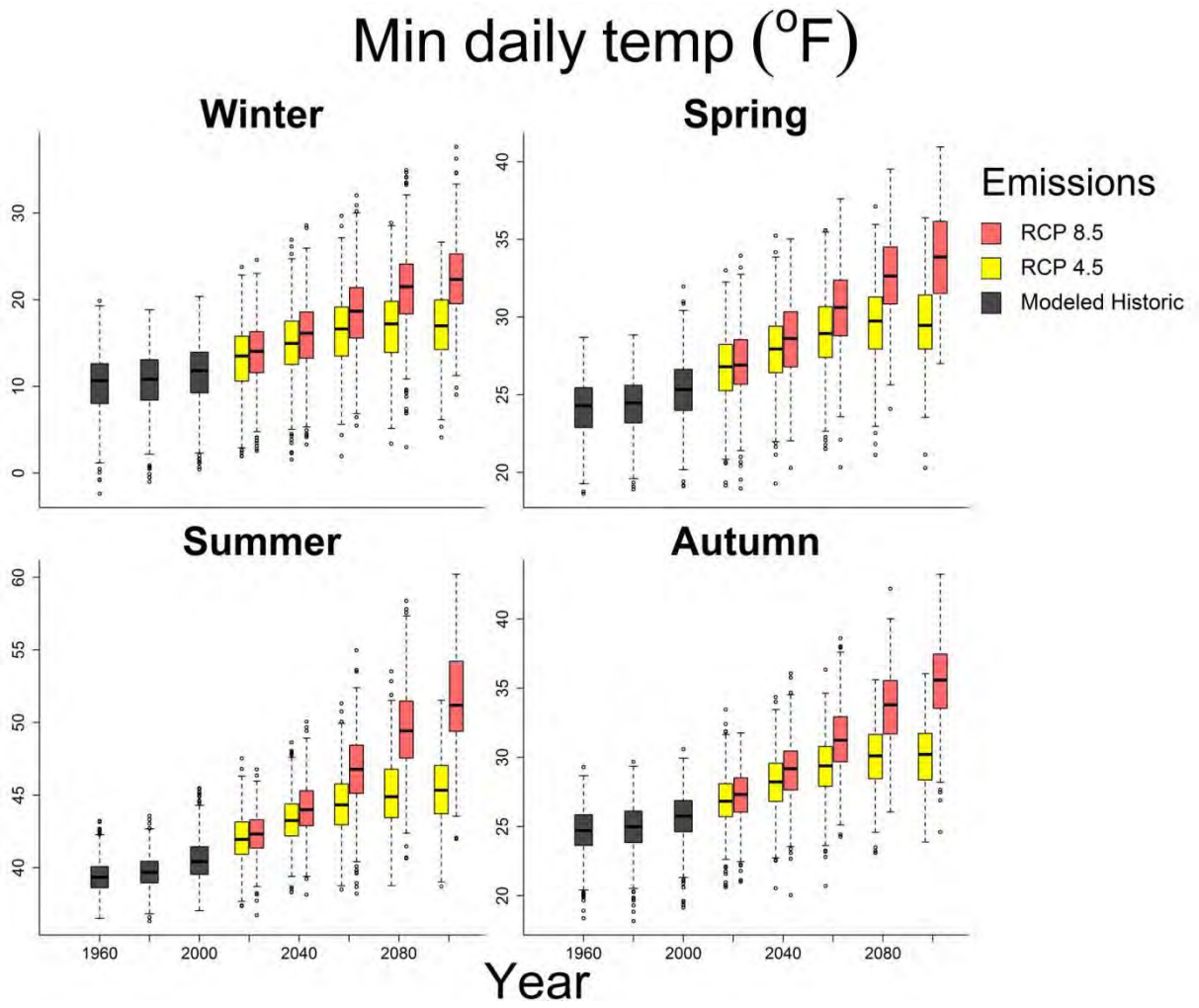


Figure 3.12—Seasonal mean monthly minimum temperature for 1950-2100. Each box is an aggregation of 20 years of modeled historical or projected seasonal data for the NRAP Central subregion (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.

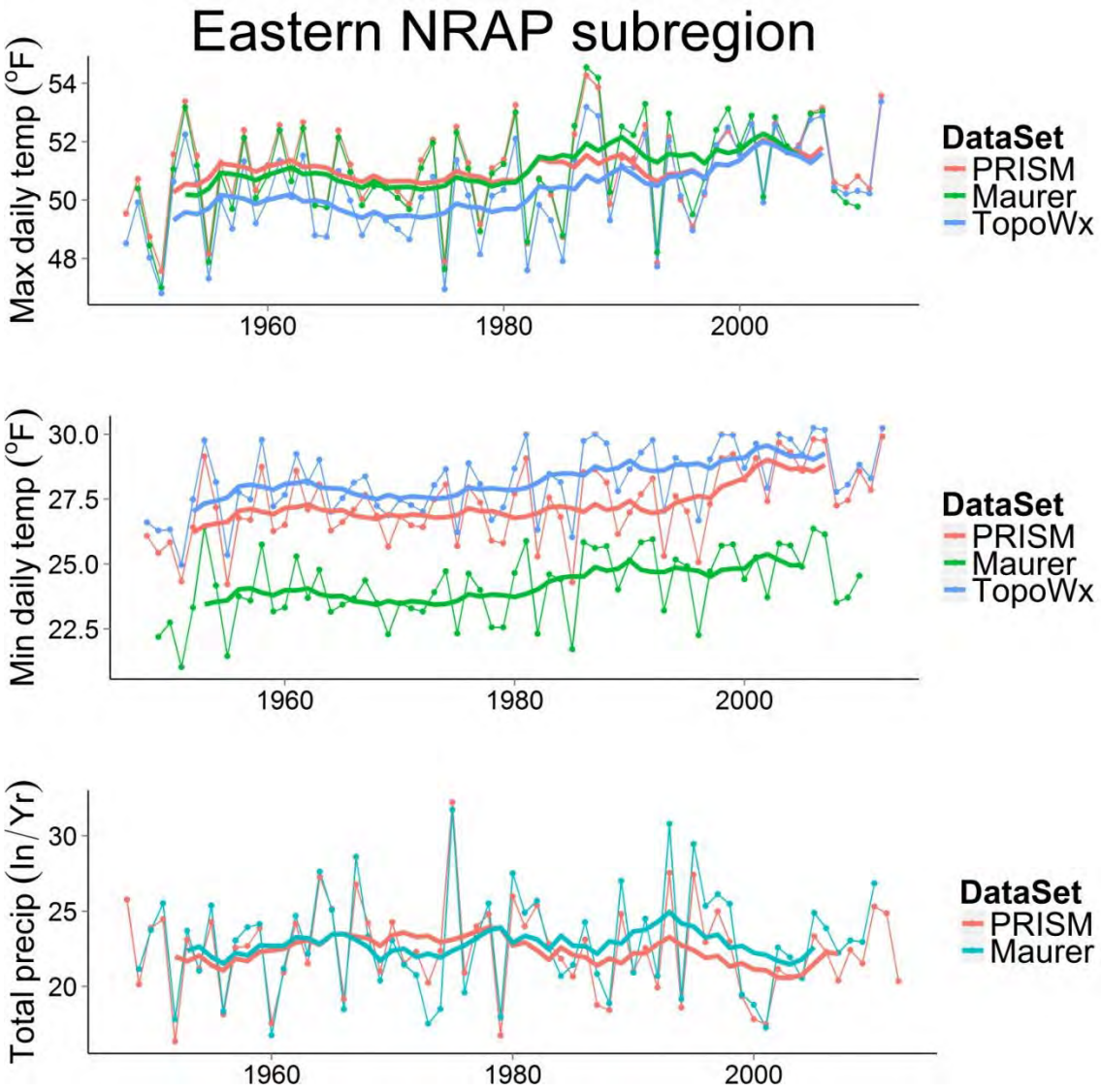


Figure 3.13—Annual historical mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation from monthly gridded PRISM, Maurer and TopoWx for 1949 to 2010 for the NRAP Eastern subregion. The heavy lines are the 10-year rolling average which show short-term trends

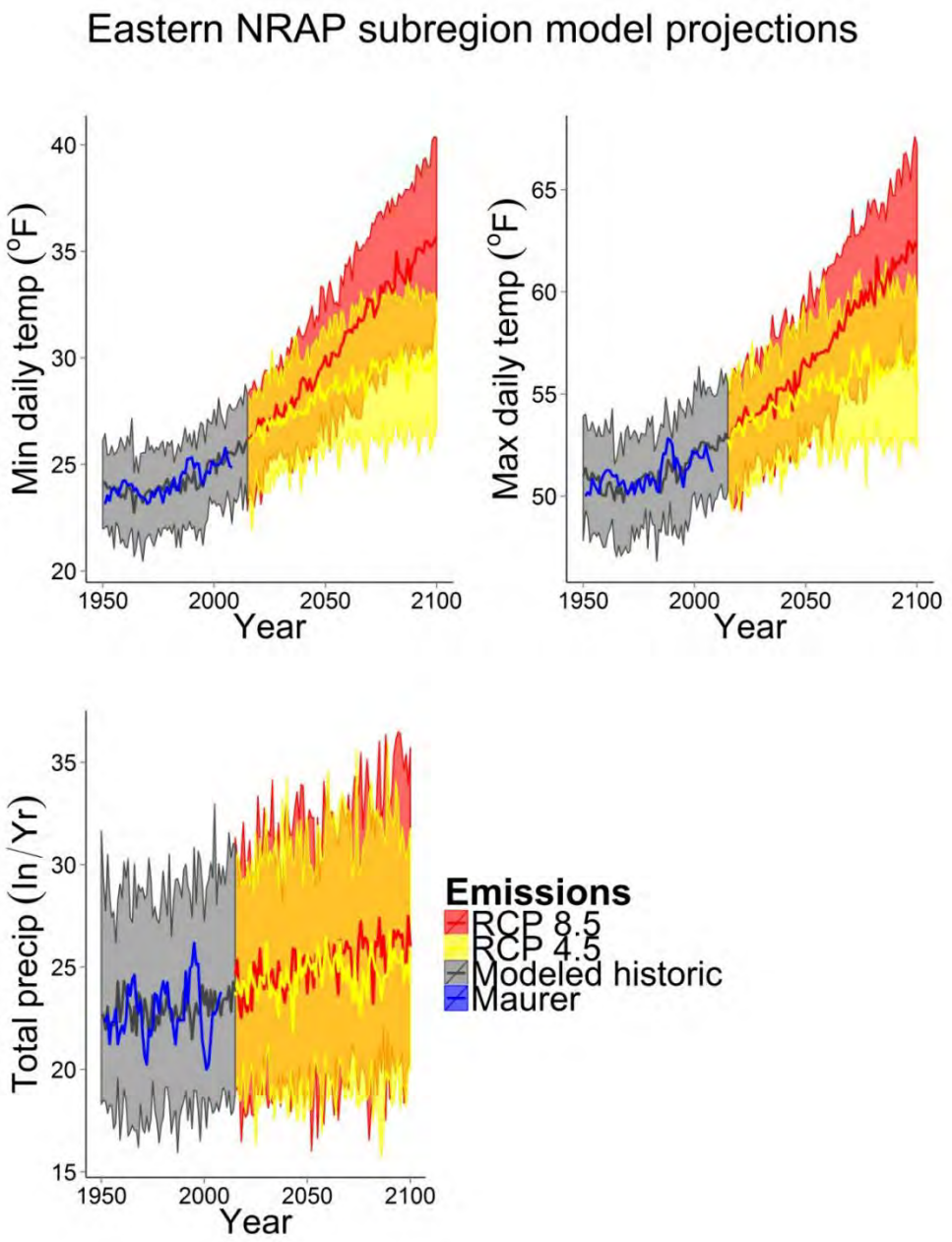


Figure 3.14—Historical modeled and projected annual mean monthly maximum temperature, annual mean monthly temperature, and total annual precipitation for the RCP 4.5 and RCP 8.5 emission scenarios based on CMIP5 data for the NRAP Eastern subregion. Historic modeled results are indicated in gray, projections in colors. The 5th and 95th percent quantiles for all models are shown by the shaded area. The ensemble median is illustrated by the grey, red, or yellow heavy line; the heavy blue line is the gridded historical observed data from Maurer et al. 2002).

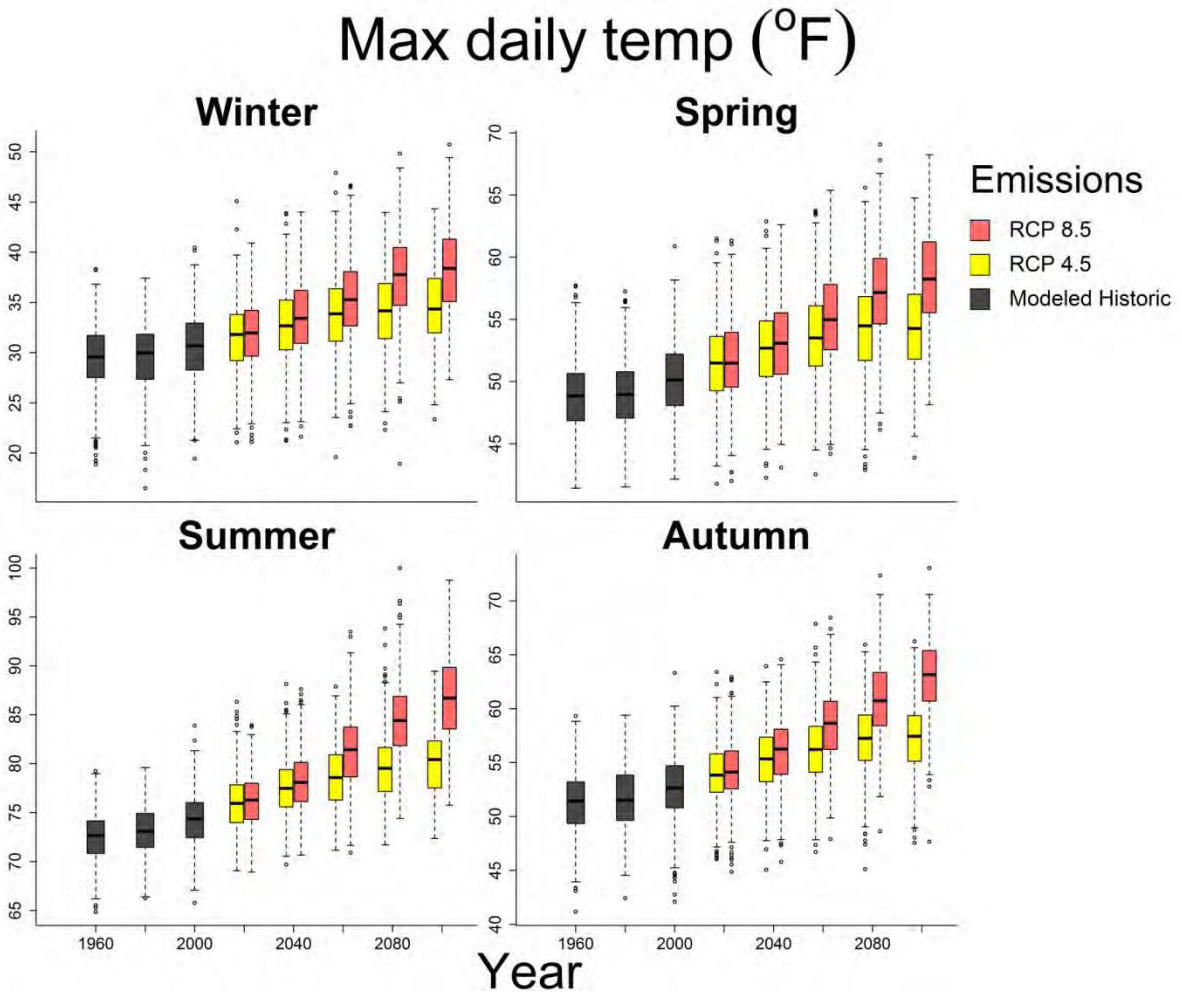


Figure 3.15—Seasonal mean monthly maximum temperature for 1950-2100 for the NRAP Eastern subregion. Each box is an aggregation of 20 years of modeled historical or projected seasonal data (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.

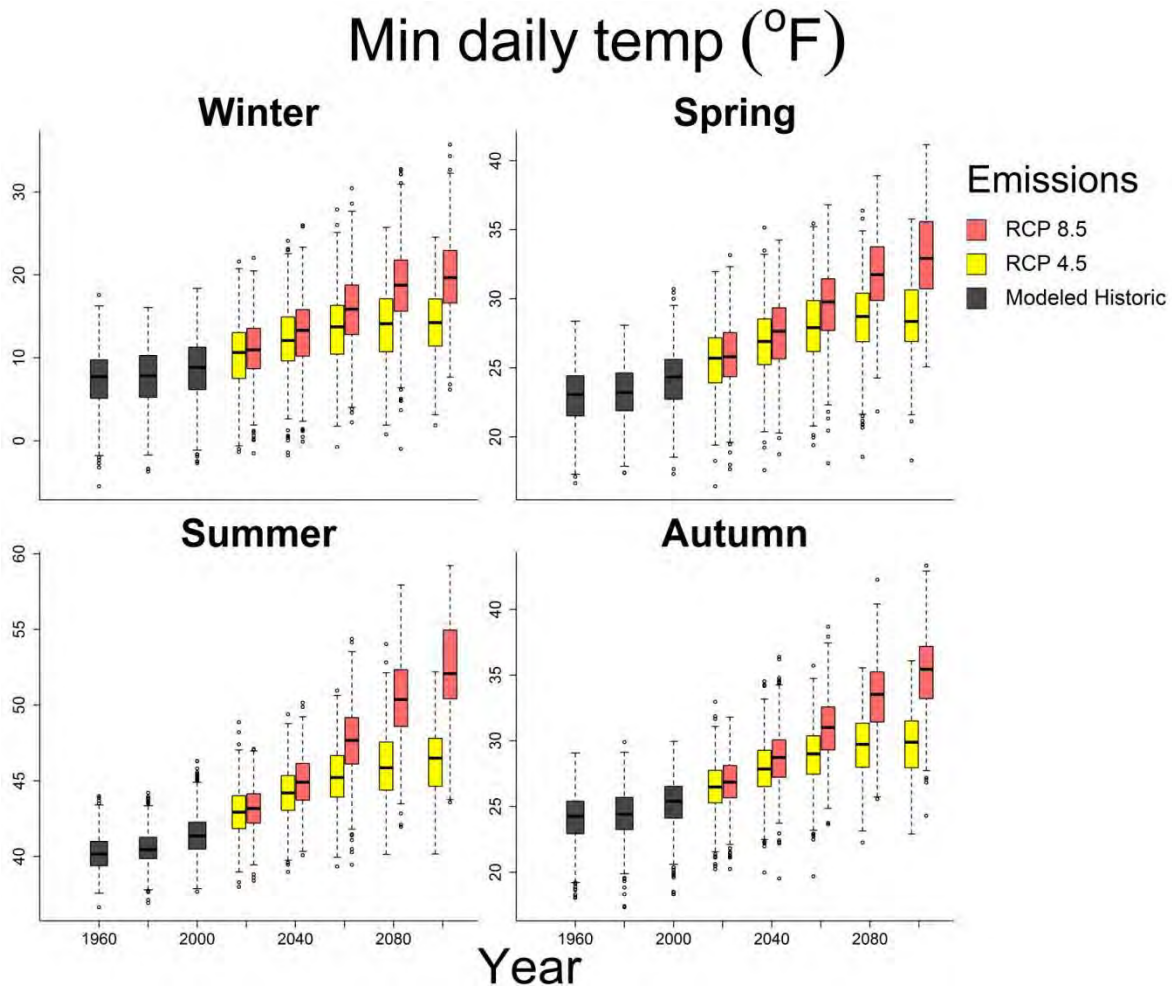


Figure 3.16—Seasonal mean monthly minimum temperature for 1950-2100 for the NRAP Eastern subregion. Each box is an aggregation of 20 years of modeled historical or projected seasonal data (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.

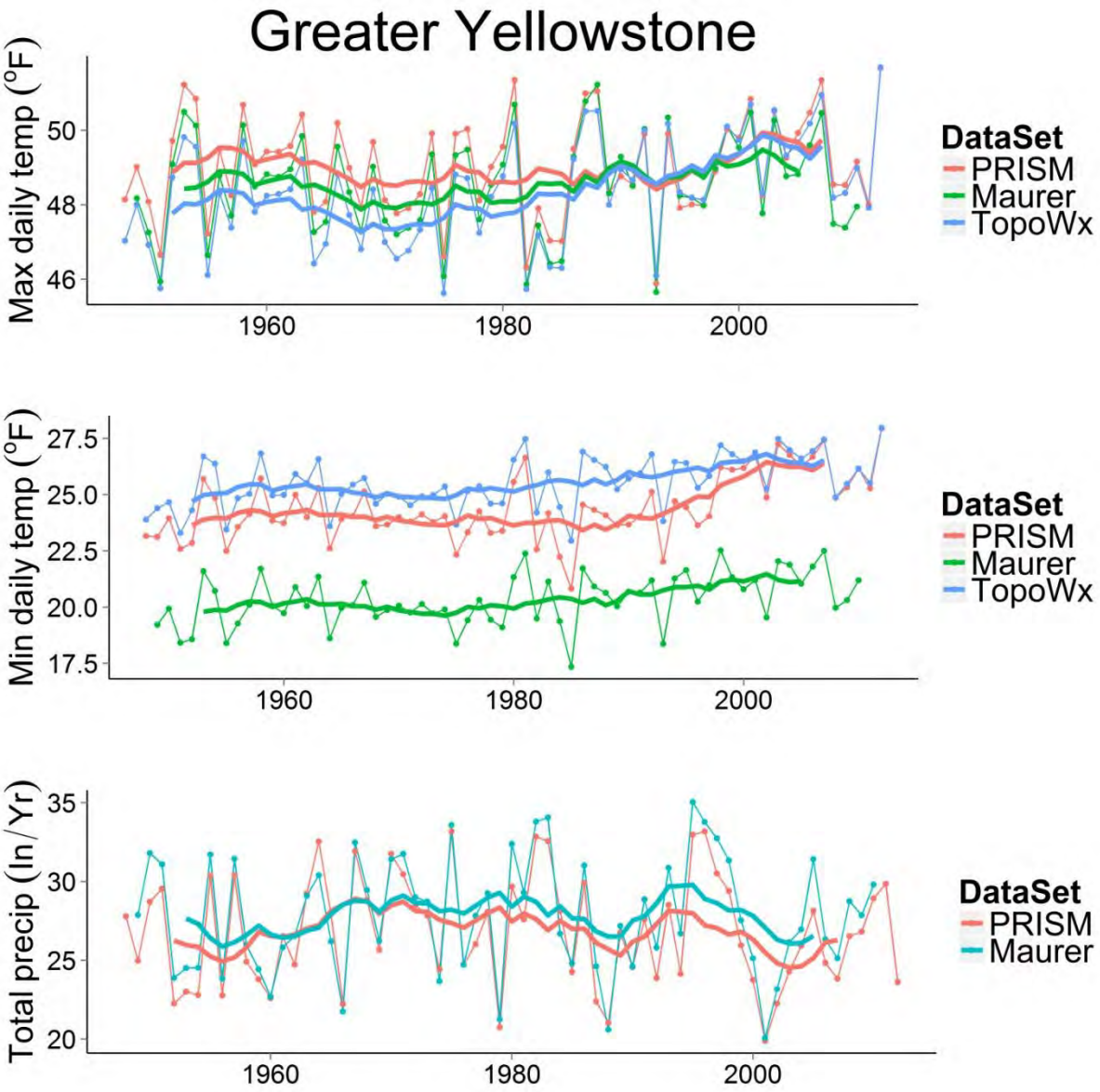


Figure 3.17—Annual historical mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation from monthly gridded PRISM, Maurer and TopoWx for 1949 to 2010 for the NRAP Greater Yellowstone subregion. The heavy lines are the 10-year rolling average which show short-term trends.

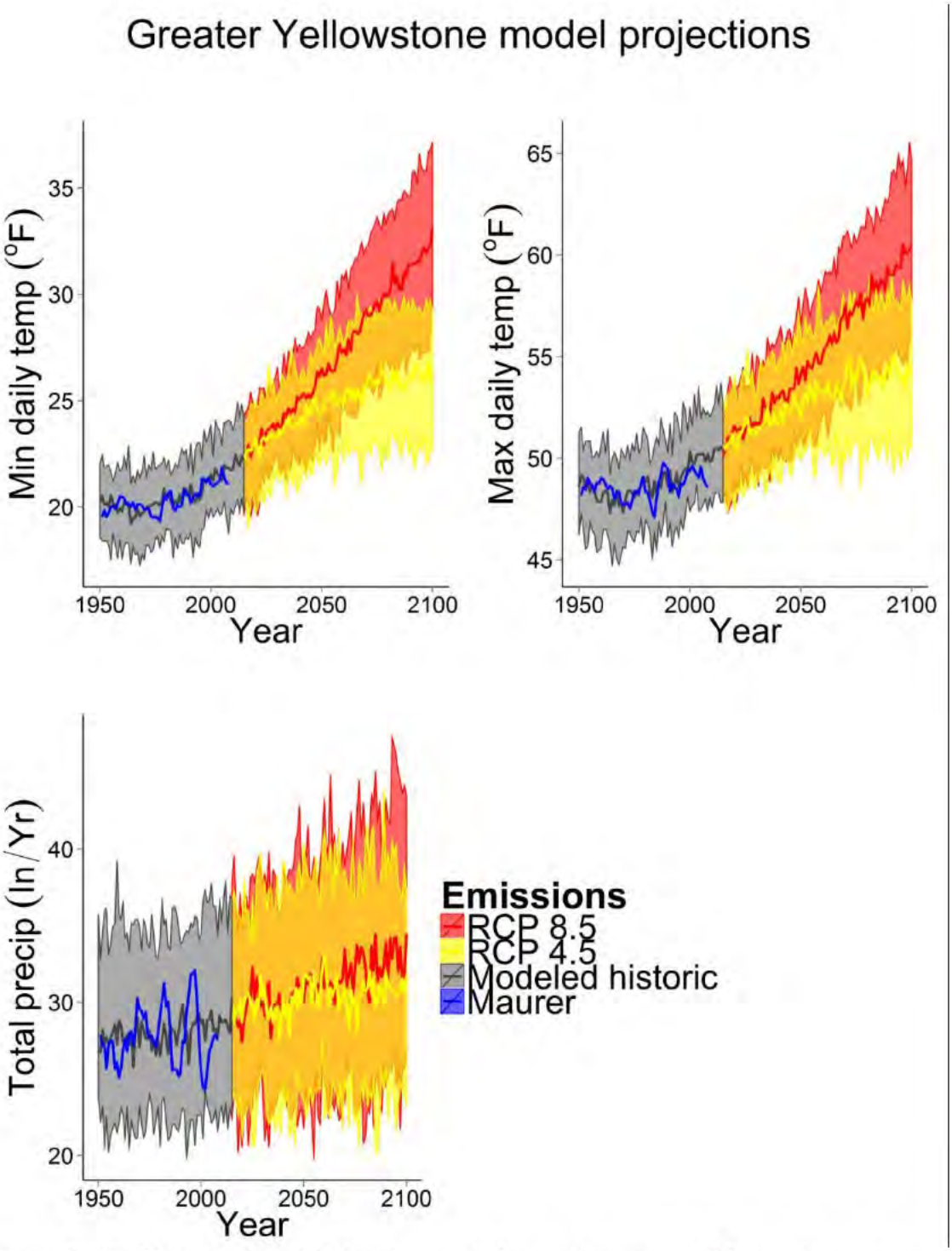


Figure 3.18—Historical modeled and projected annual mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation for the RCP 4.5 and RCP 8.5 emission scenarios based on CMIP5 data for the NRAP Greater Yellowstone subregion. Historic modeled results are indicated in gray, projections in colors. The shaded area shows the 5th and 95th percent quantiles for all models. The grey, red, or yellow heavy line illustrate ensemble median; the heavy blue line is the gridded historical observed data from Maurer et al. (2002).

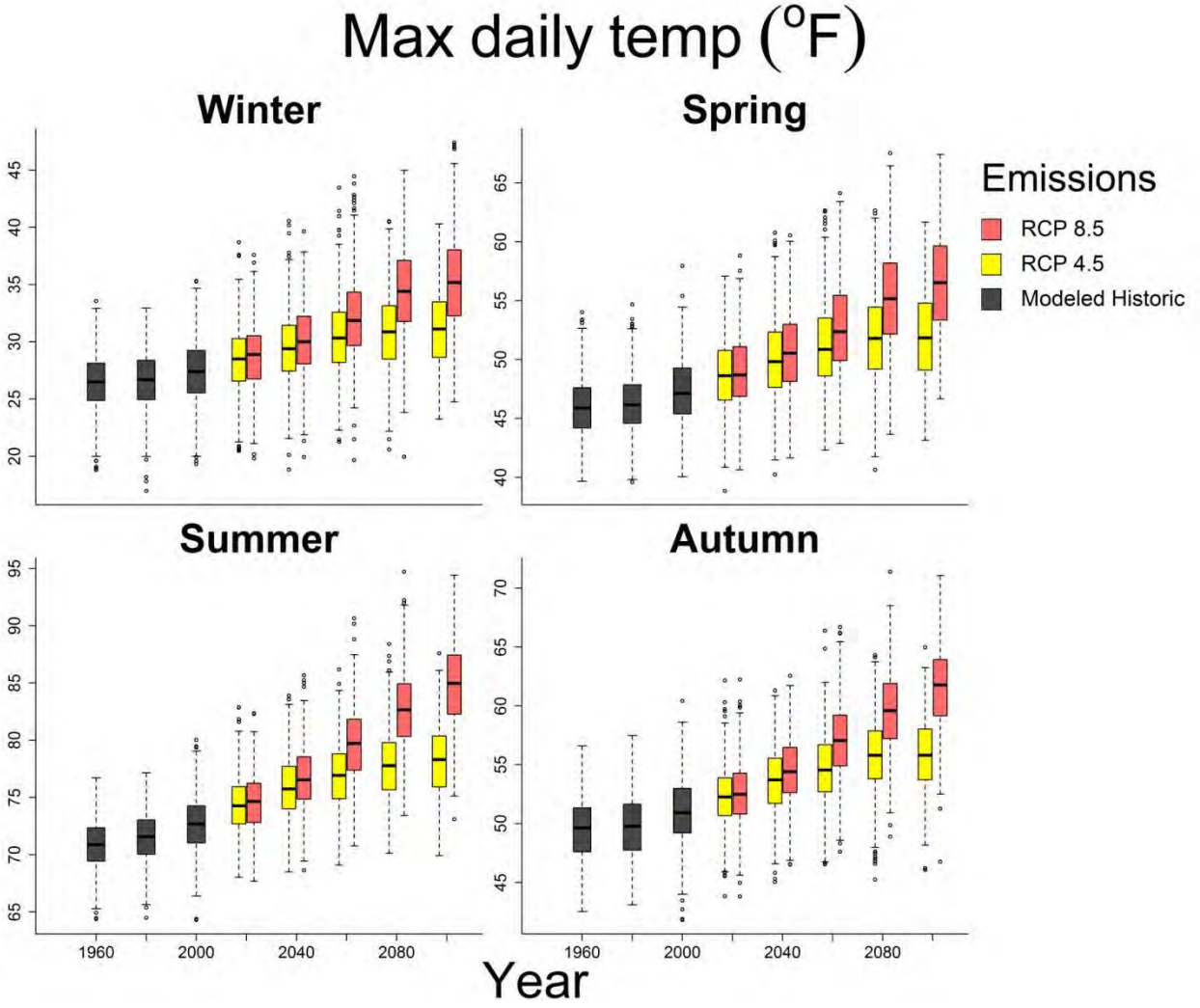


Figure 3.19—Seasonal mean monthly maximum temperature for 1950-2100 for the NRAP Greater Yellowstone subregion. Each box is an aggregation of 20 years of modeled historical or projected seasonal data (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.

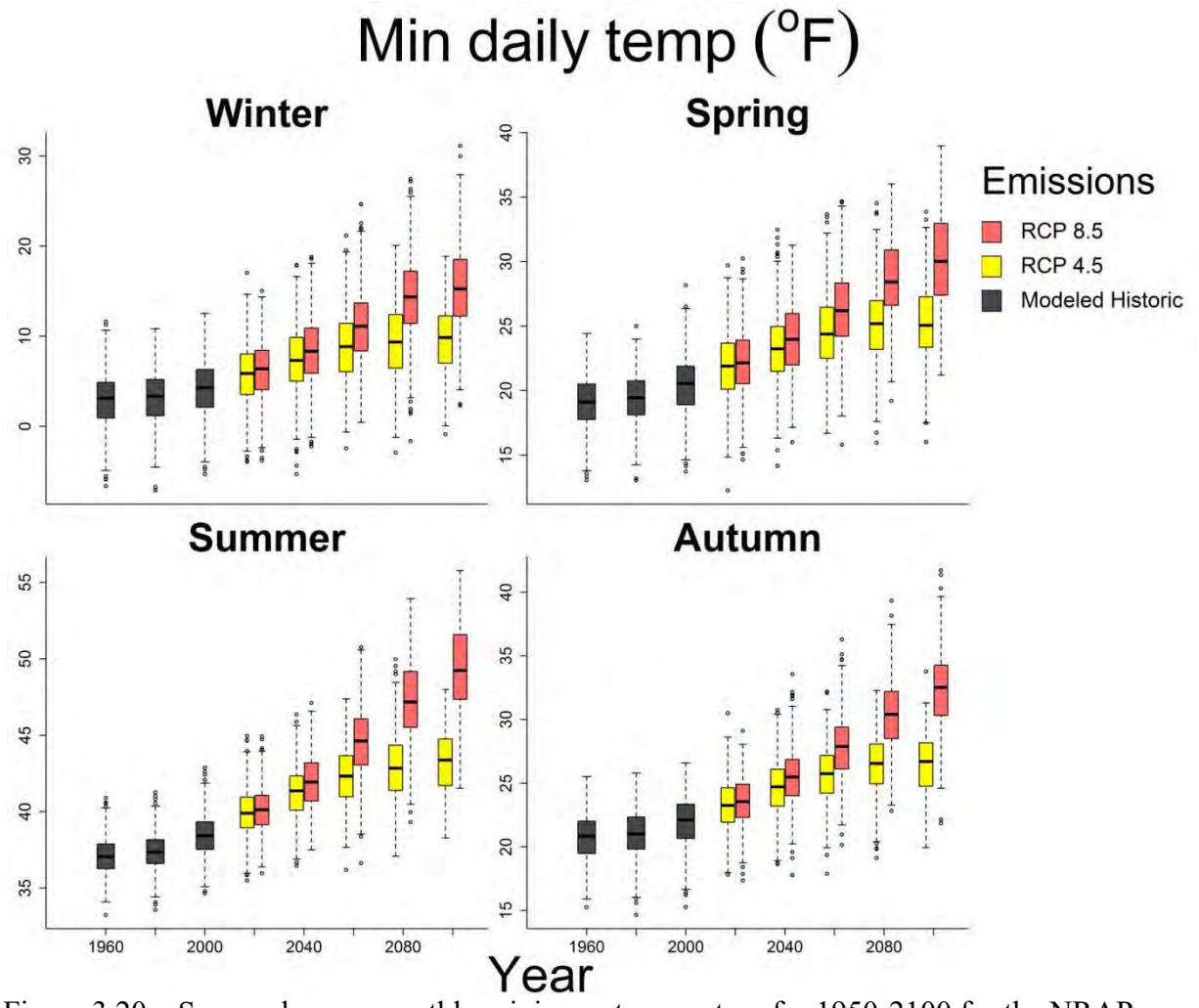


Figure 3.20—Seasonal mean monthly minimum temperature for 1950-2100 for the NRAP Greater Yellowstone subregion. Each box is an aggregation of 20 years of modeled historical or projected seasonal data (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.

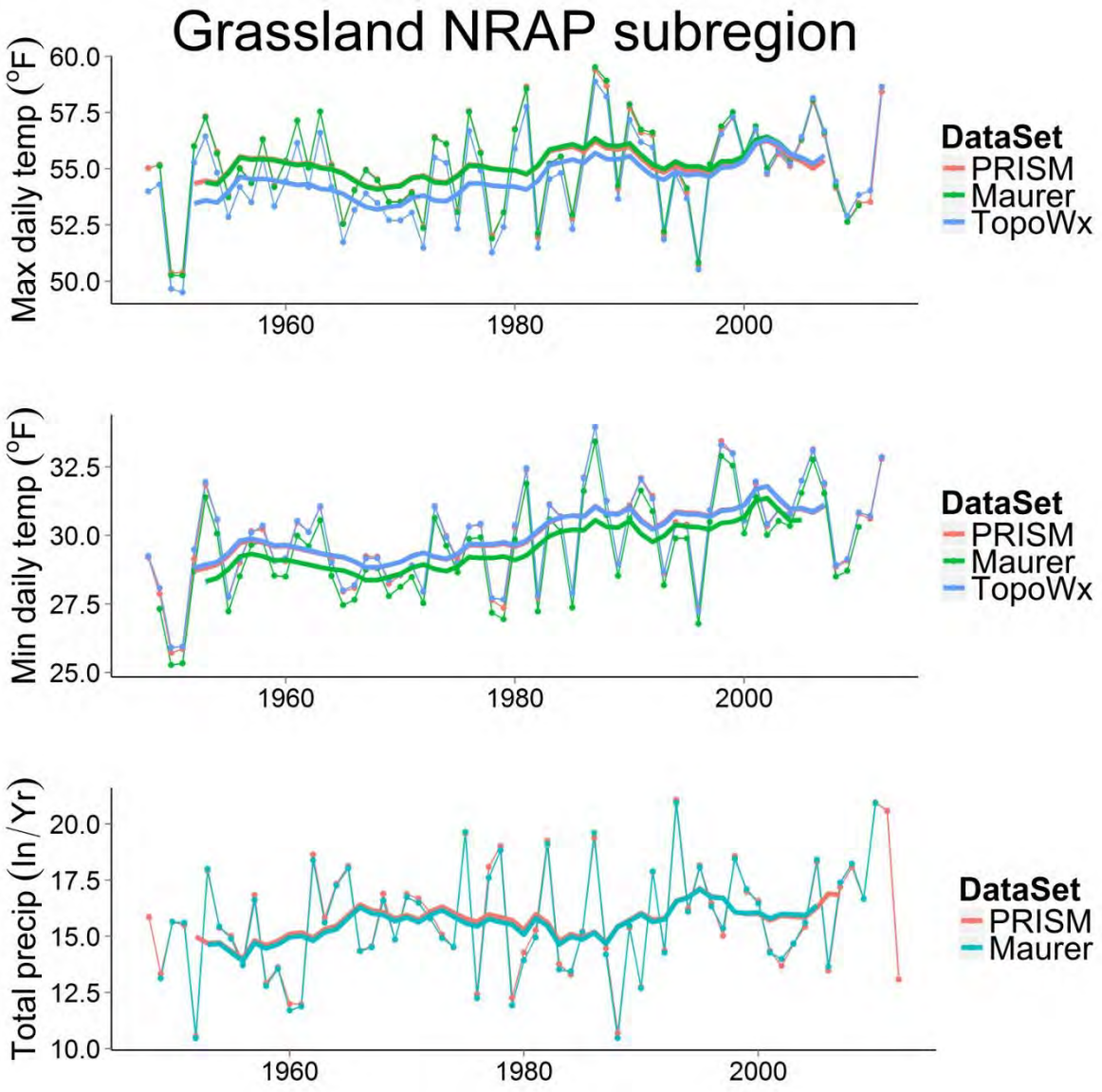


Figure 3.21—Annual historical mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation from monthly gridded PRISM, Maurer and TopoWx for 1949 to 2010 for the NRAP Grassland subregion. The heavy lines are the 10-year rolling average which show short-term trends.

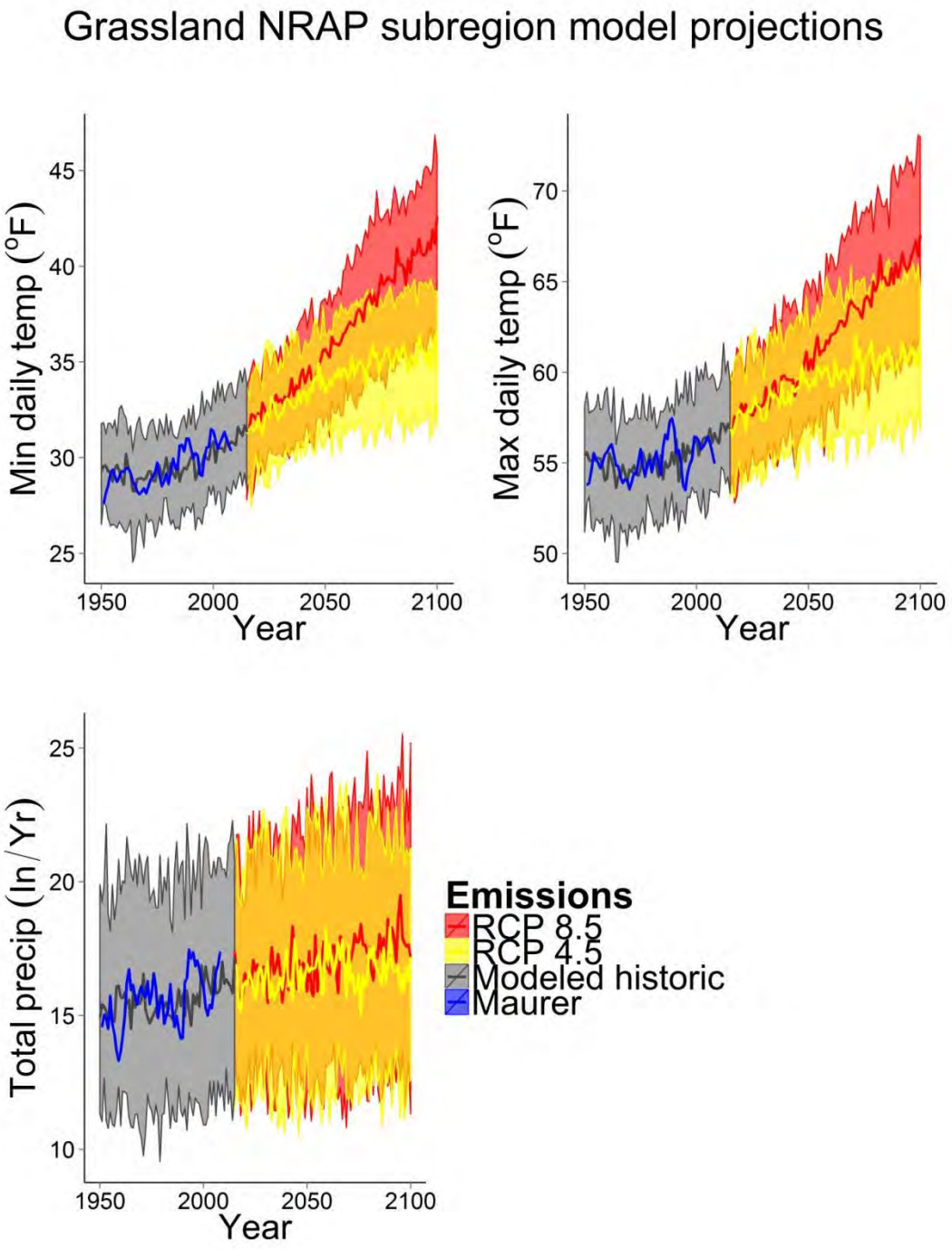


Figure 3.22—Historical modeled and projected annual mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation for the RCP 4.5 and RCP 8.5 emission scenarios based on CMIP5 data for the NRAP Grassland subregion. Historic modeled results are indicated in gray, projections in colors. The shaded area shows the 5th and 95th percent quantiles for all models. The grey, red, or yellow heavy line illustrate ensemble median; the heavy blue line is the gridded historical observed data from Maurer et al. (2002).

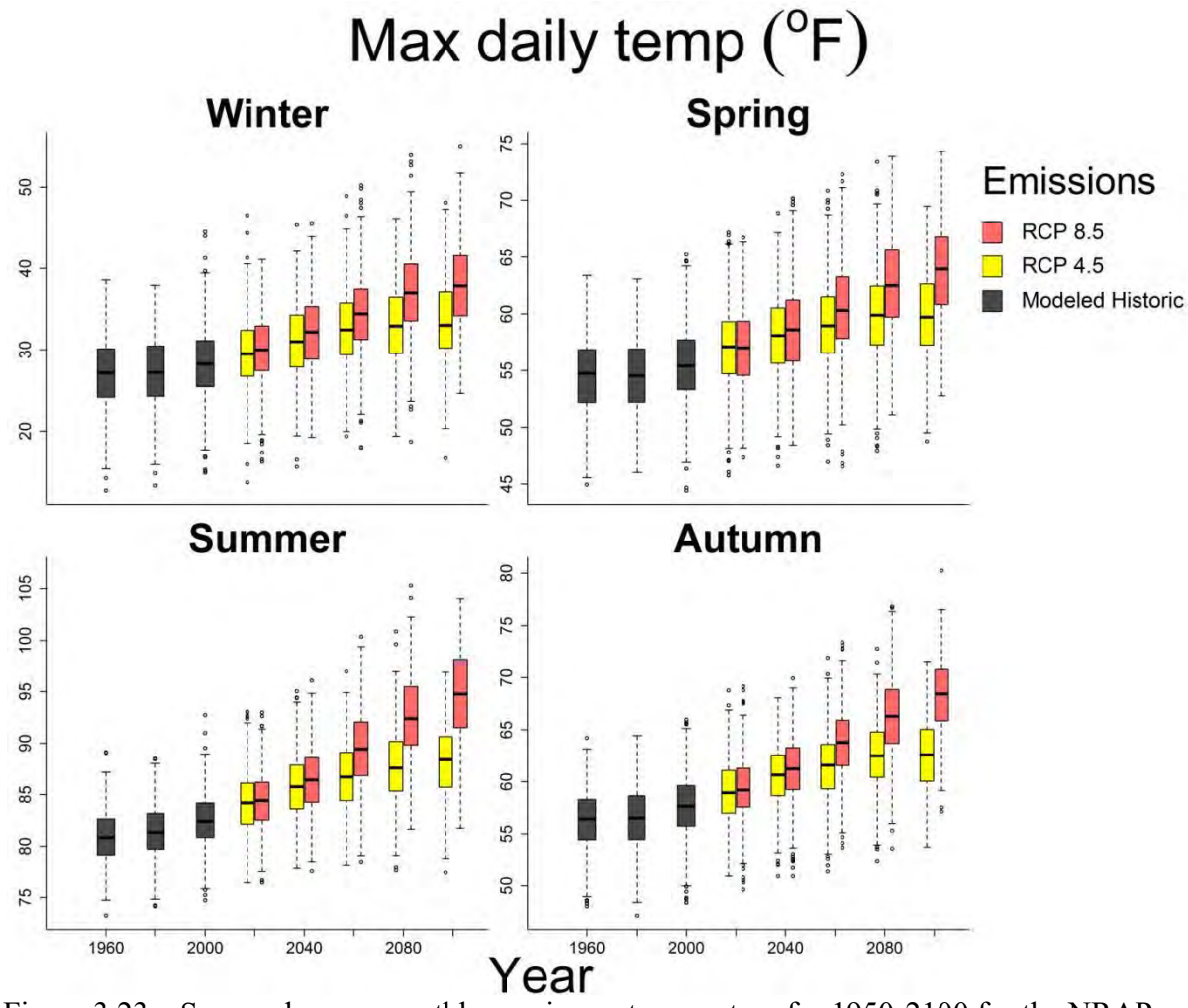


Figure 3.23—Seasonal mean monthly maximum temperature for 1950-2100 for the NRAP Grassland subregion. Each box is an aggregation of 20 years of modeled historical or projected seasonal data (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.

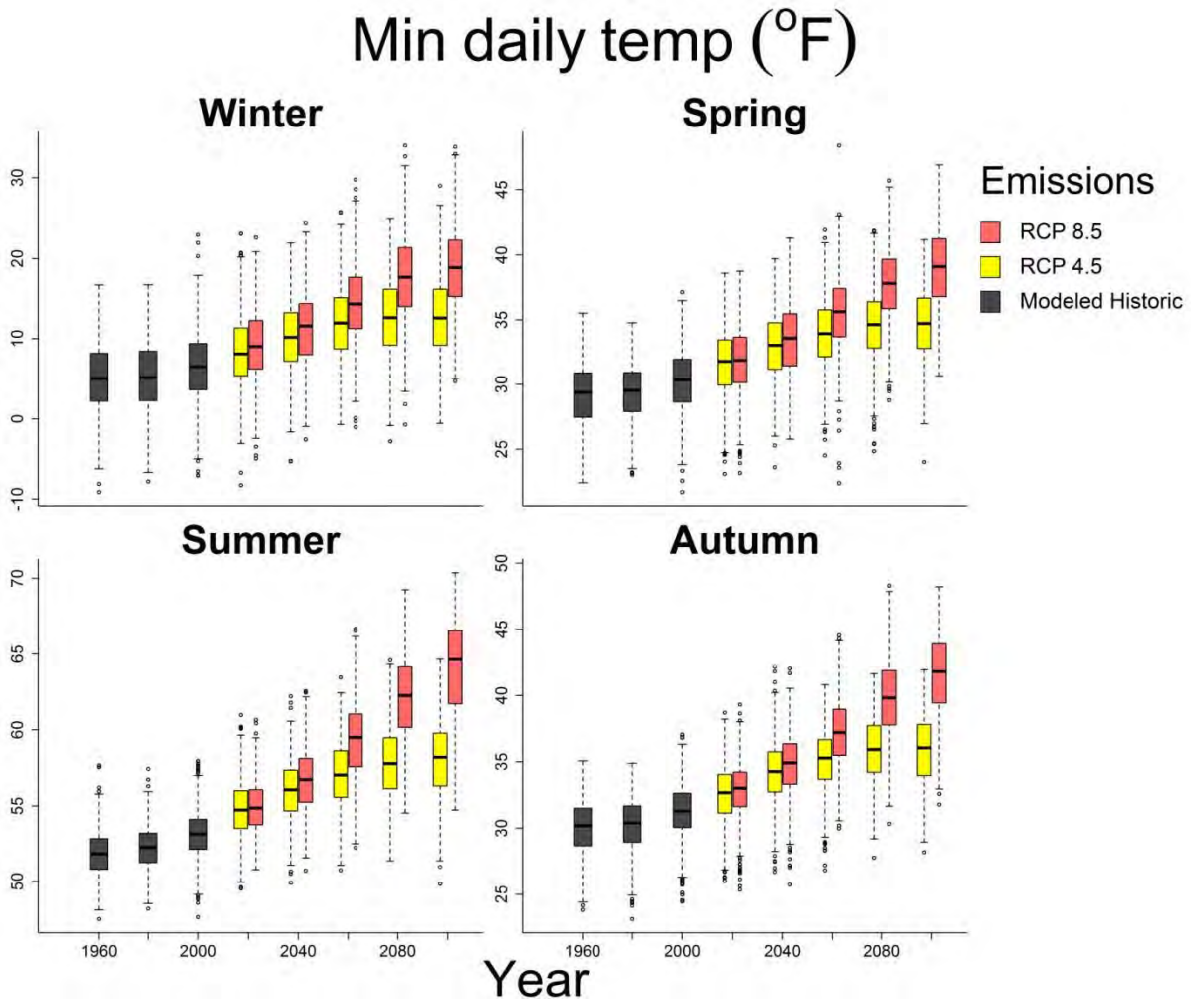


Figure 3.24—Seasonal mean monthly minimum temperature for 1950-2100 for the NRAP Grassland subregion (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). Each box is an aggregation of 20 years of modeled historical or projected seasonal data. For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.

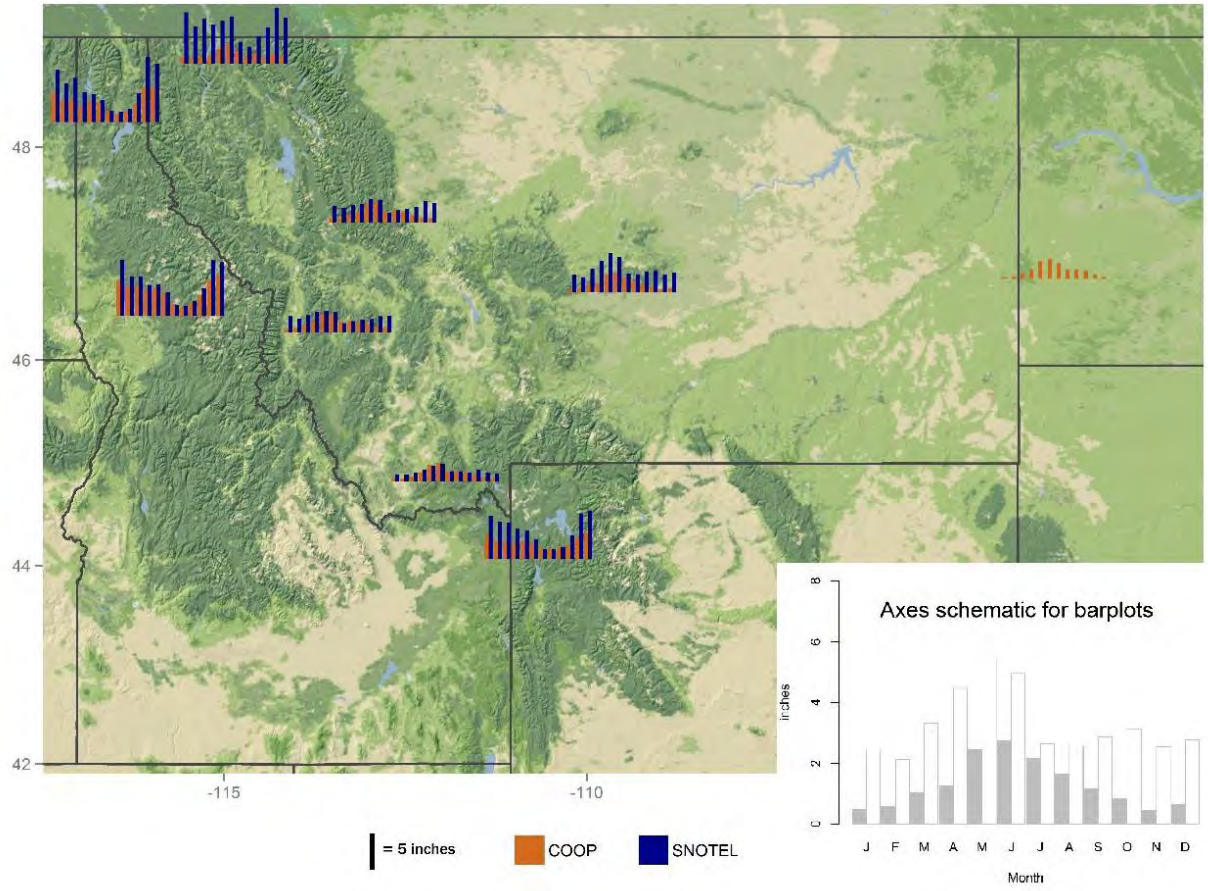


Figure 4.1—Bar graphs of annual precipitation amounts and distribution from several representative locations. More western and higher elevation sites tend to have stronger winter precipitation, with a pronounced lull in July and August. May and June precipitation is generally more pronounced than July and August precipitation and so is likely an important water source for vegetation during the summer drought.

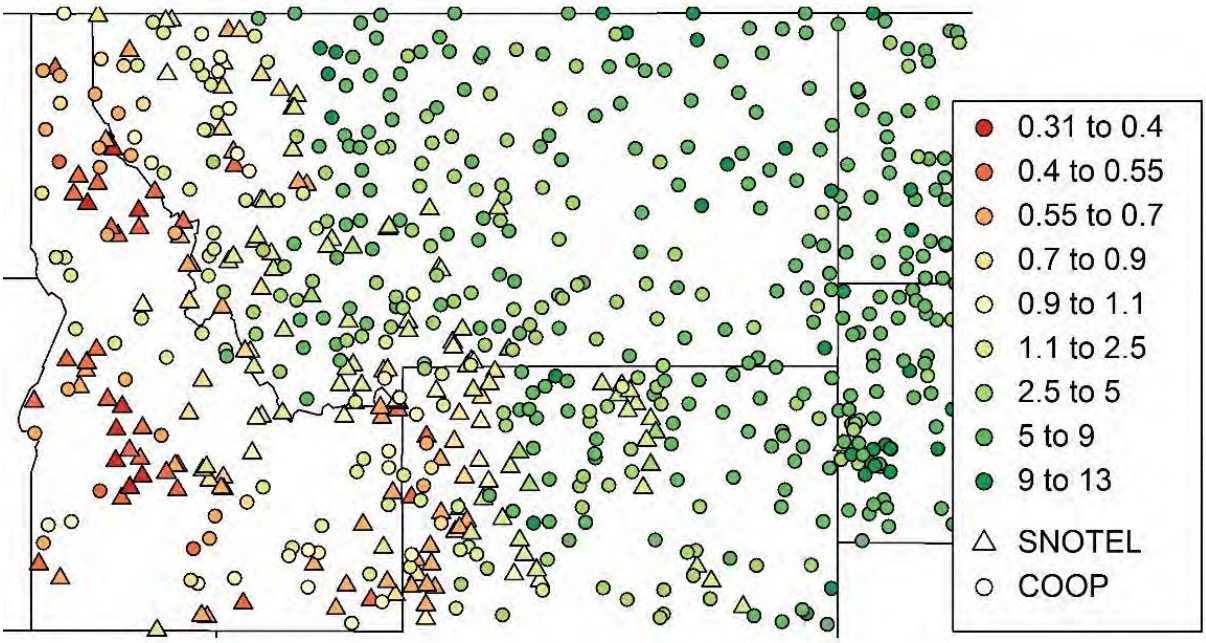


Figure 4.2—An index of precipitation seasonality in the Northern Rockies, a ratio of early summer (May-June) to winter (December-January) precipitation. Greener colors are wetter in May and June. July and August precipitation is low for most locations. Of note is the relative contribution of May through June precipitation in western Montana and central Idaho compared to mountains (SNOTEL sites) further south. There is also a notable difference in mountain versus local valley (COOP sites) seasonality.

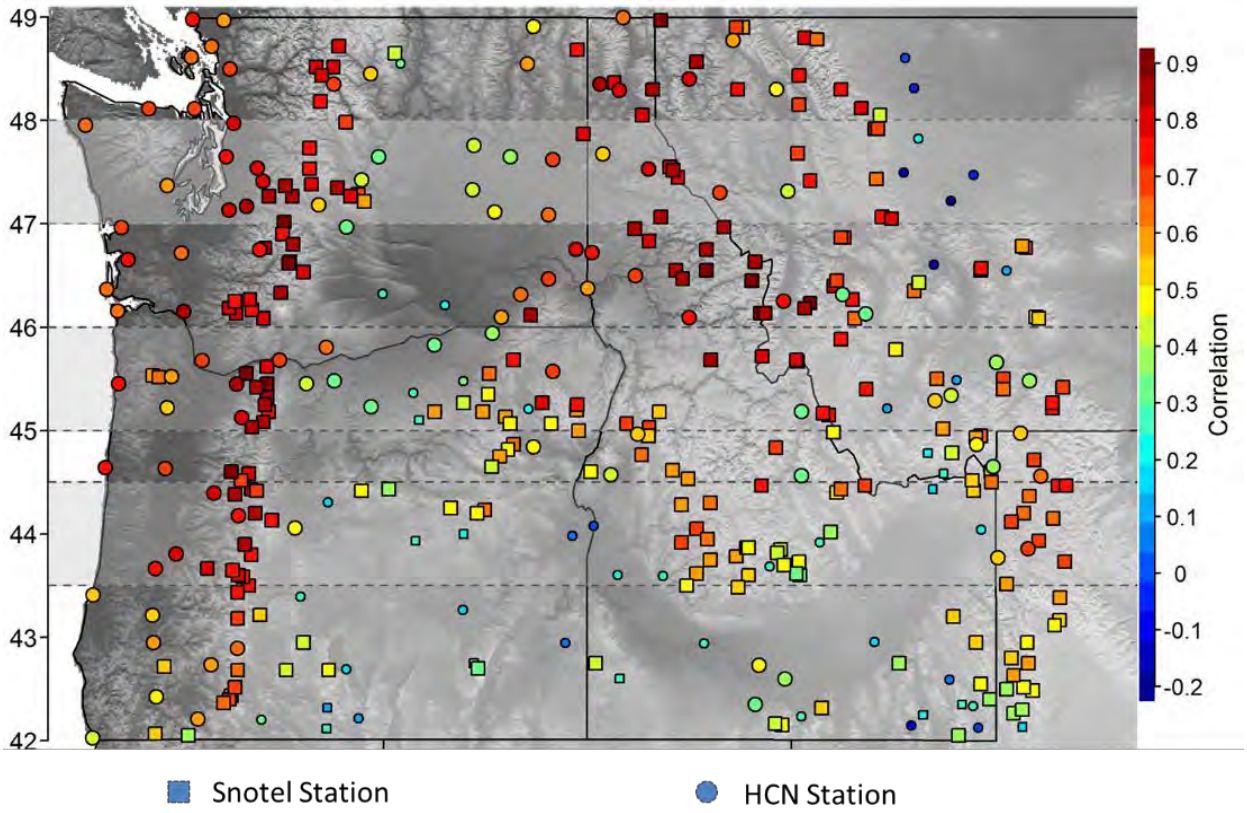


Figure 4.3—Correlation of winter precipitation to winter westerly wind speed across the Pacific Northwest (From Luce et al. 2013).

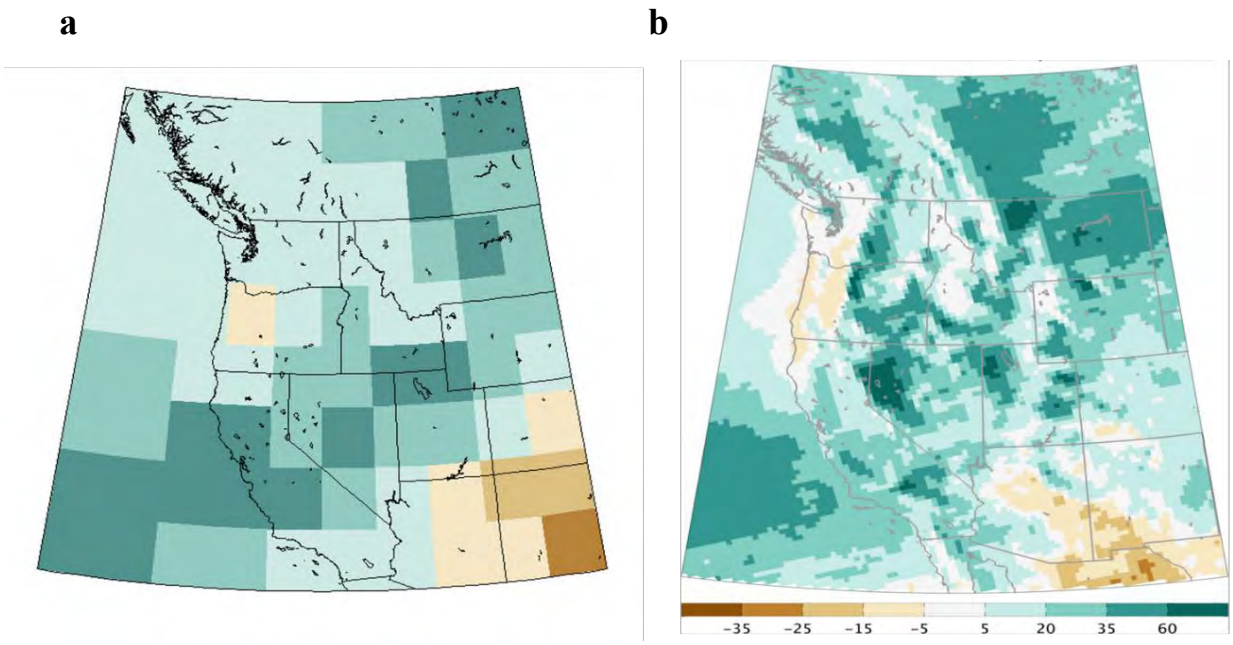


Figure 4.4—October through March precipitation change for 2041-2070 versus 1971-2000 as represented by a) a global circulation model (CanESM2) and b) a regional climate model with finer topographic detail.

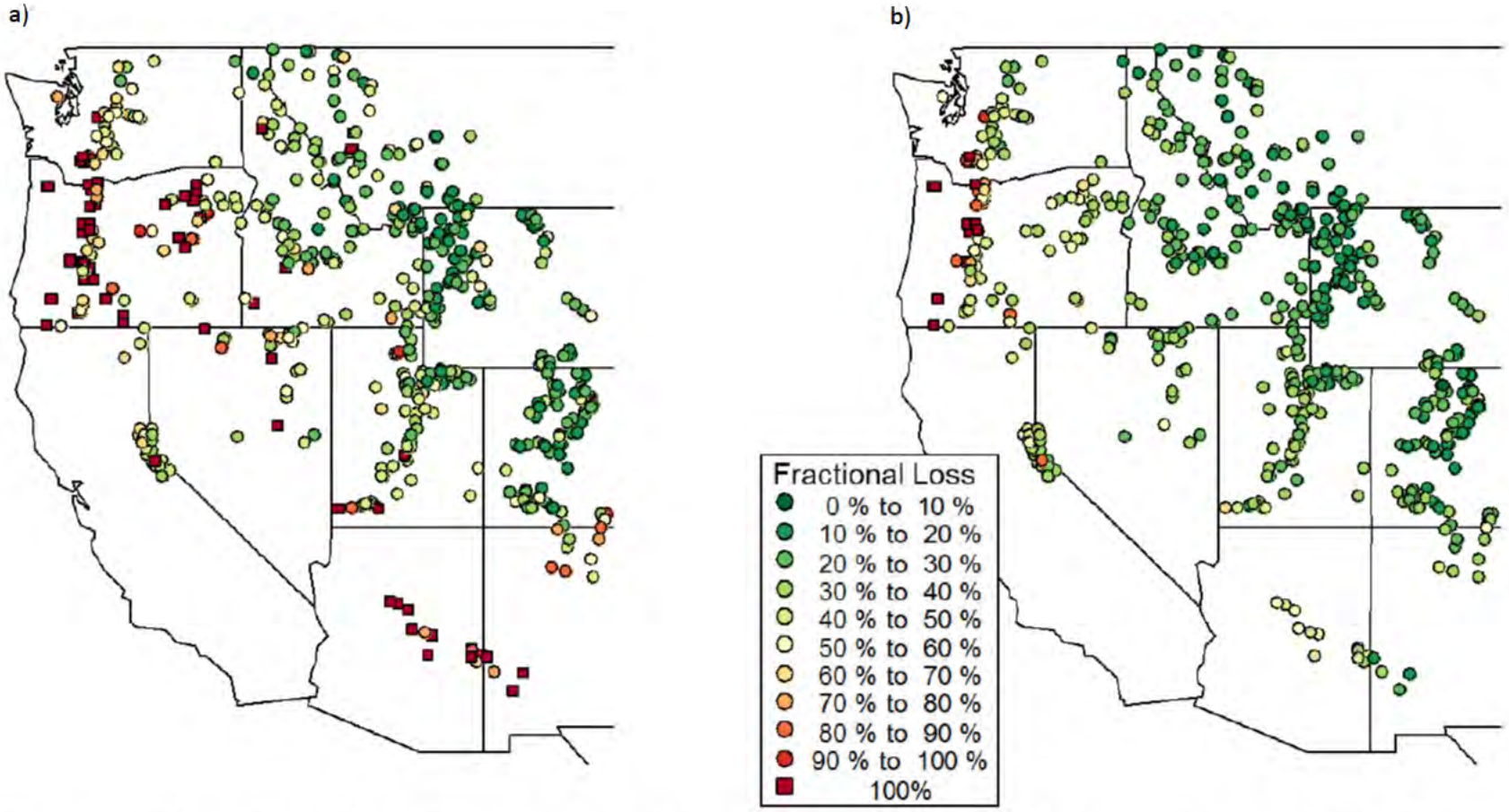


Figure 4.5—Estimated loss of a) April 1 snow water equivalent and b) mean snow residence time as related to warming of 5.4 °F (from Luce et al. 2014).

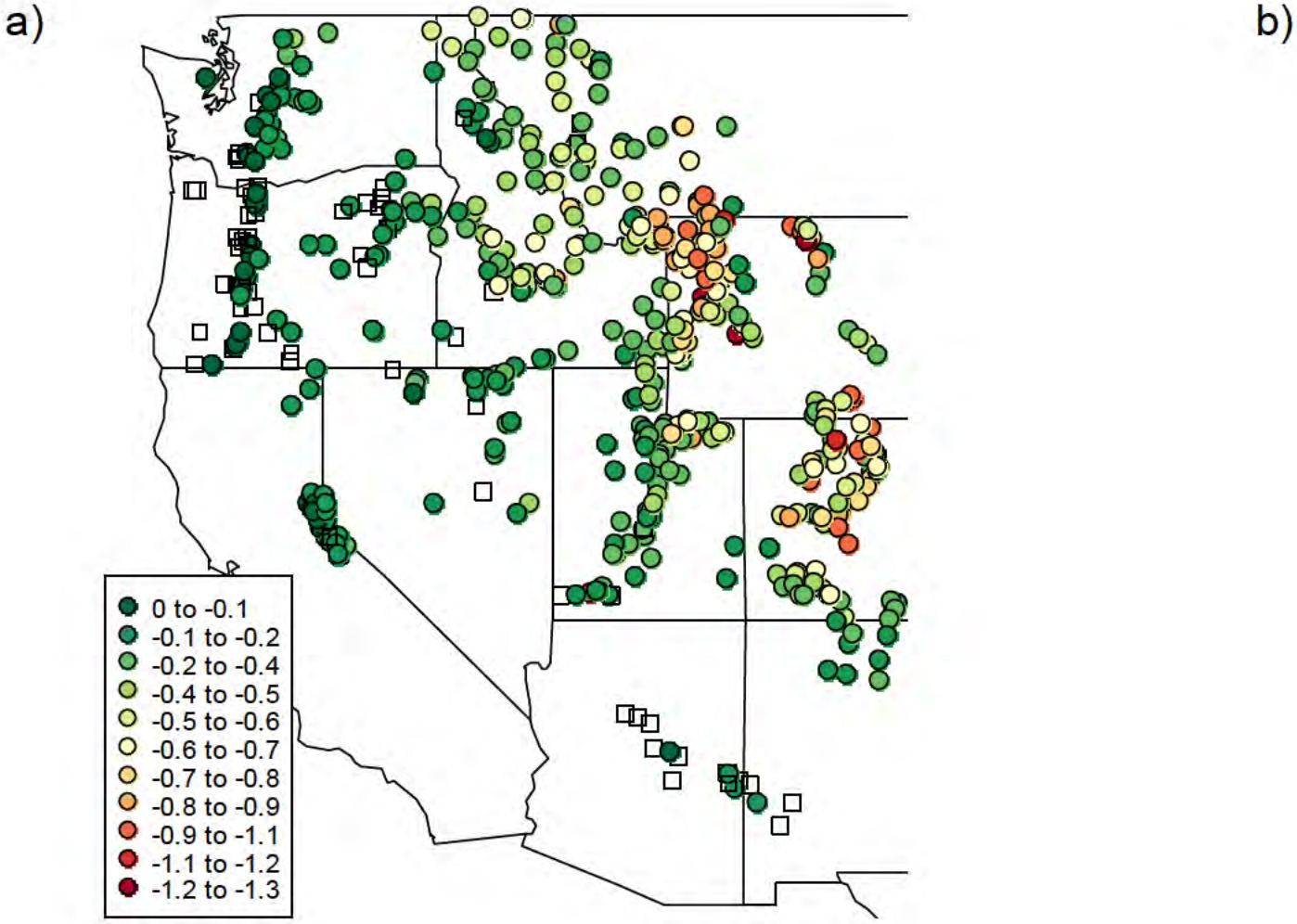


Figure 4.6—Uncertainty ratio for April 1 snow water equivalent. Orange to dark red sites are strongly influenced by precipitation in contrast to temperature. Thus, temperature based projections in those sites may be inaccurate if precipitation changes are large. At dark green (and white) sites, temperature effects will predominate, and precipitation changes in either direction are inconsequential.

Figure 4.7—Oblique view of Grinnell Glacier taken from the summit of Mount Gould, Glacier National Park (After Fagre 2005).

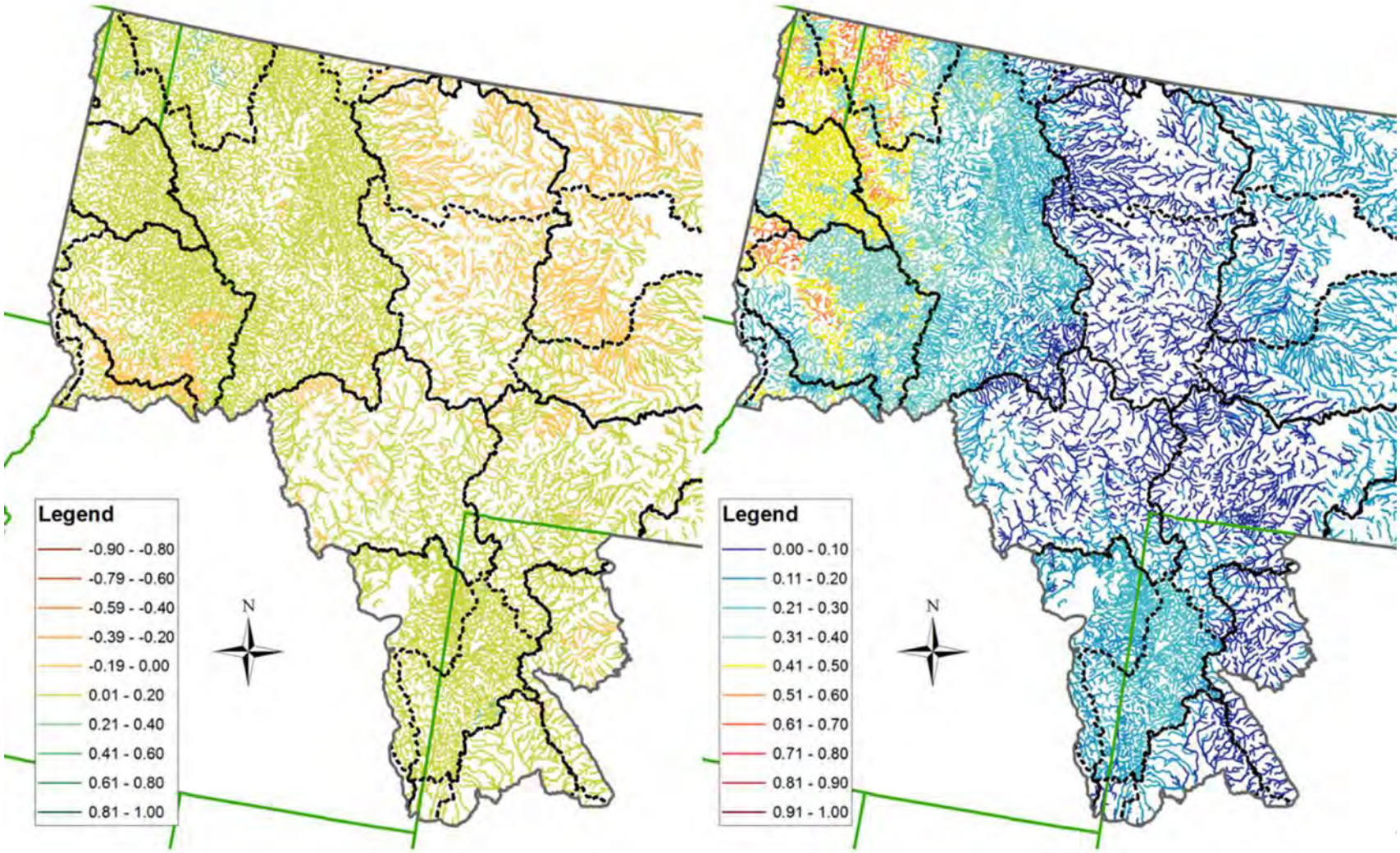


Figure 4.8—Projections for fractional change in mean annual flow for the 2080s compared to 1977-2006. The ensemble mean is on the left while the range between two disagreeing projections is shown on the right.

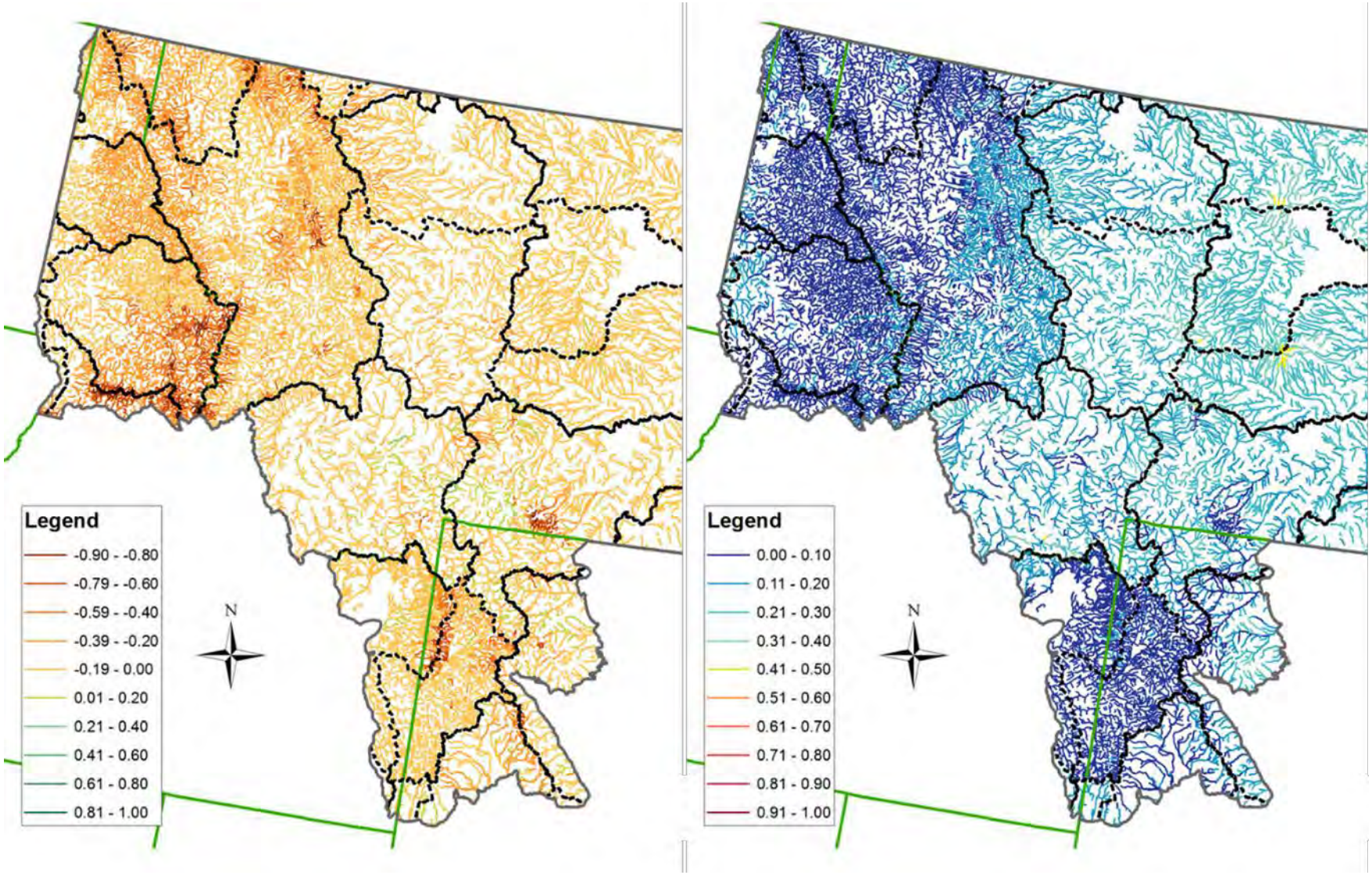


Figure 4.9—Projections for fractional change in mean summer flow (June-September) for the 2080s compared to 1977-2006. The ensemble mean is on the left while the range between two disagreeing projections is shown on the right.

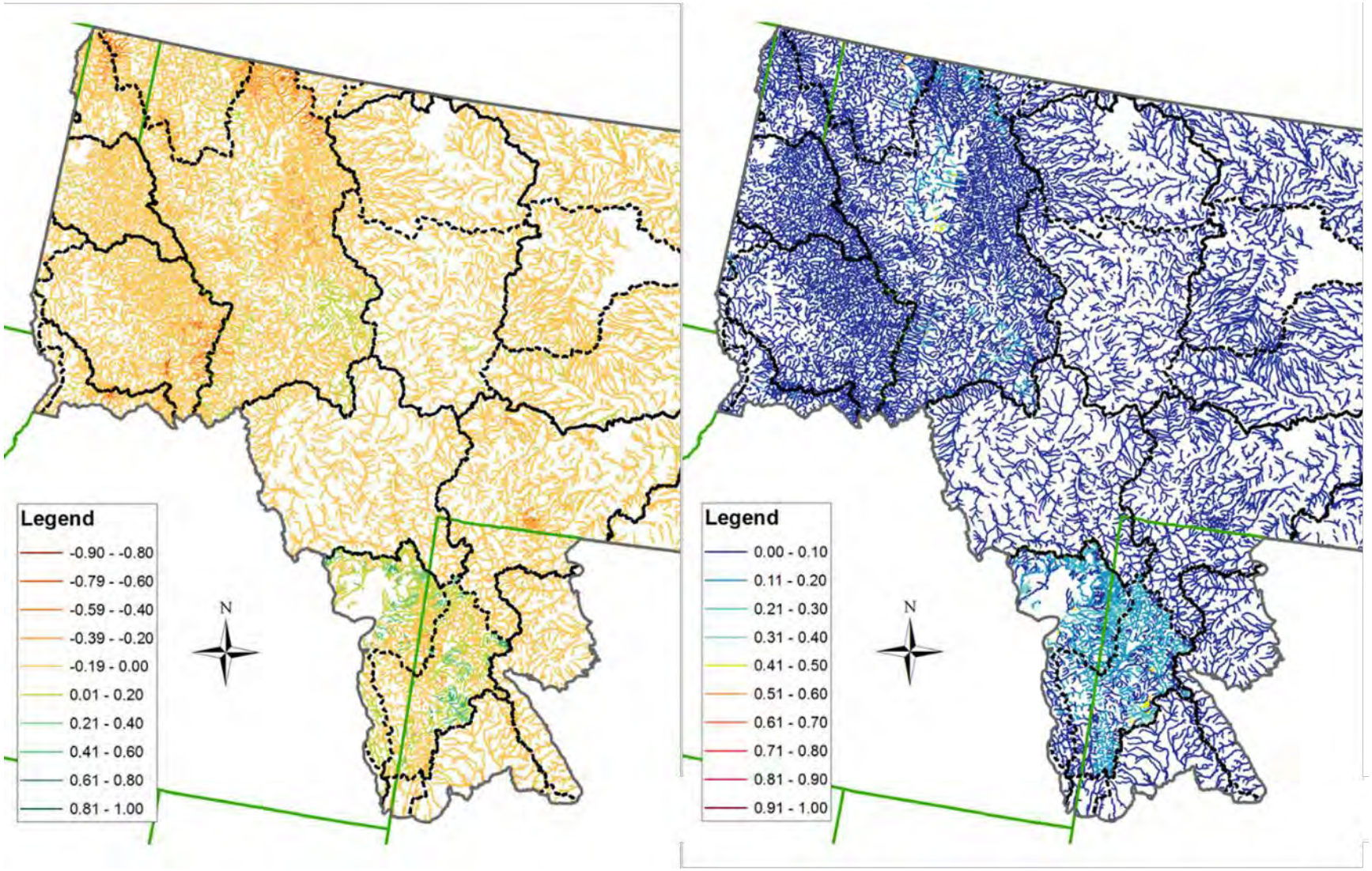


Figure 4.10—Projections for fractional change in minimum weekly flow with a 10-year return probability (7Q10) for the 2080s compared to 1977-2006. The ensemble mean is on the left while the range between two disagreeing projections is shown on the right.

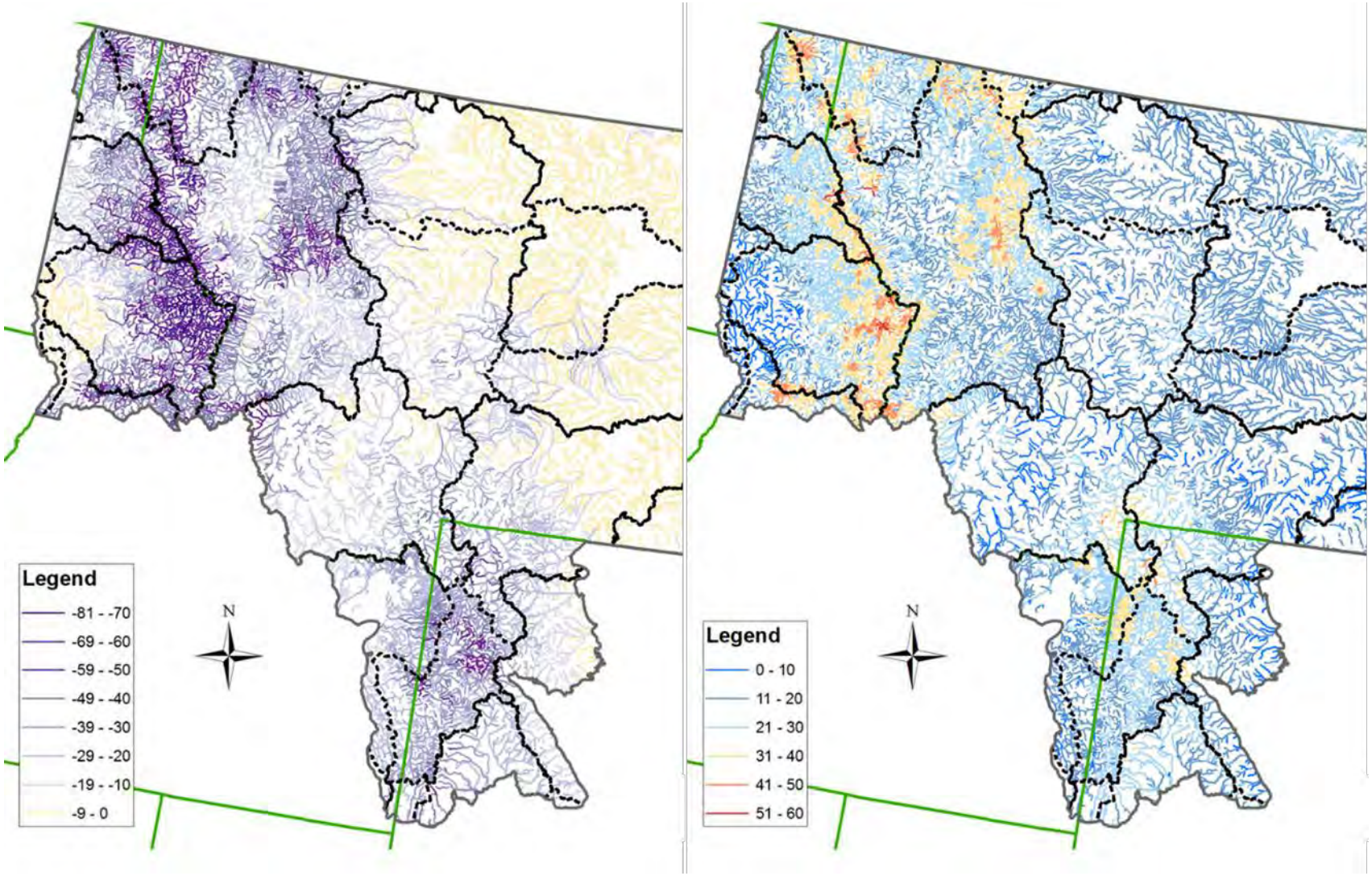


Figure 4.11—Projections for number of days of change in center of streamflow timing for the 2080s compared to 1977-2006. The ensemble mean is on the left while the range between two disagreeing projections is shown on the right.

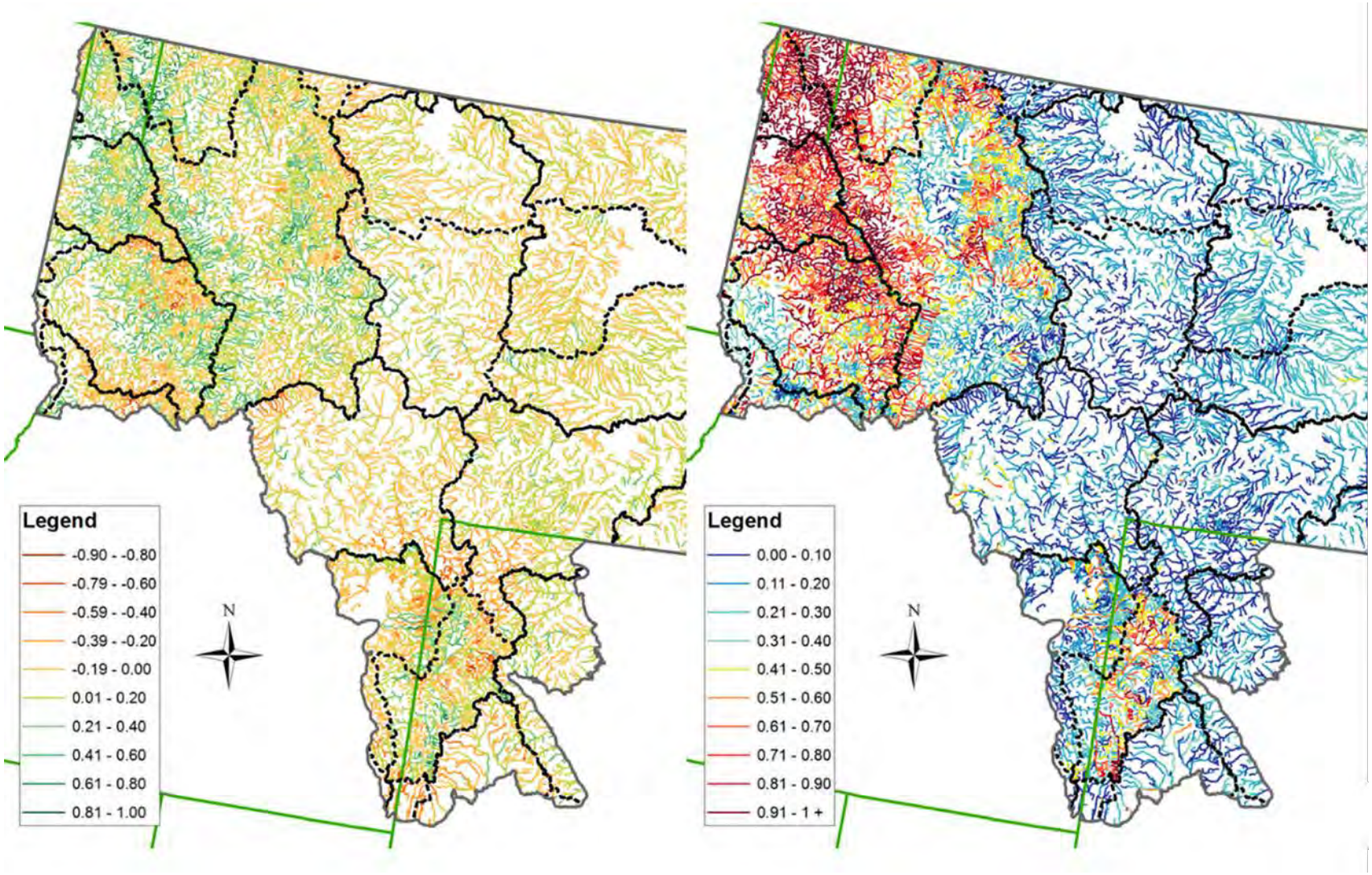


Figure 4.12—Projections for fractional change in 1.5-year flood magnitude (approximate "bankfull" flow) for the 2080s compared to 1977-2006. The ensemble mean is on the left while the range between two disagreeing projections is shown on the right.

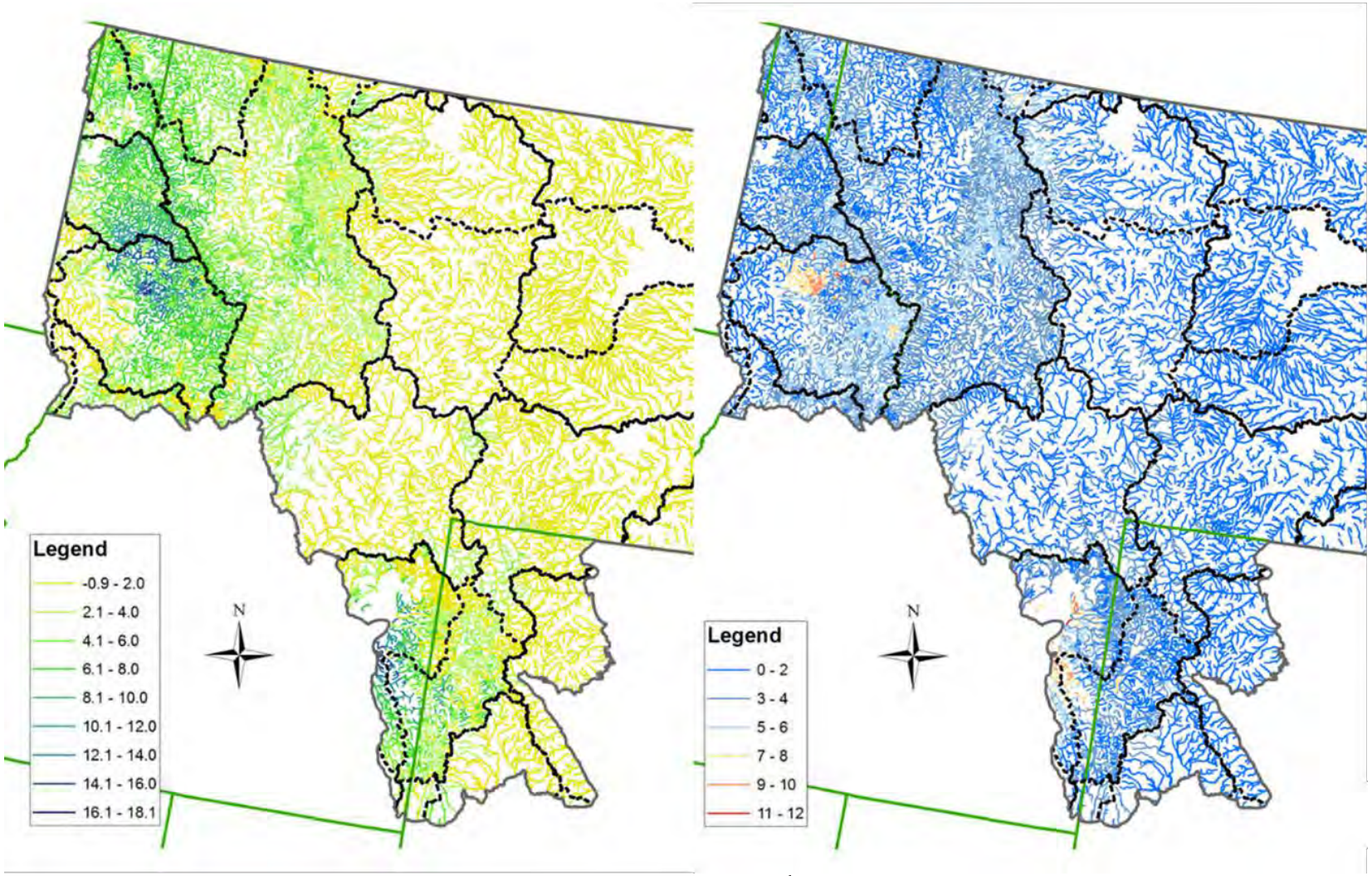


Figure 4.13—Projections for number of days in winter that exceed the 95th percentile flow in each year, an indicator of when floods are likely to happen, for the 2080s compared to 1977-2006. The value of this metric can take on values between 0 and 18.25, and the difference can take on the same range. The ensemble mean is on the left while the range between two disagreeing projections is shown on the right.

Figure 5.1—Northern Rockies Adaptation Partnership analysis area for cutthroat trout and bull trout, including the U.S. Forest Service Northern Region (white border). Bull trout range encompasses basins west of the Continental Divide and the St. Mary River basin (yellow dashed line), whereas historical cutthroat trout range includes most of the analysis area.

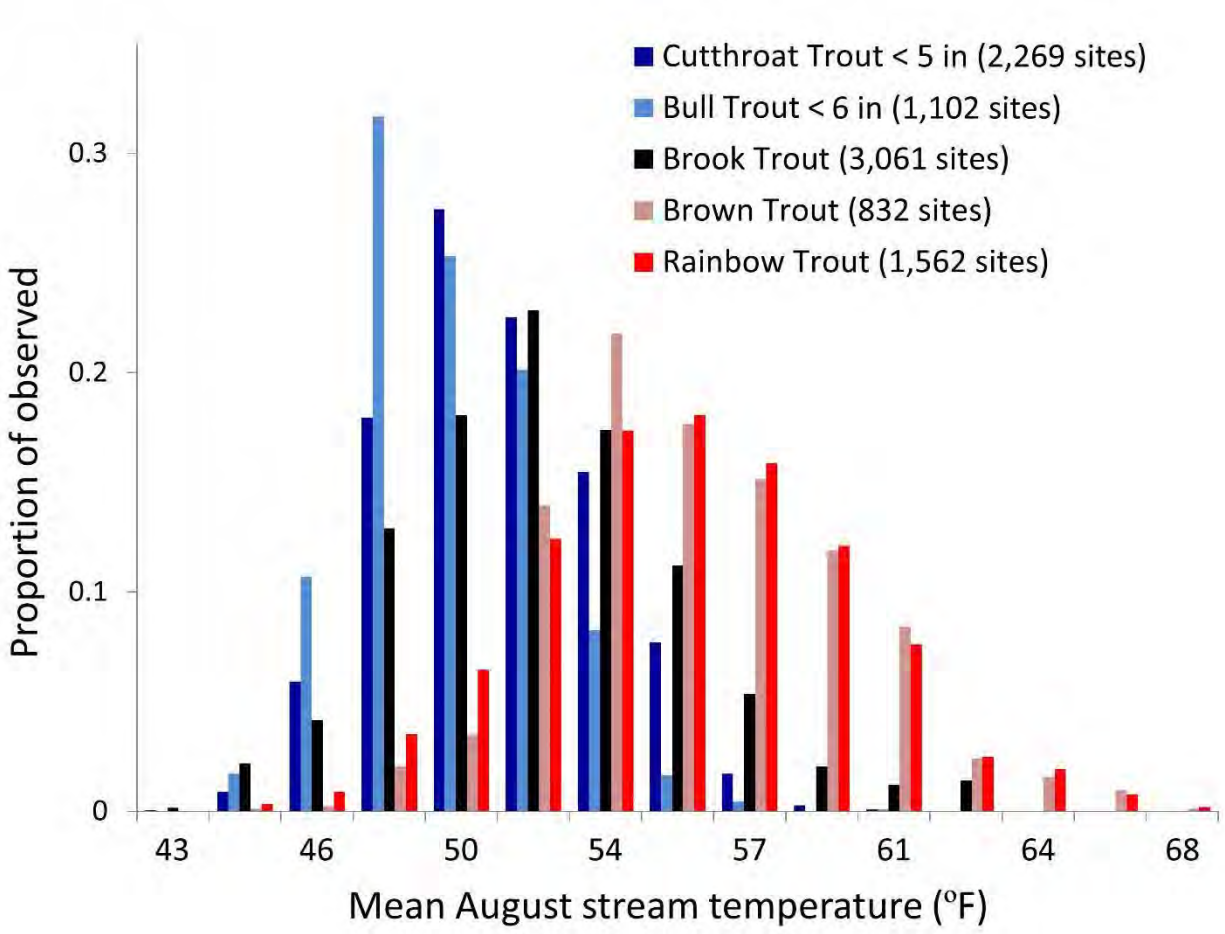


Figure 5.2—Presence of juvenile bull trout and cutthroat trout and all age classes of other trout species at sampling sites relative to temperature projections from the NorWeST baseline scenario of mean August temperature. Figure reproduced from Isaak et al. (2015).

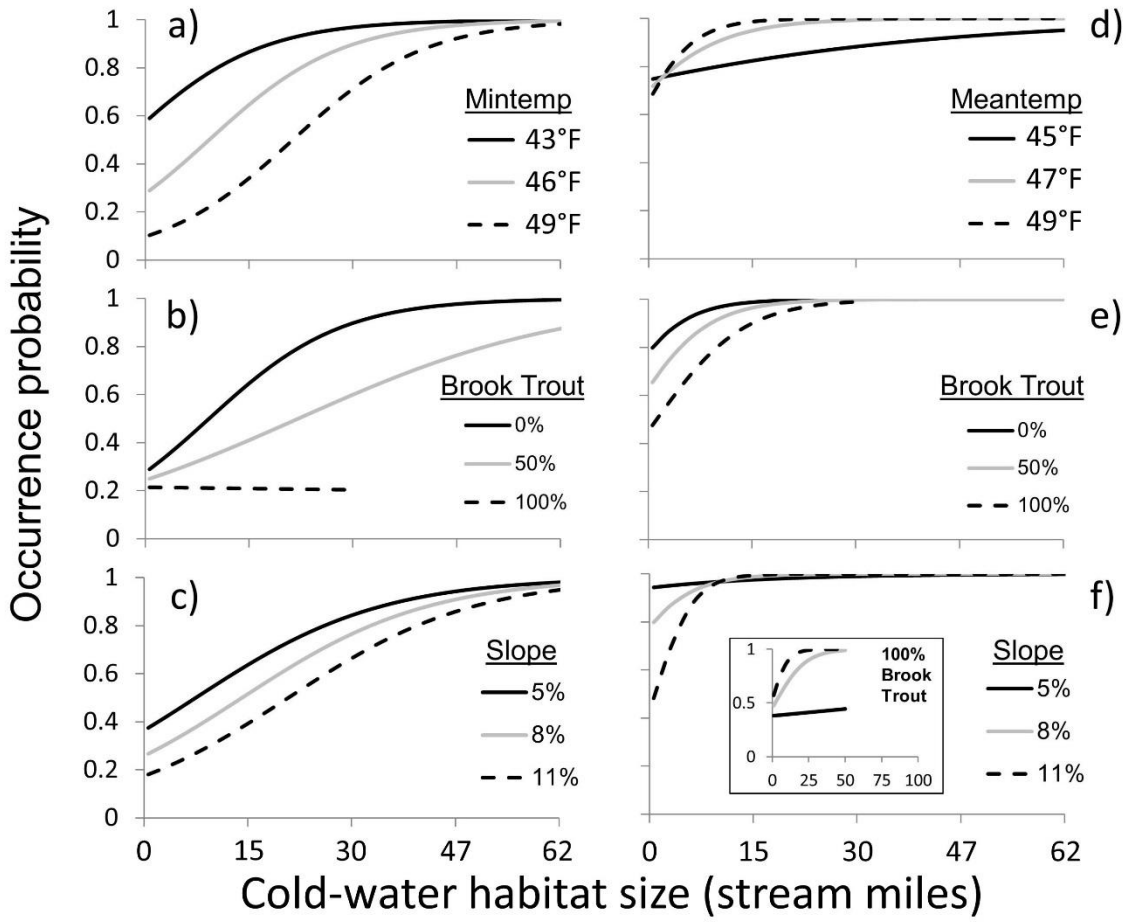


Figure 5.3—Relations between environmental covariates and probability of occupancy of juvenile native trout developed from 512 bull trout (a, b, c) and 566 cutthroat trout (d, e, f) cold-water habitats. Relations are conditioned on mean values of two independent variables not shown in a panel. An exception occurs for cutthroat trout with regard to stream slope (f) where brook trout values of 0% and 100% were used to highlight the interaction between these covariates. Figure reproduced from Isaak et al. (2015).

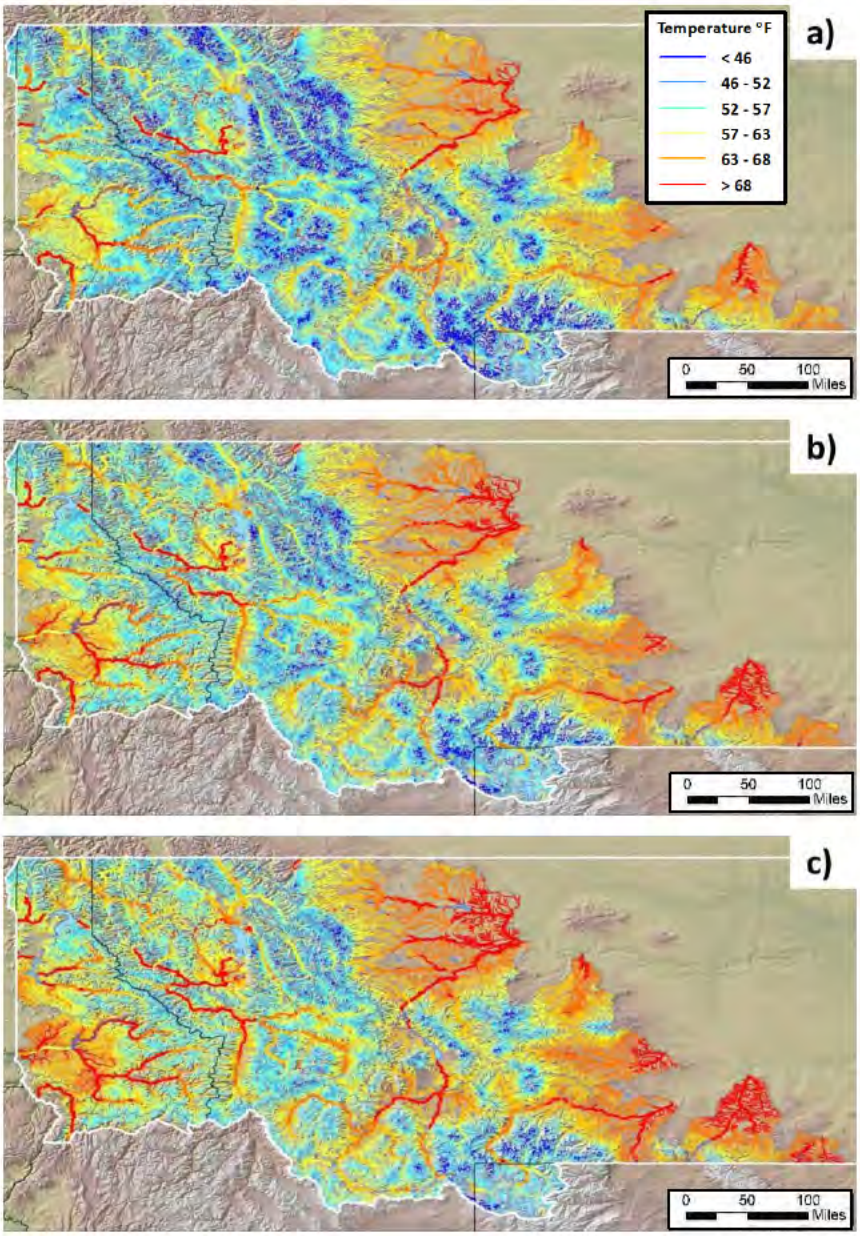


Figure 5.4—NorWeST August mean stream temperature maps interpolated from 11,703 summers of monitoring data at 5,461 unique stream sites across the 114,000 mi of streams in the analysis area. Map panels show conditions during baseline (a, 1980s), moderate (b, 2040s), and extreme change scenarios (c, 2080s). Networks were trimmed to represent potential fish-bearing streams by excluding reaches with slopes greater than 15 percent and Variable Infiltration Capacity model summer flows less than 0.20 $ft^3 s^{-1}$. High-resolution digital images of these maps and ArcGIS databases with reach-scale predictions are available at the NorWeST website (http://www.fs.fed.us/rm/boise/AWAE/projects/NorWeST.html).

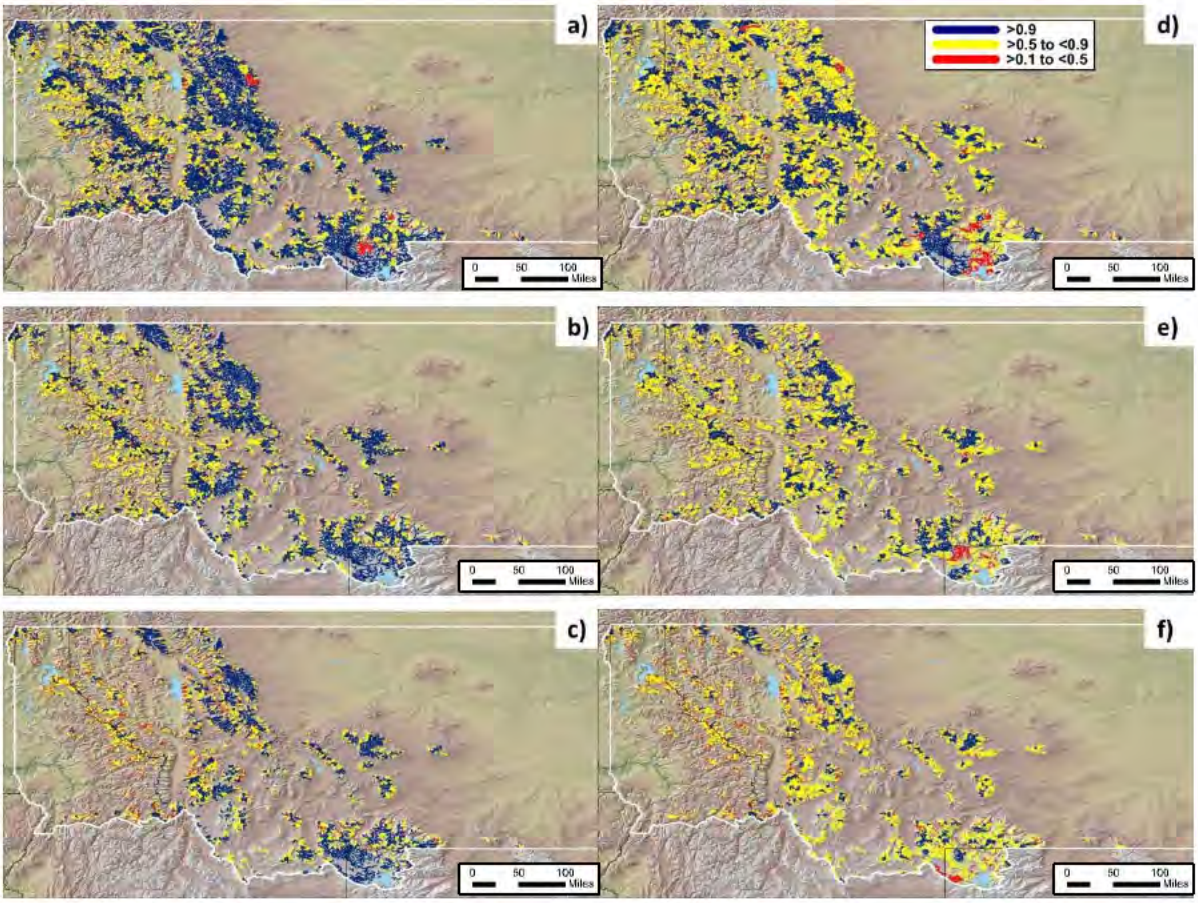


Figure 5.5—Distribution of cold-water habitats with probabilities of occupancy greater than 0.1 for juvenile cutthroat trout during baseline (a and d, 1980s), moderate change (b and e, 2040s), and extreme change scenarios (c and f, 2080s). Panels a–c illustrate occupancy when brook trout are absent. Panels d–f illustrate occupancy when brook trout prevalence is 50 percent. High-resolution digital images and ArcGIS databases of these maps with stream-specific projections are available at the Climate Shield website (http://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield/maps.html).

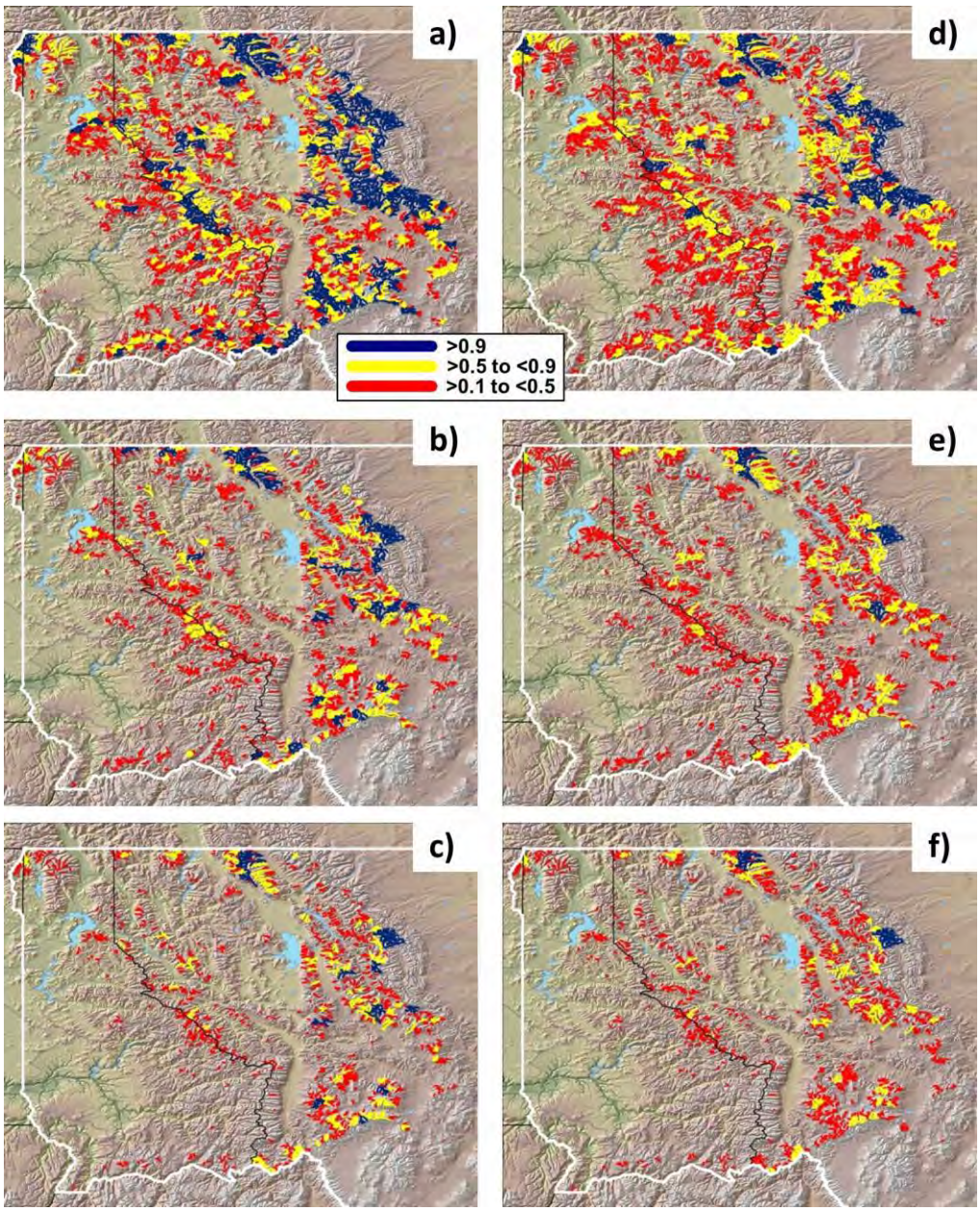


Figure 5.6—Distribution of cold-water habitats with probabilities of occupancy greater than 0.1 for juvenile bull trout during baseline (a and d, 1980s), moderate change (b and e, 2040s), and extreme change scenarios (c and f, 2080s). Panels a–c illustrate occupancy when brook trout are absent. Panels d–f illustrate occupancy when brook trout prevalence is 50 percent. High-resolution digital images and ArcGIS databases of these maps with stream-specific predictions are available at the Climate Shield website (http://www.fs.fed.us/rm/boise/AWAE/projects/ClimateShield/maps.html).

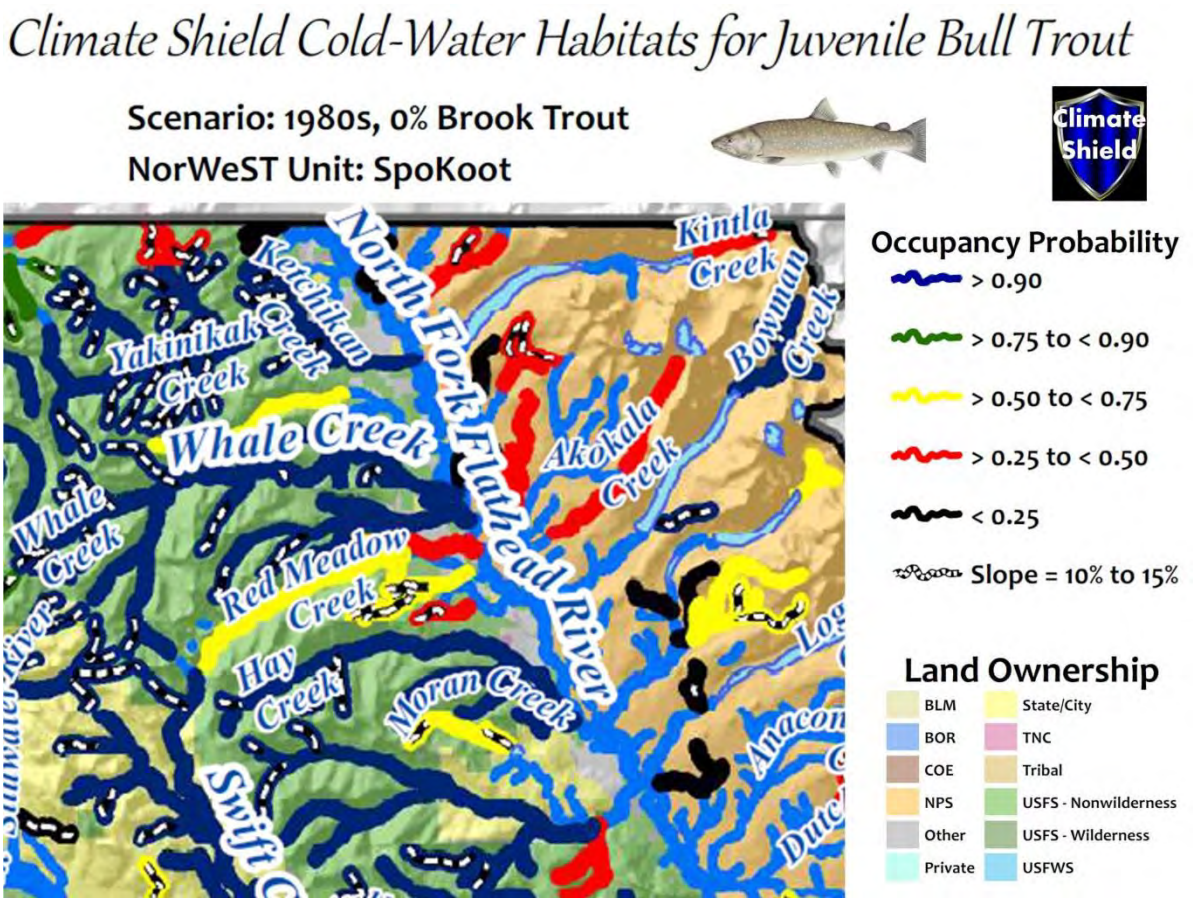


Figure 5.7—Example of a detailed Climate Shield map available at the project website that shows probabilities of juvenile bull trout occupancy in cold-water habitats during the 1980s baseline period in the North Fork Flathead River basin. Maps with identical formats for three climate periods and five brook trout invasion scenarios are available as .pdf and ArcGIS files for all bull trout and cutthroat trout streams across the northwestern United States.

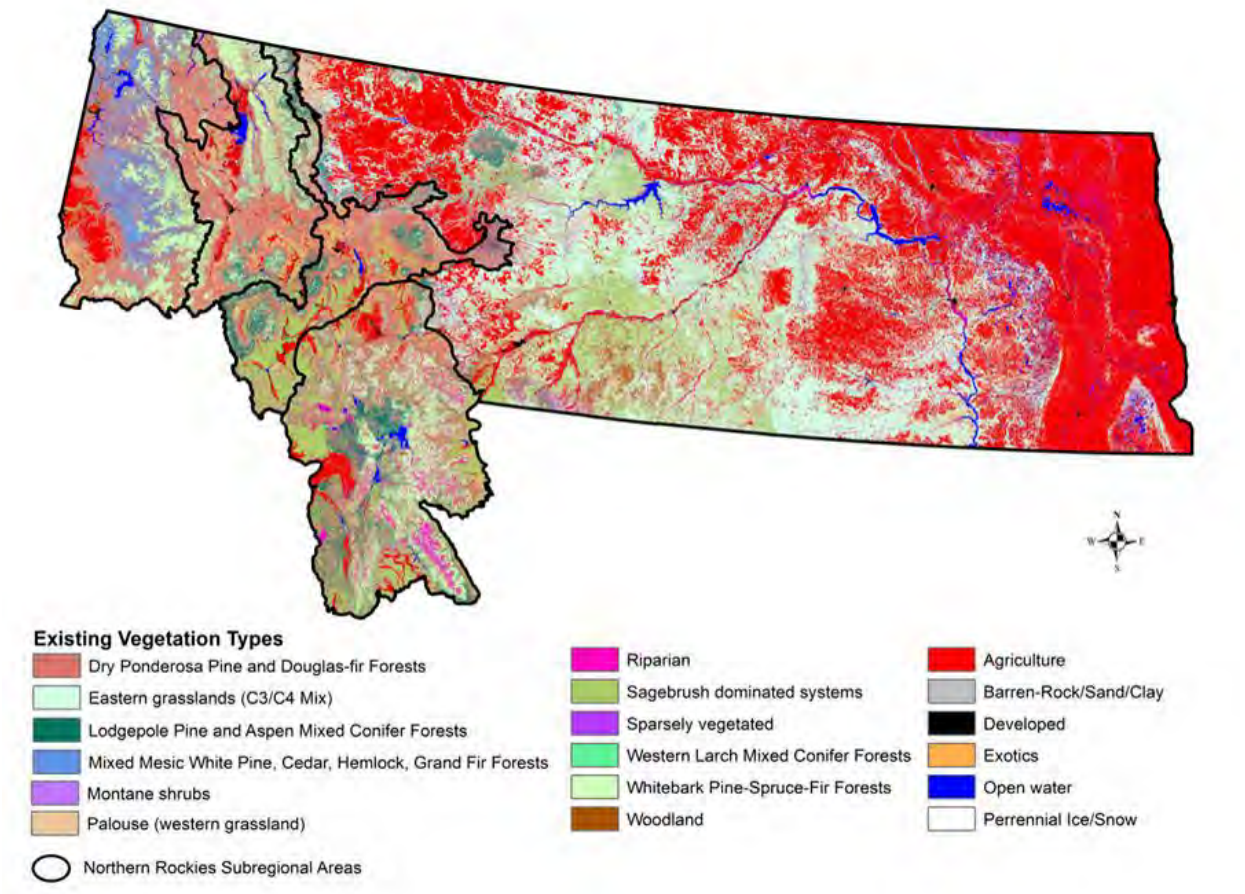


Figure 6.1—The Northern Rockies (NR) assessment area that includes the Northern Region of the U.S. Forest Service and the Greater Yellowstone Area (Yellowstone National Park and surrounding areas). Presented are existing vegetation types by the five geographic sub-areas used to stratify assessments in this report. This map was created from the LANDFIRE Existing Vegetation Type map by aggregating the National Vegetation Classification Standard vegetation types into a set of vegetation types that has some meaning across the NR at this coarse scale. This map is intended to convey current vegetation of the NR.

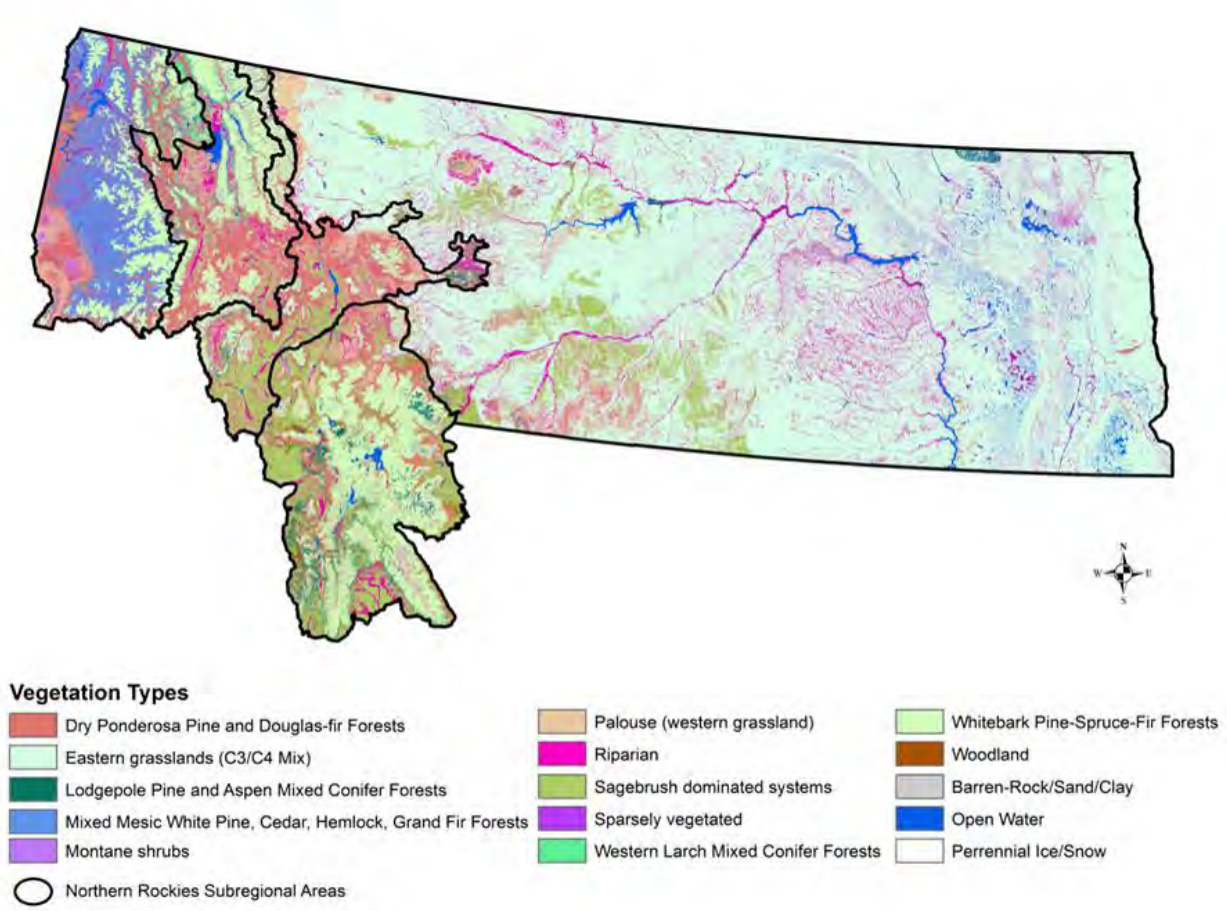


Figure 6.2—Potential vegetation types for the entire NRAP assessment area by the five geographic sub-areas. This map was created from the LANDFIRE Biophysical settings map by aggregating the National Vegetation Classification Standard vegetation types into a set of vegetation types that has some meaning across the NR at this coarse scale.

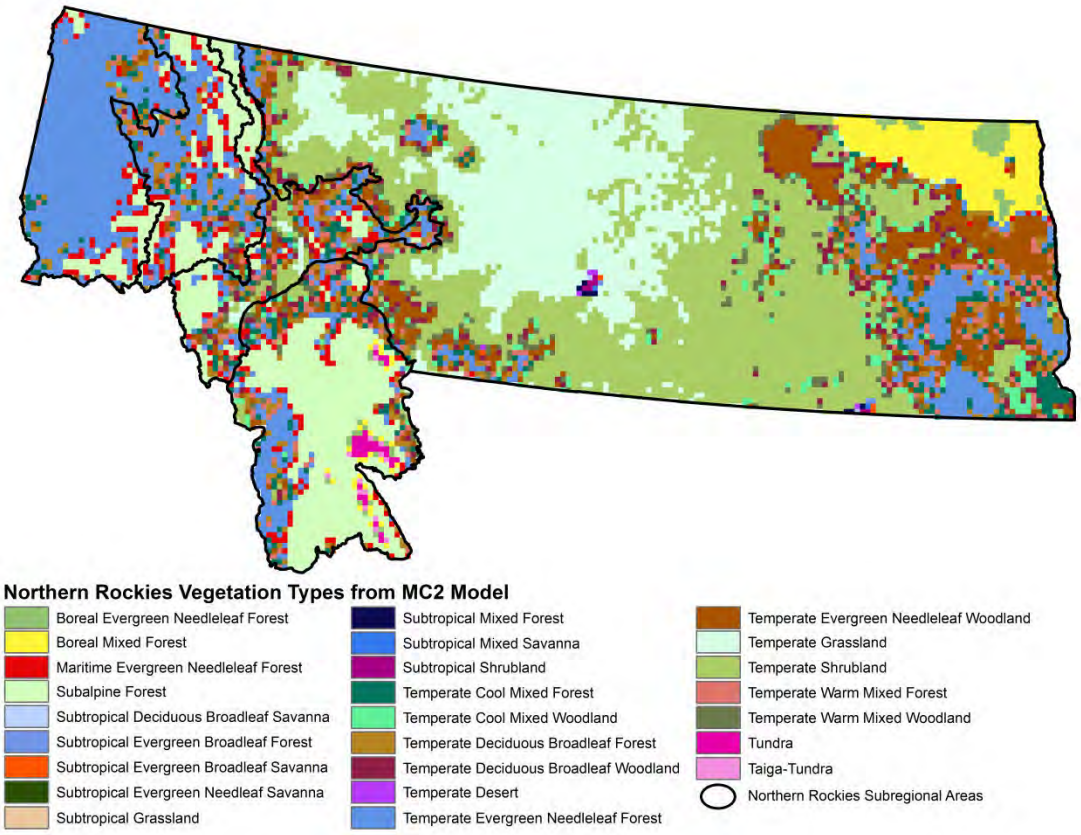


Figure 6.3—The MC2 vegetation types for the asses ment ar a by the five geographic sub-areas. This map was created from a MC2 modeling effort (see appendix 6A).

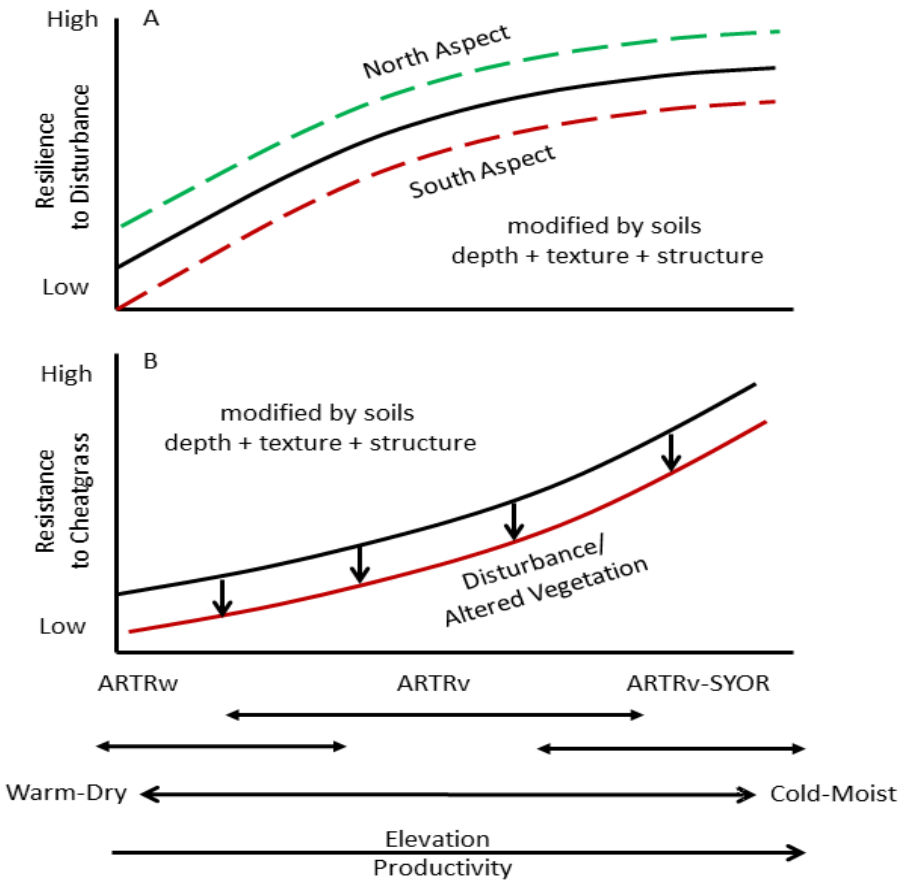


Figure 7.1—Resilience to disturbance (A) and resistance to cheatgrass (B) over a typical temperature/precipitation gradient in the cold desert. Dominant ecological sites occur along a continuum that includes Wyoming big sagebrush on warm and dry sites, to mountain big sagebrush on cool and moist sites, to mountain big sagebrush and root-sprouting shrubs on cold and moist sites. Resilience increases along the temperature/precipitation gradient and is influenced by site characteristics like aspect. Resistance also increases along the temperature/precipitation gradient and is affected by disturbances and management treatments that alter vegetation structure and composition and increase resource availability. Modified from Chambers et al. (2014). ARTRw = Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*); ARTRv = mountain big sagebrush (*A. tridentata* ssp. *vaseyana*); SYOR = mountain snowberry (*Symphoricarpos oreophilus*)

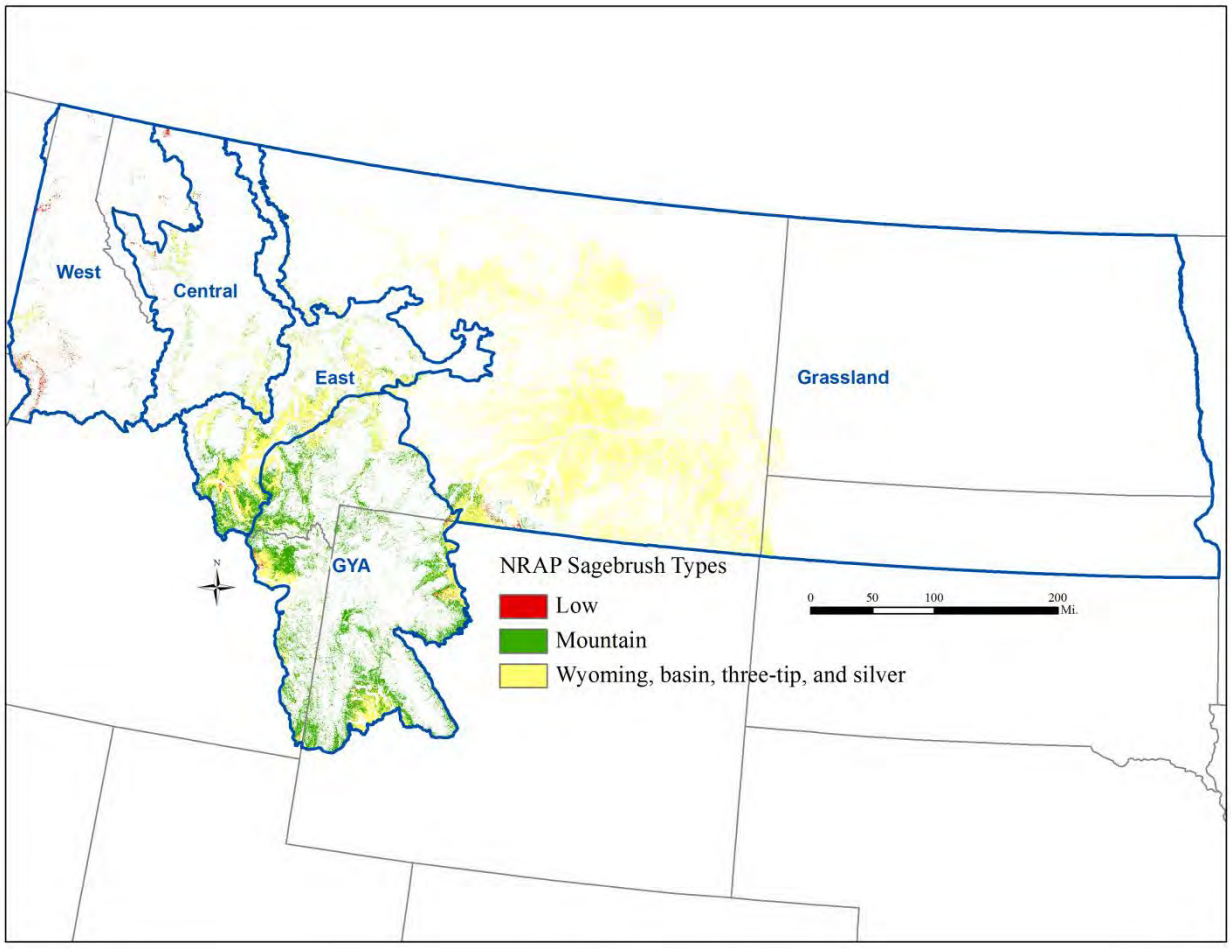


Figure 7.2—Estimated distribution of various sagebrush vegetation classes in the Northern Rockies.

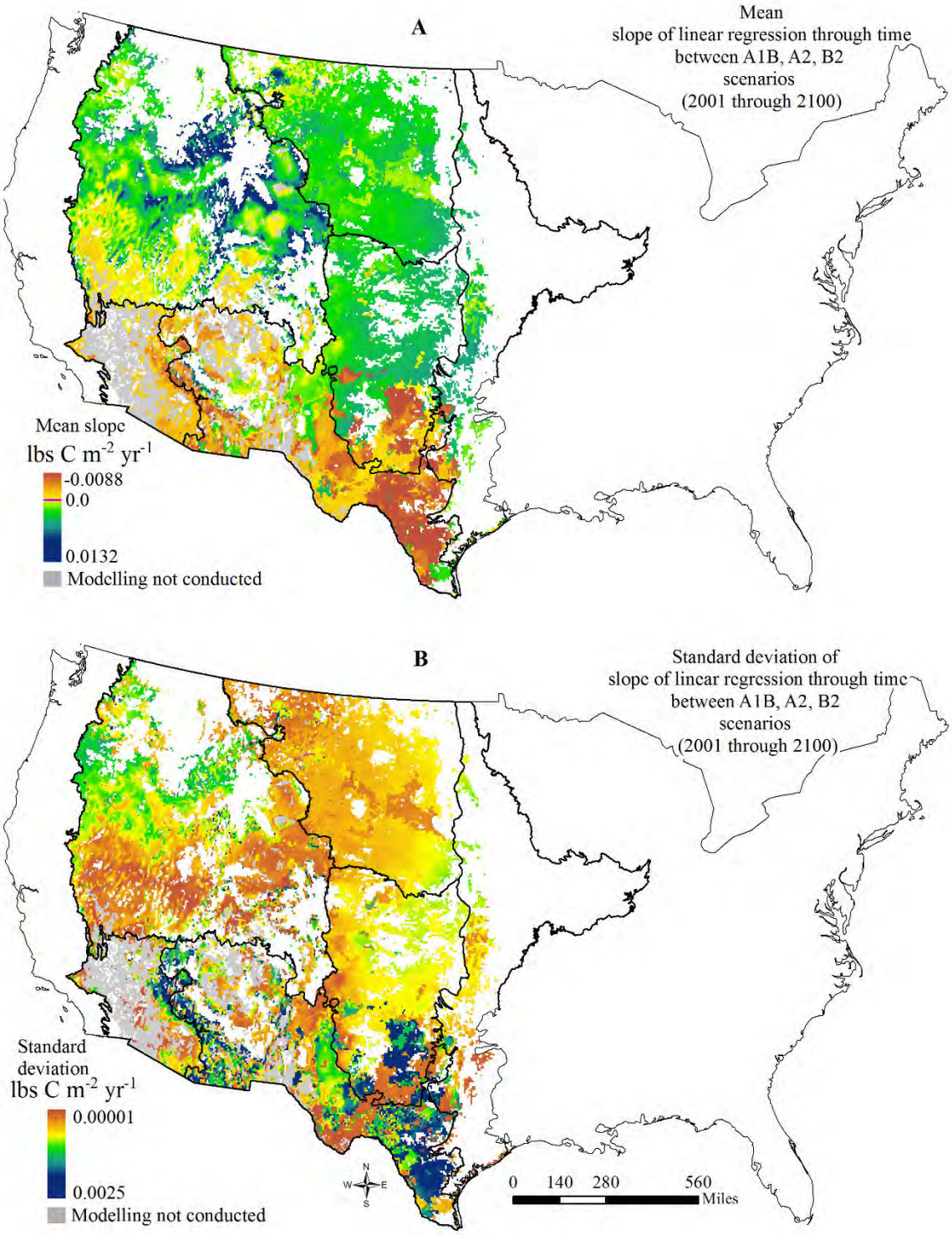


Figure 7.3—Mean slope of linear regression of the net primary productivity trend for the B2, A1B, and A2 emission scenarios (models averaged here include: GCGM2, HadCM3, CSIRO, MK2, MIROC3.2)(A) and standard deviation of the mean slope of linear regression of the net primary productivity trend for the same scenarios (B). From Reeves et al. (2014).

Figure 7.4—Conifer encroachment, predominantly ponderosa pine into a montane grassland, including the ubiquitous graminoid rough fescue. (Photo by Mary Manning, Forest Service, U.S. Department of Agriculture)

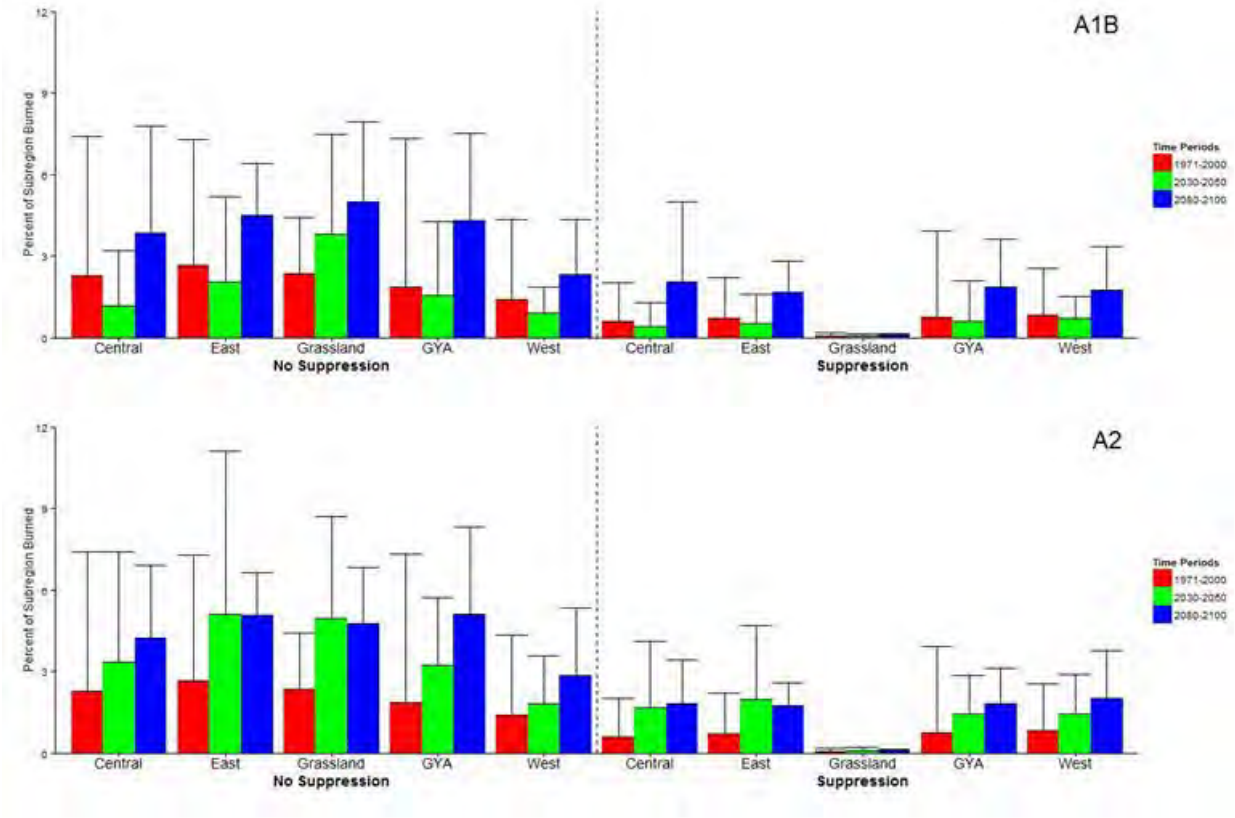


Figure 7.5—Mean and standard deviation of percent of subregions burned across three time spans (historic, 2030-2050, 2080-2100) and without/with fire suppression.

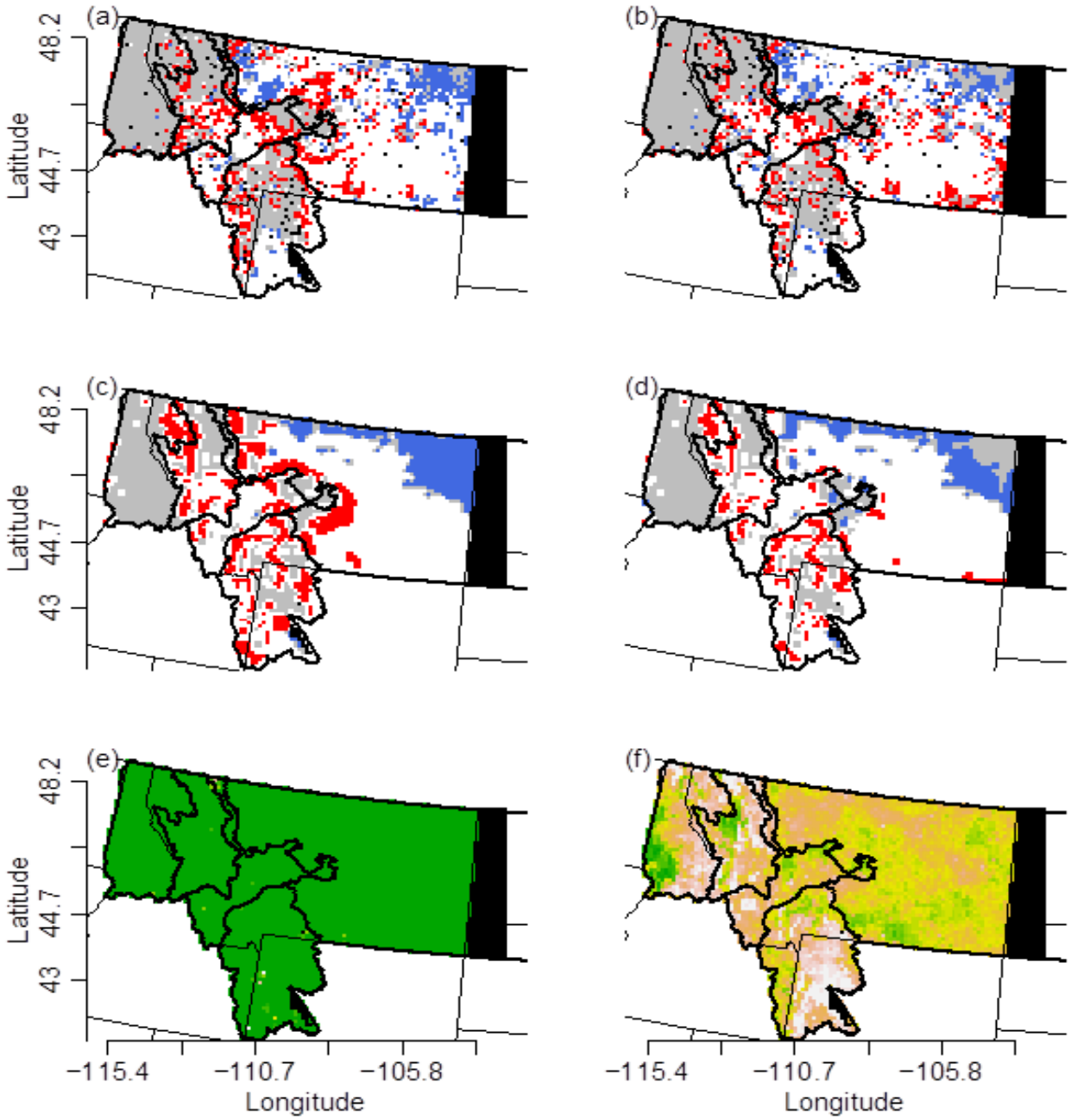


Figure 7.6—Change in big sagebrush habitat suitability (a-d) based on species distribution models using climate (c)-(d) or ecohydrology (a)-(b), along with germination (e) and seedling survival potential (f) for NR (outlined in bold). Projected change in big sagebrush habitat suitability is between 1970-1999 climate and future A2 scenario (a)-(c) and B1 scenario (b)-(d) 2070-2099 emission scenarios. Red cells indicate areas of decrease in big sagebrush habitat suitability, blue cells indicate areas of increase, white cells indicate stable areas, and gray cells indicate absence of big sagebrush. Maps of germination (e) and seedling survival (f) represent current conditions and are summarized as fraction of years with successes: red (0, no years with success), tan (>0), green (1, every year with success). Black cells indicate data not available (Schlaepfer et al. 2012).

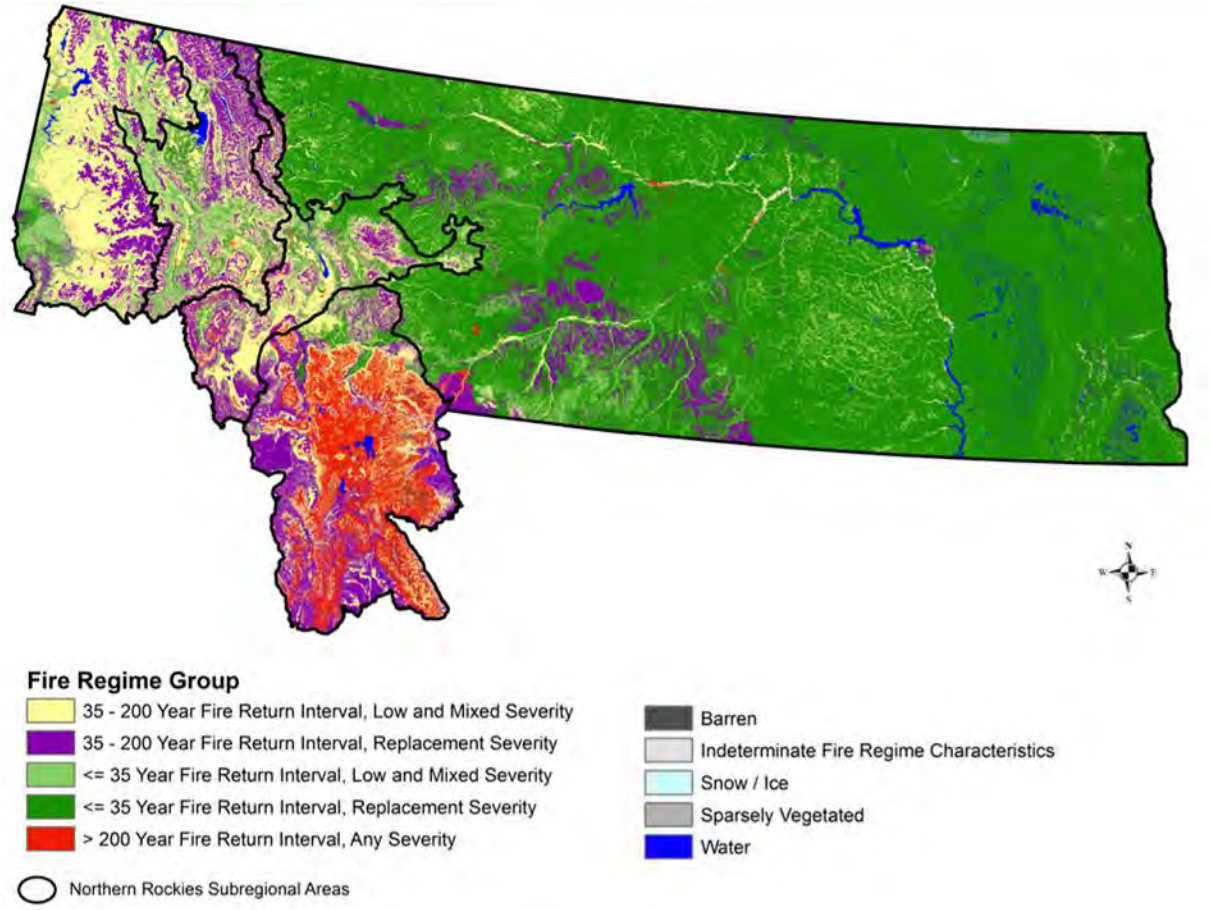


Figure 8.1—Fire regime groups for the Northern Rockies, LANDFIRE mapping program. The fire regime group layer characterizes the presumed historical fire regimes within landscapes based on interactions among vegetation dynamics, fire spread, fire effects, and spatial context. See http://www.landfire.gov/NationalProductDescriptions12.php.

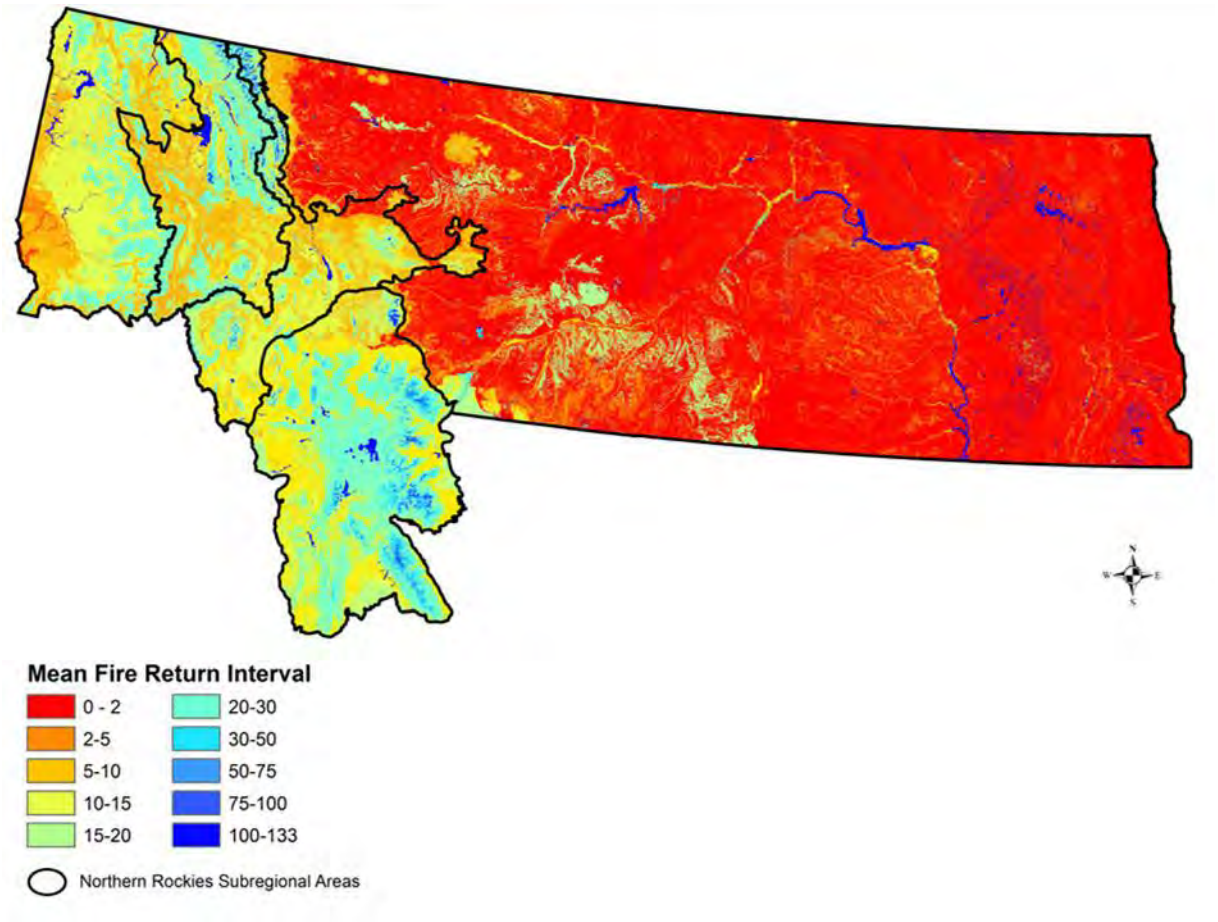


Figure 8.2—Mean fire return interval for the Northern Rockies, LANDFIRE mapping program. The mean fire return interval layer quantifies the average period between fires under the presumed historical fire regime. See http://www.landfire.gov/NationalProductDescriptions13.php for more information.

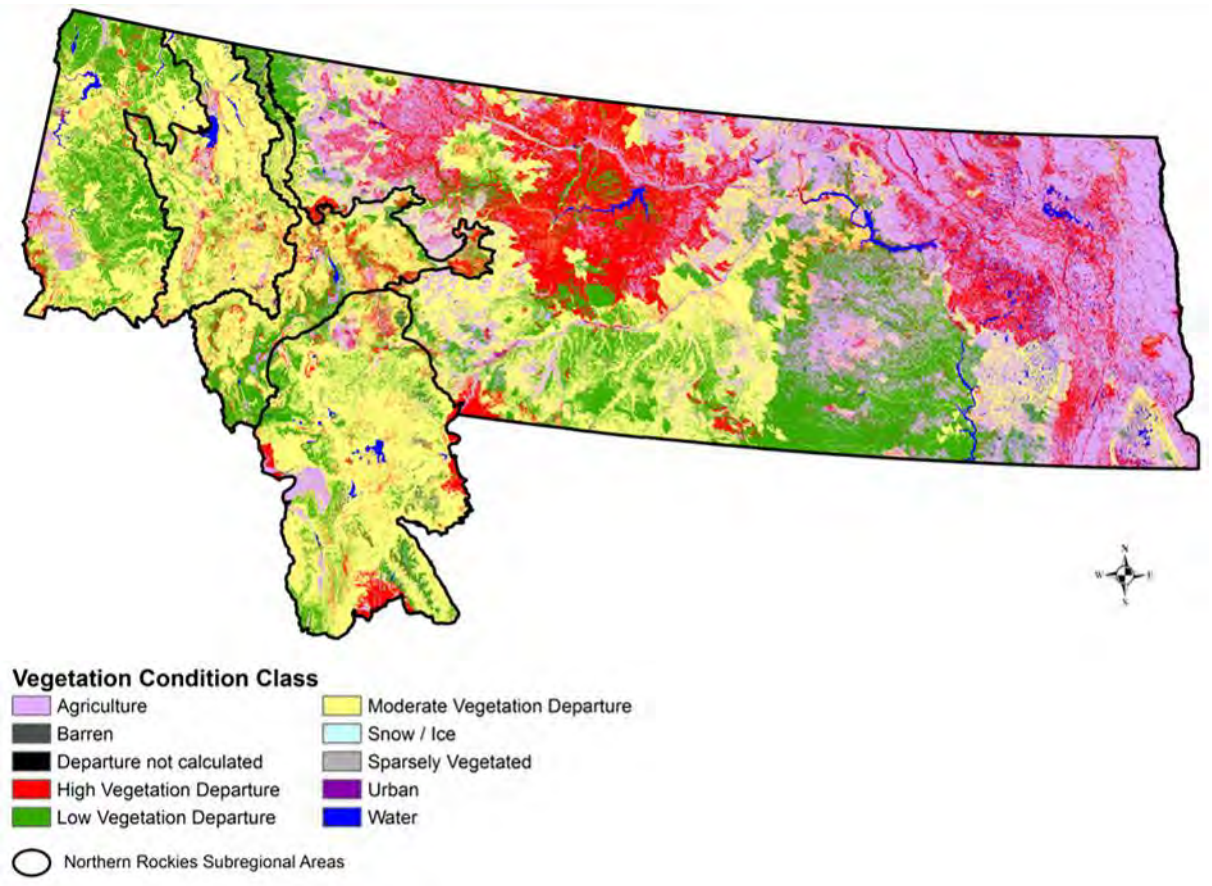


Figure 8.3—Vegetation condition class for the Northern Rockies, LANDFIRE mapping program. The vegetation condition class layer quantifies the amount that current vegetation has departed from the simulated historical vegetation reference conditions. See http://www.landfire.gov/NationalProductDescriptions10.php.

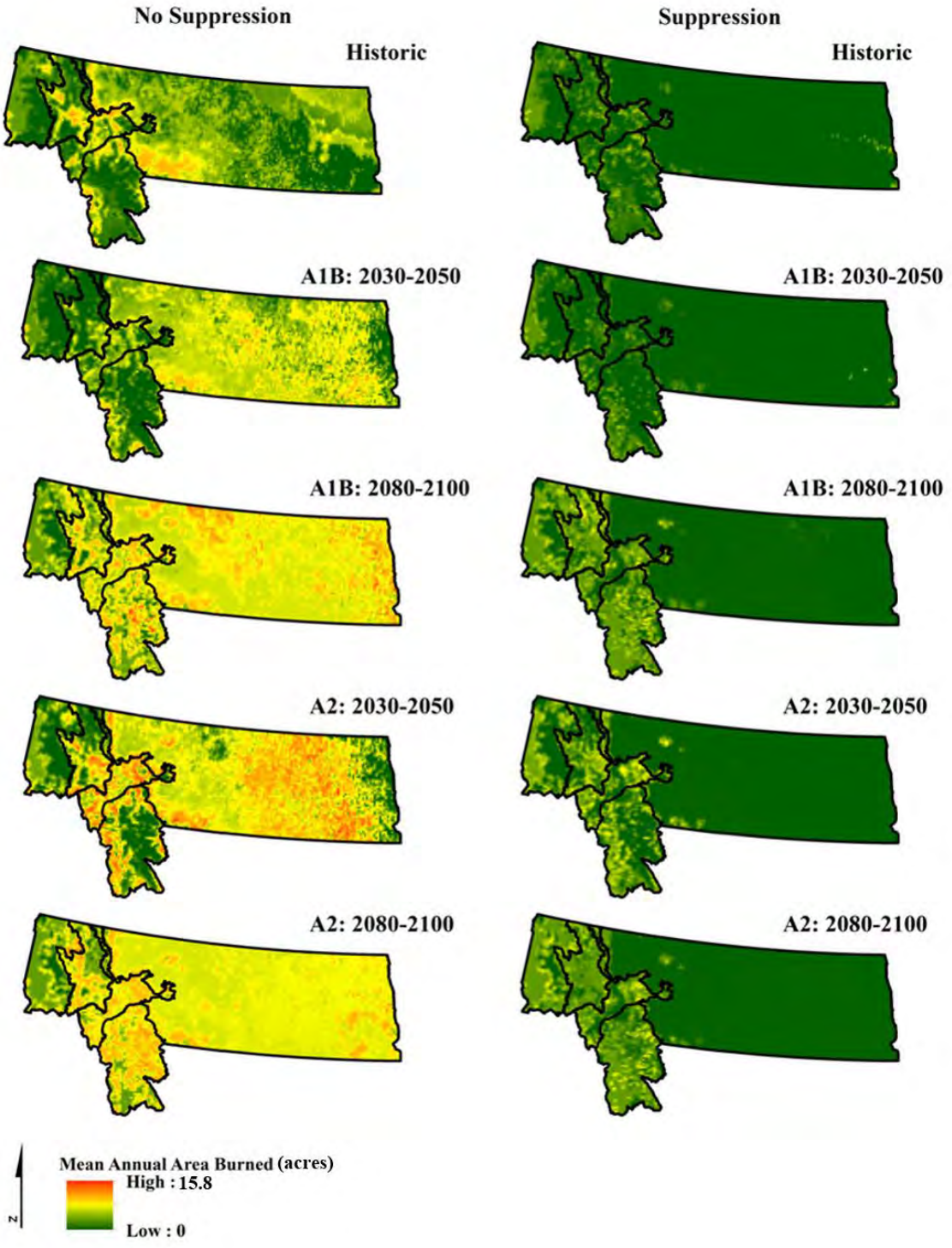


Figure 8.4—Changes in mean annual area burned (ha) for current levels of fire suppression and no fire suppression, A1B (moderate) and A2 (hgh) emission scenarios, and for the time periods 2030-2050 and 2080-2100, as projected by the MC2 dynamic global vegetation model (Bachelet et al. 2003).

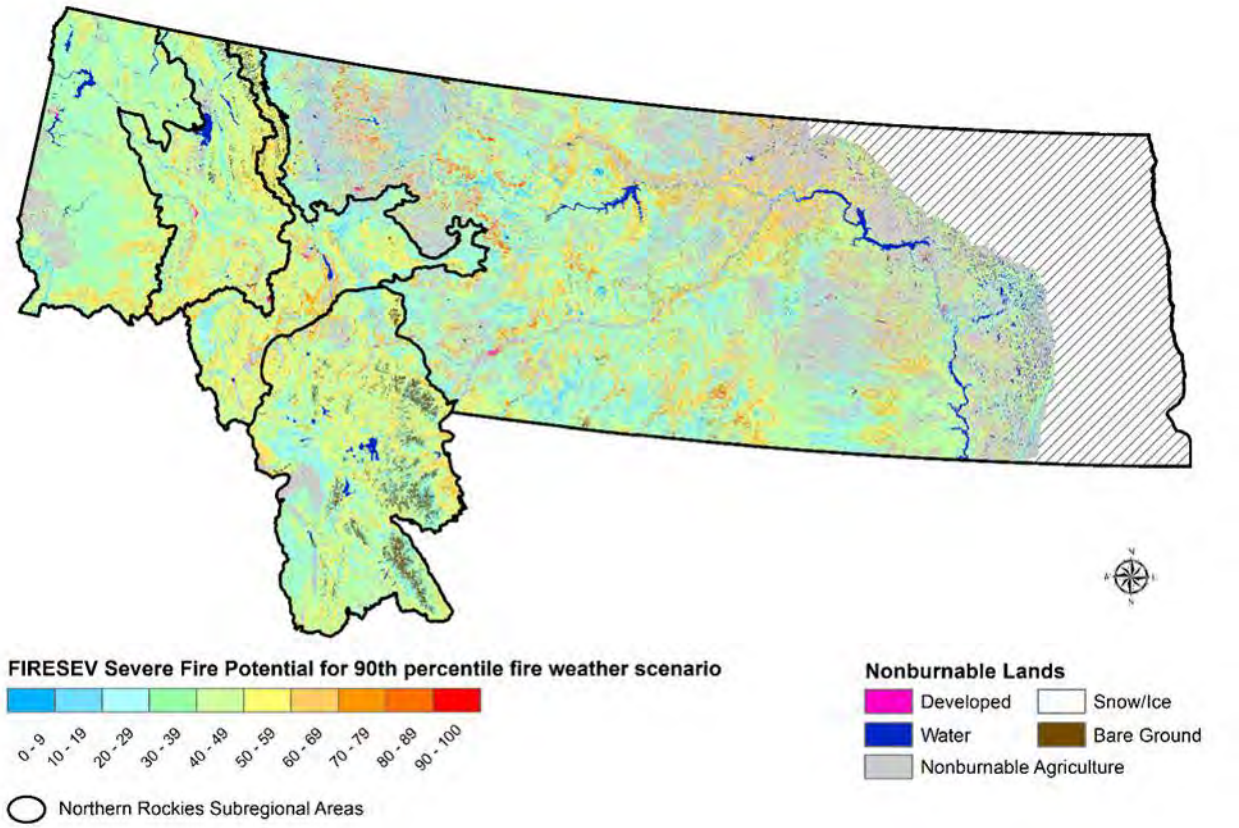


Figure 8.5—Severe fire potential (probability) for 90th percentile fire weather scenario, with non-burnable areas added in from the LANDFIRE 2008 Fire Behavior Fuel Model layer (Dillon et al. 2011).

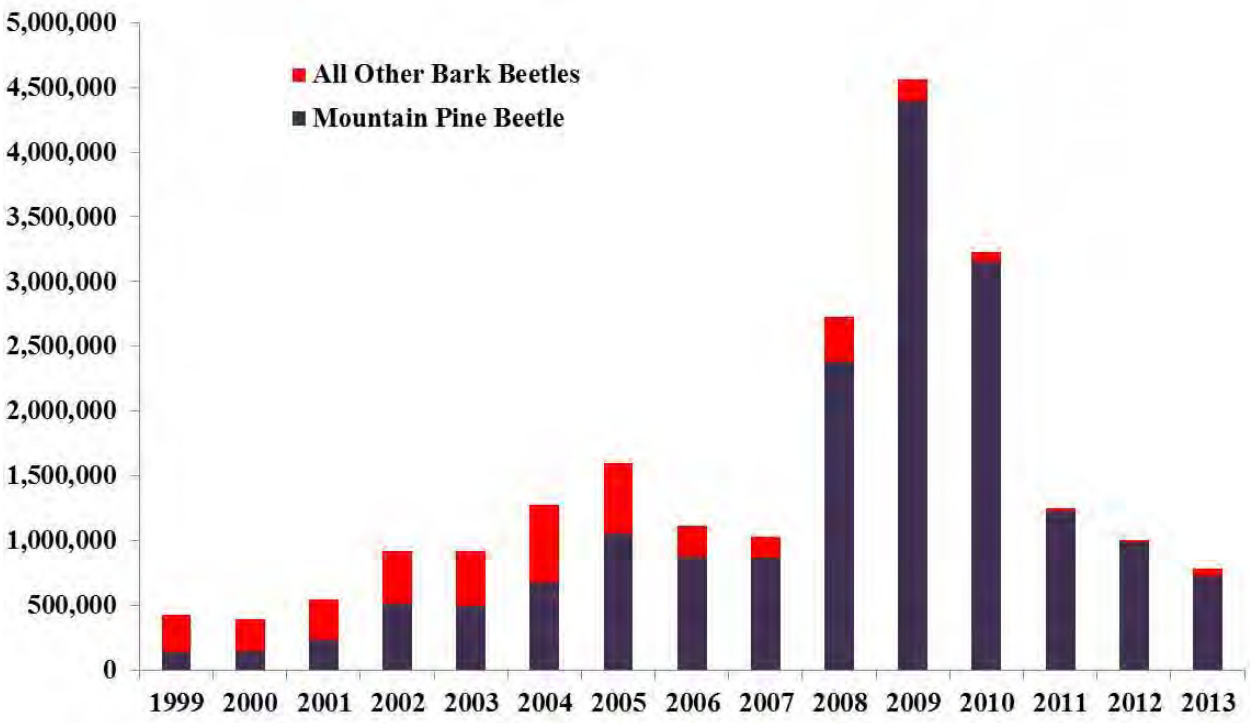


Figure 8.6—Area (acres) affected by bark beetles in the U.S. Forest Service Northern Region. Data based on Forest Health Protection aerial detections surveys.

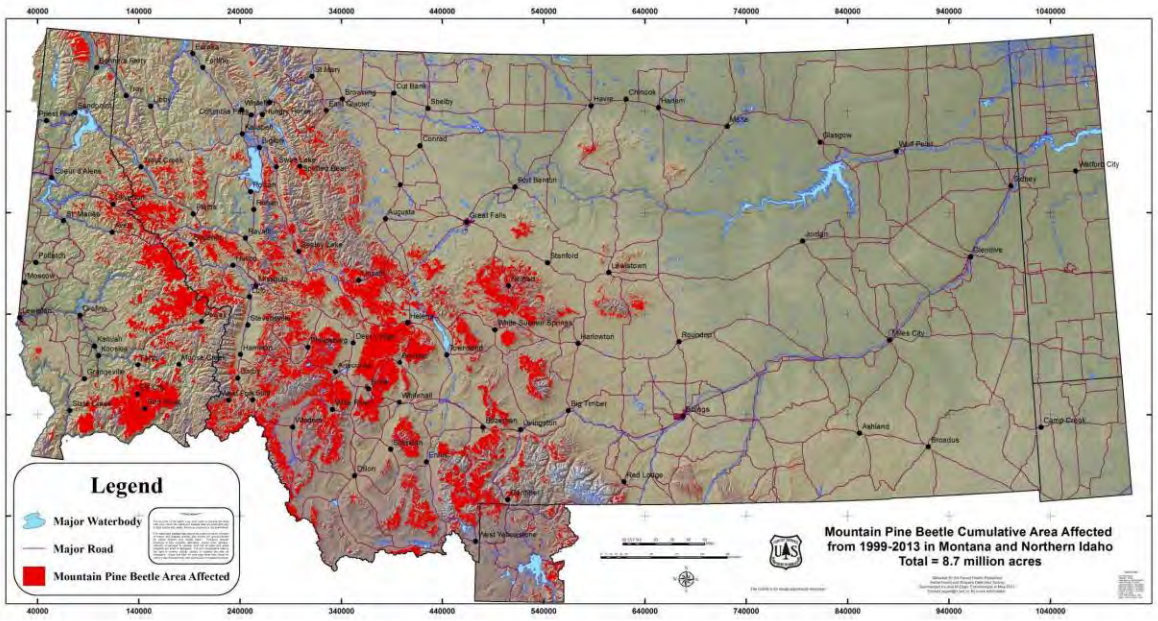


Figure 8.7—Cumulative area affected by mountain pine beetle between 1999 and 2013 in the Northern Rockies. Data based on Forest Health Protection aerial detection surveys.

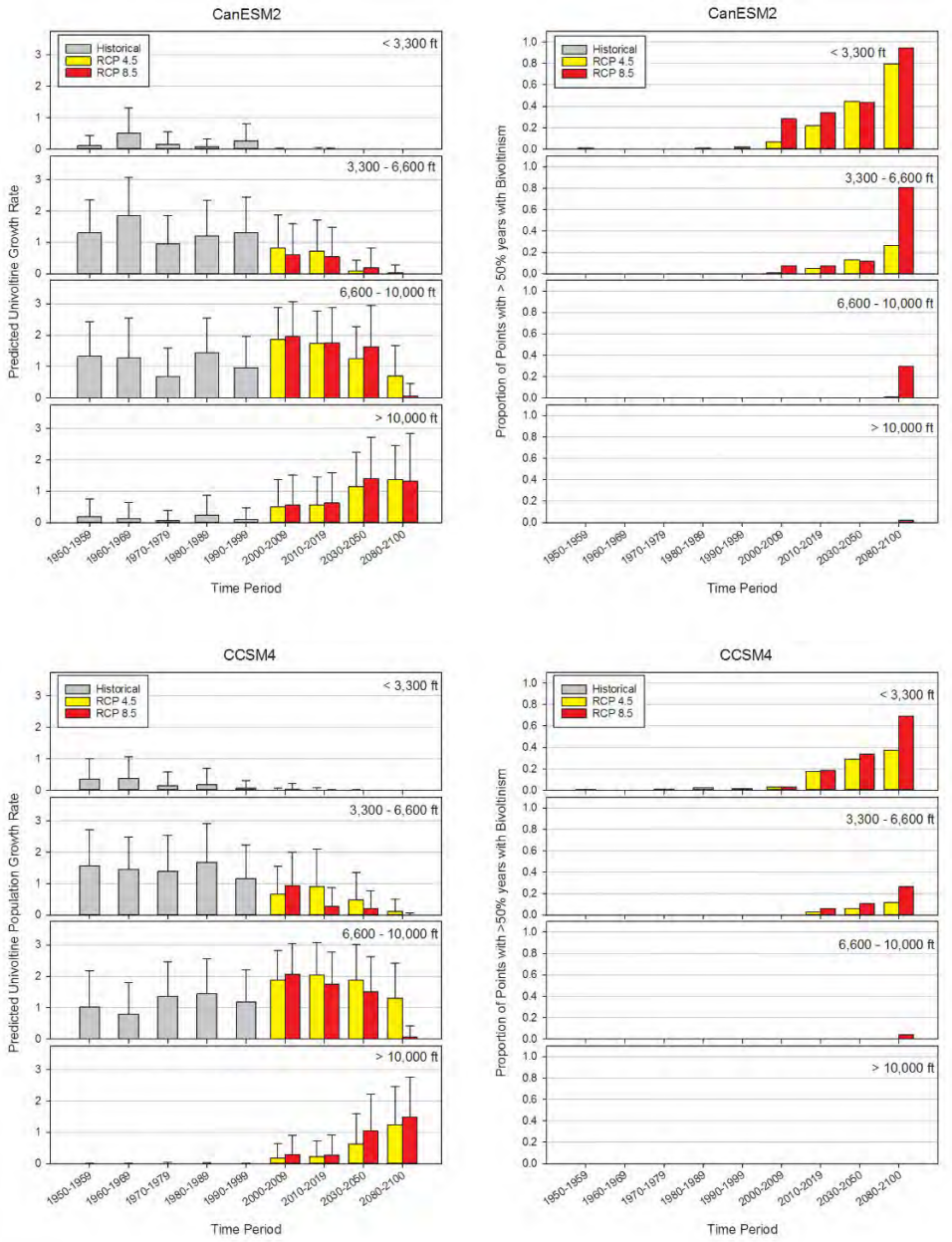


Figure 8.8—Left panel: projected mountain pine beetle (MPB) population growth rate (mean, standard deviation) of univoltine populations (one generation per year) over decades (historical) and 20-year periods (projected) from 1950 to 2100. Shown are the mean and standard deviation among locations of decadal (historic) and 2-decadal (projected) growth rates. Right panel: proportion of simulation points in which bivoltinism (two generations in one year) is projected for more than 50 percent of years in each time period. Projections are based on a temperature-dependent model of MPB development and population growth (Powell and Bentz 2009) using temperatures from the CanESM2 and CCSM4 GCMs and two emission scenarios (Representative Concentration Pathways [RCP] 4.5 and 8.5). Model output is shown by elevation category (in feet). Simulation points are geographic locations of downscaled temperatures where pines occur (sample size = 17,616).

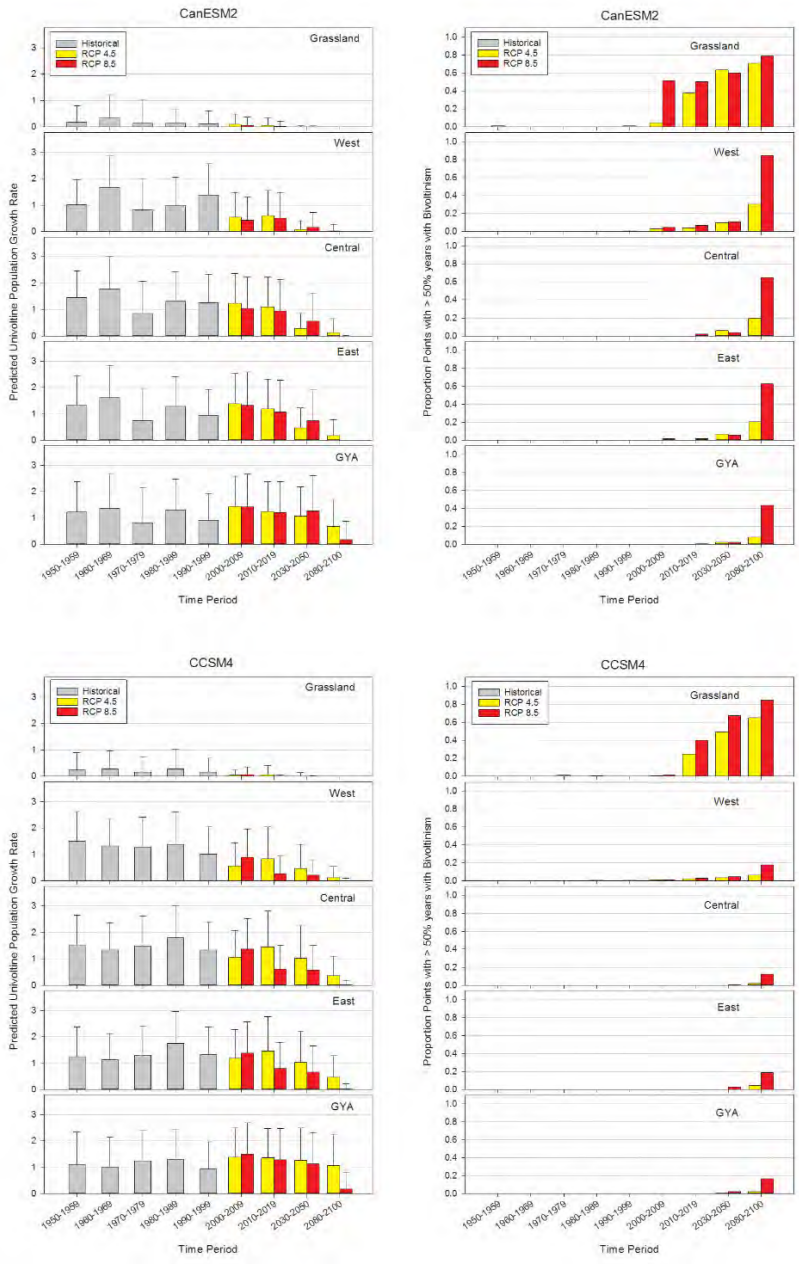


Figure 8.9—Left panel: Predicted mountain pine beetle (MPB) population growth rate (mean, standard deviation) of univoltine populations (one generation per year) over decades (historical) and 20 year periods (projected) from 1950 to 2100. Shown are the mean and standard deviation among locations of decadal (historic) and 2-decadal (projected) growth rates. Right panel: proportion of simulation points where bivoltinism (i.e., two generations in one year) is projected for more than 50 percent of years in each time period. Predictions are based on a temperature-dependent model of MPB development and population growth (Powell and Bentz 2009) using temperatures from the CanESM2 and CCSM4 GCMs and two emission scenarios (RCP 4.5, RCP 8.5). Model output is shown by Northern Rockies Adaptation Partners (NRAP) subregion. Simulation points are geographic locations of downscaled temperatures where pines occur (sample size = 17,616).

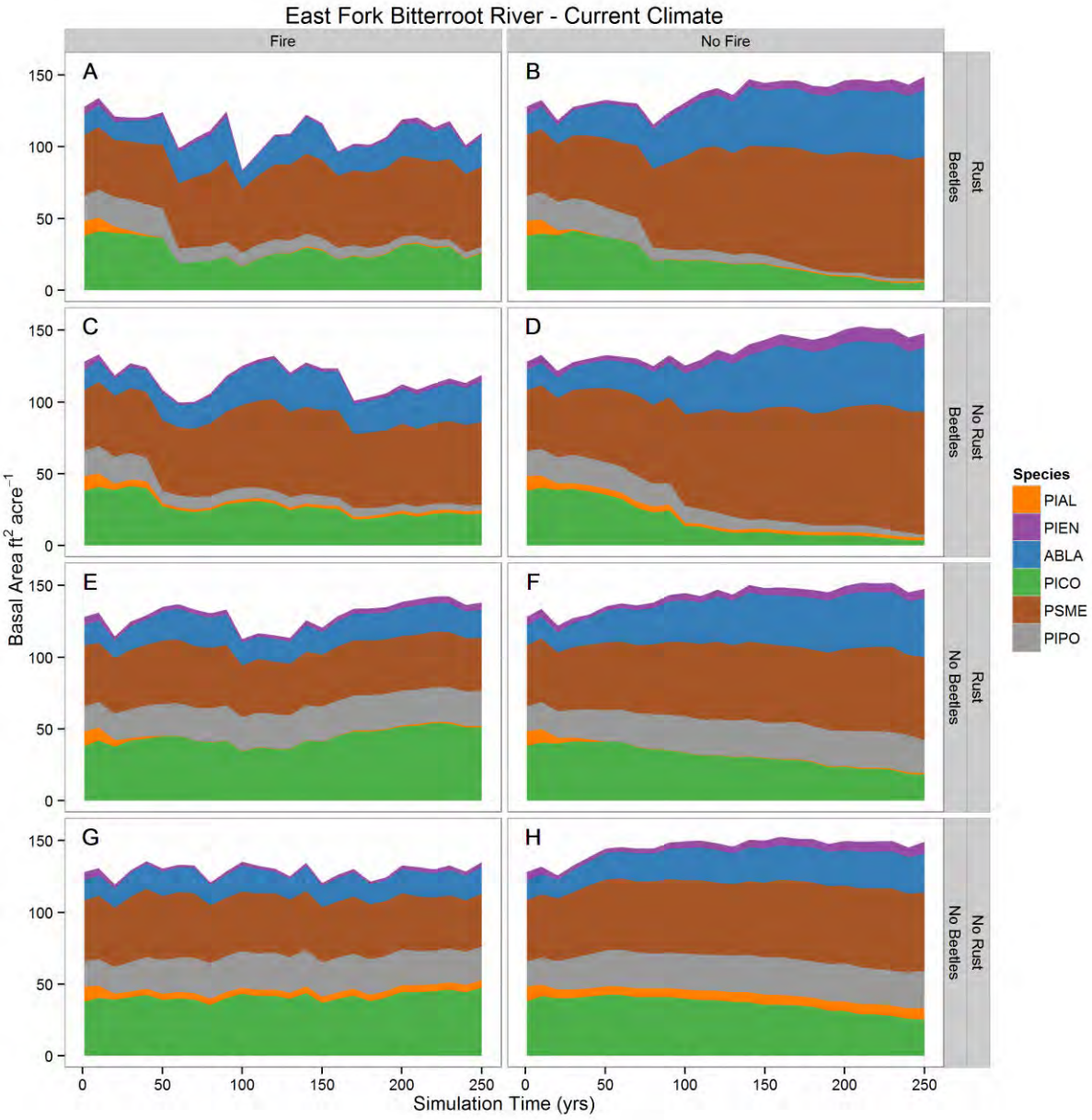


Figure 8.10—Landscape composition of species cover types using the plurality of basal area for *current climate* for the East Fork of the Bitterroot River landscape with all combinations of fire, white pine blister rust (WPBR), and mountain pine beetle (MPB): (A) fire, WPBR, and MPB, (B) no fire, WPBR, MPB, (C) fire and MPB, (D) MPB only, (E) fire and WPBR, (F) WPBR only, (G) fire only, and (H) no disturbances. Species: PIAL-whitebark pine, PIEN-Engelmann spruce, ABLA = subalpine fir, PICO-lodgepole pine, PSME-Douglas-fir, and PIPO-ponderosa pine. Produced using the FireBGCv2 mechanistic ecosystem-fire process model (Keane et al. 2015).

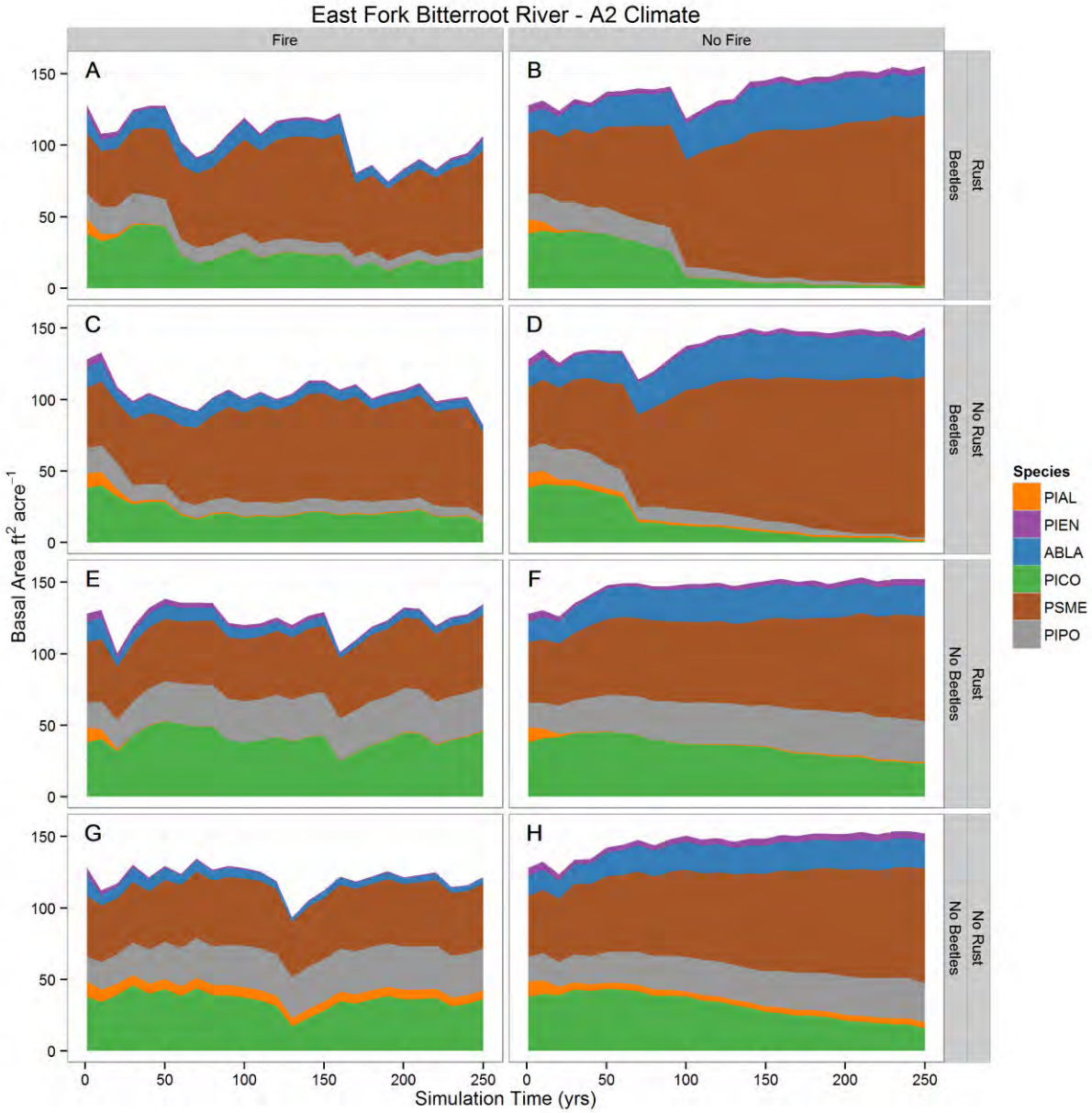


Figure 8.11—Landscape composition of species cover types using the plurality of basal area for a *warmer climate* (A2 emission scenario) for the East Fork of the Bitterroot River landscape with all combinations of fire, white pine blister rust (WPBR), and mountain pine beetle (MPB): (A) fire, WPBR, and MPB, (B) no fire, WPBR, MPB, (C) fire and MPB, (D) MPB only, (E) fire and WPBR, (F) WPBR only, (G) fire only, and (H) no disturbances. Species: PIAL = whitebark pine, PIEN = Engelmann spruce, ABLA = subalpine fir, PICO = lodgepole pine, PSME = Douglas-fir, and PIPO = ponderosa pine. Produced using the FireBGCv2 mechanistic ecosystem-fire process model (Keane et al. 2015).

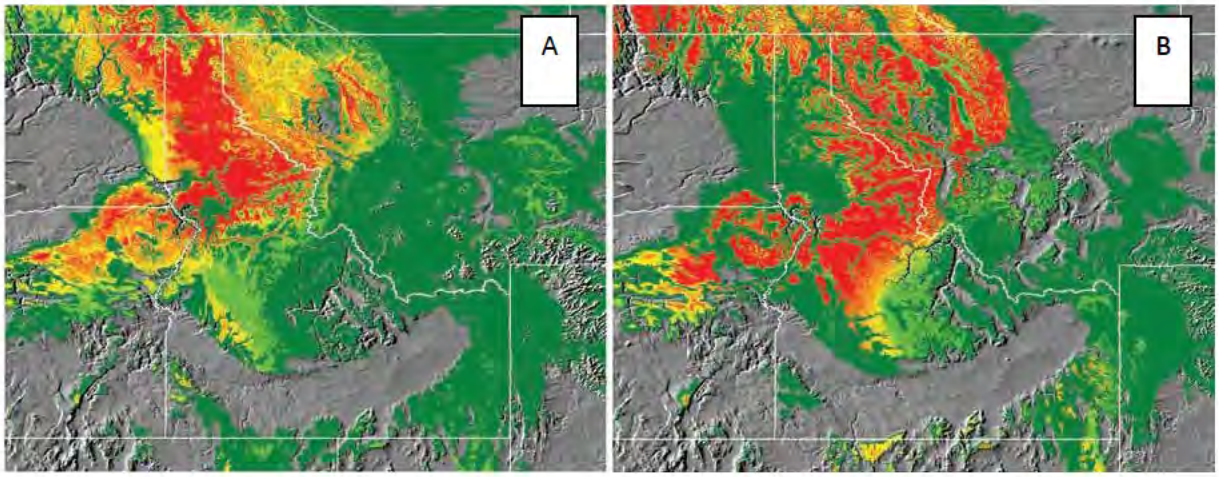


Figure 8.12—Modeled (A) current and (B) future (year 2060) climate space for *Armillaria solidipes* (Klopfenstein et al. 2009). Colors represent the number of tree votes cast, analogous to the probability of occurrence. Yellow = 50 to 75 votes, red = 76 to 100 votes.

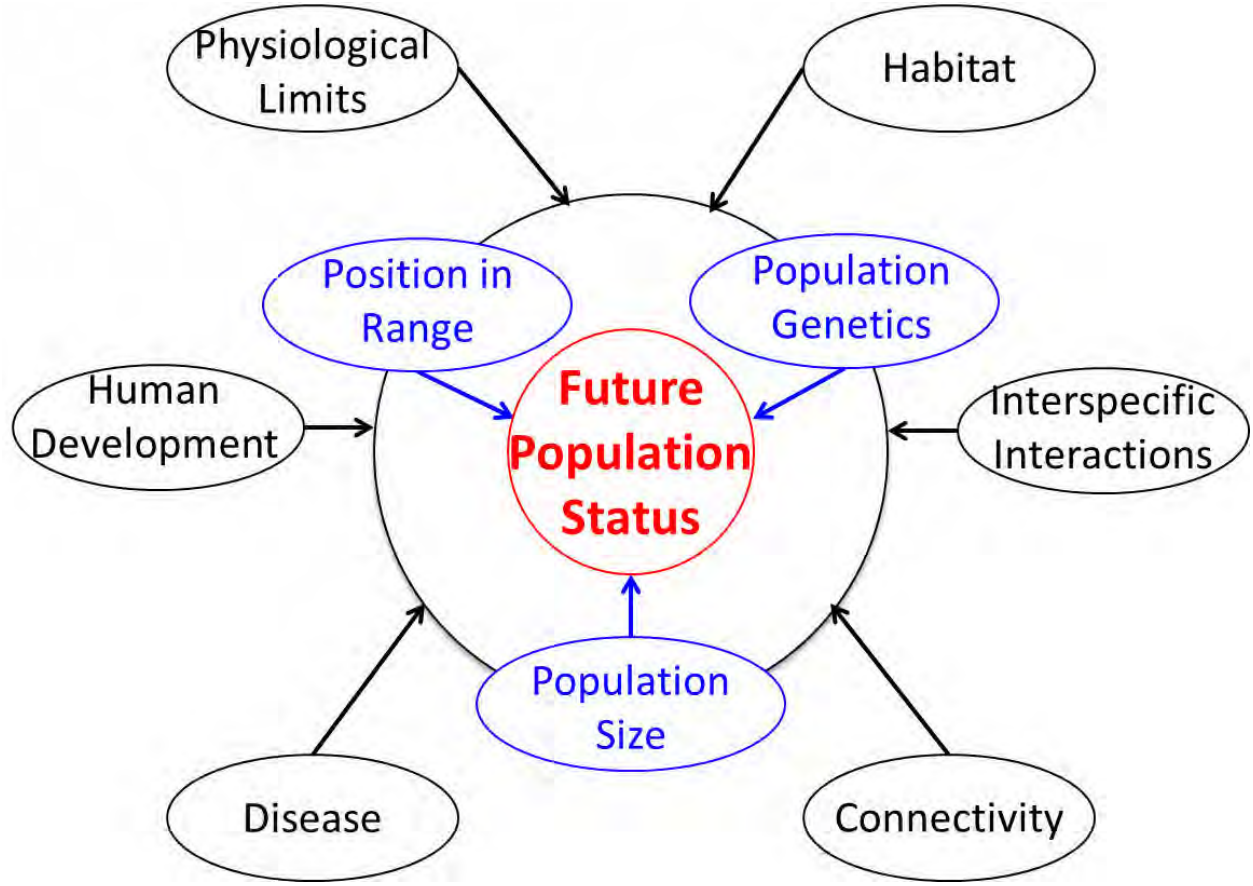


Figure 9.1—Visual summary of workshop discussions on the influence of climate on wildlife populations in the Northern Rockies Adaptation Partnership. Pathways of climate influence (black) interact with population characteristics (blue) to affect the future population status (red). A given pathway affects multiple species, and multiple pathways affect a given species.

Figure 9.2—Canada lynx have snow-specific adaptations (oversized feet, long legs, and a thin, light skeleton), and snowshoe hares dominate their diets. Snowshoe hares undergo seasonal pelage changes from brown to white, and the effectiveness of this strategy depends on synchrony with snow cover. A mismatch between the hare's fur color and its environment would make it more vulnerable to predation by lynx. (Left photo by Milo Burcham, right photo by L. Scott Mills)

Figure 9.3—Maintenance and restoration of American beaver populations are an adaptation tactic for maintaining water on the landscape. Although beavers are not particularly climate sensitive themselves, the structures beavers create and their effects on aquatic habitats and floodplains may help to ameliorate the effects of climatic change on cold-water fish species and other aquatic organisms. (Photo by E. Himmel, National Park Service)

Figure 9.4—The American pika is a small lagomorph that collects grass and herbs throughout the summer as winter food and remains active throughout the winter. It depends on the relatively warm subnivean environment associated with deep winter snowpack. (Photo by Jim Jacobson)

Figure 9.5—Ungulates generally respond favorably to wildfires that create patchy habitat, especially if forage availability improves, as shown in this photo of an elk browsing adjacent to a recently burned lodgepole pine forest. (Photo by Jeff Henry, National Park Service)

Figure 9.6—Since climate change is expected to reduce the extent of mature sagebrush through increased wildfire, sagebrush-obligate species such as Brewer's sparrow (shown here) and greater sage-grouse may have less nesting habitat in the future. (Photo by Paul Higgins, www.utahbirds.org)

Figure 9.7—Warmer air temperature and less snowpack are expected to decrease the presence of shallow water during the summer, reducing habitat for the Columbia spotted frog (shown here) and western toad. Higher water air and water temperatures may also increase infections from amphibian chytrid fungus. (Photo by Roger Myers, Alaska Department of Fish and Game)

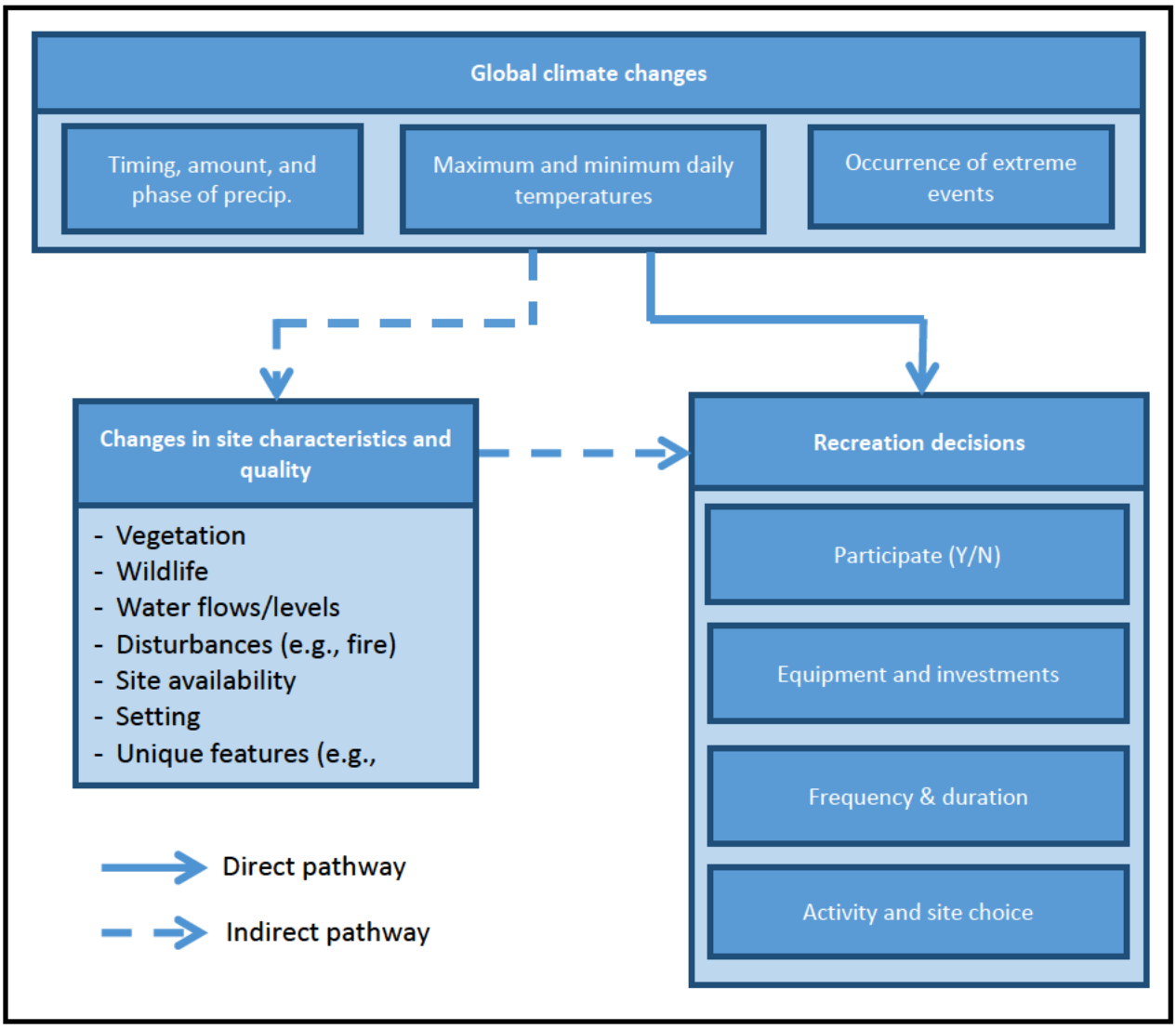


Figure 10.1—Direct and indirect effects of climate on recreation decisions.

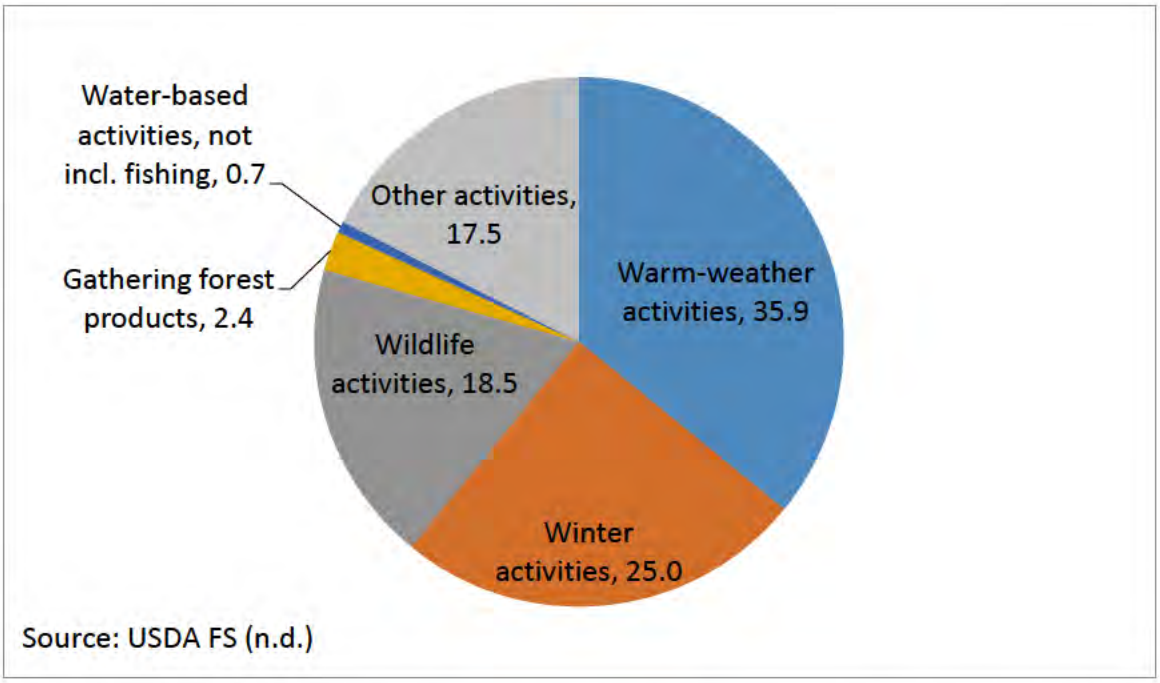


Figure 10.2—Percent of total national forest visits by climate-sensitive primary activity (Source: USDA FS n.d.)

Figure 10.3—Expectations for extent and severity of wildfires in a warmer climate will create forest conditions that may be less desirable for hiking and other recreational activities. (Photo courtesy of Dave Pahlas, http://IdahoAlpineZone.com)

Figure 10.4—Cross-country skiing at lower elevation locations (shown here in the Beaverhead-Deerlodge National Forest) may be vulnerable as snowpack decreasee in future decades. (Photo courtesy of U.S. Forest Service)

Figure 10.5—Algal blooms, shown here in Hayden Lake, Idaho, may become more common in a warmer climate. These conditions are undesirable for water-based recreation and some fish species. (Photo courtesy of Panhandle Health District)

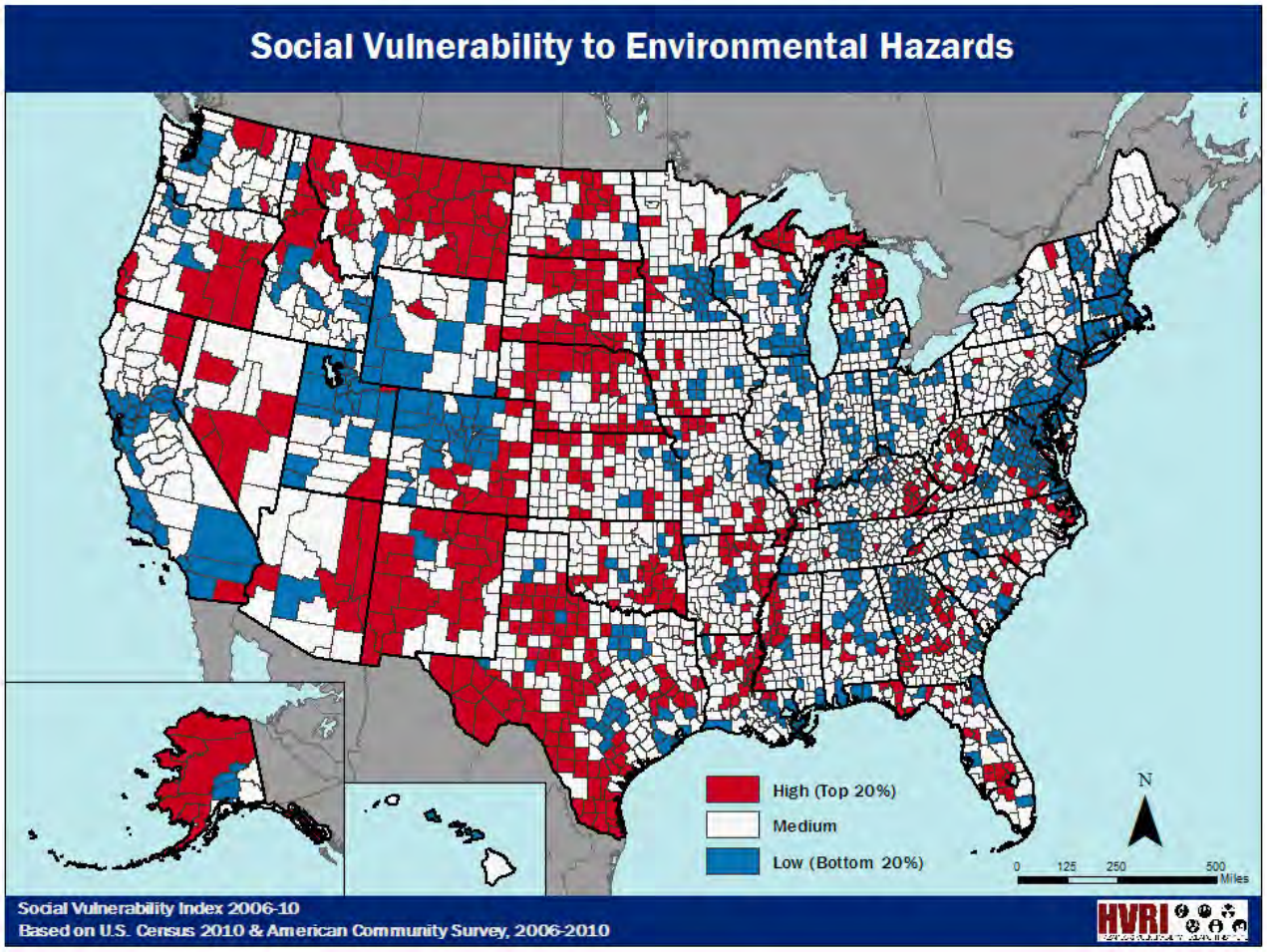
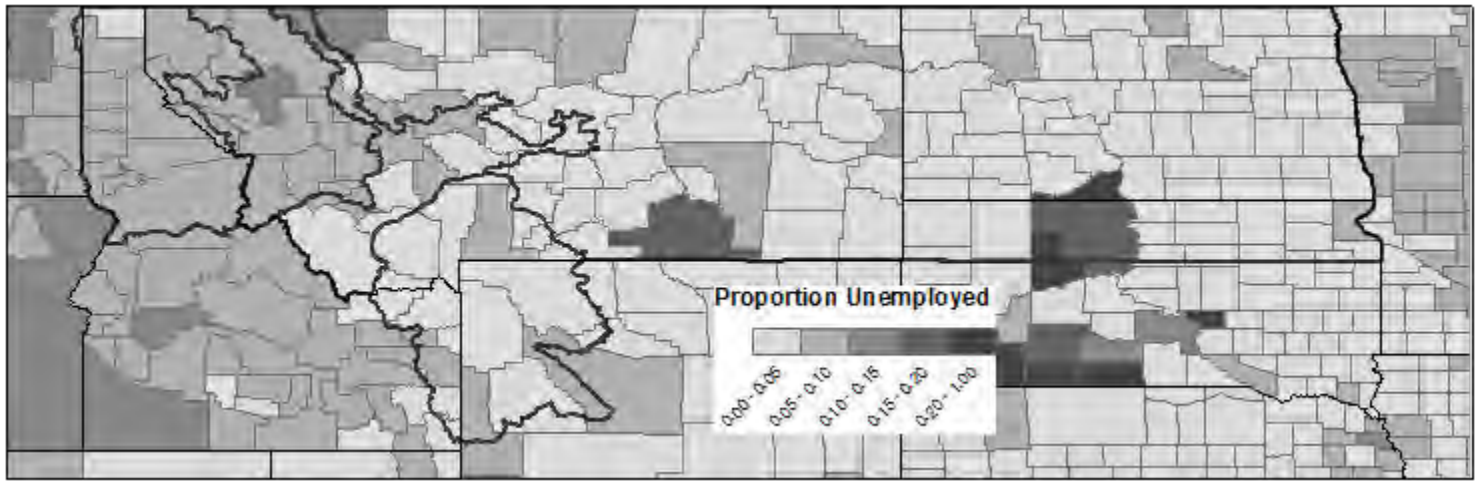
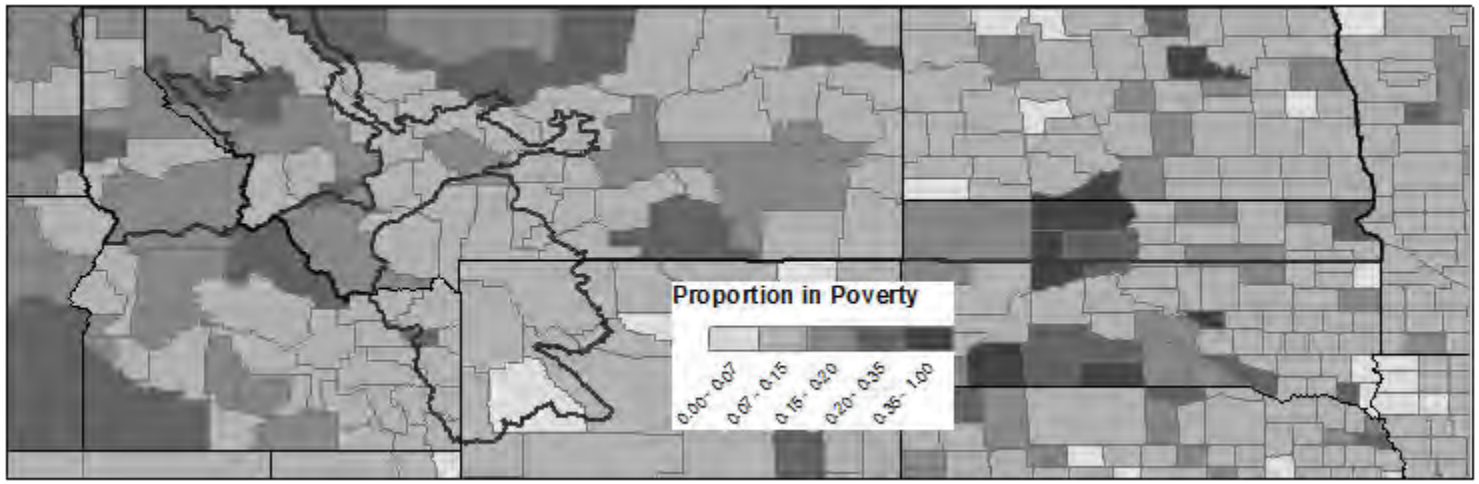


Figure 11.1— The Social Vulnerability Index (SoVI) to environmental hazards for U.S. counties (managed and updated by the Hazards and Vulnerability Research Institute at the University of South Carolina; Cutter et al. 2003). The SoVI is based on 11 underlying factors identified to affect social vulnerability: personal wealth, age, density of the built environment, single-sector economic dependence, housing stock and tenancy, race, ethnicity, occupation, and infrastructure dependence. For each county in the U.S., scores based on these 11 factors are summed to form a composite vulnerability score. To highlight counties with the most "extreme" scores, composite scores are then converted to standard deviations and mapped.

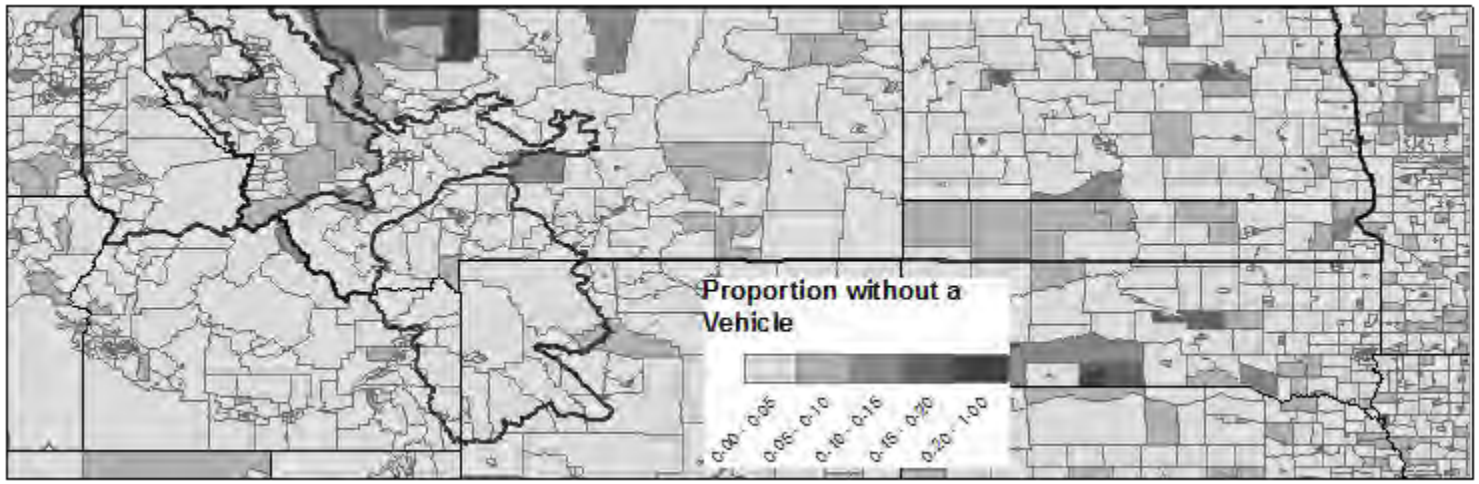
a


Proportion Unemployed
0.00 - 0.05
0.05 - 0.10
0.10 - 0.15
0.15 - 0.20
0.20 - 1.00

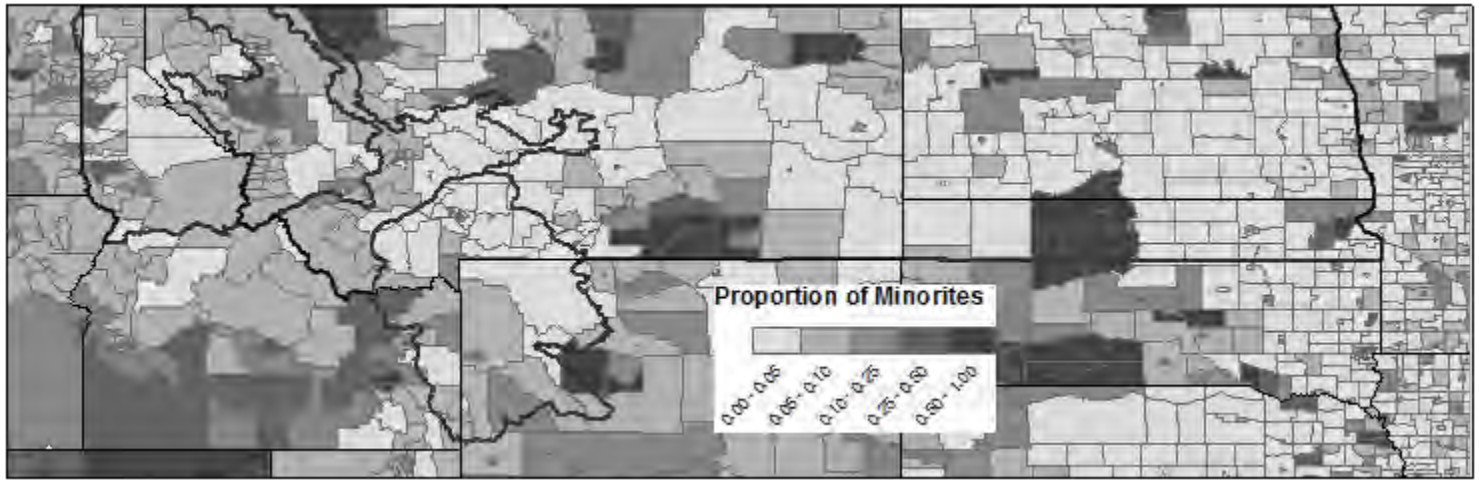
b


Proportion in Poverty
0.00 - 0.07
0.07 - 0.15
0.15 - 0.20
0.20 - 0.35
0.35 - 1.00

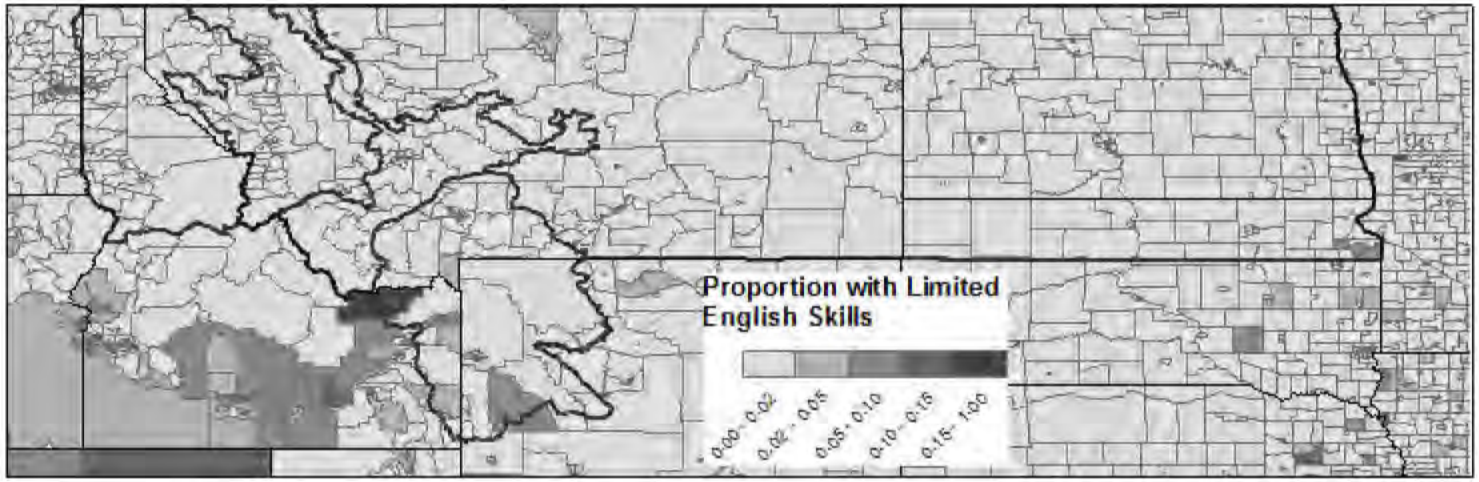
c


Proportion without a Vehicle
0.00 - 0.05
0.05 - 0.10
0.10 - 0.15
0.15 - 0.20
0.20 - 1.00

d


Proportion of Minorites
0.00 - 0.05
0.05 - 0.10
0.10 - 0.25
0.25 - 0.50
0.50 - 1.00

e


Proportion with Limited English Skills
0.00 - 0.02
0.02 - 0.05
0.05 - 0.10
0.10 - 0.15
0.15 - 1.00

f

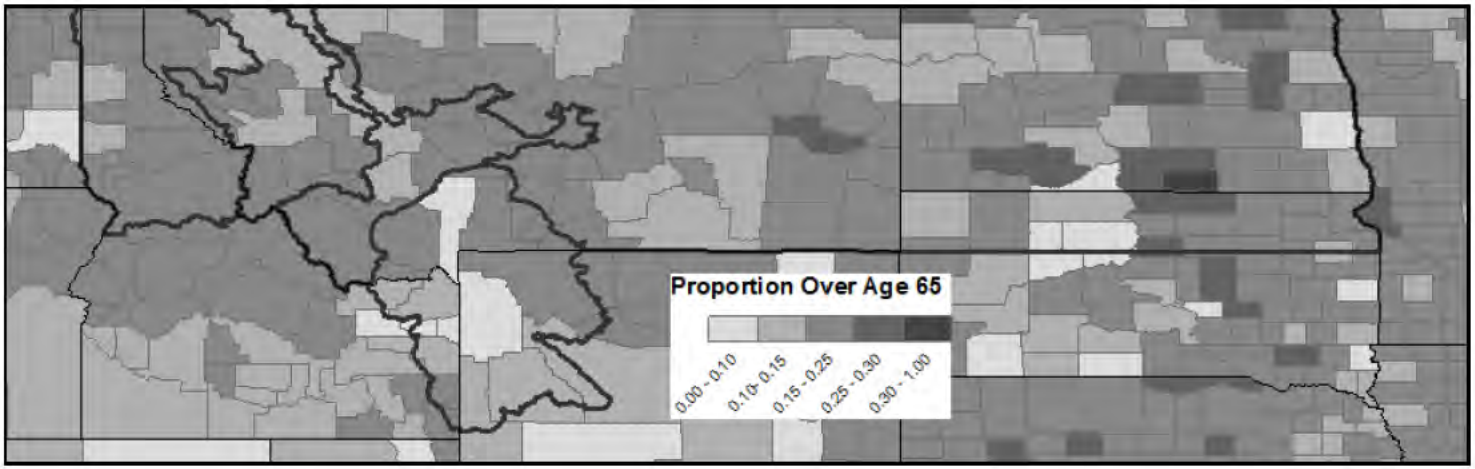

Proportion Over Age 65
0.00 - 0.10
0.10 - 0.15
0.15 - 0.25
0.25 - 0.30
0.30 - 1.00

Figure 11.2—Demographic information for the Northern Rockies region, including proportion unemployed (a), proportion in poverty (b), proportion without a vehicle (c), proportion of minorities (d), proportion with limited English skills (e), and proportion over age 65 (f).

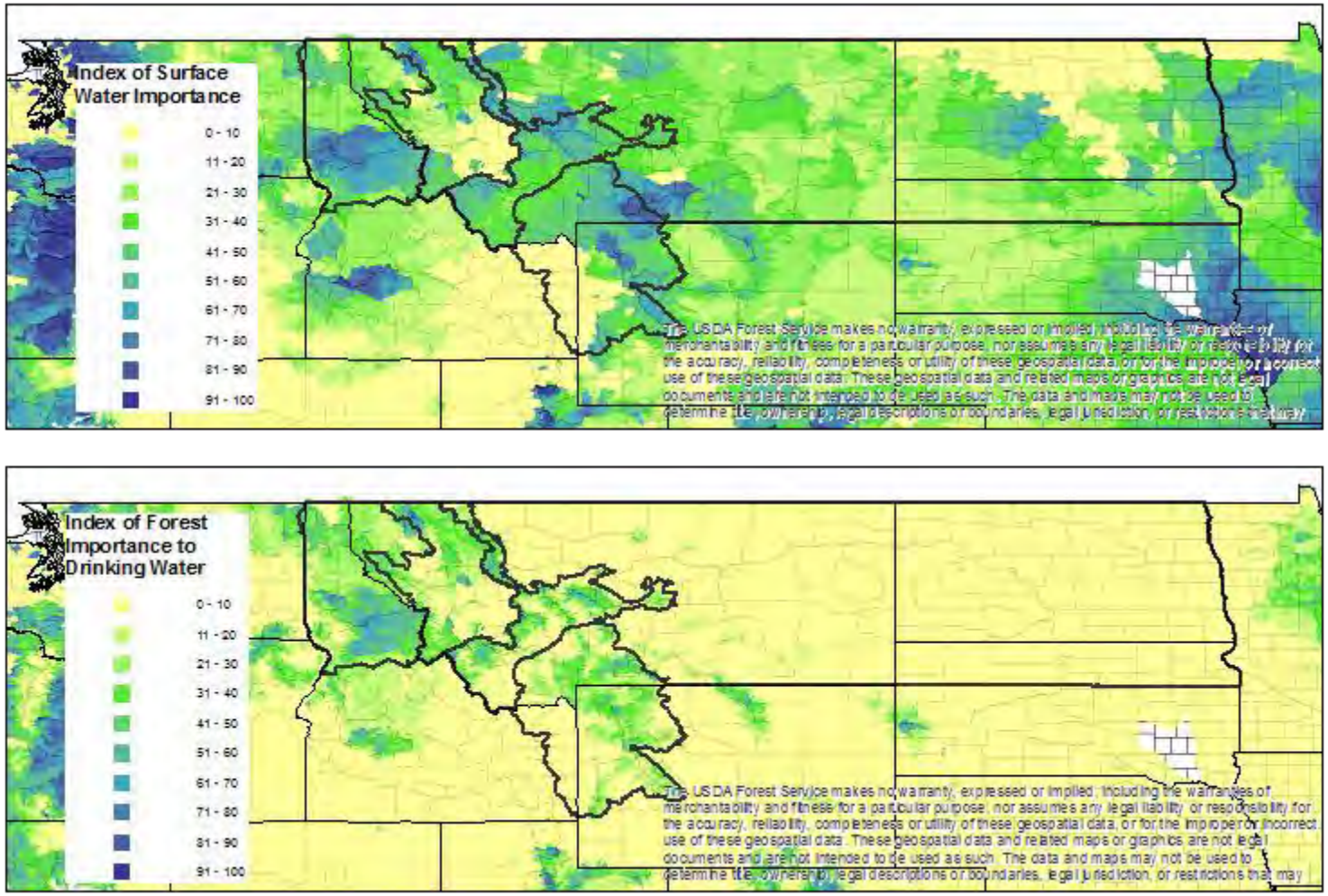


Figure 11.3—Forests to Faucets data showing the relative importance of surface water for municipal water supply (top) and forests for maintaining watershed health (bottom). The index depends on both the amount of water coming off forests and the population served by that water. Higher numbers indicate higher levels of importance (from Weidner and Todd 2011).

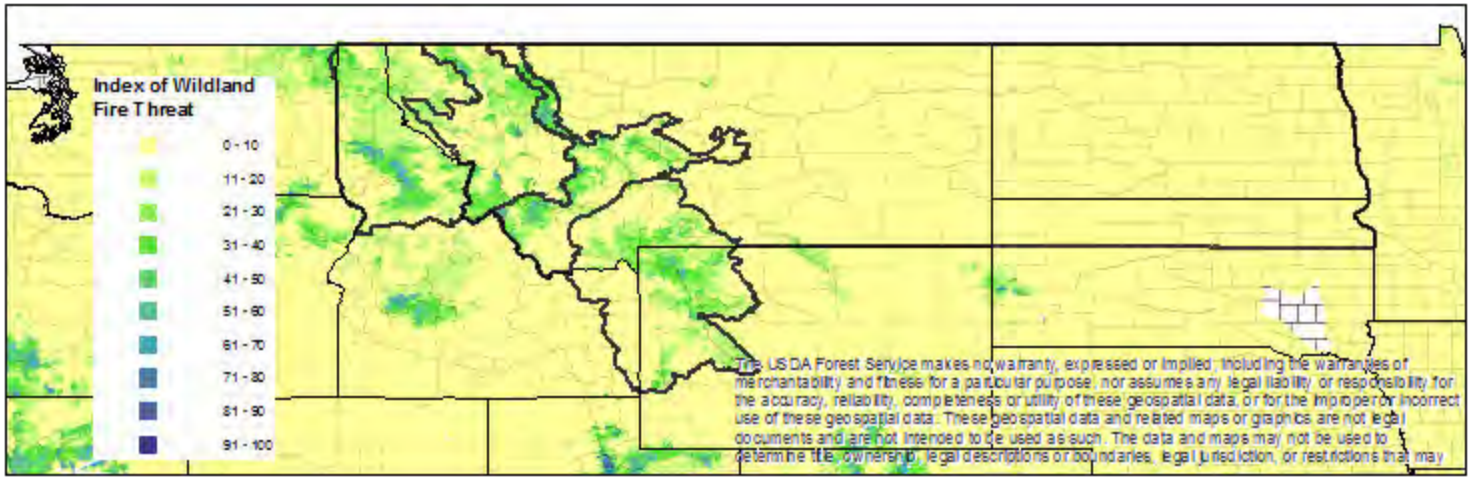


Figure 11.4—Wildland fire threat to forests and importance to surface drinking water. Higher numbers indicate higher risk of wildland fire (from Weidner and Todd 2011).

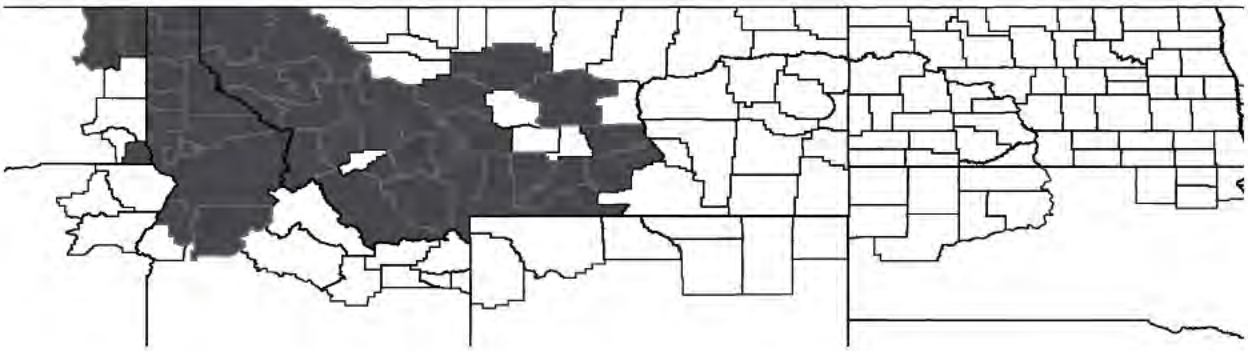


Figure 11.5—Primary area where timber is processed from national forests in the U.S. Forest Service Northern Region.

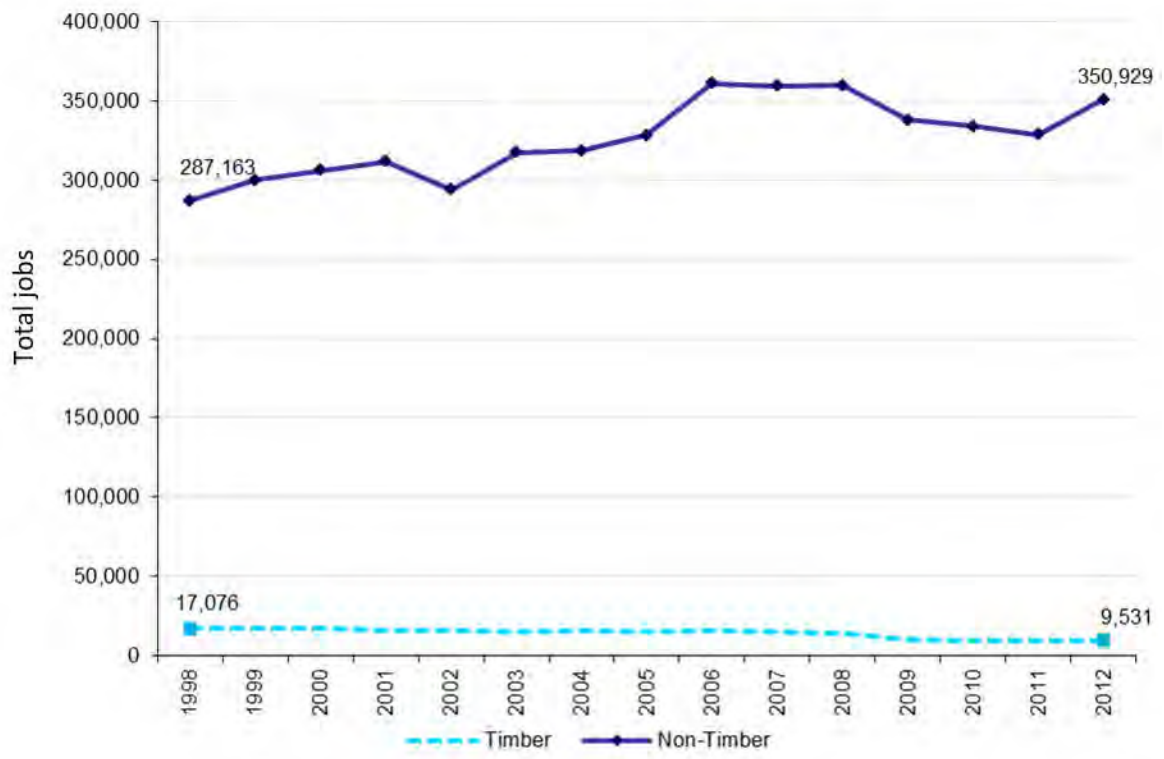


Figure 11.6—Total jobs in timber and non-timber for national forests in the U.S. Forest Service Northern Region (from U.S. Department of Commerce 2014).

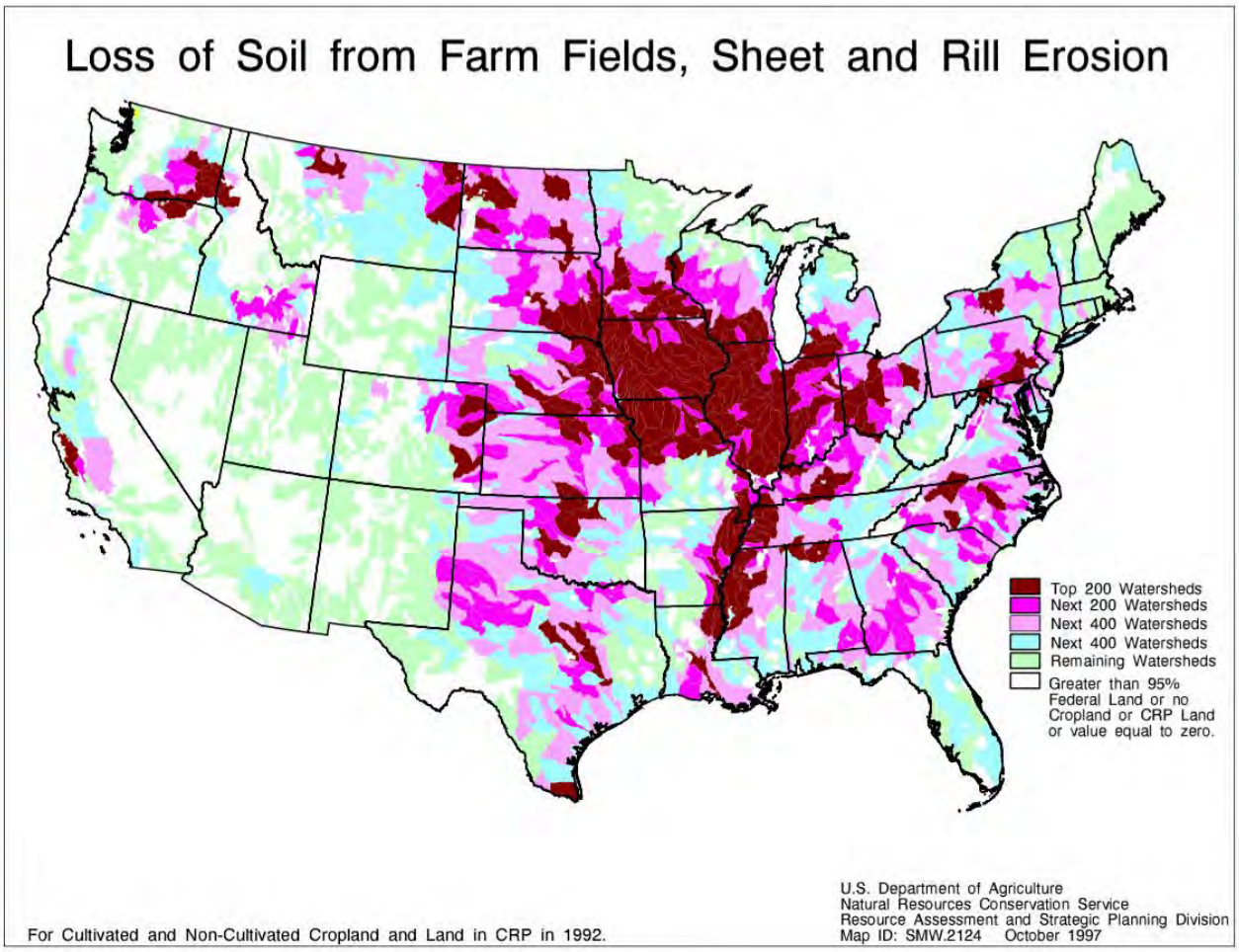


Figure 11.7—Ranking of watersheds in U.S. by their potential for soil loss from sheet and rill erosion (from U.S. Department of Agriculture, Natural Resources Conservation Service, http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/home/?cid=nrcs143_014067).

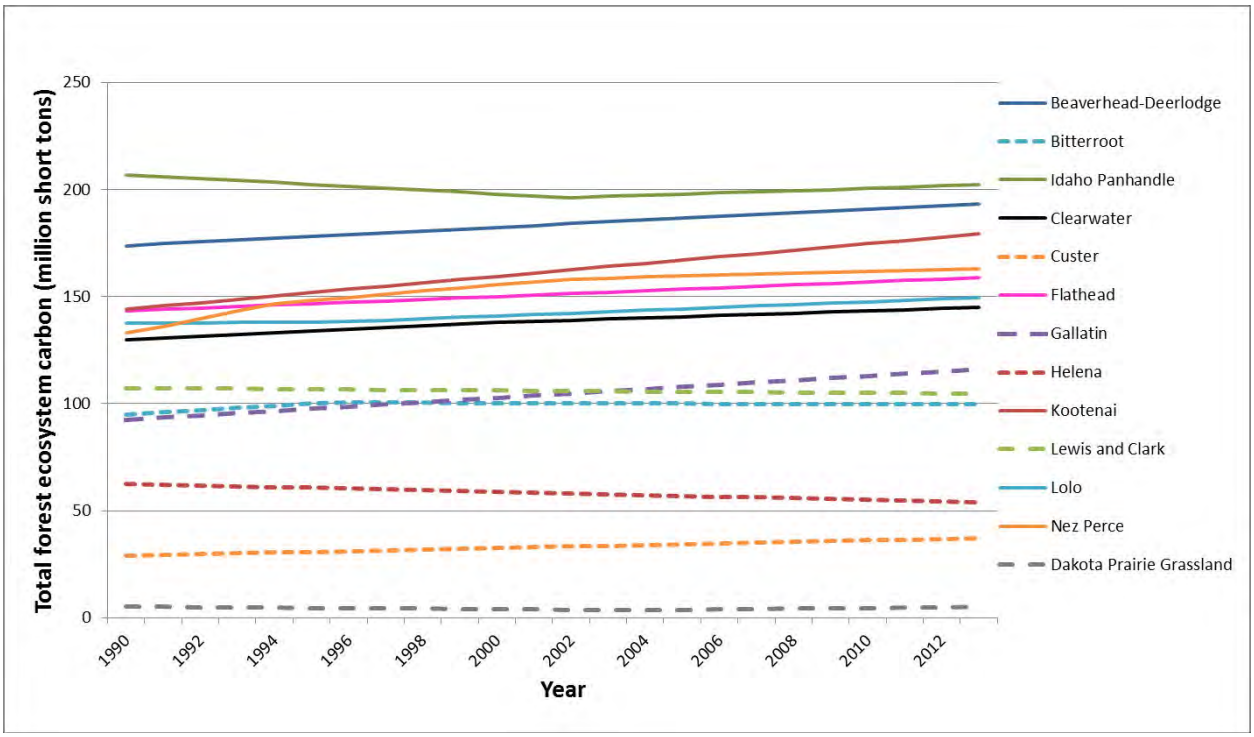


Figure 11.8—Total forest ecosystem carbon for the national forests and grassland in the Northern Region from 1990 to 2013.

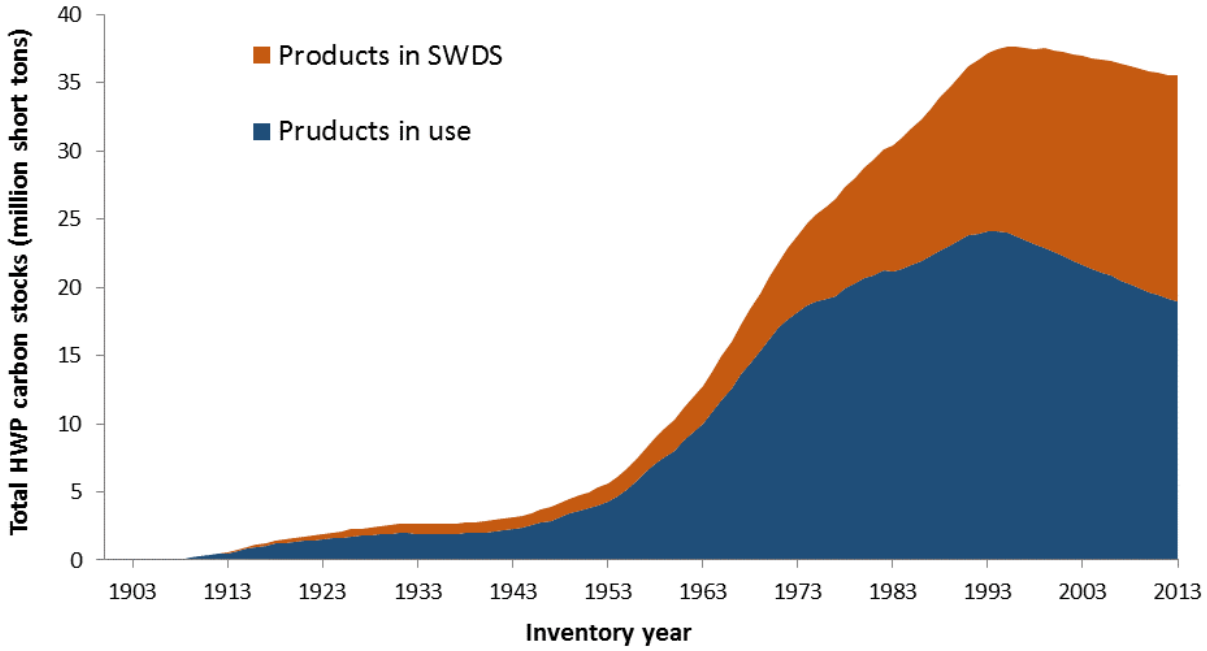


Figure 11.9—Cumulative total carbon stored in harvested wood products (HWP) manufactured from the Northern Region timber. Carbon in HWP includes both products that are still in use and carbon stored at solid waste disposals sites (SWDS), including landfills and dumps (Stockmann et al. 2014).

Figure 12.1—Prehistoric stone cairn exposed by wildfire in Custer National Forest. Intense wildfires, suppression, and rehabilitation activities annually affect hundreds of cultural resources in the Northern Rockies. (Photo by Halcyon LaPoint, Custer-Gallatin National Forest)

Figure 12.2—Prehistoric artifacts exposed in soil-deflated surface caused by drought conditions. Exposed artifacts are vulnerable to illegal collecting and livestock trampling. (Photo by Carl Davis, U.S. Forest Service)

Figure 12.3—Post-wildfire debris flow that obliterated or covered cultural resources in Meriwether Canyon, Helena National Forest. Early, intense spring runoff events may become more common in the future. (Photo by Carl Davis, U.S. Forest Service)

Figure 12.4—Melting perennial ice patches expose prehistoric artifacts in Custer-Gallatin National Forest. These high-elevation locations document activities by Native American groups in the recent and distant past. (Photo by Craig Lee, Montana State University)

Figure 12.5—Whitebark pine mortality may affect the integrity and status of cultural sites, such as the Lewis and Clark Pass cultural landscape and National Register District shown here. Significant landscape change may also affect indigenous peoples and local communities who use the area and its resources. (Photo by Sara Scott, Montana Department of Fish, Wildlife, and Parks)

Figure 12.6—Installing emergency roof supports in the main lodge, OTO Dude Ranch, Custer-Gallatin National Forest. Routine and emergency projects to stabilize, protect, and maintain historic buildings are likely to increase in a warmer climate. (Photo by Marcia Pablo, Custer-Gallatin National Forest)

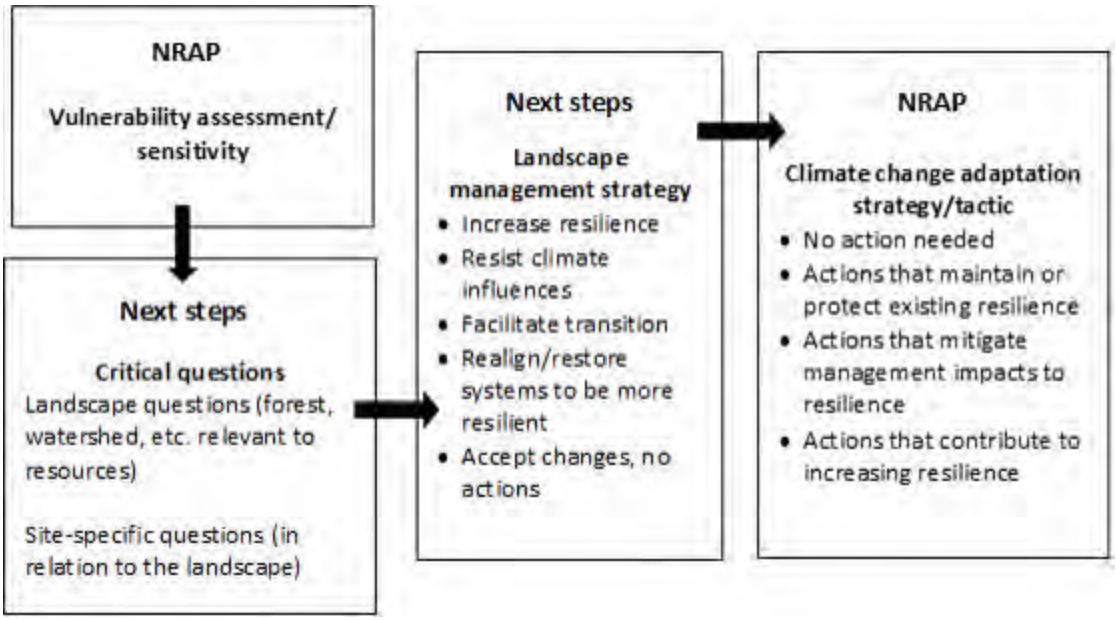


Figure 13.1—General framework for use of the Northern Rockies Adaptation Partnership vulnerability assessment and adaptation strategies and tactics to ask critical questions and develop a landscape management strategy.

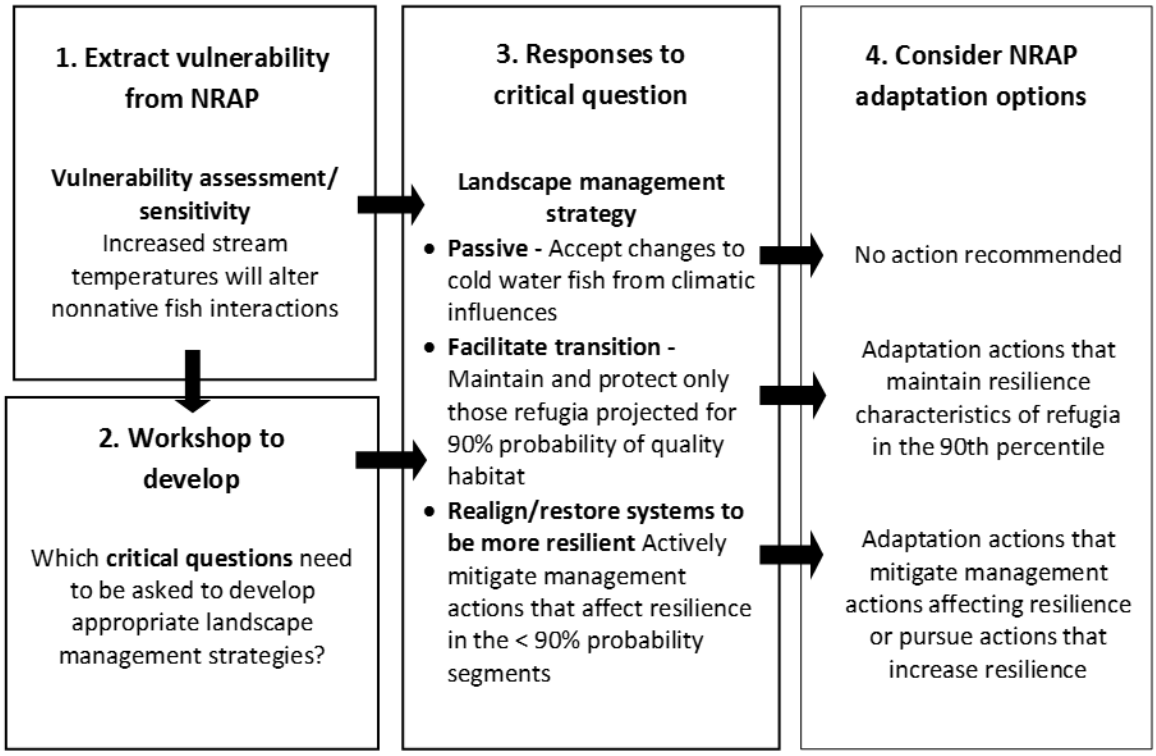


Figure 13.2—Example of how a workshop can be conducted to answer critical questions and develop a landscape management strategy for cold-water fish

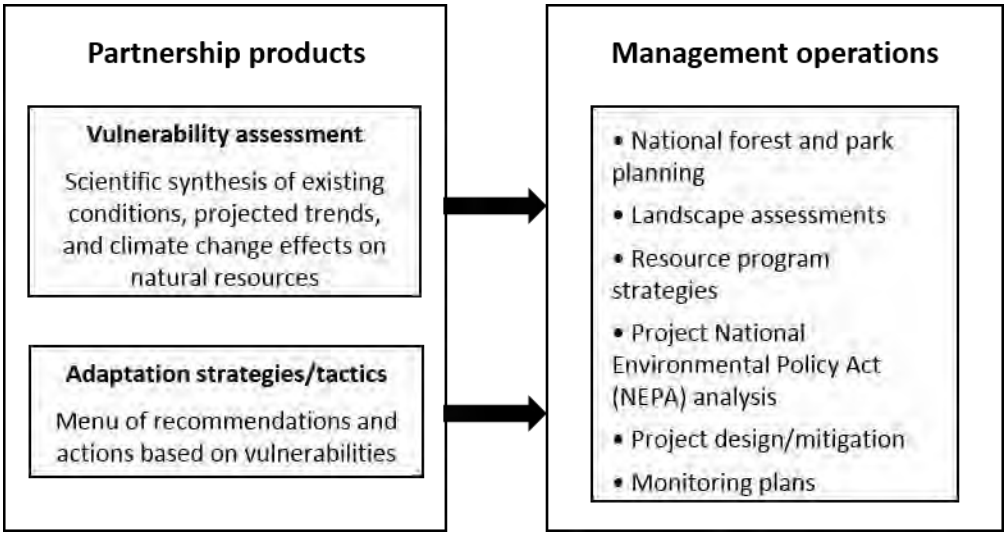


Figure 13.3—Example applications of Northern Rockies Adaptation Partnership products to land management operations.

Boxes

Box 3.1—Comparing CMIP3 and CMIP5 for temperature and precipitation projections for Oregon and Washington

Model evaluation

One way to evaluate a model's "skill" is to have it simulate (recreate) past climate and compare those results to observed climate. Both CMIP3 and CMIP5 models reproduce important characteristics of climate in the NRAP region fairly well, including wet winters, dry summers, annual temperature, and a 20th century warming trend (~1.4 °F per century). However, both CMIP3 and CMIP5 models are wetter on an annual basis than observations (Mote and Salathé 2010, Rupp et al. 2013).

Future temperature

- CMIP5 climate experiments based on RCP 4.5 and RCP 8.5 are warmer for the NRAP region, on average, than the CMIP3 scenarios based on SRES-B1 and SRES-A2.
- Most of the difference in temperature projections can be explained through increased forcing between the two sets of emissions/concentration scenarios, rather than modifications to the models between CMIP3 and CMIP5.

Future precipitation

- CMIP3 and CMIP5 both project a slightly wetter future on average by mid-21st century.
- CMIP3 and CMIP5 both project slightly drier summers and slightly wetter conditions the rest of the year.
- High natural variability in precipitation masks differences between CMIP3 and CMIP5.

Box 3.2—Summary: Climatic variability and change for the Northern Rockies Adaptation Partnership region

- The mountainous West, Central, East, and Greater Yellowstone Ecosystem subregions sit at the boundary between the warm, wet, maritime airflows from the Pacific Ocean, and the cooler, drier airflows from Canada. The Grassland subregion is influenced primarily by the cooler, drier airflows from Canada.

- Climatic variability in the mountainous areas of Idaho, Montana, and the Greater Yellowstone Ecosystem is strongly influenced by interactions with topography, elevation, and aspect.

- Historically, the coolest areas are found in the Greater Yellowstone Ecosystem, and the warmest areas are associated with grasslands in central Montana and into South Dakota and North Dakota.

- By the 2040s, mean annual monthly temperatures are projected to increase in the NRAP region. The warmest areas continue to be associated with central Montana. For the Grassland subregion, projections show a pattern of drier west and wetter east, with the mean of climate models showing a slight increase in the wetter eastern area.

- Projections for precipitation suggest a very slight increase in the future. Precipitation projections, in general, have much higher uncertainty than those for temperature.

- Seasonally, projected winter maximum temperature begins to rise above freezing (32 ^{o}F) in the mid-21st century in several of the subregions.

- Projected climate was derived from climate models in the Coupled Model Intercomparison Project version 5 (CMIP5) database, which was used in the most recent Intergovernmental Panel on Climate Change reports.

- Some chapters in this publication draw from existing scientific literature that used climate projections from the 2007 IPCC reports (CMIP3 database). In the mid- 21st century (2040-2060), CMIP3 and CMIP5 temperature projections are similar, whereas CMIP5 precipitation projections are slightly wetter than those in CMIP3.

Box. 3.3—Summary: Historical and projected climate for the NRAP Western subregion

- Climatologically, this mountainous region sits at the boundary between warm, wet, maritime airflows from the Pacific Ocean, and cooler, drier airflows from Canada.

- Changes in climate affecting mountain snowpack will have important hydrological implications.

- Over the historical period of record (1895-2012), the annual mean monthly minimum temperature increased by about 3.0 °F, while the annual mean monthly maximum temperature increased by about 0.6 °F. During the same period, annual mean monthly precipitation increased slightly, by an average of about 0.1 per month.

- Temperature is projected to increase 5-10 °F is by 2100, including increases in both the annual mean monthly minimum and annual mean monthly maximum.

- Mean monthly maximum and minimum temperatures are projected to increase for all seasons. The mean monthly minimum temperature (spring and autumn) and the mean monthly maximum temperature (winter) may rise above freezing.

- Seasonal precipitation is projected to be slightly wetter in winter and spring, slightly drier in summer.

Box. 3.4—Summary: Historical and projected climate for the NRAP Central subregion

- Climatologically, this mountainous region sits at the boundary between warm, wet, maritime airflows from the Pacific Ocean, and cooler, drier airflows from Canada.

- Changes in climate affecting mountain snowpack will have important hydrological implications.

- Over the historical period of record (1895-2012), the annual mean monthly minimum temperature increased by about 2.6 °F, while the annual mean monthly maximum temperature increased by about 1.3 °F.

- By 2100, temperature is projected to increase 6-12 °F for the annual mean monthly minimum, and 5-11 °F for the annual mean monthly maximum.

- Mean monthly maximum and minimum temperatures are projected to increase for all seasons. The mean monthly minimum temperature (spring and autumn) and the mean monthly maximum temperature (winter) may rise above freezing.

- Seasonal precipitation is projected to be slightly wetter in winter and spring, slightly drier in summer.

Box. 3.5—Summary: Historical and projected climate for the NRAP Eastern subregion

- Climatologically, this mountainous region sits at the boundary between warm, wet, maritime airflows from the Pacific Ocean, and cooler, drier airflows from Canada.

- Changes in climate affecting mountain snowpack will have important hydrological implications.

- Over the historical period of record (1895-2012), the annual mean monthly minimum temperature increased by about 2.2 °F, while the annual mean monthly maximum temperature increased by about 1.8 °F. During the same period, annual mean monthly precipitation was unchanged.

- By 2100, temperature is projected to increase 6-11 °F for the annual mean monthly minimum, and 5-11 °F for the annual mean monthly maximum.

- Mean monthly maximum and minimum temperatures are projected to increase for all seasons. The mean monthly minimum temperature (spring and autumn) and the mean monthly maximum temperature (winter) may rise above freezing.

- Seasonal precipitation is projected to be slightly wetter in winter and spring, slightly drier in summer.

Box. 3.6—Summary: Historical and projected climate for the NRAP Greater Yellowstone subregion

- In the Greater Yellowstone Ecosystem subregion, climatic variability is strongly influenced by interactions with topography, elevation, and aspect.

- Over the historical period of record (1895-2012), the annual mean monthly minimum temperature increased by about 2.9 °F, while the annual mean monthly maximum temperature increased by about 1.2 °F.

- By 2100, temperature is projected to increase 5-10 °F for the annual mean monthly minimum, and 7-12 °F for the annual mean monthly maximum.

- Annual mean monthly precipitation is projected to increase slightly by 2100, although projections for precipitation have high uncertainty compared to temperature.

- Projected winter maximum temperature is projected to increase above freezing in the mid-21st century. Projected summer temperature is projected to increase 5 °F by 2060 and 10 °F by 2100.

Box. 3.7—Summary: Historical and projected climate for the NRAP Grassland subregion

- Warming trends indicate that future climate will be similar to the area south of this region.
- Even with little or no change in precipitation, there is the potential for summer drying or drought due to the increased heat and increased evapotranspiration.
- Early snow melt from the west will imply changes in streamflow, with implications for streamflow and temperature, therefore reservoir management and stream ecology.
- There is a pattern of a drier west and wetter east, with the average of climate models showing a slight shift for more of the wetter east.

Box 5.1—Effects of Climate Change on Arctic Grayling

Arctic grayling (*Thymallus arcticus*) are a salmonid species native to Arctic Ocean drainages in North America and northern Eurasia, and Pacific Ocean basins in Alaska and British Columbia, with two disjunct inland groups in Michigan (now extinct) and the upper Missouri River basin in Montana and Wyoming (Kaya 1992, Scott and Crossman 1998). Within its range in Montana and Wyoming, grayling was represented by four adfluvial (lake living, stream spawning) populations in the Red Rock and Big Hole River basins, and by fluvial populations widely but irregularly distributed in the Missouri River basin above the Great Falls (USFWS 2014). Relative to this historical distribution, the current range and abundance of Arctic grayling have decreased greatly. Lacustrine populations are more common recently because of introductions inside and outside its historical range (Kaya 1992). Declines of riverine populations were caused by habitat degradation and fragmentation, inundation by reservoirs, overharvest, and interactions with nonnative fish, particularly rainbow trout, brook trout, and brown trout (Kaya 1992). The distinct population segment in the upper Missouri River basin was petitioned for listing under the ESA, but has not been listed (USFWS 2014). Recent activities focused on increasing instream flows, improving habitat connectivity, supplementing existing populations, and founding new populations (some in historically fishless lakes) appear to have arrested declines in most grayling populations in this basin (USFWS 2014).

Arctic grayling are regarded as a cold-water species (Elliott and Elliott 2010). Grayling life histories are often characterized by extensive movements to habitats for growth, reproduction, and overwintering, especially in riverine systems (Northcote 1995). Access to thermal refugia may be important to population persistence at the southern extreme of its range; many of the fluvial systems that retain grayling in the upper Missouri River basin are heavily influenced by groundwater inputs (USFWS 2014). Although the thermal preferences of this species are uncertain, the upper thermal limits of grayling in the Big Hole River basin are comparable to those of cutthroat trout (Johnstone and Rahel 2003; Lohr et al. 1996; Wagner et al. 2001).

The influence of climate change on Arctic grayling is uncertain, because data are lacking on this topic, but their reliance on mobility emphasizes the need for connectivity among complementary habitats. Ameliorating the effects of low summer discharge has been a target of management (USFWS 2014), but this problem may become more severe and difficult to overcome if projected climate-related changes in discharge (chapter 4) are realized. Many of the extant populations are in high-elevation lakes that are presumed to be less vulnerable to the effects of warming or reduced streamflow (USFWS 2014).

Responses to warmer stream temperatures may be complex. With warming summer water temperatures, initiation of the spawning season advanced by more than three weeks over the course of four decades in a population of adfluvial European grayling (*T. thymallus*) in Switzerland (Wedekind and Küng 2010). Paradoxically, earlier spawning meant a longer exposure of incubating eggs and fry to colder spring water temperatures, patterns that coincide with substantial declines in the number of female spawners. This pattern may reflect declining survival of juvenile fish (Wedekind and Küng 2010) or sex-specific vulnerability to changes in thermal regimes (Pompini et al. 2013). Whether this is symptomatic of a broader trend or case study is unknown, but warming stream temperatures, population declines, and sex ratio shifts in salmonids have been observed elsewhere in Europe (Hari et al. 2006). Regardless, the few Arctic grayling populations extant in their historical range are likely to remain the focus of management efforts (USFWS 2014), and the continuation of these efforts may play a significant role in the near-term persistence of grayling in the upper Missouri River basin. At longer time scales, the "climate velocity" associated with warming of low-gradient stream habitats (Isaak and Rieman 2013) may challenge our ability to maintain recent improvements in the conservation status of this species.

Box 5.2—Effects of Climate Change on Fish Species in the Grassland Subregion

Several native fish species are found in the Grassland subregion of NRAP. Located in the eastern portions of the Custer-Gallatin National Forest and the Dakota Prairies National Grassland, these species have received little scientific study and monitoring compared to cold-water salmonids and warm-water sportfish. Many prairie streams have never been sampled or are sampled sporadically at best (S. Barndt, personal observation; G. Gallinat, South Dakota Fish and Game, personal communication; Montana Fish, Wildlife and Parks database). As a result, fish distribution and aquatic habitat are poorly understood at all spatial scales. However, as in most dendritic stream networks, small streams constitute the majority of fish habitat, and species favoring those habitats are likely to be the most common. Small streams may also provide seasonal habitats for spawning and rearing of species favoring larger streams, rivers, and lakes (Thornbrugh and Gido 2009).

Prairie streams are dynamic, tending to vary between periods of floods and flow intermittency, among and sometimes within years (Dodds et al. 2004). Extirpation and recolonization of local habitats by fish species is typical (Falke et al. 2012), and patterns of occupancy by fish species can be considered in the context of metapopulation theory, in which the presence of subpopulations of each species depends on habitat connectivity and duration (Falke and Fausch 2010). Although it is typical for prairie streams to be reduced to sets of disconnected pools in some years, this pattern is more prevalent in agricultural landscapes where surface and groundwater withdrawals are common (Gido et al. 2010; Falke et al. 2011). Climate change is expected to exacerbate these patterns (Jaeger et al. 2014) and lead to greater extremes, including severe droughts and more intense storms and wet intervals in plains and dryland systems (Michels et al. 2007; Starks et al. 2014).

Projecting the responses of prairie fishes to climate change is complicated by difficulty in identifying habitat preferences, partly because many fish species are habitat generalists (Wuellner et al. 2013) and because the dynamics of prairie streams lead to difficulties in predicting interannual habitat occupancy (Falke et al. 2012). Prairie fish assemblages in the analysis area are represented by four species guilds—northern headwaters, darter, madtom, and turbid river guilds (Clingerman et al. 2012)—that are likely to differ in their vulnerability to climate change. Annual air temperature and various indicators of streamflow are strong predictors of presence for the northern headwaters, madtom, and darter guilds.

Observed and modeled patterns allow some inferences to be made about climate vulnerability and adaptation for prairie fishes. First, the northern headwaters guild may be most vulnerable to increasing temperature, as well as to climate-related decreases in ground water recharge (Clingerman et al. 2012). This guild includes the northern redbelly dace (*Chrosomus eos*), a sensitive species in the U.S. Forest Service Northern Region, which occupies small, stable, and relatively cool headwater streams (Stasiak 2006). Accurate mapping of habitat types, species assemblages present in them, and monitoring of habitat conditions will help refine possible climate change effects on both habitat and species, as well as define appropriate management responses. Buffering variations in flow extremes (e.g., securing instream flows) and encouraging the presence of riparian vegetation are practical responses to climate change where the northern headwaters guild is present. Although the other prairie fish guilds seem less vulnerable to changes to temperature, all are influenced by amount and timing of flow. Therefore, climate change adaptation strategies for the northern headwater guild should also be appropriate for the other guilds. Finally, all guilds are currently at risk, and may become more so if flow regimes become more variable, especially if migration barriers prevent fish from moving along stream courses. Many of these species may be ill-adapted to surmounting either height or velocity barriers (Rosenthal 2007; Perkin and Gido 2012). Therefore, removing barriers to fish passage between habitats is a prudent adaptation strategy. This strategy carries the risk of allowing nonnative species to invade, so it should be implemented within the larger conservation context of a site (Fausch et al. 2009).

Box 6.1—Using historical range and variability to assess and adapt to climate change

To effectively implement ecosystem-based management, land managers often find it necessary to obtain a reference or benchmark to represent the conditions that describe fully functional ecosystems (Cissel et al. 1994, Laughlin et al. 2004). Contemporary conditions can be evaluated against this reference to determine status, trend, and magnitude of change, and to design treatments that provide society with valuable ecosystem services while returning declining ecosystems to a more sustainable condition (Hessburg et al. 1999, Swetnam et al. 1999). Reference conditions are assumed to represent the dynamic character of ecosystems and landscapes, varying across time and space (Swanson et al. 1994, Watt 1947).

The concept of *historical range and variability* (HRV) was introduced in the 1990s to describe past spatial and temporal variability of ecosystems (Landres et al. 1999), providing a spatial and temporal foundation for planning and management. HRV has sometimes been equated with "target" conditions (Harrod et al. 1999), although targets can be subjective and somewhat arbitrary, representing only one possible situation from a range of potential conditions (Keane et al. 2009). HRV encompasses a full range of conditions that have occurred across multiple spatiotemporal scales.

HRV represents a broad historical envelope of possible ecosystem conditions—burned area, vegetation cover type area, patch size distribution—that can provide a time series of reference conditions. This assumes that (1) ecosystems are dynamic, not static, and their responses to changing processes are represented by past variability; (2) ecosystems are complex and have a range of conditions within which they are self-sustaining, and beyond this range they transition to disequilibrium (Egan and Howell 2001); (3) historical conditions can serve as a proxy for ecosystem health; (4) the time and space domains that define HRV are sufficient to quantify observed variation; and (5) the ecological characteristics being assessed for the ecosystem or landscapes match the management objective (Keane et al. 2009).

The use of HRV has been challenged because a warmer climate may permanently alter the environment of ecosystems beyond what was observed under historical conditions (Millar et al. 2007a), particularly altered disturbance processes, shifts in plant species distribution, and hydrologic dynamics (Notaro et al. 2007). However, a critical evaluation of possible alternatives suggests that HRV might still be the most viable approach in the near term because it has relatively low uncertainty.

An alternative to HRV is forecasting future variations of landscapes under changing climates using complex empirical and mechanistic models. However, the range of projections for future climate from the commonly used global climate models may be greater than the variability of climate over the past three centuries (Stainforth et al. 2005). This uncertainty increases when we factor in projected responses to climate change through technological advances, behavioral adaptations, and population growth (Schneider et al. 2007). Moreover, the variability of climate extremes, not the gradual change of average climate, will drive most ecosystem response to climate-mediated disturbance and plant dynamics (Smith 2011) that are difficult to project. Uncertainty will also increase as climate projections are extrapolated to the finer scales and longer time periods needed to quantify *future range and variability* (FRV) for landscapes (Araujo et al. 2005, Keane et al. 2009).

Given these cumulative uncertainties, time series of HRV may have lower uncertainty than simulated projections of future conditions, especially because large variations in past climates are already captured in the time series. It may be prudent to wait until simulation technology has improved enough to create credible FRV landscape pattern and composition, a process that may require decades. In the meantime, attaining HRV would be a significant improvement in the functionality of most ecosystems in the Northern Rockies, and would be unlikely to result in negative outcomes from a management perspective. As with any approach to reference conditions, HRV is useful as a guide, not a target, for restoration and other management activities.

Box 7.1—Rangeland definitions used by different federal agencies

U.S. Forest Service

Land primarily composed of grasses, forbs, or shrubs. This includes lands vegetated naturally or artificially to provide a plant cover managed like native vegetation and does not meet the definition of pasture. The area must be at least 1.0 acre in size and 120.0 ft wide.
(USDA FS 2010)

Bureau of Land Management

Land on which the indigenous vegetation (climax or natural potential) is predominantly grasses, grass-like plants, forbs, or shrubs and is managed as a natural ecosystem. If plants are introduced, they are managed similarly. Rangelands include natural grasslands, savannas, shrublands, many deserts, tundra, alpine communities, marshes, and wet meadows.
(Society for Range Management 1998)

Natural Resources Conservation Service

A land cover/use category that includes land on which the climax or potential plant cover is composed principally of native grasses, grass-like plants, forbs or shrubs suitable for grazing and browsing, and introduced forage species that are managed like rangeland. This would include areas where introduced hardy and persistent grasses, such as crested wheatgrass, are planted and practices such as deferred grazing, burning, chaining, and rotational grazing, are used with little or no chemicals/fertilizer being applied. Grasslands, savannas, many wetlands, some deserts, and tundra are considered to be rangeland. Certain low forb and shrub communities, such as mesquite, chaparral, mountain shrub, and pinyon-juniper, are also included as rangeland"
(USDA 2007).

Box 10.1—Subregional assessment of climate change effects on recreation

The broad links between climate, ecological changes, and recreation behavior that form the basis of the activity category assessments are designed to be generally applicable to all locations in the Northern Rockies region. However, in a region that encompasses parts of five states and stretches hundreds miles from east to west, significant subregional heterogeneity in climate effects may exist. The five subregions (Western Rockies, Central Rockies, Eastern Rockies, Grassland, Greater Yellowstone Area [GYA]) represent a wide variety of geographic and ecological features, and each has distinctive recreation opportunities that may be sensitive to climate changes. Assessing differences between the subregions can yield more geographically specific information about the effects of climate on recreation.

Table 10.B1 summarizes national forest visits by primary activity category for each subregion. Warm-weather activities are the most common category for all subregions, but there are significant differences in the relative importance of each activity category. Snow-based recreation is relatively more important in the Central Rockies, Eastern Rockies, and GYA subregions where there are multiple sites with consistently viable snow seasons and developed ski areas. In contrast, much less snow-based recreation (as a share of total visits) occurs in the West Rockies and Grassland subregions. Wildlife recreation activities (hunting, fishing, wildlife viewing) are most important in the Western Rockies and Grassland, although the Central Rockies, Eastern Rockies, and GYA see a significant minority of visitors engaging in these activities. Forest product gathering and water-based (not fishing) activities represent a small share of visits in all subregions, but the Grassland subregion sees almost no visitation for these activities.

The differences in activity participation also suggest that climate will have different effects on recreation in each subregion. The largest differences in activity participation are for snow-based activities; these activities are also the most likely to see negative impacts due to warming temperatures and decreased precipitation as snow. The Grassland subregion and to a lesser extent the Western Rockies have relatively low exposure to this effect because snow-based recreation is less prominent. The Central Rockies, Eastern Rockies, and GYA have higher participation in snow-based activities that could be exposed to climate change, although it is unclear to what extent snow-based sites will experience changes that degrade conditions for snow-based activities.

Other differences between subregions likely depend on differences in climate effects between subregions. For example, one subregion could experience warming that increases the incidence of extreme heat days, which has a negative impact on warm-weather recreation, whereas another sub-region experiences warming that extends the warm-weather season without a significant increase in the incidence of extreme heat days.

Box 10.2—Climate change in the Greater Yellowstone Area and Glacier National Park

The Greater Yellowstone Area (GYA) provides a wide range of recreation opportunities. The GYA is comprised of two national parks (Yellowstone, Grand Teton), parts of six national forests (Beaverhead-Deerlodge, Bridger-Teton, Caribou-Targhee, Custer, Gallatin, Shoshone), and other federally administered protected areas (John D. Rockefeller Memorial Parkway, National Elk Refuge, Red Rock Lakes National Wildlife Reserve [NWR]). These areas offer the full spectrum of recreation opportunities, from developed and urban settings to wilderness and primitive sites. Glacier National Park (GNP), which straddles the Western and Eastern Rockies subregions of NRAP in northwestern Montana, also provides a broad range of recreation opportunities comparable to those in the GYA.

Recreation visitation to federal units within the GYA and Glacier National Park is summarized in table 10.B2. Yellowstone National Park (YNP) and Grand Teton National Park (GTNP) respectively receive an average of 3.4 million and 2.6 million visitors annually. For both parks, the most common activities included viewing wildlife and viewing scenery and natural features. A majority of YNP visitors also indicated that they engaged in developed camping, walking or hiking, and visiting museums and visitor centers, while GTNP visitors indicated pleasure driving and walking or hiking as common activities (NPS 2006). Wildlife viewing is also an important activity for visitors to the Red Rock Lakes NWR and the National Elk Refuge, although these sites receive only a fraction of the visitors compared with the national parks (NPS 2006). Sightseeing is the dominant activity for the 2.1 million annual visitors in GNP.

National forests in the GYA receive a combined 7.6 million visitors annually. The most popular activity for visitors varies across forests. In the Gallatin and Caribou-Targhee National Forests, hiking and walking are the most popular activities, whereas downhill skiing is the most popular activity in Bridger-Teton and Custer National Forests. In Beaverhead-Deerlodge National Forest, hunting is the most popular activity (32 percent of visitors) and in Shoshone National Forest, viewing natural features is the most popular activity (25 percent of visitors).

Most of the general assessment of climate change effects on recreation in the Northern Rockies applies to the GYA and GNP, although the different activity profile means that exposure to the effects of climate change differs in this subregion. Visitation is dominated by warm-weather visits; 80 percent of visits to YNP and GTNP are during the June-September period. An additional 11 percent of visits occur during the "shoulder" season months of May and October. Warmer temperatures are expected to increase warm-weather recreation; earlier and later season periods of snow- and ice-free sites in the parks may encourage additional off-peak visitation. Some visitors may also substitute early- or late-season visits to avoid extreme summer heat. However, seasonal shifts in visitation may be constrained by summer vacation months determined by academic calendars.

Changes in the distribution and abundance of wildlife may affect recreation visitation and enjoyment due to the large number of YNP and GTNP visitors that engage in wildlife viewing. However, many climate-related changes in target wildlife species are ambiguous because of complex interactions between species, vegetation and forage opportunities, and disturbances (see chapter 9).

Other popular activities, such as driving for pleasure on roads and viewing scenery and special features (e.g., geysers and thermal features in YNP, driving the Going-to-the-Sun road in GNP), may be more or less sensitive to climate changes. In some cases the qualities, characteristics, and features that draw visitors to these activities have a limited connection to climate changes. However, features such as glaciers (in GNP) and snow-capped mountains are a particular draw for some visitors, and visitation tied to such features will likely be affected. Longer warm-weather seasons will likely increase access to roads and sites inaccessible when snow and ice is present, which would have a positive effect on visitation. In addition, wildfire and other disturbances can affect site access and the desirability of visitation to fire-affected sites. For example, wildfires in YNP are ssociated with decreased visitation in the subsequent month, but there does not appear to be a lasting negative effect on visitation or wildfire occurrence (Duffield et al. 2013).

Box 12.1. National Park Service lands in the Northern Rockies emphasize preservation and management of cultural resources

The National Park Service was created by Congress through the National Park Service Organic Act of 1916, whereby the Agency would allow "access to parks for the public enjoyment of cultural resources while ensuring their protection" (NPS 2011b). Specifically, a cultural resource is considered to be "an aspect of cultural system that is valued by or significantly representative of a culture, or that contains significant information about a culture" (NPS 2015b). Cultural heritage and its preservation are emphasized in the agency's Cultural Resources, Partnerships and Science directorate, with goals to:

- Preserve cultural resources in cooperation with Indian tribes, Alaska Native villages and corporations, Native Hawaiian organizations, states, territories, local governments, nonprofit organizations, property owners, individuals, and other partners.
- Provide leadership in research and use of advanced technologies to improve the preservation of the nation's cultural heritage.
- Establish standards and guidance for managing cultural resources within the National Park System and communities nationwide.
- Enhance public understanding and appreciation for the nation's cultural heritage.

Cultural Resources of National Parks in the Northern Rockies

Glacier National Park

Glacier National Park has six National Historic Landmarks and 350 structures listed in the National Register of Historic Places. Archaeological resources found in the park include prehistoric campsites, mining claims and homesteads. Cultural landscapes in the park include the Going-to-the-Sun-Road, Chief Mountain and Headquarters Historic District.

Grand Teton National Park

Historical sites in Grand Teton National Park pre-date creation of the park, and many structures are found in the National Register of Historic Places. Some structures include homestead remnants from the people who settled in the Jackson Hole area and ranches. Several of these structures have been incorporated in the ark and restored to their natural condition. Mining Ditch is an early structure, still in the park today, that carried water in the area of Schwabacher's Landing. Cunningham Cabin, an early piece of settlement, can be found in the northern area of Jackson Hole. Menor's Ferry, created by D. Menor, was operational until 1927, taking passengers across the Snake River.

Yellowstone National Park

Yellowstone National Park has been preserved not only for biodiversity but also for information about past human activities and significant archaeological and cultural resources contained within the park. Some historical structures and sites include: (1) Obsidian Cliff where obsidian was first used for tool making over 11,000 B.P., (2) Yellowstone Lake which still has intact cultural deposits from over 9,000 B.P., (3) Mammoth Hot Springs which includes the Mammoth Post Office and Roosevelt Arch from the late 1800s, and (4) the town site of Cinnabar, Montana which was established in 1883 as the last stop on the Northern Pacific Railroad line to Yellowstone Park. The potential effects of climate change on cultural resources have been described for Big Hole National Battlefield, Montana (NPS 2011a). A warmer climate will complicate the goal of management to restore and maintain the battlefield in a biological condition representative of 1877. Scientific understanding of climate change effects provides a foundation for reconciling biological effects with management goals based on historical conditions.

Appendix 1A

NRAP Resource Team Participants

Leadership Team

- Linh Hoang – USFS, Region 1
- Dave Peterson – USFS, Pacific Northwest Research Station
- Scott Barndt – USFS, Region 1
- Barry Bollenbacher – USFS, Region 1
- Yvette Converse – USFWS, Great Northern Landscape Conservation Cooperative
- Karen Dante-Wood – USFS, Climate Change Office
- Pam Fletcher – USFS, Region 1
- Jessica Halofsky – University of Washington
- Cat Hawkins Hoffman – NPS
- Linda Joyce – USFS, Rocky Mountain Station
- Virginia Kelly – NPS, Greater Yellowstone Coordinating Committee
- Jessi Kershner – EcoAdapt
- Jerry Krueger – USFS, Region 1
- Jeff Morisette – USGS, North Central Climate Center
- Rick Nelson – USFWS, Plains & Prairie Potholes Landscape Conservation Cooperative
- Fred Noack – USFS, Region 4
- Tom Olliff – NPS, Great Northern Landscape Conservation Cooperative
- Ann Rodman – NPS
- Alicia Torregrosa – USGS, Western Geographic Center
- Andrea Woodward – USGS

Climate

- Kathie Dello – Oregon State University
- John Gross – NPS
- Bill Monahan – NPS
- John Stevenson – Oregon State University
- Marian Talbert – USGS, North Central Climate Center
- Mike Tercek – Walking Shadow Ecology/ Yellowstone National Park

Water resources

- Charlie Luce – USFS Rocky Mountain Station
- Dan Fagre – USGS, Northern Rockies Center
- Stu Hoyt – USFS, Region 1
- Bruce Sims –USFS, Region 1
- Mike Tercek – Walking Shadow Ecology / Yellowstone National Park
- Cameron Thomas – USFS, Region 1

Fisheries

- Michael Young – USFS Rocky Mountain Station
- Scott Barndt – USFS, Region 1
- Jason Dunham – USGS, Region 1
- Dan Isaak – USFS, Rocky Mountain Station
- Kevin McKelvey – USFS, Rocky Mountain Station
- Gregor Schuurman – NPS, Natural Resources Team
- Scott Spaulding – USFS, Region 1

Wildlife

- Kevin McKelvey – USFS, Rocky Mountain Station
- Eric Beever – USGS, Northern Rockies Center
- Barry Bollenbacher – USFS, Region 1
- Renate Bush – USFS, Region 1
- Alan Dohmen – USFS, Region 1
- Beth Hahn – USFS, Rocky Mountain Station
- Scott Jackson –USFS, Region 1
- Mary Manning – USFS, Region 1
- Steve Shelly – USFS, Region 1
- Gregor Schuurman – NPS, Natural Resources Team
- Meredith Webster – USFS, Region 1

Recreation

- Michael Hand – USFS, Rocky Mountain Station
- Krista Gebert – USFS, Region 1
- Stu Hoyt – USFS, Region 1
- Cynthia Manning – USFS, Region 1
- Lis Novak – USFS, Region 1

Forest Vegetation

- Bob Keane – USFS, Rocky Mountain Station
- Barry Bollenbacher – USFS, Region 1
- Kate Dwire – USFS, Rocky Mountain Station
- Greg Eckert – NPS, Resource Management Team
- John Gross – NPS, Natural Resource Science Team
- Russ Graham – USFS, Rocky Mountain Station
- Eric Henderson- USFS, Region 1
- Lisa Holsinger – USFS, Rocky Mountain Station
- Terrie Jain – USFS, Rocky Mountain Station
- Jerry Krueger – USFS, Bitterroot NF
- Andrew Larson – University of Montana
- Mary Frances Mahalovich – USFS, Region 1
- Mary Manning – USFS, Region 1
- Susan Rinehart – USFS, Region 1
- Mike Tercek – Walking Shadow Ecology, NPS
- Meredith Webster – USFS, Region 1
- Art Zack – USFS, Region 1

Non-Forest Vegetation

- Matt Reeves – USFS, Rocky Mountain Station
- Jeanne Chambers – USFS, Rocky Mountain Station
- Jeff Dibenedetto – USFS, Custer NF
- Andy Hansen – Montana State University
- Bill Lauenroth – University of Wyoming
- Mary Manning – USFS, Region 1
- Susan Rinehart – USFS, Region 1

Disturbance

- Rachel Loehman – USFS, Rocky Mountain Station

- Barb Bentz – USFS, Rocky Mountain Station
- Ann Lynch – USFS, Rocky Mountain Station
- Gregg DeNitto – USFS, Region 1
- Joel Egan – USFS, Region 1
- John Gross – NPS, Natural Resource Science Team
- Jeff Hicke – University of Idaho
- Stu Hoyt – USFS, Region 1
- Blakey Lockman – USFS, Region 1
- Roy Renkin – NPS, Yellowstone Center for Resources
- Steve Shelly – USFS, Region 1
- Elaine Sutherland – USFS, Rocky Mountain Station

Social, economic, ecosystem services

- Travis Warziniack – USFS, Rocky Mountain Station
- Krista Gebert – USFS, Region 1
- Michael Hand – USFS, Rocky Mountain Station
- Stu Hoyt – USFS, Region 1
- Jerry Krueger – USFS, Region 1
- Megan Lawson Headwaters Economics
- Cynthia Manning – USFS, Region 1
- Lis Novak – USFS, Region 1

Acronyms:
- USFS: US Forest Service
- USFWS: US Fish and Wildlife Service
- NPS: National Park Service

NRAP Workshop Participants

Bozeman, MT October 9 – 10, 2014

Vegetation

- Andrew Hasen – Montana State University, Ecology Department
- Ann Rodman – Yellowstone National Park, Branch Chief, Physical Sciences
- Bob Keane – USFS Rocky Mountain Research Station, Research Ecologist
- Ben Poulter – Montana State University, Climate Change Modeler
- Cavan Fitzsimmons – Custer/Gallatin National Forest, Hebgen District Ranger
- Jill McMurray – USFS R1/R4, Air Quality
- Julie Shea – Custer/Gallatin National Forest, Fire Ecologist
- Keith Konen – Gallatin National Forest, Silviculturist
- Kelly McCloskey – Grand Teton National Park, Ecologist
- Mary Mahalovich – USFS Rocky Mountain Research Station, Regional Geneticist
- Traute Parrie – Custer/G tin National Forest, Beartooth District Ranger

Non-Forest Vegetation

- Denice Swanke
- Diane Abendroth Grand T on Na nal Park, Fire Ecologist
- Jeff Dibenedetto – C t Nation l Fores Ecologist
- Jessi Salix – Beaverhead-Dee od e Natio l Forest, Botany
- Kevin Suzuki –Beaverhead Deerlod e Na onal Forest, Weeds/Botany
- Mary Manning – USFS Region 1 R gional Office, Regional Ecologist
- Matt Reeves – USFS Rocky Moun in Research t ion, Research Ecologist
- Rose Lehman – Caribou-Targhee National orest orest Botanist
- Susan Lamont – Gallatin National Forest, W eds
- Travis Ziehl – Teton County, Assistant Superv or Weed & Pest District
- Walt Allen – Custer/Gallatin National Forest, ardin District Ranger

Wildlife

- Amie Shovlain – Beaverhead Deerlodge National Forest, Wildlife
- Jeff Burrell – Wildlife Conservation Society , Northern Rockies an Yellowstone Program
- Jodie Canfield – Gallatin National Forest, Wildlife
- Kevin McKelvey – USFS Rocky Mountain Research Station, Wildlife Ecologist
- Kristin Legg – Greater Yellowstone Network, Inventory Monitoring Coordinator
- Mary Erickson – Custer/Gallatin National Forest, Forest Supervisor
- Polly Buotte – University of Idaho, Research Associate, Geography
- Rachel Feigley – Custer/Gallatin National Forest, Wildlife Biologist
- Rob Mickelson – Caribou-Targhee National Forest, Resource Staff Officer
- Sue Consolo Murphy – Grand Teton National Park, Chief of Resources

Hydrology

- Alex Sienkiewicz – Custer/Gallatin National Forest, Yellowstone District Ranger
- Andy Ray – NPS Inventory and Monitoring, Hydrologist
- Dave Thoma – NPS Inventory and Monitoring, Hydrologist
- Ed Snook – USFS Region 1 Regional Office, Regional Hydrologist
- Eric Winthers – Bridger-Teton National Forest, Soil and Water Program Manager
- Gretchen Hurley – BLM, Geologist
- Karri Cary – Shoshone National Forest, Hydrologist
- Mike Tercek – Yellowstone National Park Contractor, Ecologist

- Pam Fletcher – Beaverhead-Deerlodge National Forest, Forest Inventory & Monitoring Coordinator
- Richard Raione – Bridger-Teton National Forest, Greys River District Ranger

Fisheries
- Brad Shepard – Wildlife Conservation Society
- Dan Isaak – USFS Rocky Mountain Research Station, Fisheries Scientist
- Dave Hallac – Yellowstone National Park
- Gary Tabor – Center for Large Landscape Conservation , Director
- Jessi Kershner – EcoAdapt, Lead Scientist
- Lisa Stoeffler – Custer/Gallatin National Forest, Bozeman District Ranger
- Michael Young – USFS Rocky Mountain Research Station, Fisheries Biologist
- Molly Cross – Wildlife Conservation Society
- Robert Al-Chokhachy – USGS Northern Rocky Mountain Science Center, Research Fish Biologist
- Scott Barndt – Custer-G tin National Forest, Ecosystem Staff Officer
- Shawn Anderson – Sh shone National Forest, Forest Fish Biologist
- Yvette Converse – reat North rn Landscape Conservation Cooperative/NPS, Co-Coordinator

Recreation
- Jamie Schoen – Bridg Teton N tional Forest, Archeologist
- Jane Ruchman – Custer/Galla n National orest, Landscape Architect Developed Recreation
- Krista Gebert – USFS Regi n 1 Reg onal ffice, Regional Economist
- Megan Lawson – Headwaters Econ mics
- Natalie Little – USFS Region 4, Cl mate Chang C ordinator
- Travis Warziniack – USFS Rocky Mount in Rese rch Station, Research Economist
- Trey Schillie – USFS Region 2, Regional In ent y and Monitoring and Climate Change Coordinator
- Virginia Kelly – Greater Yellowstone Coordin ting C mmittee, Executive Coordinator

Bismarck, ND October 15 – 16, 2014

Non-Forest Vegetation
- Adnan Akyuz – North Dakota State University, Climatologist
- Bernadette Braun – Dakota Prairie Grassland, Range
- Chad Prosser – Dakota Prairie Grassland, Weeds
- Karen Dunlap – Dakota Prairie Grassland, NEPA, Appeals, Litigation
- Kurt Hansen – Custer National Forest – Sioux Ranger District, District Ranger
- Libby Knotts – Dakota Prairie Grassland, Botany
- Mary Manning – USFS Region 1 Regional Office, Regional Ecologist
- Meghan Dinkins – Dakota Prairie Grassland, Wildlife Biologist

Hydrology
- Alison Schlag – Dakota Prairie Grassland, Hydrology
- Andy Efta – Custer National Forest, Hydrology, Soils
- Karen Ryberg – USGS North Dakota Water Science Center, Statistician
- Mike Philbin – BLM, Montana, Physical Scientist
- Pam Fletcher – Beaverhead-Deerlodge National Forest, Forest Inventory & Monitoring Coordinator
- Rick Nelson – Plains & Prairie Pothole Landscape Conservation Cooperative, Coordinator
- Scott Barndt – Custer-Gallatin National Forest, Ecosystem Staff Officer

- Steven Krentz – US Fish and Wildlife Service, Mountain Prairie Region, Fisheries Biologist
- Robert Swithers – Dakota Prairie Grassland, Staff Officer
- Kevin Shelley – US Fish and Wildlife Service, Ecological Services
- Babete Anderson – Dakota Prairie Grassland, Public Affairs Officer
- Meredith Webster – USFS Region 1 Regional Office, Regional Soils Scientist

Missoula, MT October 20 – 21, 2014

Vegetation

- Barry Bollenbacher – USFS Region 1 Regional Office, Regional Silviculturist
- Bob Keane – USFS Rocky Mountain Research Station, Research Ecologist
- Bruce Erikson – Lolo National Forest, Silviculturist
- C. Alina Cansler – University of Washington, Fire and Mountain Ecology Lab
- Cheri Hartless – Bitterroot National Forest, Silviculturist
- Elaine Sutherland – USFS Rocky Mountain Research Station, Biologist
- Greg Denitto – USFS Re on 1 Regional Office, Forest Pathologist
- Heidi Trechsel – Flath ad Na ional Forest, Silviculturist
- Jeremy Amberson Bitterroot Restoration Committee
- Jerry Kruger – B tterroot National Forest, Planning sTaff Officer
- LaWen Hollingsw rth – Fire Model g Institute, Spatial Fire Analyst
- Linda Donner – Flath d ation Fores IDT Leader
- Melissa Hayes – Montana For t Restorati n Committee, Coordinator
- Melissa Jenkins – Flathead Nationa Fores Forest Silviculturist
- Rob Carlin – Flathead National For t, Forest Staff Officer
- Shelagh Fox – USFS Region 1 Reg onal Office Re orestation Specialist
- Sheryl Gunn – Lolo National Fores , Silvi ulturist

Non-Forest Vegetation

- Chantelle Delay – Flathead National Forest, B tany
- Gil Gale – Bitterroot National Forest, Weeds
- Holger Jensen – USFS Region 1 Regional Office, Regional Range Program Leader
- Karen Stockmann – Lolo National Forest, Weeds/Botany
- Mary Manning – USFS Region 1 Regional Office, Regional Ecologist
- Matt Reeves – USFS Rocky Mountain Research Station, Research Ecologist
- Susan Rinehart – USFS Region 1 Regional Office, Native Plant Program Manager
- Tara Carolin – Glacier National Park, Botanist

Wildlife

- Alan Dohmen – USFS Region 1 Regional Office, Wildlife Ecologist
- Greg Gustina – Lolo National Forest, Planning and Preparation Staff Officer
- Kari Eneas – Confederate Salish and Kootenai Tribes, Wildlife Biologist
- Kuennen Reed – Flathead National Forest, Wildlife
- Len Broberg – University of Montana, Environmental Studies
- Melly Reuling – Center for Large Landscape Conservation, Senior Conservation Officer
- Peter Nelson – Defenders of Wildlife, Senior Policy Advisor
- Polly Buotte – University of Idaho, Research Associate, Geography
- Renate Bush – USFS Region 1 Regional Office, Inventory and Analysis
- Tom Reed – Lee Metcalf National Wildlife Refuge, Manager
- Whisper Means – Confederate Salish & Kootenai Tribes, Wildlife Biologist

Hydrology

- Amber Richardson – Bitterroot National Forest, Forest Engineer
- Caryn Miske – Flathead Basin Commission, Executive Director
- Charlie Luce – USFS Rocky Mountain Research Station, Research Hydrologist
- Chris Brick – Clark Fork Coalition, Science Director
- Craig Kendall – Flathead National Forest, Forest Hydrologist
- Ed Snook – USFS Region 1 Regional Office, Regional Hydrologist
- Nate Dieterich – Flathead National Forest, Forest Hydrologist
- Regan Nelson – Crown of the Continent Conservation Initiative

Fisheries

- Anne Carlson – Wilderness Society
- Aubree Benson – Lolo National Forest, Fisheries Biologist
- Bruce Farling – Trout Unlimited
- Cameron Thomas – USFS Region 1 Regional Office, Regional Aquatic Ecologist
- Clint Muhlfeld – USGS Northern Rocky Mountain Science Center, Research Fish Biologist
- Dan Brewer – US Fish a Wildlife Service, Fisheries Biologist
- Dan Isaak – USFS Ro ky Mo ntain Research Station, Research Fisheries Scientist
- David Schmetterling – Montan Fish, Wildlife and Parks, Fisheries Biologist
- Erin Sexton – U iversity of M ntana, Research Scientist
- Michael Young – USFS Rocky Mou ain Research Station, Research Fisheries Biologist
- Pat Van Eimeren – F th d Nati nal Fo est, Fisheries
- Robert Davies – Flathead Nati n l Forest, Glacier View Ranger District Ranger
- Ryan Kovach – USGS NOROCK, F heri Biologist
- Sims Wade – Idaho Panhandle Nati nal Forest, Aquatic Ecologist
- Wade Fredenberg – Montana Ecolo ical Services SubOffice, Fisheries Biologist
- Scott Spaulding — USFS Region 1 Regional Office, Fisheries Biologist

Recreation

- Byron Stringham – Lolo National Forest, Zone Landscape Architect
- Carl Davis – USFS Region 1 Regional Office, Regional Archeologist
- Cynthia Manning – USFS Region 1 Regional Office, Social Scientist
- Jeff Ward – USFS Region 1 Regional Office, Recreation Business Program Manager
- Krista Gebert – USFS Region 1 Regional Office, Regional Economist
- Marsha Moore – Flathead National Forest, Recreation/Wilderness Planner
- Michael Hand – USFS Rocky Mountain Research Station, Research Forester
- Rosa Nygaard – USFS Region 1 Regional Office, Natural Resource Information Coordinator
- Rusty Wilder – Lola National Forest, Infrastructure and Operations
- Keith Stockmann – USFS Region 1 Regional Office, Economist

Coeur d'Alene, ID October 23 – 24, 2014

Vegetation

- Art Zack – Idaho Panhandle National Forest, Silviculturist, Ecologist
- Barry Bollenbacher – USFS Region 1 Regional Office, Regional Silviculturist
- Bob Boeh –Idaho Forest Group
- Carol McKenzie – Idaho Panhandle National Forest, Deputy Forest Supervisor
- Christopher Schnepf – University of Idaho Extension, Educator - Forestry
- Jason Jerman – Idaho Panhandle National Forest, Silviculturist
- Jessie Grossman – Yaak Valley Forest Council, Forest Watch Coordinator
- Kevin Greenleaf – Kootenai Tribe of Idaho, Environmental Director
- Lee Pederson – USFS Region 1 Regional Office, Forest Entomologist

- Malcolm Edwards – Kootenai National Forest, Libby District, District Ranger
- Megan Strom – Kootenai National Forest, Silviculturist
- Mike Giesey – Kootenai National Forest, Silviculturist
- Pat Behrens – Idaho Panhandle National Forest, Silviculturist
- Paul Zambino – USFS Region 1 Regional Office, Plant Pathologist

Non-Forest Vegetation

- Derek Antonelli – Idaho Native Plant Society
- Jennifer Costich – Thompson – Idaho Panhandle National Forest, Botanist
- LeAnn Abell – BLM, Botanist
- Many Manning – USFS Region 1 Regional Office, Regional Ecologist
- Megan Lucas – Clearwater/Nez Perce National Forest, Hydrologist/Soils Specialist
- Mike Hays – Clearwater/Nez Perce National Forest, Botany
- Valerie Goodnow – Idaho Panhandle National Forest, Weeds/Botany

Wildlife

- Guy Wagner – Clearwater/N z Perce National Forest, Wildlife Biologist
- Jason Flory – US F h and Wil life Service, Northern Idaho Field Office
- JJ Teare – Idaho Department F h and Game, Regional Supervisor
- Kevin McKelvey USFS Ro ky M ntain Research Station, Wildlife Ecologist
- Leona Svancara – Id h Departm nt of Fish and Game
- Lynn M Johnson – Kootenai Nati nal Fore t, Wildlife Biologist
- Polly Buotte – University o Idaho, esea h Associate – Geography
- Rema Sadak – Clearwater/Nez Perc National Forest, Wildlife

Hydrology

- Cara Farr – Clearwater/Nez Perce National Forest, Soil Scientist
- Ed Snook – USFS Region 1 Regional Office, Regional Hydrologist
- Laura Jungst – Kootenai National Forest, Hydrologist
- Shandra Dekome – Idaho Panhandle National Forest, Ecosystem Staff Officer

Fisheries

- Dan Isaak – USFS Rocky Mountain Research Station, Research Fisheries Scientist
- Dan Kenny – Clearwater/Nez Perce National Forest, Fisheries
- Greg Hoffman – US Army Corps of Engineers Libby Dam Kootenai River, Fisheries Biologist
- Jessie Kershner – EcoAdapt, Lead Scientist
- Jim Fredericks – Idaho Fish and Game
- Kathrine Thompson – Clearwater/Nez Perce National Forest, Fisheries
- Michael Young – USFS Rocky Mountain Research Station, Research Fisheries Biologist
- William Young – Idaho Panhandle National Forest, Fisheries

Recreation

- Diane Jones – Clearwater/Nez Perce National Forest, Landscape Architect
- Krista Gebert – USFS Region 1 Regional Office, Regional Economist
- Loretta Stevens – Kootenai National Forest/Confederated Salish and Kootenai Tribes, Tribal Liaison
- Morai Helfen – Idaho Panhandle National Forest, Forest Landscape Architect
- Timory Peel – Kootenai National Forest, Forest Planner
- Pam Fletcher – Beaverhead –Deerlodge National Forest, Planner

Helena, MT November 4 – 5, 2014

Vegetation

- Alicia Torregrosa – USGS, Physical Scientist
- Amanda Milburn – Helena National Forest, Forest Silviculturist
- Andrea Woodward – USGS, Biologist
- Rob Gump – Beaverhead-Deerlodge National Forest, Forest Silviculturist
- Stamm Elisa – Beaverhead-Deerlodge National Forest, Silviculturist
- Tanya Murphy – Helena National Forest, Silviculturist

Non-Forested Vegetation

- Amanda Hendrix – Helena/Lewis & Clark National Forest, Wildlife/Botany Technician
- Beth Anderson – Lewis & Clark National Forest, Soil Scientist
- Casey Johnson – Lewis & Clark National Forest, Weeds
- Mary Manning – USFS Region 1 Regional Office, Regional Ecologist
- Matt Reeves – USFS Rocky Mountain Research Station, Research Ecologist
- Rowdy Wood – Helena/L wis & Clark National Forest, Range Program Leader
- Steve Black – Bighol Battlefield, Superintendent
- Steve Shelly – USF Region 1 Regional Office, Regional Botanist
- Tammy Cherull – Beaverhea – Deerlodge National Forest, North Zone Archaeologist

Wildlife

- Anne Roberts – Beaverhead – De rlodge N tional Forest, Wildlife Biologist
- Denise Pengeroth – Helena Nationa Fore , Wildlife
- Justin Gude – Montana Fish, Wildl e and Parks, Biologist
- Kevin McKelvey – USFS Rocky M untain Research Station, Wildlife Ecologist
- Polly Buotte – University of Idaho, Research Associate – Geography
- Bray Beltron – Heart of the Rockies Initiative, Spatial Ecologist
- Gregg DeNitto – USFS Region 1 Regional Office, Forest Health Protection
- Ryan Quire – Helena National Forest, Biological Technician

Hydrology

- Deb Entuistle – Helena National Forest
- Brian Sugden – Plum Creek, Forest Hydrologist
- David Callery – Helena/Lewis & Clark National Forest, Watershed Program Manager
- Ed Snook – USFS Region 1 Regional Office, Regional Hydrologist
- Larry Dolan – Montana Department of Natural Resources and Conservation, Hydrologist
- Pam Fletcher – Beaverhead-Deerlodge National Forest, Forest Inventory & Monitoring Coordinator
- Robert Ray – Montana Department of Environmental Quality
- Sara Rouse – Beaverhead-Deerlodge National Forest, Soil Scientist
- Sue Higgins – Roundtable on the Crown of the Continent, Support Team
- Wayne Green – Lewis & Clark National Forest, Forest Hydrologist

Fisheries

- Anne Carlson – Wilderness Society
- David Moser – Montana Fish, Wildlife and Parks, Fish/Wildlife Biologist
- Jessie Kershner – EcoAdapt, Lead Scientist
- Jim Brammer – Beaverhead-Deerlodge National Forest, Forest Aquatics Program Manager
- Kendall Cikanek – Lewis & Clark National Forest, Fisheries
- Less Nelson – Montana Fish, Wildlife and Parks
- Peru Suernam – Beaverhead-Deerlodge National Forest, Planning Staff Officer

- Scott Spaulding — USFS Region 1 Regional Office, Fisheries Biologist

Recreation

- Charlene Bucha – Beaverhead-Deerlodge National Forest, District Ranger
- David Fothergill – Helena National Forest, Landscape Architect/Recreation
- Elizabeth Casselli – Helena/Lewis and Clark National Forest, Recreation Program Manager
- Jocelyn Dodge – Beaverhead-Deerlodge National Forest, Recreation Forester
- Lis Novack – USFS Region 1 Regional Office, Recreation
- Michael Hand – USFS Rocky Mountain Research Station, Research Forester
- Mike Munoz – Lewis & Clark National Forest, District Ranger
- Patty Bates – Beaverhead-Deerlodge National Forest, Public Services Staff Officer

Organizations Represented in NRAP

- Bitterroot Restoration Committee
- Bureau of Land Management
- Center for Large Landscape Conservation
- Clark Fork Coalition
- Confederate Salish and Kootenai Tribes
- Crown of the Continent Conservation Initiative
- Defenders of Wildlife
- Department of Interior North Central Climate Science Center
- EcoAdapt
- Fire Modeling Insistute
- Flathead Basin Commission
- Great Northern Landscape Conservation Cooperative
- Greater Yellowstone Coordinating Committee
- Headwaters Economics
- Heart of the Rockies Initiative
- Idaho Fish and Game
- Idaho Forest Group
- Idaho Native Plant Society
- Kootenai Tribe of Idaho
- Lee Metcalf National Wildlife Refuge
- Montana Department of Environmental Quality
- Montana Department of Natural Resources and Conservation
- Montana Fish, Wildlife and Parks
- Montana State University
- National Park Service
- North Dakota State University
- Oregon State University
- Plains and Prairie Pothole Landscape Conservation Cooperative
- Plum Creek
- Roundtable on the Crown of the Continent
- The Climate Impacts Research Consortium
- Trout Unlimited
- University of Idaho
- University of Montana
- University of Washington
- US Army Corps of Engineers
- US Fish and Wildlife Service
- US Forest Service
- US Geological Survey
- Walking Shadow Ecology
- Wilderness Society
- Wildlife Conservation Society
- Yaak Valley Forest Council

APPENDIX 1B—AUTHOR AFFILIATIONS

CHAPTER 1

S. Karen Dante-Wood is a Natural Resource Specialist, U.S. Department of Agriculture, Forest Service, Office of Sustainability and Climate Change in Washington, DC.

CHAPTER 2

S. Karen Dante-Wood is a Natural Resource Specialist, U.S. Department of Agriculture, Forest Service, Office of Sustainability and Climate Change in Washington, DC.

CHAPTER 3

Linda A. Joyce is a Research Ecologist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Human Dimensions Research Program in Fort Collins, Colorado.

Marian Talbert is a Biostatistician with the U.S. Department of the Interior, North Central Climate Science Center in Fort Collins, Colorado.

Darrin Sharp is a Faculty Research Assistant with Oregon State University, Oregon Climate Change Research Institute, College of Earth, Ocean, and Atmospheric Sciences in Corvallis, Oregon.

Jeffrey Morisette is the Director of the U.S. Department of the Interior, North Central Climate Science Center in Fort Collins, Colorado.

John Stevenson is a Regional Climate Extension Specialist with the Climate Impacts Research Consortium, Oregon State University in Corvallis, Oregon.

CHAPTER 4

Charles H. Luce is a Research Hydrologist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station in Boise, Idaho.

CHAPTER 5

Michael K. Young is a Research Fisheries Biologist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station in Missoula, Montana.

Daniel J. Isaak is a Research Fish Biologist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station in Boise, Idaho.

Scott Spaulding is the Fisheries Program Leader with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

Cameron A. Thomas is an Aquatic Ecologist with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

Scott A. Barndt is a Fisheries Program Leader with the U.S. Department of Agriculture, Forest Service, Gallatin National Forest in Bozeman, Montana.

Matthew C. Groce is an ORISE Technology Transfer Specialist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station in Boise, Idaho.

Dona Horan is a Fish Biologist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station in Boise, Idaho.

David E. Nagel is a Physical Scientist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station in Boise, Idaho.

CHAPTER 6

Robert E. Keane is a Research Ecologist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory in Missoula, Montana.

Mary Frances Mahalovich is the Regional Geneticist with the U.S. Department of Agriculture, Forest Service, Northern, Rocky Mountain, Southwestern, and Intermountain Regions, Forestry Sciences Laboratory in Moscow, Idaho.

Barry L. Bollenbacher is the Regional Silviculturist with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

Mary E. Manning is the Regional Vegetation Ecologist with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

Rachel A. Loehman is a Research Landscape Ecologist, U.S. Geological Survey, Alaska Science Center in Anchorage, Alaska.

Terrie B. Jain is a Research Forester with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station in Moscow, Idaho.

Lisa M. Holsinger is an Ecologist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory in Missoula, Montana.

Andrew J. Larson is an Associate Professor of Forest Ecology with the University of Montana, College of Forestry and Conservation, Department of Forest Management in Missoula, Montana.

Meredith M. Webster is the Regional Soil Scientist with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

CHAPTER 7

Matt C. Reeves is a Research Ecologist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station in Missoula, Montana.

Mary E. Manning is the Regional Vegetation Ecologist with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

Jeff P. DiBenedetto is a Landscape and Vegetation Ecologist with the U.S. Department of Agriculture, Forest Service, Custer National Forest in Billings, Montana.

Kyle A. Palmquist is a Postdoctoral Research Associate with the University of Wyoming, Department of Botany in Laramie, Wyoming.

William K. Lauenroth is a Professor with the University of Wyoming, Department of Botany in Laramie, Wyoming.

John B. Bradford is a Research Ecologist with the U.S. Geological Survey, Southwest Biological Science Center in Flagstaff, Arizona.

Daniel R. Schlaepfer is a Junior Group Leader with the University of Basel, Department of Environmental Sciences in Basel, Switzerland.

CHAPTER 8

Rachel A. Loehman is a Research Landscape Ecologist, U.S. Geological Survey, Alaska Science Center in Anchorage, Alaska.

Barbara J. Bentz is a Research Entomologist, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station in Logan, Utah.

Gregg A. DeNitto is the Forest Health Protection Missoula Field Office Leader with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana

Robert E. Keane is a Research Ecologist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory in Missoula, Montana.

Mary E. Manning is the Regional Vegetation Ecologist with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

Jacob P. Duncan is a PhD Student with Utah State University, Department of Mathematics and Statistics in Logan, Utah.

Joel M. Egan is an Entomologist with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

Marcus B. Jackson is a Plant Pathologist with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

Sandra Kegley is an Entomologist with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

I. Blakey Lockman is a Forest Pathologist with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

Dean E. Pearson is a Research Ecologist U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station in Missoula, Montana.

James A. Powell is a Professor with Utah State University, Department of Mathematics and Statistics in Logan, Utah.

Steve Shelly is the Regional Botanist with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

Brytten E. Steed is an Entomologist with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

Paul J. Zambino is a Plant Pathologist with the U.S. Department of Agriculture, Forest Service, Northern Region in Coeur d'Alene, Idaho.

CHAPTER 9

Kevin S. McKelvey is a Research Ecologist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station in Missoula, Montana.

Polly C. Buotte is a PhD Student with the University of Idaho, Environmental Science Program in Moscow, Idaho.

CHAPTER 10

Michael S. Hand is a Research Economist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station in Missoula, Montana.

Megan Lawson is an Economist with Headwaters Economics in Bozeman, Montana.

CHAPTER 11

Travis Warziniak is an Economist with the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station Human Dimensions Program in Fort Collins, Colorado.

Megan Lawson is an Economist with Headwaters Economics in Bozeman, Montana.

S. Karen Dante-Wood is a Natural Resource Specialist, U.S. Department of Agriculture, Forest Service, Office of Sustainability and Climate Change in Washington, DC.

CHAPTER 12

Carl M. Davis is the Regional Archaeologist with the U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

CHAPTER 13

S. Karen Dante-Wood is a Natural Resource Specialist, U.S. Department of Agriculture, Forest Service, Office of Sustainability and Climate Change in Washington, DC.

Linh Hoang is the Regional Inventory, Monitoring, Assessment and Climate Change Coordinator, U.S. Department of Agriculture, Forest Service, Northern Region in Missoula, Montana.

Table 4A.1—Adaptation options that address climate change effects on water resources in the Central Subregion.

Sensitivity to climatic variability and change: Increased flooding will increase damage to roads and infrastructure.

Adaption Strategy / Approach: Identify and proactively decrease vulnerability of infrastructure to flooding.

Strategy Objective: Increase resilience.

Tactic	**Specific Tactic – A** Identify and restore degraded riparian areas in order to reduce flooding and increase natural storage. Reduce the amount of infrastructure in the floodplain.	**Specific Tactic – B** Conduct a basin-wide risk assessment of hydrologic interactions with roads and other infrastructure where vulnerability of infrastructure is highest.	**Specific Tactic – C** Educate private landowners, county managers, and recreational users to increase knowledge on benefits of riparian vegetation, water storage, and effects of floodplain development.
Tactic effectiveness (risks)	High	High	Moderate
Implementation urgency	Near term and ongoing	Near term	Near term and ongoing
Where can tactics be applied? (geographic)	All lands	Federal and private lands	Partnerships with state agencies, county and municipal governments, and private property owners
Opportunities for implementation	Partnerships with other federal and state agencies, and county and municipal governments	Partnerships with other federal and state agencies, and county and municipal governments	Partnerships with other federal and state agencies, and county and municipal governments
Cost	Moderate	Inexpensive, mostly employee time required	Low
Barriers to implementation	Property rights issues	Social resistance to change (e.g., property rights)	Social resistance to change (e.g., property rights)

Table 4A.2—Adaptation options that address climate change effects on water resources in the Central Subregion.

Sensitivity to climatic variability and change: Reduced base flows will shrinking riparian habitats and alter morphology, affecting groundwater, storage, and shallow alluvial aquifers.

Adaption Strategy / Approach: Increase natural storage and built storage.

Strategy Objective: Increase resilience.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Increase natural water storage (mirroring natural processes) with constructed wetlands, beavers, and road obliteration.	Promote distributed small-scale water storage, using small dams, retention ponds, and swales in stream channels and uplands.	Use groundwater injection wells and sills to retain water upstream in alluvial deposits (and retain higher water table).
Tactic effectiveness (risks)	Highly effective at small scales	Dams – high Swales – low to unknown	Variable
Implementation urgency	Near term	Mid term to long term	Near term to long term
Where can tactics be applied? (geographic)	Multiple land ownerships	Agricultural lands, headwaters without native fish species	Injection wells, large aquifers, sills
Opportunities for implementation	Collaboration with other land management activities (timber sales, road decommissioning)	Collaboration with Bureau of reclamation and NGOs, combined with hydropower projects	Areas near high-value water supplies
Cost	Moderate to high	High	High
Barriers to implementation	Lack of available sites, plans for future land use, social acceptance	For dams – significant environmental effects, safety risks, cost, access	Lack of available sites

Table 4A.3—Adaptation options that address climate change effects on water resources in the Central Subregion.

Sensitivity to climatic variability and change: Reduced base flows will shrink riparian habitats and alter morphology, affecting groundwater, storage, and shallow alluvial aquifers.

Adaption Strategy / Approach: Increase knowledge about the groundwater resource.

Strategy Objective: Increase knowledge.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Map aquifers and alluvial deposits.	Determine legal availability and better understanding of physical availability of water for aquifer recharge.	Improve monitoring of streamflow and groundwater to improve understanding of surface water-groundwater interactions; obtain real-time data.
Tactic effectiveness (risks)	Moderate	Moderate	Moderate
Implementation urgency	Near term – information needed for both water and fisheries	Near term – information needed for both water and fisheries	Near term – information needed for both water and fisheries
Where can tactics be applied? (geographic)	All lands and locations	All lands and locations	All lands and locations
Opportunities for implementation	Collaboration with USFS Rocky Mountain Research Station	Collaboration with state of Montana Water Court and Dept. of Natural Resources and Conservation	Collaboration with USGS; state and research partnerships
Cost	Low to moderate	Moderate	High
Barriers to implementation	Availability of staff and funding	Availability of staff and funding	Availability of staff and funding

Table 4A.4—Adaptation options that address climate change effects on water resources in the Central Subregion.

Sensitivity to climatic variability and change: Reduced base flows will shrinking riparian habitats and alter morphology, affecting groundwater, storage, and shallow alluvial aquifers.

Adaption Strategy / Approach: Reduce evaporation and transpiration losses.

Strategy Objective: Increase resilience.

	Specific Tactic – A	**Specific Tactic – B**
Tactic	Evaluate how increasing western larch cover would decrease evapotranspiration.	Selectively use forest harvest (patch clearcuts) to increase water yield.
Tactic effectiveness (risks)	Unknown	Low
Implementation urgency	Near term	Long term
Where can tactics be applied? (geographic)	Areas where western larch is currently present	Areas with moderate to high precipitation
Opportunities for implementation	Projects where western larch is planted	Minimal opportunities
Cost	Moderate for study	Moderate for treatment, high for maintenance
Barriers to implementation	Cost	Environmental consequences (loss of forested habitat, more edge, less interior species, more roads); political and social acceptance

Table 4A.5—Adaptation options that address climate change effects on water resources in the Central Subregion.

Sensitivity to climatic variability and change: Reduced snowpack will reduce the quantity and quality of municipal water supplies.

Adaption Strategy / Approach: Reduce erosion potential to protect municipal water supplies; prioritize municipal systems for protection.

Strategy Objective: Increase resilience.

Tactic	**Specific Tactic – A** Evaluate how increasing western larch cover would decrease evapotranspiration.	**Specific Tactic – B** Selectively use forest harvest (patch clearcuts) to increase water yield.
Tactic effectiveness (risks)	Unknown	Low
Implementation urgency	Near term	Long term
Where can tactics be applied? (geographic)	Areas where western larch is currently present	Areas with moderate to high precipitation
Opportunities for implementation	Projects where western larch is planted	Minimal opportunities
Cost	Moderate for study	Moderate for treatment, high for maintenance
Barriers to implementation	Cost	Environmental consequences (loss of forested habitat, more edge, less interior species, more roads); political and social acceptance

Table 4A.6—Adaptation options that address climate change effects on water resources in the Central Subregion.

Sensitivity to climatic variability and change: Increased occurrence of disturbances such as drought and flooding will reduce water quality.

Adaption Strategy / Approach: Build an information base for a timely response to disturbance, thus ensuring that data are available to inform decision making.

Strategy Objective: Increase knowledge.

Tactic	**Specific Tactic – A** Prioritize data collection based on projections of future drought.	**Specific Tactic – B** Collect pre-disturbance data on stream and riparian conditions, including high-quality values and habitat in need of protection.	**Specific Tactic – C** Develop a clearinghouse for available funding and programs related to fire and other disturbances.
Tactic effectiveness (risks)	Moderate	High	Moderate
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Mostly federal lands	Mostly federal lands	Mostly federal lands
Opportunities for implementation	NEPA, USFWS	NEPA, ESA, USFWS	Emergency Relief for Federally Owned Roads; BAER implementation; NRCS, Federal Highway Administration
Cost	Low	Low	Low
Barriers to implementation	Agency culture, staffing, budget	Agency culture, staffing, budget	Agency requirements and time to manage clearinghouse

Table 4A.7—Adaptation options that address climate change effects on water resources in the Eastern Subregion.

Sensitivity to climatic variability and change: Large riverine systems are susceptible to a change in timing and quantity of peak flows as well as lower low flows associated with warming temperatures. Lower low flows and flashier flow regimes could lead to bank instability due to loss of vegetation. Changes in precipitation and/or temperature may reduce base flows.

Adaption Strategy / Approach: Determine how climate change will alter lakes and reservoirs.

Strategy Objective: Increase resilience; reduce stressors.

Tactic	**Specific Tactic – A** Optimize grazing management practices to enhance riparian health and stream channel stability, soil water holding capacity, and shallow groundwater storage.	**Specific Tactic – B** Promote beaver recolonization and maintenance of beavers where appropriate.	**Specific Tactic – C** Promote cottonwood, willow, and aspen to improve riparian health and support beaver recolonization.
Tactic effectiveness (risks)	High for riparian health and baseflows	High	Moderate
Implementation urgency	Near term – information needed for water, fisheries, and amphibians	Near term – information needed for water, fisheries, and amphibians	Near term – information needed for water, fisheries, and amphibians
Where can tactics be applied? (geographic)	Forest wide, especially priority watersheds and allotments	Where appropriate, based on local knowledge and inventory and monitoring data	Where appropriate, based on local knowledge and inventory and monitoring data
Opportunities for implementation	Collaboration with private partners, local ranchers, permittees, non-governmental organizations (NGOs), and Montana Fish, Wildlife, and Parks; Clean Water Act, ESA, grass banking	Collaboration with private partners, local ranchers, permittees, NGOs, and Montana Fish, Wildlife, and Parks; Clean Water Act, Endangered Species Act, grass banking	Collaboration with USFS wildlife program, NGOS, and Montana Fish, Wildlife, and Parks
Cost	Inexpensive	Inexpensive	Moderate
Barriers to implementation	Political and social opposition, concern about offsite water use; education and perhaps incentives needed	Social opposition; need education and identification of appropriate locations	Funding, staff availability, competing priorities

Table 4A.8—Adaptation options that address climate change effects on water resources in the Grassland Subregion.

Sensitivity to climatic variability and change: Decreased snowpack will lead to increased frequency of high peak flows.

Adaption Strategy / Approach: Maintain hydrological and ecological function of watersheds.

Strategy Objective: Promote resilience, reduce stressors, engage coordination

Tactic	**Specific Tactic – A** Implement 17 Indicators of rangeland health, and maintain or restore forest vegetation resilience.	**Specific Tactic – B** Promote/maintain proper functioning condition of riparian areas and wetlands, including: ensure adequate grazing regimes, adequate riparian buffers, beaver colonization, and restoration of riparian vegetation.	**Specific Tactic – C** Maintain/improve streamflow continuity by optimizing hydrologic connectivity, including: reduce sediment loading, properly design in-channel infrastructure, ensure adequate culvert size, promote beaver colonization, and procure in-stream flow water rights.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	All federal lands	All federal lands	Where watersheds have been heavily fragmented, prioritizing intact habitat where native guilds exist
Opportunities for implementation	State wildlife action plans, grassland/forest plan direction, interdisciplinary approach to management	Coordination with tribes. Watershed Condition Framework documents where this is an issue at the 6th code scale	Opportunities exist, but need work to be identified; coordination with federal and state agencies, tribes, counties, and watershed restoration plans
Cost	Inexpensive to moderately expensive	Inexpensive to expensive, depending on treatments	Inexpensive to expensive, depending on treatments
Barriers to implementation	Personnel availability, litigation barriers with vegetation management projects, common understanding of purpose	Social barriers – lack of understanding, not valued by some.	Funding, coordination, data gaps

Table 4A.8 (cont.)—Adaptation options that address climate change effects on water resources in the Grassland Subregion

Sensitivity to climatic variability and change: Decreased snowpack will lead to increased frequency of high peak flows.

Adaption Strategy / Approach: Maintain hydrological and ecological function of watersheds.

Strategy Objective: Promote resilience, reduce stressors, engage coordination

	Specific Tactic – D	**Specific Tactic – E**	**Specific Tactic – F**
Tactic	Minimize expansion of drainage network by disconnecting road system from stream system, including improved road drainage and road decommissioning.	Develop off-channel watering strategies; minimize in-stream dewatering (e.g., horizontal wells), for both livestock and other water uses.	Move infrastructure out of floodplains, and encourage use of best management practices throughout watershed to protect and restore water quality.
Tactic effectiveness (risks)	High	Low	High
Implementation urgency	Near term	Near term	Near to mid term
Where can tactics be applied? (geographic)	Prioritize by value of downstream water and associated biota	Priority watersheds	Where assets exist on floodplains
Opportunities for implementation	Prioritize by value of downstream water and associated biota	Coordination with tribes, federal and state agencies, and counties	Prioritize by values at risk associated with assets; public education opportunity
Cost	Inexpensive to expensive	Inexpensive to moderate	Moderate to expensive
Barriers to implementation	Funding, legal authority (including NEPA), social opposition (road access, changing traditional land use practices)	Water rights, social opposition	Social opposition (effects on recreation sites, public perception), cultural resource concerns

Table 4A.9—Adaptation options that address climate change effects on water resources in the Grassland Subregion.

Sensitivity to climatic variability and change: Higher temperatures will lead to lower low stream flows in the summer.

Adaption Strategy / Approach: Maintain hydrological and ecological function of watersheds.

Strategy Objective: Promote resilience, reduce stressors, engage coordination

Tactic	**Specific Tactic – A** Implement 17 Indicators of rangeland health, and maintain or restore forest vegetation resilience.	**Specific Tactic – B** Promote/maintain proper functioning condition of riparian areas and wetlands, including: ensure adequate grazing regimes, adequate riparian buffers, beaver colonization, and restoration of riparian vegetation.	**Specific Tactic – C** Maintain/improve streamflow continuity by optimizing hydrologic connectivity, including: reduce sediment loading, properly design in-channel infrastructure, ensure adequate culvert size, promote beaver colonization, and procure in-stream flow water rights.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	All federal lands	All federal lands	Where watersheds have been heavily fragmented, prioritizing intact habitat where native guilds exist
Opportunities for implementation	State wildlife action plans, grassland/forest plan direction, interdisciplinary approach to management	Coordination with tribes. Watershed Condition Framework documents where this is an issue at the 6th code scale	Opportunities exist, but need work to be identified; coordination with federal and state agencies, tribes, counties, and watershed restoration plans
Cost	Inexpensive to moderate	Inexpensive to expensive, depending on treatments	Inexpensive to expensive, depending on treatments
Barriers to implementation	Personnel availability, litigation barriers with vegetation management projects, common understanding of purpose	Social barriers – lack of understanding, not valued by some.	Funding, coordination, data gaps

Table 4A.10—Adaptation options that address climate change effects on water resources in the Grassland Subregion.

Sensitivity to climatic variability and change: Increasing air temperature will lead to increased stream temperature, changes in the hydrograph, and changes in land use, affecting water quality.

Adaption Strategy / Approach: Ensure riparian function and resilience, including groundwater-surface water interactions

Strategy Objective: Promote resilience, reduce stressors, engage coordination

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Promote/maintain proper functioning condition of riparian areas and wetlands: ensure adequate grazing regimes and adequate riparian buffers, promote beaver colonization, and restore riparian vegetation.	Develop adequate inventory and promote protection of spring sources and shallow aquifers.	Promote and educate regarding best management practices for agricultural runoff; form/participate in task forces and working groups.
Tactic effectiveness (risks)	Moderate to high, depending on degree of implementation	Moderate to high	Low to moderate, depending on social factors
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	All lands	Priority watersheds	Mostly non-federal lands
Opportunities for implementation	Coordination with tribes; Watershed Condition Framework documents where this is an issue at the 6th HUC scale	Work with botanists, soil scientists, hydrologists to compile existing information	Partnerships with NRCS, Praire Potholes Landscape Conservation Cooperative
Cost	Inexpensive to expensive, depending on treatments	Inexpensive to moderate, depending on scale	Inexpensive to moderate
Barriers to implementation	Social opposition – lack of understanding and not valued by some	Lack of funding and staff time	Social opposition, lack of staff time, crop values

Table 4A.11—Adaptation options that address climate change effects on water resources in the GYA Subregion.

Sensitivity to climatic variability and change: Higher temperatures and decreased snowpack will reduce water availability.

Adaption Strategy / Approach: Reduce water use and increase efficiency, demonstrate leadership in water efficiency, and create outreach opportunities.

Strategy Objective: Reduce stressors, facilitate transition, increase knowledge.

Tactic	**Specific Tactic – A** Research successful water saving tactics and apply tactics where appropriate.	**Specific Tactic – B** Install low -low appliances at administrative sites; replace landscaping with drought tolerant plants.	**Specific Tactic – C** Communicate water saving tactics and benefits.
Tactic effectiveness (risks)	High	High	Variable—difficult to measure effects
Implementation urgency	Near term	Mid term	Near term
Where can tactics be applied? (geographic)	All lands, where appropriate	All lands, including administrative locations (campgrounds, visitor centers, etc.)	All lands, including administrative locations (campgrounds, visitor centers, etc.); use Internet, press releases, interpretive signing, etc.
Opportunities for implementation	Collaboration with GYCC	Collaboration with GYCC	Collaboration with GYCC
Cost	Inexpensive	Inexpensive	Inexpensive
Barriers to implementation	None	Resistance to xeriscaping, low-flow toilets	None

Table 4A.12—Adaptation options that address climate change effects on water resources in the GYA Subregion.

Sensitivity to climatic variability and change: Discharge from natural springs and seeps may be reduced, affecting water quantity and quality, wetland plant species, wildlife habitat, and water for livestock.

Adaption Strategy / Approach: Protect natural springs and seeps from potential degradation and development.

Strategy Objective: Reduce stressors.

Tactic	**Specific Tactic – A** Develop map/inventory of springs and seeps locations (6th code level).	**Specific Tactic – B** Instrument (piezometer) prioritized representative springs to get detailed flow information.	**Specific Tactic – C** Develop local protection strategies such as fencing, stock fencing; develop alternative water sources; moratoriums on wells where appropriate.
Tactic effectiveness (risks)	High	High	Variable depending on strategy and stakeholder support
Implementation urgency	Near term	Near to mid term	Near to mid term
Where can tactics be applied? (geographic)	All lands	Priority areas with springs and seeps	Priority areas with springs and seeps
Opportunities for implementation	Collaborations with USGS, state agencies that manage water, NOAA, USFS remote sensing center	Collaborations with USGS, state agencies that manage water, NOAA	Collaborations with federal and state agencies, private landowners, range permittees
Cost	Moderate	Inexpensive to moderate	Inexpensive to moderate
Barriers to implementation	Information may be sensitive	None	Social and legal opposition, especially based on water rights

Table 4A.13—Adaptation options that address climate change effects on water resources in the GYA Subregion.

Sensitivity to climatic variability and change: Higher flows may lead to flooding of valuable infrastructure (roads, buildings, campgrounds, etc.).

Adaption Strategy / Approach: Reduce risk of damage to infrastructure.

Strategy Objective: Promote resilience.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Map and prioritize areas with higher peak flows to determine high-risk locations.	Implement tactic A—replace, remove, adjust, and resize as necessary; implement early warning systems.	Communicate risk with all stakeholders, including affected public and private entities.
Tactic effectiveness (risks)	High	Variable, depending on tactic/location. Low—replacing culverts, due to variable nature of stream types and unknown changes in climate affecting flows High—removal of campgrounds from floodplains, installation of bridges, removal of culverts	Variable, depending on reception of information, severity of risk, and ability to implement changes
Implementation urgency	Near term – need this information to take further steps toward adaptation	Near to long term, depending on model predictions and expected flows	Near term, especially where human safety is a concern
Where can tactics be applied? (geographic)	All lands	Priority areas	All locations where stakeholders are at risk
Opportunities for implementation	Collaboration with USGS, FEMA, county emergency management, NOAA	Collaboration with state and local, USGS, FEMA, county emergency management, NOAA	Collaboration with state and local, USGS, FEMA, county emergency management, NOAA
Cost	Inexpensive	Inexpensive to moderate	Inexpensive
Barriers to implementation	None	Legal—NEPA, Social—removal of favorite recreation spots	None

Table 4A.14—Adaptation options that address climate change effects on water resources in the GYA Subregion.

Sensitivity to climatic variability and change: Higher temperatures, higher evapotranspiration rates, and earlier runoff may reduce recharge to shallow aquifers reducing downstream domestic water yields.

Adaption Strategy / Approach: Identify and protect shallow aquifer recharge zones by communicating and partnering with stakeholders.

Strategy Objective: Reduce stressors, facilitate transition, engage coordination.

Tactic	**Specific Tactic – A** Map/inventory recharge zones, especially in areas where water is heavily utilized (municipal watersheds).	**Specific Tactic – B** Form watershed user groups—coordinated resource management groups (CRM – federal, state, stakeholders) to identify concerns and solutions.	**Specific Tactic – C** Improve diversion efficiencies (install headgates, convert from ditch to pipeline, install weirs as needed, etc).
Tactic effectiveness (risks)	High	High to moderate	High
Implementation urgency	Near term	Near to mid term	Near to mid term
Where can tactics be applied? (geographic)	Recharge zones and identified CRMs	Identified CRMs, identified watersheds with stakeholders	Site specific within affected watersheds
Opportunities for implementation	GYA partners. USGS, university, GYCC	Conservation districts, NRCS, state agencies that regulate water, advisory groups, landscape conservation cooperatives, Trout Unlimited	Conservation districts, NRCS, state agencies that regulate water, advisory groups, landscape conservation cooperatives, Trout Unlimited
Cost	Moderate	Inexpensive	Inexpensive to moderate
Barriers to implementation	None	Social opposition; need communication to work through barrier	Variable legal and social opposition; concerns about listed fish species and downstream users.

Table 4A.15—Adaptation options that address climate change effects on water resources in the GYA Subregion.

Sensitivity to climatic variability and change: Higher temperatures and evapotranspiration rates may lead to increased loss of lower elevation, isolated wetlands,

Adaption Strategy / Approach: Increase understanding of location and risk for all wetland types and apply appropriate management actions to reduce loss.

Strategy Objective: Reduce stressors, promote resilience.

Tactic	**Specific Tactic – A** Update National Wetland Inventory maps for all wetlands, including hydrologic regime and type.	**Specific Tactic – B** Assess vulnerability of all wetlands.	**Specific Tactic – C** Increase connectivity of wetlands (e.g., prevent road bisections); avoid degradation of wetlands by new structures; protect beaver dams; consider artificial wetland construction/augmentation of natural wetlands in vulnerable watersheds.
Tactic effectiveness (risks)	High	High	Variable, depending on action
Implementation urgency	Near term	Near term	Mid to long term
Where can tactics be applied? (geographic)	All lands	All lands	Mostly federal lands
Opportunities for implementation	Collaborations with GYCC, Ducks Unlimited, National Academy of Sciences, National Science Foundation, USFWS, National Wildlife Federation	Collaborations with GYCC, Ducks Unlimited, National Academy of Sciences, National Science Foundation, USFWS, National Wildlife Federation	Collaborations with state and federal agencies, private land owners
Cost	Inexpensive	Inexpensive	Moderate
Barriers to implementation	None	None	Social and legal opposition (road removal, augmenting wetlands)

Table 4A.16—Adaptation options that address climate change effects on water resources in the Western Subregion.

Sensitivity to climatic variability and change: Decreased snowpack will increase flooding and damage to roads and infrastructure.

Adaption Strategy / Approach: Identify and proactively decrease vulnerability of roads and infrastructure to flooding.

Strategy Objective: Increase resilience.

Tactic	**Specific Tactic – A** Identify and restore degraded riparian areas in order to reduce flooding and increase natural storage; reduce the amount of infrastructure in the floodplain.	**Specific Tactic – B** Increase resilience of infrastructure: culvert sizing, hardened fords, road drainage; remove and relocate infrastructure (e.g., roads, campgrounds).	**Specific Tactic – C** Increase resilience of stream resources by identifying and restoring degraded riparian areas to reduce flooding and increase natural storage; add large woody debris, improve floodplain connectivity, increase riparian roughness, restore beavers.
Tactic effectiveness (risks)	Moderate	Moderate	Moderate
Implementation urgency	Near term and ongoing	Near term and ongoing	Near term and ongoing
Where can tactics be applied? (geographic)	Across the west subregion	Across the west subregion	Across the west subregion
Opportunities for implementation	Partnerships with federal and state agencies, county and municipal governments, NGOs, private landowners	Partnerships with federal and state agencies, NGOs, Avista, US Army Corps of Engineers, Idaho Power	Partnerships with federal and state agencies, NGOs, Avista, US Army Corps of Engineers, Idaho Power
Cost	Moderate to expensive	Expensive	Inexpensive to expensive
Barriers to implementation	Property rights advocates	Public acceptance; depends on location, scale of project, and partnerships.	Public acceptance; depends on location, scale of project, and partnerships.

Table 4A.17—Adaptation options that address climate change effects on water resources in the Western Subregion.

Sensitivity to climatic variability and change: Decreased snowpack will reduce base flows and shrink riparian habitats, altering groundwater, storage, and shallow alluvial aquifers.

Adaption Strategy / Approach: Increase knowledge of the groundwater resource.

Strategy Objective: Increase knowledge.

Tactic	**Specific Tactic – A** Map aquifers and alluvial deposits; identify groundwater influenced streams.	**Specific Tactic – B** Determine legal availability and better understanding of physical availability of water for aquifer recharge.	**Specific Tactic – C** Improve streamflow and groundwater monitoring information to improve understanding of surface water-groundwater interactions; obtain real-time data.
Tactic effectiveness (risks)	Moderate	Moderate	Moderate
Implementation urgency	Near term – Information is needed for both water and fisheries	Near term – Information is needed for both water and fisheries	Near term – Information is needed for both water and fisheries
Where can tactics be applied? (geographic)	All lands	All lands	All lands
Opportunities for implementation	USFS Rocky Mountain Research Station, universities, Montana Bureau of Mines	State agencies	USGS, state and research partnerships
Cost	Moderate	Moderate	High
Barriers to implementation	Availability of staff and funding	Availability of staff and funding	Availability of staff and funding

Table 4A.18—Adaptation options that address climate change effects on water resources in the Western Subregion.

Sensitivity to climatic variability and change: Decreased snowpack and increased disturbance will reduce municipal water supply and quality.

Adaption Strategy / Approach: Reduce erosion potential to protect municipal water supplies; prioritize municipal systems for protection.

Strategy Objective: Increase resilience.

Tactic	**Specific Tactic – A** Reduce hazardous fuels.	**Specific Tactic – B** Reduce disturbance (e.g., off-road vehicles, grazing, riparian roads).	**Specific Tactic – C** Manage roads to reduce erosion.
Tactic effectiveness (risks)	Moderate	High	High, although detecting improvements can be difficult and site dependent
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	High-value locations	High-value locations on public and private lands	High value locations on public lands
Opportunities for implementation	Partnerships with municipalities, counties, NGOs, tribes, private landowners.	Partnerships with municipalities, counties, NGOs, tribes, private landowners.	Partnerships with municipalities, counties, NGOs, tribes, private landowners.
Cost	Expensive	Inexpensive to moderate	Moderate to high
Barriers to implementation	Public acceptance, cost	Public acceptance, cost	Public acceptance, cost, some user groups

Table 4A.19—Adaptation options that address climate change effects on water resources in the Western Subregion.

Sensitivity to climatic variability and change: Increased droughts and flooding will reduce water quality.

Adaption Strategy / Approach: Build an information base for a timely response to disturbance, thus ensuring data are available to inform decision making.

Strategy Objective: Increase knowledge.

Tactic	**Specific Tactic – A** Prioritize data collection based on forecasted drought.	**Specific Tactic – B** Collect pre-disturbance data on stream and riparian conditions (high-quality values, habitat most in need of protection).	**Specific Tactic – C** Develop a directory/checklist for sites where disturbance has a direct effect on water quality (metals).
Tactic effectiveness (risks)	Moderate	High	Moderate
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Mostly federal lands	Mostly federal lands	All lands
Opportunities for implementation	Collaboration with other agencies, universities	Collaboration with other agencies, universities	Collaborate with USEPA (TMDL, CERCLA, Natural Resource Damage Assessment
Cost	Moderate	Moderate	Expensive
Barriers to implementation	Staffing, budget	Staffing, budget	Agency requirements, time to staff and manage the clearinghouse

Table 4A.20—Adaptation options that address climate change effects on water resources in the Western Subregion.

Sensitivity to climatic variability and change: Decreased snowpack and increased disturbance will alter water quantity and quality of lakes and reservoirs (including dam operations).

Adaption Strategy / Approach: Determine how climate change will alter lakes and reservoirs.

Strategy Objective: Increase knowledge.

Tactic	**Specific Tactic – A** Develop a clearinghouse of information on the effects of climate change from all available sources.	**Specific Tactic – B** Increase coordination between all partners (federal, state, tribal, private).	**Specific Tactic – C** Improve understanding about connectivity and interaction of streams and lakes (temperature, nutrient sinks, sources, etc.).
Tactic effectiveness (risks)	High	High	Moderate
Implementation urgency	Near term – Information needed for water, fisheries, and amphibians	Near term – Information needed for water, fisheries, and amphibians	Near term – Information needed for water and fisheries
Where can tactics be applied? (geographic)	All lands	All lands	All lands
Opportunities for implementation	Forest or regional level for identified sources of data	Forest or regional level for identified sources of data	Collaborations with USGS, state, and research institutions
Cost	Moderate	Moderate	Expensive
Barriers to implementation	Availability of staff and funding	Availability of staff and funding	Availability of staff and funding

Appendix 5A

For the Central Subregion, geographically specific adaptation options were compiled as lists to complement Table 5A.1. Adaptation tactics and other issues are summarized for each location.

Flathead National Forest

- Need aggressive suppression and eradication of non-native fish
- Brook trout more in the Middle Fork Flathead and less in the North Fork; bull trout tanked on west side of the park (Bowman, Logging, Kintla) because of brook trout; Quartz Lake has very active suppression of non-natives
- Some effects from logging (lack of wood in streams, some roads) in Coal Creek, Big Creek, Whale, Red Meadow); active logging in Canada in same drainage has effects (non-natives going upstream, logging effects coming downstream)
- In order to protect westslope cutthroat trout, Montana Fish, Wildlife, and Parks (FWP) are focused on eradicating rainbow trout through rotenone and other techniques
- Efforts to slow spread of hybrids; targeting rainbow trout sources in lower Flathead
- Barriers being installed or removed in North Fork Flathead; removing barriers in Rose Creek; removing culverts in Langford tributary to Big Creek
- Ongoing habitat work by Montana FWP in South Fork of Cold Creek
- Suppression of brook trout in Flathead Lake is a high priority
- Translocated bull trout this year; can use stocks to move them above barriers;
- Genetic rescue of westslope cutthroat trout (tributary to Swan Lake)
- Land acquisition presents huge opportunities for protection of habitat

South Fork Flathead River

- Try to maintain the status quo in Hungry Horse Reservoir, a genetic refuge for bull trout
- Try to manage more natural burns in South Fork of the Flathead; could apply this tactic to land around Hungry Horse Reservoir
- Need a check station at the dam and ranger station to prevent introduction of non-native fish, in combination with public outreach on this issue
- Montana FWP restored connectivity around Hungry Horse reservoir (also around Emery Creek) that was severed when road was constructed, but additional opportunities exist

Swan River

- Non-native issues are similar to Flathead River
- Westslope cutthroat trout are more hybridized with more brook trout characteristics
- Need small barriers to protect bull trout headwater populations
- Need to explore passage barrier issues
- Consider pulling road segments back from streams in critical locations
- Major road management issues exist on former Plum Creek lands, which have a large amount of spawning and rearing habitat relative to size
- Need thermographs throughout floodplains because of the importance of groundwater upwelling for bull trout; this will help improve models of these cold water systems

Clearwater River, Blackfoot River

- Long-term effects of timber harvest and roads, including the effects of roads on connectivity of the hydrologic system
- Unmanaged roads deliver low amounts of sediment;

- Continuing work with The Blackfoot Challenge to expand voluntary drought response plans; irrigation efficiency programs are addressing de-watering issues (particularly in drought years)
- Livestock grazing issues in Monture Creek
- Need to address contaminants issues near Mike Horse Mine
- Conservation easements need to be added more strategically (rather than opportunistically only)
- Restorative work is needed to narrow and deepen creeks to significantly reduce stream temperatures (Nevada Creek); could be applied strategically in other areas (Shanley Creek), as suggested by bull trout recovery plan
- Restoration of the main stem of the Blackfoot River is needed to reduce channel simplification and restore functionality and complexity
- One option is to identify reaches on private land and work to connect landscape and habitat up to higher elevation habitat on public lands
- Ongoing efforts to connect cold-water tributaries in the Upper Blackfoot; also need to do bank restoration in locations with land conversion
- This area has high use for recreation and fishing; this level of use may not be sustainable if habitat quality declines in the future

Upper Clark Fork River, Bitterroot River

- Heavy fishing pressure (catch and release) in this location
- East side of Bitterroot is a stronghold for native fish, but west side has no apparent occupancy (need to confirm)
- Dewatering events in tributaries are important, including issues for mitigation of water quality and quantity
- West Fork of Bitterroot above Painted Rocks Dam has been affected by forest management; road mitigation and removal are helping
- Sleeping Child/Darby timber land restoration is removing roads
- Habitat in Daily Creek (strong producer of bull trout out of Skalkaho) is being improved by placing woody debris in streams
- South Fork Lolo Creek is likely native fish stronghold, although Highway 12 and private land management limit potential restoration options

Middle and Lower Clark Fork River

- Fish passage at the reservoir dams has a huge effect on downstream rearing of westslope cutthroat trout and bull trout
- Legacy effects of management (e.g., placer mining) on cold water patches (Cedar Creek, Trout Creek) have degraded habitat, requiring structural channel remediation and road relocation and mitigation
- Thompson River native fish strong holds (Fish Trap, West Fork Thompson) provide options for improving channel complexity and habitat
- Little Joe River is a very cold water patch but with seasonal disconnection; unclear if this hinders access by bull trout
- Moore Lake is a source of brook trout to the South Fork Little Joe River

Rock Creek

- Bull trout populations are decreasing faster here than anywhere else; brown trout numbers are correspondingly increasing; East Fork above the reservoir has agricultural issues including effects of dewatering events caused by irrigation withdrawals
- Easy restore options have already been implemented to improve connectivity
- Options on east side for road relocation (Burnt Fork)

- Lower Rock Creek has heavy angling pressure
- Water and land restoration options on Ranch Creek

Rattlesnake Creek

- Current bull trout producer, but warming with few options for improving management
- Large wood and channel complexity, especially in the urban interface.

For the Western Subregion, adaptation options were compiled as lists rather than in tabular format. Adaptation options below are summarized by climate change stressor.

Temperature

Adaptation tactics

- Identify and protect groundwater areas and side channels
    - Increase density of sensor network
    - Develop GIS layer and incorporate into stream temperature maps
        - Action application: where groundwater has not yet been captured; everywhere native cold-water fish species occur
    - Remote sensing at microscale (longitudinal profile of larger rivers), which provides more fine-scale temperature mapping to help identify areas of groundwater inputs
        - Action application: Clearwater, St. Joe; anywhere there is private land or proposed development (feeds into floodplain or road development issues); rivers large enough to support this kind of sampling
- Restrict floodplain development and channelization
    - Action application: 3rd order streams
- Remove/relocate roads from creeks/streams
    - Action application: prioritize areas based on proximity to and presence of fish doing well. For example, the Clearwater has one HUC 6 with no human effects that is prioritized for restoration. Alternatively, the Selway is connected to lots of good habitat so less important to prioritize for road removal/relocation.
        - At a site-specific scale, prioritize similarly to watershed but on smaller scale; look at the potential of that habitat to support native fish both now and in the future
- Limit exploitation of groundwater/water withdrawals
    - Action application: anywhere tied to groundwater upwelling
- Hypolimnitic withdrawal
    - Action application: where possible (e.g., Priest Lake, Libby Dam, Albany Falls, Dworshak and Clark Fork dams)
    - In some cases (e.g., Kootenai) the water has been too cold for fish species, but this may change in the future
- Use beaver and/or large woody debris to increase groundwater storage
    - Action application: headwaters/headwater storage in high elevation areas
- Maintain current shade and microclimate characteristics
    - Action application: everywhere
- Identify, prioritize, and protect high-quality watersheds (HUC 6/7) and generate specific standards and guidelines for the area
    - Implement in national forest land management plans. Use this as an overarching strategy to identify high, moderate, and low priority watersheds with specific actions in each
- Reduce grazing effects
    - Identify thresholds that, once exceeded, trigger movement of the cattle to another pasture
    - Generate and implement adaptive management scenarios (similar to described above)
    - Re-evaluate timing of grazing and the amount of time between grazing activities
    - Riparian fencing (not as feasible in forested environments)
    - Retire allotments
        - Action application: target areas most susceptible to grazing (low-elevation meadows) (especially on Nez Perce-Clearwater NF)
- Remove barriers to fish passage

    - Action application: remove if barrier prevents bull trout migration (not necessarily westslope cutthroat trout)
    - Other: westslope cutthroat trout database can compared with stream temperature maps
- Water temperature management through dams. For example, Dworshak dam has contributed to resilience of downstream fish b/c of temperature mitigations (i.e., they can create thermal refugia downstream of these facilities).
    - Need to match fish migration with thermal window (i.e., when fish migrate and temperatures necessary to sustain that migration) and consider longer, warmer stream temperatures in the future and how that may affect fish migration ability
    - Re-examine water temperature release in light of climate change (e.g., Kootenai)
    - Develop temperature models to better inform this action
- Install snowpack sensors to better anticipate changes in stream temperature and flow regimes

Runoff regime

- Address site-specific activities that make narrower and deeper channels and affect runoff characteristics and peak flow (e.g., clear cutting) by reducing surface area to depth
    - Action application: anywhere with narrow and deep channels, clearcut areas
- Limit actions (e.g., vegetation removal) that contribute to peak yield
    - Action application: primarily in rain-on-snow areas; north end of Clearwater has private/state/federal lands interspersed; need an analysis to determine effects from management activities (e.g., vegetation removal) on all lands to understand potential impacts on runoff characteristics and sedimentation
- Reconnect floodplains to improve the ability of system to deal with large flow events
    - Consider using beavers and large woody debris to help facilitate this process
    - Action application: prioritize areas of past dredge mining, where possible/feasible given social/financial constraints
- Restore water holding capacity using beaver or mechanical storage methods
    - Action application: degraded headwater streams
- Re-examine flow release (variable Q) from dams with projected climate changes (currently use from 1999 and back)
    - Action application: dams
- Increase connectivity, where possible, to allow fish to move to cope with changing conditions
    - Action application: remove mainstem dam passages/impoundments (although these may be non-native selectors too so this needs to be considered at site-level)
- Increase capacity of infrastructure to handle flows (e.g., upsizing culverts/structures to 100-yr flood)
    - Action application: take advantage of Burned Area Emergency Rehabilitation to replace culverts; take advantage of vegetation projects to replace culverts; road and trail relocation outside of 100-year floodplain
- Conduct roads analysis within proposed timber harvest areas, considering riparian/aquatic habitat and fish impacts (e.g., road density is a concern for fish)
- Hydrologically disconnect roads from streams (e.g., adding cross-drains or culverts or outsloping roads)
- Examine current and proposed future campgrounds/dispersed campgrounds on creeks and potential future changes in flow regimes (permanent disturbance regimes for fish habitat)

Invasive species

- Remove brook trout in higher elevations that are likely to be cold-water refugia for bull trout

    - Action application: headwater lakes in wilderness (rotenone can be used for brook trout suppression in wilderness); when removing fish, we need to provide an alternative for recreational fisheries
- Create an integrated strategy across the sub-region that supports multiple species. For example, leave some lakes fishless for amphibians, incorporate brook trout strategy (below) at basin scale (HUC5) to balance public need (i.e., recreational fishery) with ecological need (i.e., bull trout)
- Identify brook trout locations and prioritize where to eradicate
    - Need: strong partnership with state and wildlife agencies to do a cross-agency effort (see action above as well); also support from leadership and funding
    - Eradication and preventing re-invasion by:
        - Install barriers
        - Avoid rotenone by using combo of electrofishing and tiger musky (although may be difficult to eliminate source entirely)
        - Expand options for brook trout management (e.g., gill netting)
        - Manipulate gametes and "swamp" current population so species essentially eradicates itself
    - Action application: meadow creeks in upper North Fork Clearwater
- Public education and outreach
- Brown trout and pike are newer invasive species, although management options are limited
    - Take limit off the fisheries (already done)
    - Where feasible and biology of species lends itself to it (e.g., Pend Oreille), can do some suppression
- Manage reservoirs and lakes (e.g., suppression efforts) to protect adult bull trout breeders from smallmouth bass and lake trout
- Utilize changing flow regimes and temperatures to keep invasives out
    - This has been used in Pend Oreille to keep pike out
    - Action application: dams/reservoirs
- Reservoir manipulation
    - Fertilization of species (kokanee); application: putting kokanee in headwater areas
- Establish barriers to invasive species movement
    - Have to make conscious decision to write off fluvial form of bull trout
    - Many factors have to coincide to make this work
    - Small-scale application for cutthroat (e.g., above barriers and more opportunistic)

In areas projected to be cold-water refugia until 2040:

- Suppress non-native fish
- Conduct a status assessment of current species and management actions
- Mange fire and fire effects
- Note: many of these areas in Nez Perce-Clearwater NF are in wilderness, so fewer management options
- Aggressive fish management (e.g., hatcheries)
    - Action application: Lake Coeur d'Alene drainage is historical bull trout drainage and critical habitat, but none there now
        - Questions: where to get fish and how many
        - This is a viable future habitat but may be social barriers (cattlemen's association, political will, social will) to implementation
        - Use this as template for future
    - Action application: in areas with non-native species, use hatcheries to bring fish in, rotenone habitat, and aggressively re-stock

In areas with fish currently, but projected to be gone by 2040:

- Suppress non-native fish
- Improve connectivity
- Address higher river mainstem temperatures that act as barrier
- Monitor areas (fish there now, historical records, eDNA, presence/absence of juveniles, physical characteristics)

During warm phases of the Pacific Decadal Oscillation

- Warmer, drier conditions may affect year-class strength , potential barometer of how populations may respond in the future.

High-severity wildfire areas

- With connectivity, fire effects and debris torrents may not be an issue
- Nez Perce-Clearwater NF probably would not move fish unless they were spawning populations with limited connectivity
    - Strategy: monitor over time to understand distributions of spawning populations and how they respond to disturbances
    - Action application: translocate brood stocks only in certain situations (no connectivity)

Valued species other than cold-water fish

- Sturgeon and burbot
    - Opportunities: management of dam (temperature and flow), specifically temperature for these species (dependent on season and species)
    - Potential conflict: want to reduce flow in winter for water to cool off, but Bonneville Power Administration wants to release more flow during this time to generate power
- Western pearlshell mussel: increased peak flows may wipe out colonies

Table 5A.1—Adaptation options that address climate change effects on fisheries in the Central Subregion.

Sensitivity to climatic variability and change: Reduced snowpack will alter the thermal regime of streams in space and time.

Adaption Strategy / Approach: Improve riparian function and increase functional riparian area.

Strategy Objective: Promote resilience, reduce stressors.

Tactic	**Specific Tactic – A** Re-vegetate denuded sections of riparian areas (leading to additional refined tactics for grazing effects, fire effects, etc.).	**Specific Tactic – B** Strategically relocate, eliminate, and minimize the effects of riparian and upland road segments.	**Specific Tactic – C** Restore groundwater and hyporheic exchange through beaver reintroduction/protection, channel restoration, and re-establishment of fire regimes.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied?	All locations where riparian areas have been damaged, especially if native fish populations are present or nearby	All locations where streams have been or could be damaged, especially if native fish populations are present or nearby	All locations where each specific tactic is appropriate and likely to be effective
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 5A.2—Adaptation options that address climate change effects on fisheries in the Eastern Subregion.

Sensitivity to climatic variability and change: Reduced snowpack will increase stream temperatures and alter flow regimes.

Adaption Strategy / Approach: Increase habitat resilience for cold-water aquatic organisms by restoring structure and function of streams.

Strategy Objective: Promote resilience

Tactic	**Specific Tactic – A** Restore natural channel and floodplain form and function (e.g., restore areas with human-caused bank and bed instability).	**Specific Tactic – B** Restore aquatic organism passage structures through design and placement of appropriate structures.	**Specific Tactic – C** Maintain functional stream channel morphology with adequate width:depth rations, pool frequency, and healthy riparian vegetation.
Tactic effectiveness (risks)	Moderate-high	High	High
Implementation urgency	Near term (gradual process, but need to get started)	Near term	Near term
Where can tactics be applied? (geographic)	Areas with ongoing restoration activities and where habitat is a primary limiting factor (especially where roads are present)	Drainages with frequent high peak flows, areas with sensitive geology, areas with important rearing streams	Areas with ongoing restoration activities and where habitat is a primary limiting factor (especially where roads are present)
Opportunities for implementation	Mining restoration projects	Talk to insurance companies to see if they will fund replacements (e.g., in locations where flows can affect downstream communities)	
Cost			
Barriers to implementation			

Table 5A.3—Adaptation options that address climate change effects on fisheries in the Eastern Subregion.

Sensitivity to climatic variability and change: Reduced snowpack will increase stream temperatures and alter flow regimes.

Adaption Strategy / Approach: Increase habitat resilience for cold-water aquatic organisms by restoring structure and function of streams.

Strategy Objective: Promote resilience

Tactic	**Specific Tactic – A** Restore riparian areas to increase hydrologic function and retain cold water.	**Specific Tactic – B** Reintroduce beaver where beaver and management of westslope cutthroat trout are compatible.	**Specific Tactic – C** Remove or relocate roads adjacent to riparian areas, channels, and floodplains where they inhibit complexity; minimize cumulative effect of road network on surface and subsurface flow.
Tactic effectiveness (risks)	High	Moderate	High, but spatially limited
Implementation urgency	Near term	Long term	Near-medium term
Where can tactics be applied? (geographic)	Where riparian areas limit the availability of cold-water habitat	Where beaver will not affect barriers; in stream reaches > 1 mile; in larger population conservation networks; where brook trout are absent	Where roads currently cause problems or may in the future, especially where roads have substantial linear effects
Opportunities for implementation	Mining restoration projects	Talk to insurance companies to see if they will fund replacements (e.g., in locations where flows can affect downstream communities)	
Cost			Very high cost
Barriers to implementation		Beaver habitat can enhance brook trout populations	

Table 5A.4—Adaptation options that address climate change effects on fisheries in the Eastern Subregion.

Sensitivity to climatic variability and change: Reduced snowpack will increase stream temperatures and alter flow regimes.

Adaption Strategy / Approach: Increase habitat resilience for cold-water aquatic organisms by restoring structure and function of streams.

Strategy Objective: Promote resilience.

Tactic	**Specific Tactic – A** Acquire Montana water compact/rights in a strategic way.	**Specific Tactic – B** Increase efficiency of irrigation techniques.
Tactic effectiveness (risks)	Low-moderate (for instream flows)	Low-moderate
Implementation urgency	Long term	Long term
Where can tactics be applied? (geographic)	Where future plans for water development may overlap with areas where native fish populations may be declining	Where future plans for water development may overlap with areas where native fish populations may be declining
Opportunities for implementation		
Cost		
Barriers to implementation		

Table 5A.5—Adaptation options that address climate change effects on fisheries in the Eastern Subregion.

Sensitivity to climatic variability and change: Continued livestock grazing will compound stress caused by increased stream temperatures.

Adaption Strategy / Approach: Manage livestock grazing to restore ecological function of riparian vegetation and channels.

Strategy Objective: Promote resilience, reduce stressors

Tactic	**Specific Tactic – A** Comply with all existing standards and guidelines for maintaining water quality in streams and riparian areas; facilitate compliance through monitoring.	**Specific Tactic – B** Use innovative techniques to fund and maintain and implement improvements (e.g., riparian fencing, rest-rotation systems, off-channel water, exclosures).	**Specific Tactic – C** Identify and prioritize vacant allotments for retirement.
Tactic effectiveness (risks)	Moderate	Moderate-high (high for techniques that physically prevent access)	High, but spatially limited and opportunistic
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	All locations, with emphasis on areas that are important in terms of ecological value and large financial investment	All locations, with emphasis on areas that are important in terms of ecological value and prior financial investment; prioritize areas with pure native fish populations that are under imminent threat	All locations where vacant allotments exist and opportunities allow
Opportunities for implementation			
Cost			
Barriers to implementation	Lack of public support	Beetle-killed trees damage fences	

Table 5A.6—Adaptation options that address climate change effects on fisheries in the Eastern Subregion.

Sensitivity to climatic variability and change: Continued livestock grazing will compound stress caused by increased stream temperatures.

Adaption Strategy / Approach: Manage livestock grazing to restore ecological function of riparian vegetation and channels.

Strategy Objective: Promote resilience, reduce stressors.

Tactic	**Specific Tactic – A** Incorporate aquatic resource values in prioritization and implementation of land management plans.	**Specific Tactic – B** Convene regional meeting to identify and prioritize key fisheries areas; develop implementation plan that describes line officer actions.	**Specific Tactic – C** Continue and formalize agency coordination for fish habitat conservation (where projects are planned).
Tactic effectiveness (risks)	Moderate-high, depending on how well values are incorporated	High, but depends on spatial extent and number of stakeholders involved	High, but spatially dependent
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	All locations, as management plan revisions occur	All areas of Montana	Where projects are planned and where existing conservation issues related to grazing exist
Opportunities for implementation		East-side range meetings; efforts to avoid listing of westside cutthroat trout populations; monitoring plans	
Cost			
Barriers to implementation			

Table 5A.7—Adaptation options that address climate change effects on fisheries in the Eastern Subregion.

Sensitivity to climatic variability and change: Warmer temperatures will increase stream temperature and risk of invasion by non-native fish species.

Adaption Strategy / Approach: Manage non-native fish populations to eliminate or reduce their impact on native fish.

Strategy Objective: Promote resilience, reduce stressors.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Construct barriers to restrict non-native fish.	Remove non-native fish and re-establish or restore western cutthroat trout populations.	Secure, maintain, and improve riparian stream function and flows, including temperature.
Tactic effectiveness (risks)	High	High	Moderate
Implementation urgency	Near term (Big Hole and other locations with urgent issues); Long term (everywhere else)	Near term (Big Hole and other locations with urgent issues); Long term (everywhere else)	Near term
Where can tactics be applied? (geographic)	Where feasible and necessary (Big Hole, Selway Meadows-Red Rock, all drainages on Rocky Mountains front)	Where feasible and necessary (Big Hole, Selway Meadows-Red Rock, all drainages on Rocky Mountains front)	Where native fish populations and impaired riparian function exist, as identified in annual coordination meetings
Opportunities for implementation		East-side range meetings; efforts to avoid listing of westside cutthroat trout populations; monitoring plans	
Cost		Potentially high	
Barriers to implementation	Not socially feasible	Not socially feasible (e.g., high value recreational fishery) or may be unacceptable to kill all non-natives	

Table 5A.8—Adaptation options that address climate change effects on fisheries in the GYA Subregion.

Sensitivity to climatic variability and change: Reduced snowpack will reduce summer streamflows.

Adaption Strategy / Approach: Increase streamflows and moderate changes in instream flows.

Strategy Objective: Promote resilience.

Tactic	**Specific Tactic – A** Pulse flows during critical times (high temperatures) from regulated streams.	**Specific Tactic – B** Reduce water withdrawals and improve efficiency for agriculture (especially irrigation), municipal, and industrial uses.	**Specific Tactic – C** Secure water rights for instream flows.
Tactic effectiveness (risks)	Moderate-high	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	All regulated streams	Where water demands overlap with current and future suitable habitat	Where fish and suitable habitat overlap
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 5A.9—Adaptation options that address climate change effects on fisheries in the GYA Subregion.

Sensitivity to climatic variability and change: Reduced snowpack will reduce summer streamflows.

Adaption Strategy / Approach: Provide opportunities for native fish to move and find suitable stream temperatures.

Strategy Objective: Promote resilience.

Tactic	**Specific Tactic – A** Increase the patch size of favorable habitat to enhance viable populations and allow adfluvial life histories.	**Specific Tactic – B** Modify or remove barriers to increase connectivity between areas of cold-water habitat.	**Specific Tactic – C** Identify and map where groundwater inputs provide cold water.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Mid term
Where can tactics be applied? (geographic)	Where native fish currently exist; where suitable habitat is nearby; where non-natives are not present or can be effectively managed; where populations are fragmented and need greater connectivity	Where barriers prevent movement to suitable habitat, and where removal will not increase invasion of non-natives	All locations
Opportunities for implementation		Locations that are economically advantageous	
Cost			
Barriers to implementation			

Table 5A.10—Adaptation options that address climate change effects on fisheries in the GYA Subregion.

Sensitivity to climatic variability and change: Water temperature will increase, and the hydrograph will change in terms of magnitude and seasonality.

Adaption Strategy / Approach: Protect and enhance fish habitat.

Strategy Objective: Promote resilience.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Restore degraded riparian vegetation, reconnect floodplains to rivers.	Reintroduce beaver, encourage beaver recolonization.	Disconnect roads from stream networks to reduce sedimentation.
Tactic effectiveness (risks)	Moderate-high	Moderate	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Smaller streams will be most effective, especially in lower-elevation valleys; prioritize areas with native fish or potentially suitable habitat	Where brook trout do not occur (beaver dams tend to facilitate brook trout) and where suitable beaver habitat exists	Where roads adjacent to streams have the potential to erode and deliver sediment
Opportunities for implementation	Smaller streams	Locations that are economically advantageous	
Cost			
Barriers to implementation			

Table 5A.11—Adaptation options that address climate change effects on fisheries in the GYA Subregion.

Sensitivity to climatic variability and change: Water temperature will increase, and cold-water fish habitat will decline.

Adaption Strategy / Approach: Reduce stress on native fish species to enhance their ability to tolerate climate-induced stress.

Strategy Objective: Reduce stressors

Tactic	**Specific Tactic – A** Limit angling pressures on native fish.	**Specific Tactic – B** Reduce effects of recreation and grazing disturbance in streams.	**Specific Tactic – C** Reduce non-native (non-fish) aquatic species and diseases.
Tactic effectiveness (risks)	Moderate	Moderate	Moderate
Implementation urgency	Mid term	Mid term	Near term
Where can tactics be applied? (geographic)	Locations that are at or near temperature thresholds for native fish	Where recreation and grazing activities are high, coincident with occupied or projected suitable fish habitat	Where non-native aquatic species and diseases occur, coincident with occupied or projected suitable fish habitat
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 5A.12—Adaptation options that address climate change effects on fisheries in the GYA Subregion.

Sensitivity to climatic variability and change: Warmer temperatures will increase stream temperature and risk of invasion by non-native fish species.

Adaption Strategy / Approach: Manage non-native fish populations to eliminate or reduce their impact on native fish.

Strategy Objective: Promote resilience, reduce stressors.

Tactic	**Specific Tactic – A** Encourage increased take/harvest of non-natives, especially near long-term strongholds for natives.	**Specific Tactic – B** Remove non-natives with manual or chemical techniques.	**Specific Tactic – C** Implement physical or electrical barriers to exclude non-natives.
Tactic effectiveness (risks)	Low-Moderate (need heavy harvest at the invasion front)	Moderate-High	Moderate-High
Implementation urgency	Mid term	Near term	Near term
Where can tactics be applied? (geographic)	Areas with heavy recreation and sport fishing; most effective at the front of invasions	Where long-term suitable habitat for natives is available and non-natives are present	Where long-term suitable habitat for natives is available and non-natives are present
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 5A.13—Adaptation options that address climate change effects on fisheries in the GYA Subregion.

Sensitivity to climatic variability and change: Higher temperatures will increase wildfire occurrence that can lead to erosion and mass wasting.

Adaption Strategy / Approach: Increase resilience to fire-related disturbance.

Strategy Objective: Promote resilience, reduce stressors.

Tactic	**Specific Tactic – A** Implement fuel treatments (thinning, prescribed burning) to reduce wildfire severity and size.	**Specific Tactic – B** Disconnect roads from stream networks to reduce erosion and sediment delivery to streams.	**Specific Tactic – C** Install erosion control structures following wildfires.
Tactic effectiveness (risks)	Moderate	Moderate	Moderate
Implementation urgency	Mid term	Mid term	Near term
Where can tactics be applied? (geographic)	Areas where canopy and surface fuels are high, adjacent to known native fish populations and habitat	Areas adjacent to known native fish populations and habitat	Where wildfire has occurred and erosion would affect known native fish populations and habitat
Opportunities for implementation	Areas that are already being targeted for fuel treatment, especially in the wildland-urban interface		
Cost			
Barriers to implementation			

Table 6B.1—Vulnerability assessment for the three scales of analysis (species, vegetation type, resource concern) for vegetation of the Northern Rockies (NR).

Habitat, ecosystem function, or species	Broad-scale climate change effect	Current condition, existing stressors	Sensitivity to climatic variability and change	Expected effects of climate change
Species				
Limber pine	Warming temperatures, eastern portion of Northern Rockies anticipated increase in precipitation, less snow pack, variable precipitation during growing season	Reduced abundance due to exotic white-pine blister rust infections, native mountain pine beetle outbreaks, continued fire exclusion, and on wetter sites, limber pine dwarf mistletoe can be more of a problem resulting in mortality as compared to blister rust	Shade intolerant, early seral to pioneer species following fire or tree removal; difficulty in competing with other encroaching species on more productive sites; Little to no reproduction at low tree densities (lack of effective pollination cloud) and those seeds that are produced have increased likelihood of inbreeding; minimum of 25 cone-bearing trees per hectare is needed for dispersal by birds (i.e., corvids)	Increased growth; larger seed crops; increased seed dispersal into burned areas due to bird dispersal; lower seed germination due to warmer, drier conditions; loss of ectomycorrhizal associations, increased competition from wind-dispersed conifers; less blister rust infection due to higher temperatures and lower relative humidity disrupting the blister rust cycle; except in wave years; higher blister rust and dwarf mistletoe infections on eastside where precipitation is projected to increase; large and intense wildfires could threaten seed sources
Ponderosa Pine – var. scopulorum	Increasing temperatures; deeper and longer droughts; increasing fire severity and occurrence; shorter growing seasons and longer dormant seasons	Higher than historical tree densities	Generalist adaptive strategy; high phenotypic plasticity; early- to mid-seral species; moderate shade-tolerance; well-adapted to drought	Decreases in dwarf mistletoe and western gull rust damage; competitive capacity will increase; fire effects uncertain; more highly vulnerable to loss of disjunct and isolated populations, as compared to var. ponderosa; declining precipitation and variable spatial and temporal pattern may cause declines in regeneration, except in eastern portion of northern region where precipitation is expected to increase; increases in mountain pine beetle outbreaks; advancing competition, increasing western pine shoot

				borer occurrence; large and intense wildfires could threaten seed sources
Ponderosa pine-var. *ponderosa*	Minor cold hardiness issues at lower elevations	Precipitation pattern may favor regeneration; increases in pine beetle (western and mountain) *Lophodermium* sp. *Elytroderma,* Armillaria root rot, *Mycosphaerella pini;* extreme fire behavior; competition from grand fir and Douglas-fir	Intermediate adaptive strategy at low to mid elevations; specialist adaptive strategy at higher elevations; moderate phenotypic plasticity; early- to mid-seral species; little shade-tolerance; less adapted to drought	Competitive capacity will increase; increasing fires may have both beneficial and detrimental effects (high uncertainty); dwarf mistletoe and western gull rust may decrease; loss of disjunct and isolated populations on edges of range; limited ectomycorrhizae availability at higher elevations; suitable substrates for may not exist upslope, impedes both natural and artificial regeneration; large and intense wildfires could threaten seed sources
Douglas-fir	Increase in temperature causing increase in soil moisture deficits and less available water especially at lower elevation dry sites	Increase in tree density has increased risk of mortality from a large fire standpoint with will also limit regeneration and species distribution locally; root disease a major cause of mortality in northern Idaho and western Montana	Sensitive to increasing temperatures and increasing soil moisture deficits, this will predispose Douglas-fir to other related mortality agents such as insect and disease	At lower elevation southerly aspects expect ponderosa pine to be better able to cope with moisture deficits and disturbance such as fire, spruce bud worm, less seed source due fire size and due to cone production problems with spruce bud worm, mesic sites expect increase in mortality due to root disease, higher elevation southerly slopes may provide increased climate suitability for Douglas-fir; large and intense wildfires could threaten seed sources
Western larch	Increase in temperature causing increase in evaporative demand and soil moisture deficits	Increase in forest density has increased mortality risk from a fire standpoint, especially existing large size larch trees; past selective harvest and lack of fire has reduced species	Very sensitive to changes in temperature; Spring frosts often reduce pollen, cone and seed production that leads to sporadic seed years; very sensitive to warm temperatures to establish regeneration on high energy,	Range expansion and/or shift to more northerly aspects; reduction of size/age diversity of trees; larger fires may facilitate larch regeneration because the larger larch trees may provide seed on burned areas; increased drought on drier sites may

		distribution and density especially very large individuals.	southerly slopes; rising temperatures and increasing soil moisture deficits will affect potential distribution; increasing amount of fire will likely benefit larch as long as it is not in overly dense forest conditions with poor vigor leading to loss of seed source after fire.	exacerbate competition stress caused by invading shade tolerant species.
Western white pine	Warming temperatures; longer growing seasons; increased fire; increases in drought	Local rates of blister rust infection may hold steady but remains highly susceptible to wave years of infection; increases in Armillaria root rot, mountain pine beetle (endemic-depends on white pine population size and tree size), *Lophodermium nitens, Lecanosticta aciocola* severe needle blight on-going issue with cool-wet protracted springs; potential seed sources vulnerable to fire damage; critical thresholds for regeneration establishment may be possible resulting in ineffective pollen cloud, no seed production and higher probability of inbreeding	Early spring frost – cold hardiness – may not be physiologically in tune as individuals migrate upslope Moisture: lower elevation ecotones (<25" per year precipitation threshold); moderate shade-tolerance; early- to mid-seral Good competitive ability; up to three (3) years seed viability in soil bank; generalist adaptive strategy; high phenotypic plasticity	Increased growth; increased abundance with less grand fir provided there is a seed source or planting; less blister rust infection due to high temperatures and lower relative humidity except for wave years; if seed source exists fire will increase growing space providing for regeneration potential; the species is dependent on ash cap on many sites which may prevent migration to wetter/warmer sites; limited ectomycorrhizae availability at higher elevations; suitable substrate may not exist upslope so migration may not be expedited; both natural and artificial regeneration may occur with drought; pole blight may occur

Aspen	Warming temperatures, decreasing snowpack, increase in severity and frequency of wildfires	While there are stable climax aspen communities, most aspen is a fire-maintained, early seral component of a forested community; stands are declining in number and size; stressors include competition with and shading by conifers, typically due to fire exclusion, domestic and native ungulate herbivory, and increasing temperature coupled with declining precipitation; reduction of soil moisture may cause severe water stress which reduces aspen's ability to survive (e.g., sudden aspen decline) and to reproduce both vegetatively and by seed, thereby reducing genetic variability.	Sensitivity varies based on site characteristics, primarily soil moisture and solar radiation; it is mostly shade-intolerant; ubiquitous across most of North America; aspen is most persistent on sites with high solar radiation coupled with moist to wet soils; it does not tolerate extended drought; highly fire-adapted and regenerates abundantly after stand-replacing fire, although it can regenerate in conifer dominated stands in some settings ; it will persist or possibly increase with warmer temperatures as long as there is sufficient soil moisture; fringe communities may succumb to sudden aspen decline with long-term and severe water deficit, which will kill the roots.	Communities on warmer, drier sites could decrease due to water deficit; some stands may have significant mortality with little or no regeneration due to herbivory; sudden aspen decline has been associated with severe, prolonged drought, particularly in aspen stands that are on the fringe of the species' distribution (warmer and drier sites than those typically considered optimal for aspen persistence); fewer and smaller stands and of those that persist, there will be increased plant stress due to increased severity of summer droughts; increased fire frequency may likely favor aspen regeneration by removing shading conifers; younger stands (<40 years old) may be more resilient to drought and frequent fires could favor aspen on moister sites; severe fire may kill shallow root systems and eliminate aspen in some hotter and drier sitess; growth may increase because photosynthetic rates appear to increase more in aspen than other tree species as atmospheric carbon increases, but this may be offset by increased drought stress and increased atmospheric ozone, which reduces photosynthesis and may increase susceptibility to insects and disease; higher herbivory (browsing) on regenerating stands is possible as adjacent upland vegetation senesces and desiccates earlier in the growing season; areas with mountain pine beetle-caused conifer mortality (especially in lodgepole pine) may release aspen and regenerate once the conifer canopy is removed; conifers use more water than aspen so aspen stands mean more streamflows; aspen forms natural fuel breaks that can be used effectively in fire

				management; pathological rotation is short-lived.
Grand fir	Increasing drought; longer growing seasons; increased fire and disease; highly variable weather	Fire exclusion has increased grand fir in dry and mesic sites but increased tree densities have also stressed fir trees contributing to increased fuel loadings, higher root rot, and greater insect damage and mortality	Late seral, shade tolerant species highly susceptible to fire; usually exists in areas where competition and tree density is high so most trees are stressed; highly stress trees are more susceptible to climatic fluctuations and trends	On xeric sites, increased drought and longer growing seasons will exacerbate stress from competition resulting in high mortality mainly from insects and disease; longer fire seasons and high fuel loadings from exclusion will also reduce this species; on the mesic sites, longer growing seasons coupled with higher temperatures may increase growth rates and regeneration success thereby increasing tree density and competition; fire will reduce grand fir dominance at landscape- and stand-scales
Western redcedar	Longer growing seasons; warmer temperatures; highly variable weather; Enhanced warm and cold cycles; early frosts	Root and butt disease: *Philinus, fomis*, and Armillaria root rot; low susceptibly to pathogens	Generalist adaptive strategy; high phenotypic plasticity; high shade-tolerance; long-lived; seed production good; vegetative potential	Increased growth rate; fire adds uncertainty; warm/cold cycle may facilitate red-belt and adversely affect western redcedar (early warming followed by early frost); cedar flagging from dry seasons (entire branch is shed, interferes with seed production); ash cap dependent which may prevent it to migrate to wetter/warmer sites
Western hemlock	Longer growing seasons; warmer temperatures; highly variable weather; early frosts during the growing stage.	Confined to the moister portions of northern Rockies; susceptible to annosus root rot, *Echinodontium tinctorium*; High tolerance to Armillaria root rot	Provisionally tends to be a generalist adaptive strategy; high shade-tolerance; needs ample moisture; susceptible to spring frost; very good competitor; high seed producer; seed viability only lasts one year in soil bank; susceptible to acid rain; ash cap dependent	May stay the same and potentially not change its current distribution; vulnerable to water deficits so declines are possible on the drier sites; since the species is ash cap dependent, migration may be retarded to wetter/warmer sites without ash cap soils.
Lodgepole pine	Increasing temperatures; longer droughty periods; increasing	Advancing succession due to fire exclusion is contributing to declines in lodgepole pine in	Shade intolerant conifer that has a wide climatic amplitude in subalpine areas; exists on a wide variety of soil types	Longer drought periods and warmer temperatures may decrease growth and regeneration on the driest sites (lower elevation lodgepole stands); lodgepole is well

	fire occurrence, frequency, and severity; increased productivity;	many areas; current increases in burn areas are creating many new lodgepole stands and some may become dense thickets; increased drought may exacerbate stress from other factors including competition, endemic insects and diseases, and wind; warming temperatures may heighten bark beetle activity resulting in more frequent and severe epidemics	and may be the only species to inhabit infertile and well drained sites; Moderately drought tolerant; reproductive success depends on level of serotiny; well adapted to colonize post-burn environments; highly susceptible to bark beetles, especially when in stress from endogenous and exogenous factors such as competition, fire-damage, and drought	adapted to increases in fire occurrence and size depending on level of serotiny, but it may be eliminated from sites where fires reburn stands before established seedlings and saplings become reproductively mature; In mesic subalpine sites, continued fire exclusion coupled with higher productivities will heighten competitive interactions and put more lodgepole pine into stress thereby increasing mortality, insect and disease vulnerability, canopy and surface fuels, and accelerating succession toward subalpine fir; conversely, increasing fire could expand lodgepole pine occurrence, even when fires are large and severe; increasing insect (i.e., bark beetles) outbreaks may further acceleration towards non-host, shade tolerant species
Subalpine fir	Increased disturbance frequency and severity; highly variable weather and climate; decreasing snowpacks; lengthening growing seasons;	Fire exclusion has increased abundance of this species on many subalpine and upper subalpine landscapes; many current stands have high densities and trees may be stressed from competitive interactions resulting in increasing susceptibility to disturbances; increasing drought could further exacerbate competitive stress and increase mortality	Highly vulnerable to subtle changes in climate; shade tolerant species that is an aggressive competitor in subalpine areas; uniquely adapted to quickly occupy gaps in subalpine forest canopies; relatively intolerant of drought; unable to mature when seasonal drought is common; not adapted to disturbance, especially fire, with high mortality even after low severity fires; frequent cone crops	Longer growing seasons and reduced snowpacks will increase regenerative success, especially in those high elevation areas where snow historically controlled regenerative success; higher productivity in subalpine forests may increase regeneration and species densities, eventually resulting in high competitive stress making these fir stands vulnerable to high mortality and therefore less resilient; declines of the species on drier sites may result from new drought regimes reducing regeneration success; increases of the species on moister sites will result from increased regeneration and competitive advantages; fir may gain in upper subalpine and timberline environments that are controlled by snow dynamics; subalpine fir could also increase as it replaces rust- and beetle-killed whitebark pine, yet whitebark pine can also act as a

				nurse crop to facilate subalpine fir establishment; increased fire would decrease fir throughout the NR; the future of subalpine fir would depend on both fire suppression levels coupled with climatic responses.
Engelmann spruce	Increased disturbance frequency and severity; highly variable weather and climate; decreasing snowpacks; lengthening growing seasons	Spruce is usually associated with fir in the NR; it occurs as a minor to major component of many subalpine stands and only dominates in wetland or special land types; Fire exclusion has increased abundance of this species on many subalpine and upper subalpine landscapes; many current stands have high densities and trees may be stressed from competitive interactions resulting in increasing susceptibility to disturbances; increasing drought could further exacerbate competitive stress and increase mortality	Like fir, spruce is highly susceptible to changes in climates; it is not as an aggressive competitor and often is only a minor portion of a stand; it is highly vulnerable to drought; it can quickly regenerate in severely burned microsites providing there are seed sources; highly susceptible to windthrow and wind damage	Losses of spruce in the drier portions of its range, especially in those seasonal moist sites that will now be dry; not well adapted to fire so major declines are expected in burned areas, but these declines may be offset by increased regeneration on burned areas with mineral soil substrates; continued suppression activities may maintain spruce on the landscape but it may be at lower levels due to increased drought; it may increase in the upper subalpine when snowpacks become consistently lower and soil becomes drier thereby allowing spruce to encroach into glades, meadows, and balds.
Whitebark pine	Warming temperatures, lower snowpacks, highly variable weather, increasing fires in both intensity and severity, increasing insect and disease	Reduced abundance due to exotic white-pine blister rust infections, native mountain pine beetle outbreaks, and continued fire exclusion; survival due to cold hardiness in seedlings	Inability to compete with encroaching conifers due to low growth rates, moderate shade intolerance, and seed dispersal characteristics. Little to no reproduction may occur once tree densities are	On many upper subalpine sites there may be increased growth, larger seed crops, increased seed dispersal into increasing areas being burned due to bird-mediated dispersal providing there are adequate seed sources; lower seed germination due to warmer, drier conditions; possible loss of ectomycorrhizal associations; lack of suitable

	outbreak frequencies and severities; increase in populations of mountain pine through possible univoltism shifts	and saplings in frost pockets and swales	low; long- lived species that lasts through climate epochs	substrates (suitable soils) as species moves upslope; increased competition from wind-dispersed, shade tolerant conifers with fire exclusion; less infection due to higher temperatures and lower relative humidity disrupting the highly variable blister rust cycle except in wave years; increased fire may provide caching habitat for nutcrackers that allow decades of unfettered development in the absence of competition from fir and spruce; losses in whitebark pine due to increased beetles, rust, and fire may be offset by increases in growth, cone crops, and abundant regeneration in burned areas, but management actions are needed to augment natural regeneration by planting and direct seedling rust-resistant pine
Alpine larch	Warming temperatures; longer growing seasons; smaller snowpacks that last shorter; less summertime water; possible summertime droughts; increased fire	Found in moist upper subalpine cove sites with abundant above and belowground moisture; exists in mixed stands of whitebark pine and sometimes subalpine fir; can form extensive stands in sub-irrigated upper subalpine areas	Very shade intolerant; intergrades with western larch; while this species is quite sensitive to shifts in climate, it may initially increase because it may colonize upper subalpine non-forest sites quicker than other species, but the newly established individuals may be unable to survive to maturity as drought and temperatures increase, climates become more variable, and fires increase in the upper subalpine; susceptible to damage from fire	Increased growth rates; greater ability to populate upper subalpine and treeline ecotones because of wind-aided seed dispersal and evergreen regenerative properties; increased fire may reduce many stands that historically were too wet to burn; on mesic sites – enhanced growing environment may increase competition from other more competitive, shade tolerant conifers; lack of whitebark pine seed caching because of depressed cone crops may favor alpine larch dominance in areas that currently lack trees (e.g., treeline, subalpine balds, meadows, glades); on xeric sites – lack of summertime ground water may contribute to higher water stress and lower growth rates; years with deep droughts may kill established regeneration; alpine larch may decline in those areas with lower water availability and declining groundwater flow

Green ash	Warming temperatures, decreasing snowpack, increase in severity and frequency of wildfires.	Domestic and native ungulate herbivory has affected both structure and composition of these communities.	Green ash has broad ecological amplitude and can survive droughty conditions, but persists optimally in moist sites; as soil moisture declines, marginal sites may become less favorable for regeneration and survival of young trees; there will probably be increased vegetative regeneration and decreased production of seedlings following fire- fire often kills green ash seed on or near the soil surface, restricting seedling recruitment to surviving seed producing trees.	Green ash may benefit from increased temperatures; seedling growth may increase with increasing soil temperatures; after increased fires, green ash has both root crown and epicormic sprouts, and both are typical following disturbances such as fire; fire may be very important in woody draws and riparian areas of the Great Plains; Since woody draws are typically long and narrow, even though they are more moist than surrounding uplands, they likely were also burned during frequent fires in the surrounding grasslands. Thus ash is well-adapted to fire; low-severity fires might promote regeneration by thinning stands and stimulating sprouting (the primary response to fire); browsing pressure will likely increase with increased drought, as upland grasses and forbs desiccate and senesce earlier, or are replaced by invasive, less palatable species.
Cottonwood	Warming temperatures; decreasing snowpack; increase in severity and frequency of wildfires	There has been a reduction in area due to conversion and development of floodplains; composition and structure of cottonwood forests have been altered due to changes in flow regimes; structural alteration (typically simplification) of the channel (e.g., levees, bank armoring structures) has likely contributed to channel widening, or channel	All species of cottonwood require saturated, but aerobic substrates and full sunlight to germinate and persist; any alteration of hydrologic flow regime (e.g., timing, magnitude and duration) will affect floodplain interaction and plant available water that may reduce recruitment and establishment of seedlings (cottonwoods regenerate primarily by seed); decreased streamflows and floodplain interaction may result in a shift in streamside vegetation to upland species, along with	Timing of flooding is critical to germination success and establishment of young (sapling, pole) cottonwoods both diminished; this will vary based on winter snowpack, and amount and timing of snowmelt (and associated peakflows); seedlings establish on moist to wet bare mineral soil, typically on stream bars, in full sunlight; as the snowpack declines and melts earlier, there will be reduced, more stabilized flows (loss of extreme high and/or low flows) and/or a shift in timing of peakflows to earlier in the season, before cottonwood seed is viable for germination); with earlier peakflows and less discharge, germination success is diminished; increased demand for water (additional diversions, reservoir expansions)

	incision and loss of floodplain interaction; nonnative trees which are more drought tolerant are already present along rivers and streams in eastern Montana; increased drought stress will likely favor these species over cottonwood; additional stressors include roads, along with domestic and native ungulate browsing (particularly on young cottonwoods).	reduced growth and regeneration, and increased mortality of cottonwood; since cottonwoods are shade intolerant (require full sunlight) any conifers that establish on the drier fluvial surfaces will grow tall enough to eventually shade out the cottonwoods; as snowpacks decline and melt earlier, peakflows will be reduced and variation in discharge will decline, leading to a loss of various fluvial (depositional) surfaces along the stream, on which cottonwood germinate; the system becomes less complex; there may be fewer recruitment events; in addition, there may be a shift in timing of peakflows to earlier in the season, before cottonwood seed is viable for germination, resulting in both decreased germination and establishment of young cottonwoods; increased demand for water (additional diversions, reservoir expansions) and increased browsing pressure (adjacent upland vegetation senesces and desiccates earlier in the growing season) may also lead to a decline in cottonwood; sizes of cottonwood forests may decrease as these fluvial	and increased browsing pressure (as adjacent upland vegetation senesces and desiccates earlier in the growing season) will also likely lead to a decline in cottonwood.

			surfaces are less frequently inundated; there may be little to no recruitment of young cottonwoods.	
Vegetation types				
Dry ponderosa pine and Douglas-fir forests	Increase in temperature causing increase in soil moisture deficits and less available water especially at lower elevation dry sites	Increases in density has put at risk increased mortality from a fire severity standpoint, root disease a major cause of mortality in northern Idaho and western Montana	Sensitive to increasing temperatures and increasing soil moisture deficits; this will predispose Douglas-fir to other related mortality agents such as insect and disease; this may give ponderosa pine an advantage on these settings	At lower elevation southerly aspects expect ponderosa pine to be better able to cope with moisture deficits and disturbance such as fire, spruce bud worm; less seed source due fire size and due to cone production problems with spruce bud worm; mesic sites expect increase in mortality due to root disease; higher elevation southerly slopes may provide increased climate suitability for Douglas-fir while ponderosa pine will be favored at lower elevations; patches size will increase due to severe fire if density reductions are not implemented
Western larch mixed-conifer forests	Increase in temperatures will likely rearrange current species associations on higher energy slope positions	Larch forests have been reduced significantly in extent due to successional effect from fire suppression, and preferential harvest; forest density increases have been substantial, and it now exists in uncharacteristic dense forest conditions in many areas. In northern Idaho, forest density (and productivity) was a bit denser due to warm mesic climate and deep ash capped soils. In areas once dominated	Larch is sensitive to changes in temperature; very sensitive to warm temperatures to establish regeneration on high energy, southerly slopes; rising temperatures and increasing soil moisture deficits will affect potential distribution and pattern of larch forests especially on high energy aspects. Increasing amount of fire will likely benefit larch as long as it is not in overly dense forest conditions with poor vigor with continuous horizontal	Larch is highly vulnerable to increase in temperature and uncharacteristic fires in dense forest settings; the loss of large tree structure and larch regeneration success could be a major effect due to the current lack of heterogeneity and patch densities; this is especially true for high energy topographic locations; increases in soil moisture deficits could retract the range of western large to more northerly slopes with deep soils; cone production could be positively affected with increasing temperatures which could cause cone maturation to be earlier which could mean earlier fire seasons may still be timed with cone production and seed cast after fire. Adaptation ability for cone production and seeding distance and regeneration ability may be reduced if connectivity is reduced due

		in northern Idaho by western larch, western white pine, and ponderosa pine they are now dominated by mixed grand fir and moist site Douglas-fir forests. The spatial pattern of forest structure has been homogenized in many areas leading to a continuous nature of the horizontal fuel profile atypical of historic fire regime landscape structure in many areas once typical of mixed-severity regime.	fuel profile across landscapes.	to very large and more frequent severe fires occurring. High forest density and low landscape pattern diversity compared to HRV may put at risk medium, large, and old-growth larch stands due to increasing moisture deficits and stand replacing fire. Simplification of within and between patch structure due to increased fire severity and size could lead to loss of diversity and loss of important wildlife habitat such as cavity nesting habitat for birds and mammals. In northern Idaho, the change in species composition of the forest to more intolerant to shade species has resulted in a forest much more susceptible to wide spread root disease mortality. These areas involve millions of acres on which *less* carbon sequestration is and will take place given the relatively novel species composition of today's forests. Given the likely increase in soil moisture deficits in the future, root disease effects are not likely to reduce; Lower tree densities of reproductively mature larch and loss of connectivity between populations will increase inbreeding depression as a result of disruption of an effective pollen cloud
Lodgepole pine and aspen mixed conifer forests	Increasing temperatures; longer droughty periods; increasing fire occurrence, frequency, and severity; increased productivity;	Many stands of this type are succeeding to subalpine fir-spruce due to fire exclusion; aspen has been declining due to lack of fire and increasing drought; healthiest areas are in wilderness	This type is more sensitive to management actions than climate in that continued fire exclusion will ensure their decline; this type thrives with fire and will even survive insect and disease outbreaks if fire is present on the landscape;	This cover type actually could expand in the future with increasing fires and the warming of the subalpine; disturbances may eliminate competing conifers and facilitate serotiny-aided lodgepole pine regeneration; aspen may decline on the drier parts of its range, but could increase and make major advances into the subalpine as fires burn competing conifers and temperatures moderate creating favorable climates; if fires are too frequent, this cover type may be replaced by semi-permanent shrub-herb, but as long as fire return intervals are greater than the

				reproductive age, lodgepole and aspen should prevail; as fires increase, more areas in this type will be early seral creating more heterogeneous landscapes with more patches of pine and fir mixed with aspen.
Mixed mesic white pine, cedar, hemlock grand fir forests	Increasing temperatures; more drought; more fires	This type is limited to the northwestern portions of the NR and much of this site has had management activities (harvest); western white pine occurrence has been severely reduced by blister rust but has shown increases in some portions of this type; unharvested stands are becoming more dense creating conditions that favor rot, insects, and disease damage	This type includes a fire-tolerant, fast-growing, early seral species (western white pine) with a collection of late seral, shade tolerant, highly competitive species so the type may actually not change in coverage as fires facilitate conversion to pine on these sites.	Western white pine may become a more dominant feature of this type; declines in cedar and hemlock are possible but grand fir; moisture changes are probably not limiting on these sites as much as the dependence on ash cap soils; major gains in the type are probably not possible because of the limited distribution of ash cap soils in some areas and the decrease in moisture outside of the current type's range; Similar to other types, the distribution of seral types may be more heterogeneous due to fire but the long period of fire exclusion might foster atypical high severity fires that might burn entire landscapes in some areas and this might result in homogeneous pine stands providing sufficient rust-resistance and seed sources
Whitebark pine-spruce-fir forests	Declining snowpacks; increasing fire; increasing temperatures	This type is probably increasing in the NR from effective fire exclusion; losses in whitebark pine are successionally replaced by fir-spruce; the low elevation spruce-fir types are becoming more dense and crowded	This type might not be as sensitive as other more xeric sites to direct climate change impacts because there is abundant water, and predicted increases in both regeneration and growth may actually increase its climate resilience; increasing fires may cause a shift to more early seral communities and if whitebark pine populations were not experiencing rust outbreaks, these early seral	This type may contract into the future due to several interacting factors – whitebark pine will continue to decline due to rust and beetle outbreaks, spruce-fir forest may decline due to increased fire and reduced soil water; this site could be replaced by lodgepole-aspen in the drier parts of the NR; if agencies plant and conduct restoration activities, whitebark pine could make major gains into the increasing burned areas thereby replacing spruce-fir and limiting the contraction of this type; low elevation spruce-fir stands are probably going to move towards the western larch/mixed conifer type because of

			communities would probably be dominated by whitebark pine.	prolonged droughts and increasing temperatures, especially after fires
Resource concerns				
Landscape heterogeneity	Increased productivity causing accelerated succession; increases in disturbance frequency and extent; highly variable drought intensity and extent; migration of species to new habitats; changes in magnitude, season, and variability of water availability	Ninety years of fire exclusion coupled with past management activities (e.g., grazing) has reduced landscape heterogenity	Landscape heterogeneity is highly susceptible to subtle shifts in climate because it is the reflection of the interaction of vegetation dynamics with disturbance regimes, topography, and land use. Small changes in climate may facilitate large changes in disturbances or vegetation dynamics causing new landscape mosaics	Increased fire across most of the NR may both increase and decrease landscape heterogeneity. Wildfires and wildland fire use fires may create patchworks of fire severity types across burned areas that will increase heterogeneity and therefore landscape resilience, but some fires may burn fire-excluded landscapes with high severities causing atypical large patches of high plant mortality that may decrease heterogeneity. While large, severely burned patches occurred in historical fires, the frequency and size of these patches may be different today. The highly variable species migration rates into areas with new climates may increase heterogeneity, but the rapidly changing climates may only facilitate generalist species thereby decreasing heterogeneity.
Timber production	Increase in temperature causing increase in soil moisture deficits and less available water that larch need, will shift species composition to root disease prone species particularly Douglas-fir and grand fir. Higher temperatures likely	Composition shift causing reduced productivity is likely in the western portion of the region on root disease prone sites and in southerly exposures Region wide. Risk of uncharacteristic fire severity very high due to uncharacteristic high forest density which will reduce timber production opportunities	Sensitivity high in northern Idaho and southerly exposures Region wide due to increasing moisture deficits and increase in uncharacteristic disturbance such as severity and extent of fire and root disease	Expect some theoretical increase in production at mid and higher elevations due to warming temperatures. This could be offset overall by losses due to root disease and increase in fire severity across the areas suitable for timber productions in Forest Plans. Less production (sequestration) anticipated in northern Idaho if current species compositions are not changed.

	to extend fire season and to reduce forest inventory on areas suitable for timber production. Some increase in productivity may occur at mid to higher elevations; however increase in fire may reduce timber production opportunities.	especially in dry forest areas.		
Carbon sequestration	Increased fire; increasing drought; productivity gains and losses;	Past policies of fire exclusion have created late seral landscapes that sequester little carbon; past timber activities may have created younger stands that sequester more carbon; increasing disturbances (fire, insect, disease) has caused short-term losses in carbon sequestration	Carbon sequestration is very sensitive to climate change impacts on vegetation and disturbance; Rates of carbon sequestration are going to largely dependent on the rate of burning in the future and the gains and losses of productivity in NR ecosystems; productivity gains and losses need to be evaluated at large spatial and temporal scales to understand future carbon dynamics	fire exclusion will tend to push most ecosystems into later successional stages where sequestration rates are minimal; burning from controlled and uncontrolled wildfires and prescribed burning will cause short-term losses but the high productivity of the developing early seral stands may increase sequestration for decades; sites that were historically dry will probably experience decreases in production and carbon sequestration in the future, while those mesic sites that experience abundant water (e.g., subalpine, upper subalpine, timberline) may experience increases in productivity

Table 6B.2—Risk assessment and vulnerability ratings for species, vegetation types, and resources of concern.

Habitat, ecosystem function, or species	Adaptive capacity	Exposure	Risk Assessment Magnitude of effects	Risk Assessment Likelihood of effects	Northern Rockies Vulnerability Ranking
Species					
Limber pine	Intermediate adaptive strategy largely driving by timing of pollen cloud dispersal (elevational effect); highly adapted to populating the burned areas predicted for the future due both to wind and corvid-mediated dispersal; poor competitor on more productive sites, if future fires are larger, more severe, there will be less competition from other subalpine conifers; possesses moderate genetic variation (capacity) in blister rust resistance; major gene resistance to blister rust has not been identified in several studies of interior populations, warmer temperatures favor expansion of alternate host species (currant, lousewort and Indian paintbrush); little to no opportunity to hybridize with western white pine due to non-overlapping species distributions, cannot hybridize with whitebark pine; very high risk of loss of disjunct and isolated populations due to genetic drift, ineffective pollen cloud, and substrate availability	High	Moderate	Moderate	15
Ponderosa pine var. *scopulorum*	Generalist adaptive strategy; high phenotypic plasticity; better adapted to drought	Moderate	Low	Low	17
Ponderosa pine var. *ponderosa*	Intermediate adaptive strategy at low to mid elevations Specialist adaptive strategy at higher elevations; moderate phenotypic plasticity; less adapted to drought	Moderate	Moderate	Moderate	16
Douglas-fir	Specialist adaptive strategy at low to mid elevations, generalist adaptive strategy at higher elevations; no opportunity of hybridizing with coastal Douglas-fir subspecies since distributions do not overlap; highly adaptive to a large range of moisture and temperature gradients. In moist forest settings Douglas-fir is limited to a relatively short- lived seral species due to the influence of two root diseases; With warming temperatures and a possible decrease in summer moisture drought conditions, Rocky Mountain Douglas-fir may increase along with an increase abundance of associated stressors; vulnerable to	High	High	High	5

	uncharacteristic fire behavior and severity due to increased densities; increase in susceptibility to Douglas-fir bark beetle morality uncertain but probably an increased activity; moderate change in species distribution expected away from driest margins. High potential for natural regeneration failure due to reduced seed source from large wildfires and difficult micro climate especially on southerly exposures at lower elevations with increasing moisture deficits expected. On moist sites (mixed mesic forest), increases in root disease mortality due to increasing moisture stress on sites where western white pine, ponderosa pine and larch occurred historically. Less carbon sequestration expected in Douglas-fir in those forest setting; there is a high likelihood of change in local distribution due to moisture deficits and fire severity and a high probability of carbon sequestration in northern ID if Douglas-fir remains a dominant species in mixed mesic forests				
Western larch	Intermediate adaptive strategy, Low capacity to regenerate with increasing moisture deficits on higher energy slopes. Larch is adapted to warm moist and cool moist settings. It does best on northerly cool aspects. It is a prolific light seed cone producer but in sporadic years. High adaptive capacity on lower energy slopes; wind disperses seed further than many associates so it can take advantage of newly opened areas due to harvest or fire as an early seral species; larch has few insect and disease stressors unlike associates and is adapted to fairly frequent mixed-severity fire; it can be a dominant, long lived seal tree species in much of the western portion of the NR on lower energy slopes; concerning are potential serious reductions in extent of larch on higher energy slope positions.	High	High	Very High	4
Western white pine	Generalist adaptive strategy, high phenotypic plasticity; cold hardiness may influence distribution; Lack of abundance may influence its role in the moist forest ecosystem; especially adapted to future climates in the mesic regions of the NR; there could be major expansions into historical ranges and the subalpine as rust-resistance increases in western white pine populations	Moderate	High	High	3
Aspen	Aspen has the widest distribution of all trees in this report; it is circumpolar across multiple continents; it is highly	Moderate	Moderate	High	14

	susceptible to many insect and diseases; with a warmer climate gypsy moth may have greater impacts and cause possible mortality; aspen distribution may shift upslope or to northeast (cooler, moister) aspects if drought and repeated fire causes mortality on the warmer, drier sites. Riparian aspen communities will likely persist or increase in extent, particularly if the sites remain moist throughout the growing season and increased fire burns the riparian zone, killing conifers. Fire will favor aspen, but prolonged drought will cause mortality. Younger aged stands (<40 years) may be more resilient to drought; long distance dispersal by light seed may enhance its ability to colonize recently burned areas and establishment of young (sapling, pole) cottonwoods are both diminished; this will vary based on winter snowpack, and amount and time of melt (and associated peakflows) but only if there is sufficient moisture.				
Grand fir	Generalist adaptive strategy, only differences are racial (blue and green race); increases in disease, insects, and fire may reduce populations	Low	Moderate	Moderate	8
Western redcedar	Generalist adaptive strategy; high phenotypic plasticity; cold/warm cycles early in spring or winter may cause red belt.	Moderate	Moderate	Moderate	6
Western hemlock	Inferred or putative generalist adaptive strategy Information limited concerning western hemlock Susceptible to early frost	Moderate	Moderate	Moderate	7
Lodgepole pine	Specialist adaptive strategy; especially adapted to occupy post-burn landscapes that may be more common in the future; highly susceptible to increasing bark beetle outbreaks, especially on landscapes dominated by mature individuals; Varying levels of serotiny allow the species to both occupy new upper subalpine environments while also regenerating after fire; its intolerance of deep droughts may reduce its capacity along the xeric edges of its current range; High hetergenity at landscape scales may mitigate adverse impacts from fire and mountain pine beetles.	Moderate	Moderate	Moderate	11
Subalpine fir	Generalist adaptive strategy; increasing fire will dramatically reduce subalpine fir populations to historical levels; fire exclusion may foster subalpine fir	Low	Moderate	Moderate	10

	encroachment into larch, lodgepole pine, and whitebark pine late seral stands; increasing subalpine temperatures may increase fir growth and accelerate succession toward fir-dominated stands, however, as competition increases, the warmer climates may facilitate increased mortality from insects and disease as trees become more stressed from high densities				
Engelmann spruce	Intermediate adaptive strategy with strong opportunities to hybridize with white spruce, hybrids may be more suited to future climates and hybridization is another key driver in speciation	Low	Moderate	Moderate	9
Mountain hemlock		Low	Moderate	Moderate	12
Whitebark pine	Highly adapted to populating the greater burned areas predicted for the future due to bird-mediated dispersal; if future fires are larger, more severe, there will be less competition from other subalpine conifers; ability to survive fire better than its competitors; moderately shade tolerant so it can exist in competition with limited cone crops; delayed germination adaptation may mitigate warmer, drier conditions; possesses moderate to high genetic variation (capacity) in adaptive traits (blister rust resistance, late winter cold hardiness and drought tolerance), as well as phenotypic plasticity to respond to climate change. Warmer temperatures favor expansion of alternate host species (currant, lousewort and Indian paintbrush). No opportunity to hybridize with another stone pine and cannot cross with western white or limber pine where species distributions overlap; high risk and loss of disjunct and isolated populations; more drought tolerant than its assocates; long distance bird dispersal will increase regeneration potential as more of the landscape burns.	High	High	High	2
Alpine larch	Its specific habitat requirements may make it difficult for alpine larch to remain on the landscape over the long term; short-term gains in alpine larch encroachment in upper subalpine and treeline glades and meadows may be lost in those years with deep drought; effective, long-term establishment of alpine larch may depend on the ability of seed dispersal to find those areas with sufficient moisture to maintain the species.	High	High	High	1

Green ash	Since green ash communities are already fire adapted (most associated species display some fire tolerance and/or post-fire sprouting ability), increased fire will likely not affect most of the moister communities. However, those communities associated with either ephemeral drainages (e.g., woody draws) or moist upland microsites (e.g., northeast facing residual snow-loaded depressions) may experience more drought stress as snowpack declines and melts sooner, and regeneration may decrease, eventually resulting in loss of those communities.	Moderate	Moderate	High	18
Cottonwood	Plains cottonwood may be more persistent due to greater plant available soil water in the unsaturated zone (as a result of finer textured soils). Black and narrowleaf cottonwood typically occur in coarser substrate which will become more droughty as flows are lower and recede earlier than in the past, or are attenuated due to diversions. Seedling and sapling mortality may increase in these species. Plains cottonwood regeneration occurs with episodic flooding, whereas black and narrowleaf cottonwood typically regenerate with 1-3 year bankfull flow return intervals; therefore plains cottonwood will likely be more adapted to irregular flows (in timing, magnitude and duration) that may occur with climate change.	Moderate	Moderate	Moderate to High	13
Vegetation Types					
Dry ponderosa pine and Douglas-fir forests	Douglas-fir highly adaptive to a large range of moisture and temperature gradients. Ponderosa pine adapted to settings that are moisture limited and can grow well where moisture is less limited such in association currently with grand fir; exposure of Douglas-fir to increasing moisture deficits may change composition to more ponderosa pine; Increasing moisture deficits will give ponderosa pine the advantage on dry forest settings due to fire, insect and disease	High	High	High	3
Western larch mixed conifer forests	Larch forest thrive on northerly cool aspects locations in the Region; it is a prolific light seed cone producer but in sporadic years; may seed longer distances than many associates so can take advance of newly opened areas due to harvest or fire as an early seral species; larch has few insect and disease stressors unlike associates, and is adapted to fairly frequent fire; it can out-dominate long	High	High	Very High	2

	lived seal tree species in much of the western portion of the Region, and due to the large diameters it can attain is important to many cavity nesters as habitat when it reaches ages over 200 years in patches large enough, and connected enough to provide functional habitat; exposure on southerly aspects; with warming temperatures, and possible decrease in summer moisture and associated drought may decrease distribution of western larch which could mean that it will retreat to low energy northerly slope settings; distribution of larch in patches on high energy slopes would be reduced significantly; Serious reduction in extent of larch in patches on higher energy slope positions in the long run 50yrs + reduced distribution of wildlife habitat				
Lodgepole pine and aspen mixed conifer forests	This type has the capacity to absorb climate changes and either remain constant or expand into the upper subalpine; losses in aspen due to drought may be offset by gains in lodgepole pine, especially after fire; there may be long-term migrations of this type to higher elevation areas with increasing disturbance	High	Moderate	High	4
Mixed mesic white pine, cedar, hemlock grand fir forests	This type may also have the capacity to remain intact with changing climates; it may not be able to expand due to ash cap; increasing fire will favor western white pine while fire exclusion with favor the shade tolerant species; drier sites may see grand fir becoming more common than cedar or hemlock	Low	Moderate	Low	5
Whitebark pine-spruce-fir forests	This type may have the capacity to respond favorably to changes in climate but the depressed populations of whitebark pine coupled with the increasing fire may result in short-term losses of this type; however, if rust-resistant whitebark pine are planted and restoration activities are implemented, whitebark pine can easily dominate on these sites, especially if fires are large and severe, and whitebark pine may be able to make advances into the timberline; continued fire exclusion will probably aid in keeping this type somewhat static, and it may encroach on lower timberline sites if no fires are allowed	High	High	High	1
Resource Concerns					

Landscape heterogeneity	Since heterogeneity is an expression of disturbance, vegetation, and climate interactions it really is dependent on other factors to determine its adaptive capacity	High	Moderate	High	NA
Timber production	Productivity could increase at higher elevation sites. Productivity in northern Idaho will likely decrease on southerly aspects due to root disease reducing productivity of alternate species unless western larch, ponderosa pine and western white pine are aggressively restored; high exposure due to species composition changes and risk to increased disturbance	High	Moderate to high in north Idaho	High in north Idaho	NA
Carbon sequestration	All ecosystems have an inherent capability to store carbon and the rate and capacity of carbon storage depends on plant productivity and disturbance with the maximum levels of productivity dependent on climate while the instantaneous levels of productivity depend on successional stage or time since disturbance; Many modeling studies have shown that many areas in the NR will actually increase productivity and increase sequestration rate and magnitude; the delicate balance between disturbance and climate coupled with land management will dictate where sequestration will increase and where it will decrease; it is important to know that over the long term (centuries), sequestration is near zero (disturbance and respiration losses are balanced by productivity gains)	High	High	Moderate	NA

Table 6C.1—Adaptation options that address climate change effects on forest vegetation in the Central Subregion.

Sensitivity to climatic variability and change: Aspen will be lost with increasing drought and lack of disturbance.

Adaption Strategy / Approach: Increase aspen populations.

Strategy Objective: Increase aspen populations.

Tactic	**Specific Tactic – A** Actively decrease impact of ungulate browsing through an increase in predation of ungulates.	**Specific Tactic – B** Increase fire disturbance.	**Specific Tactic – C** Develop techniques to successfully artificially regenerate aspen; improve drought tolerance with genetic selection of drought-tolerant mother trees and identify and target areas most likely to successfully regenerate or provide favorable planting habitat.	**Specific Tactic – D** Protect existing aspen populations and regeneration treatments from browsing.
Tactic effectiveness (risks)	High where ungulates concentrate			
Implementation urgency				
Where can tactics be applied? (geographic)				
Opportunities for implementation				
Cost				
Barriers to implementation				

Table 6C.2—Adaptation options that address climate change effects on forest vegetation in the Central Subregion.

Sensitivity to climatic variability and change: Known unknowns and unknown unknowns.

Adaption Strategy / Approach: Increase knowledge and implement adaptive management.

Strategy Objective: Increase knowledge.

Tactic	**Specific Tactic – A** Monitor blister rust resistance within planted white pine stands, and try to understand the relationship between infection rates and climatic/weather drivers like fog.	**Specific Tactic – B** Identify other resource management goals (not directly related to stand structure and composition) that may modify management strategies for forest vegetation, such as water yield, snow retention, and wildlife habitat.	**Specific Tactic – C** Support the adaptive management research framework through a partnership between Region 1 and Rocky Mountain Research Station to evaluate management treatments and how they contribute to resiliency. Develop monitoring framework that will be consistently be implemented so that long-term change can be captured.
Tactic effectiveness (risks)			
Implementation urgency			
Where can tactics be applied? (geographic)			
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 6C.3—Adaptation options that address climate change effects on forest vegetation in the Central Subregion.

Sensitivity to climatic variability and change: Potential shifts in lodgepole pine ecosystems with changing climate.			
Adaption Strategy / Approach: Promote resilience by maintaining age-size class composition at the stand and landscape level.			
Strategy Objective: Maintain lodgepole pine on the landscape.			
Tactic	**Specific Tactic – A** Identify areas appropriate for wildfire use and increase flexibility in how we manage fire; emphasize modified suppression and resource benefit fire; allow moderate season fires to burn.	**Specific Tactic – B** Proactively treat stands with prescribed fire to reduce fire and insect mortality and increase individual tree vigor.	**Specific Tactic – C** Implement silvicultural mechanical treatments.
Tactic effectiveness (risks)	Other unintended consequences could lower it from high to moderate	Highly variable depending on scale, district expertise, and landscape position	Highly variable depending on scale
Implementation urgency	High/near term		
Where can tactics be applied? (geographic)	Implement Wildland Fire Decision Support System forest wide		
Opportunities for implementation	Highly dependent on other resource concerns and political and social issues		
Cost			
Barriers to implementation	Integration between forest and fire team	Prescribed fire air quality restrictions limit what we can do; other resource constraints (e.g., lynx)	Other resource constraints (e.g., thermal cover, lynx habitat, marten and wolverine)

Table 6C.4—Adaptation options that address climate change effects on forest vegetation in the Central Subregion.

Sensitivity to climatic variability and change: Homogenization of the ponderosa forest type across the landscape resulting in: increase in density causing associated increase in risk of severe stand replacing fires; increased risk of mortality from drought; loss of ponderosa pine on stressful sites; loss of large ponderosa pine and large ponderosa snag recruitment; and reduced water yield.

Adaption Strategy / Approach: Decrease the density within ponderosa pine-Douglas-fir stands, and increase structural.

Strategy Objective: Develop resilience to fire, moisture and stress.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Reduce stand density with thinning, prescribed fire, and wildland fire use, with density and structural goals based on past and predicted future conditions.	Promote age class and structural diversity across the landscape, through regeneration harvest, thinning, prescribed fire, and wildland fire use.	Monitor establishment, survival and development of ponderosa by age class and in different conditions (e.g., aspect, heat load and soil moisture) using Forest Inventory and Analysis data and project-level stocking exams.
Tactic effectiveness (risks)	Thinning = high, prescribed fire = high, wildland fire use = moderate	High where implemented	High
Implementation urgency	Near-term in Wildland Urban Interface areas. Mid-term elsewhere	Near-term in Wildland Urban Interface areas. Mid-term elsewhere	Long-term
Where can tactics be applied? (geographic)	Ponderosa pine – Douglas-fir forests	Harvesting and thinning on non-reserved lands; prescribed fire and wildland fire use where approved.	Ponderosa pine – Douglas-fir forests
Opportunities for implementation	Work with collaborators on private and state land to include the wildland urban interface; work with other organizations to get funding and do work on private lands	Work with collaborators on private and state land to include the wildland urban interface; work with other organizations to get funding and do work on private lands	Forest Inventory and Analysis; restoration and resiliency report; forest regeneration reports; adapting Common Stand Exam protocols
Cost	Varies by treatment	Varies by treatment	Inexpensive
Barriers to implementation		Some: cost, litigation	None

Table 6C.5—Adaptation options that address climate change effects on forest vegetation in the Central Subregion.

Sensitivity to climatic variability and change: Changing moisture regimes with changing climate.

Adaption Strategy / Approach: Replace plant association group-habitat typing with an index based on biophysical variables.

Strategy Objective: Increase knowledge; plant associations are not expected to remain the same under climate change.

Tactic	**Specific Tactic – A** Identify a set of biophysical predictors related to habit t types, site productivity, veget ion composition, and st cture. Possi e predictors include andform, soil depth, texture, type (specifically sh cap soil), actual evap ranspi tion, potential evapotranspiration and water balance deficit.	**Specific Tactic – B** Predict site productivity based on biophysical predictors; make concept operationally implementable so it can be used to aid in planting decisions, and aid understanding of long-term fects of management and long-term goa s for a site.	**Specific Tactic – C** Project into the future based on climate change models.
Tactic effectiveness (risks)	Unknown	Unknown	Unknown
Implementation urgency	Near term	Nea m	Near term
Where can tactics be applied? (geographic)			
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 6C.6—Adaptation options that address climate change effects on forest vegetation in the Central Subregion.

Sensitivity to climatic variability and change: Subalpine forest shifts as a result of climate change.

Adaption Strategy / Approach: Monitor and detect change through measurement of seedling survival, species composition and mortality of mature trees.

Strategy Objective: Increase knowledge on climate-induced subalpine forest shifts.

	Specific Tactic – A	**Specific Tactic – B**
Tactic	Install and analyze additiona plot where trend information is needed ove time; mo e intensified grid plots could also be inst ed.	Initiate the use of Forest Inventory and Analysis plot information.
Tactic effectiveness (risks)	High	Moderate to low, depending on how fast changes are occurring
Implementation urgency	High - need to know now	Already part of regional strategy
Where can tactics be applied? (geographic)	Target areas of risk where we expect to see changes, focusing on disturbance areas; in especially sensitive forests such as whitebark pine	Large enough geographic area that information can be statistically meaningful
Opportunities for implementation	Very few because of lack of funding, but protocols and analysis tools already established	Already paid for, and existing expertise and knowledge are available
Cost	High based on information needs; a lot of plots needed	Minimal
Barriers to implementation	Need training and oversight of data collection; need to have consistent, replicable protocol in order to be able to detect change; lack of immediate and long term funding	Difficult to get data updates in a timely manner; getting non-Forest Service data is difficult

Table 6C.6 (cont.)—Adaptation options that address climate change effects on forest vegetation in the Central Subregion

Sensitivity to climatic variability and change: Subalpine forest shifts as a result of climate change.

Adaption Strategy / Approach: Monitor and detect change through measurement of seedling survival, species composition and mortality of mature trees.

Strategy Objective: Increase knowledge on climate-induced subalpine forest shifts.

	Specific Tactic – C	**Specific Tactic – D**
Tactic	Expand reforestation monitoring to include additional monitoring and different electronic formats.	Implement pre- and post- treatment monitoring over time to be able to determine if treatments are meeting objectives.
Tactic effectiveness (risks)	High	High
Implementation urgency	High	Moderate
Where can tactics be applied? (geographic)	Everywhere we are planting sensitive vegetation types	Treated areas
Opportunities for implementation	Often doing it anyway, and methodology is already in place; need to make sure we are collecting right data in the right electronic format	Existing systems
Cost	Low unless data collection becomes arduous	Moderate to high; depends on number of plots variability, length of time to monitor, what data is being collected; less expensive than intensifying grid across landscape.
Barriers to implementation	Need to establish protocols, conduct training, identify a location for data storage and determine who would do the analysis; lack of immediate and long term funding	Lack of immediate and long term funding; lack of training and oversight; lack of treatments to monitor

Table 6C.7—Adaptation options that address climate change effects on forest vegetation in the Central Subregion.

Sensitivity to climatic variability and change: Subalpine forest shifts as a result of climate change.

Adaption Strategy / Approach: Promote resilience of subalpine forests to climate-induced shifts.

Strategy Objective: Create conditions that will be resilient to perturbations.

	Specific Tactic – A	**Specific Tactic – B**
Tactic	Identify areas appropriate for wildfire use; increase the flexibility of how we manage fire and de-emphasize suppression.	Artificially regenerate seedlings with higher levels of rust resistance than the natural population.
Tactic effectiveness (risks)	Other unintended consequences could lower it from high to moderate	High at site level; low at landscape level
Implementation urgency	High-near term	High-near term
Where can tactics be applied? (geographic)	Highly dependent on other resource concerns and political and social issues; problematic in areas with mixed ownership	Have process established to develop rust resistant seedlings; coordinate with tree improvement and nursery to continue to improve rust resistant sources
Opportunities for implementation	All lands - federal, state, districts, communities, universities	All lands - federal, state, districts, communities, universities
Cost	Inexpensive	Moderately expensive; cost of seedlings high
Barriers to implementation	Integration between forest and fire team; sociopolitical environment and backlash; lack of public support; decline in air quality	Access; cost; unable to plant in wilderness or research natural areas

Table 6C.7 (cont.)—Adaptation options that address climate change effects on forest vegetation in the Central Subregion

Sensitivity to climatic variability and change: Subalpine forest shifts as a result of climate change.

Adaption Strategy / Approach: Promote resilience of subalpine forests to climate-induced shifts.

Strategy Objective: Create conditions that will be resilient to perturbations.

Tactic	**Specific Tactic – C** Proactively treat with prescribed burn or mechanical thinning to reduce the risk of fire and insect mortality; increase individual tree vigor to establish the desired species composition and establish appropriate patch sizes.	**Specific Tactic – D** Implement a broad scale review of most current literature, develop a regional library, and implement a climate change information system.	**Specific Tactic – E** Educate the public on the need to increase resilience and develop a cohesive broader message.
Tactic effectiveness (risks)	Highly variable depending on scale, district expertise, and landscape position	High if used	Low
Implementation urgency	Moderate-mid term	High near term	Low-long term
Where can tactics be applied? (geographic)		All	National
Opportunities for implementation	All lands - federal, state, districts, communities, universities		National
Cost	Low to high depending on the combination of treatment, objectives and local conditions		
Barriers to implementation	This type is not as far from historic conditions, so there is not as much reason to restore; more complex and difficult to access; window for treatment is narrower		

Table 6C.8—Adaptation options that address climate change effects on forest vegetation in the Central Subregion.

Sensitivity to climatic variability and change: Homogenization of the larch forest type across the landscape resulting in increased density and associated increase risk of severe stand-replacing fires, increased risk of mortality from drought, loss of western larch on stressful sites, loss of large larch, large larch snag recruitment across the landscape, and reduced water yield.

Adaption Strategy / Approach: Decrease density within stands, and increase structural diversity across the landscape.

Strategy Objective: Develop resilience to fire and moisture stress.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Reduce density with thinning, prescribed fire, and wildland fire use.	Promote age class and structural diversity across the landscape, through regeneration harvest, thinning, prescribed fire and wildland fire use.	Monitor establishment and survival of western larch by age class across different aspects/heat load/soil moisture. Use Forest Inventory and Analysis data to capture regeneration success by topographical position.
Tactic effectiveness (risks)	Thinning = high; prescribed fire = moderate; wildland fire use = low when first implemented, moderate over time	High where implemented	High
Implementation urgency			
Where can tactics be applied? (geographic)			
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 6C.8 (cont.)—Adaptation options that address climate change effects on forest vegetation in the Central Subregion

Sensitivity to climatic variability and change: Homogenization of the larch forest type across the landscape resulting in increased density and associated increase risk of severe stand-replacing fires, increased risk of mortality from drought, loss of western larch on stressful sites, loss of large larch, large larch snag recruitment across the landscape, and reduced water yield.

Adaption Strategy / Approach: Decrease density within stands, and increase structural diversity across the landscape.

Strategy Objective: Develop resilience to fire and moisture stress.

Tactic	**Specific Tactic – D** Prioritize management for larch on landscape facets where monitoring indicates it is going to persist (e.g., on north aspects, but not southern aspects, or by habitat types).	**Specific Tactic – E** Maintain and promote large diameter western larch across the landscape, so that large diameter snags, larch seed sources, and wildlife habitats are also maintained.
Tactic effectiveness (risks)	High	High if A and B are implemented
Implementation urgency		
Where can tactics be applied? (geographic)		
Opportunities for implementation		
Cost		
Barriers to implementation		

Table 6C.9—Adaptation options that address climate change effects on forest vegetation in the Central Subregion.

Sensitivity to climatic variability and change: High density of mixed-mesic white pine, cedar, hemlock, grand fir forests stands, leading to lower carbon sequestration because of lower density of some species (western larch, ponderosa pine and western white pine) and increased shade tolerant species. High densities increased susceptibility to wildfire. Heart rot and root rot in cedar and hemlock decreases carbon sequestration and timber values.
Adaption Strategy / Approach: Promote diversity in species composition and structure at multiple spatial scales (within stands and across the landscape).
Strategy Objective: Promote resilience and increase carbon sequestration.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**	**Specific Tactic – D**	**Specific Tactic – E**
Tactic	Conduct regeneration harvest and planting to promote shade-intolerant tree species (western larch, ponderosa pine, white pine, birch) and rust-resistant white pine.	Promote western white pine.	Conduct density management thinning to retain shade-intolerant trees and develop large trees across the landscape; prune younger western white pine to promote resistance to blister rust.	Increase knowledge on how the different tree densities and species compositions within this group function as habitats and how the mosaic of stands influence connectivity for wildlife.	Develop a site-related prioritization approach for implementing management tactics.
Tactic effectiveness (risks)	High	High	High	Unknown	High
Implementation urgency	Mid-term				
Where can tactics be applied? (geographic)	Within this vegetation type				
Opportunities for implementation					
Cost					
Barriers to implementation					

Table 6C.10—Adaptation options that address climate change effects on forest vegetation in the Central Subregion.

Sensitivity to climatic variability and change: Whitebark pine mortality from increased mountain pine beetle outbreaks, fire and blister rust and shifts/loss of site conditions that support whitebark pine.

Adaption Strategy / Approach: Restore whitebark pine.

Strategy Objective: Increase rust resistant regeneration and cone bearing trees.

	Specific Tactic – A	**Specific Tactic – B**
Tactic	Assess condition; save seed sources; grow rust resistant seedlings; collect seed; plant seedlings; monitor activities; prioritize treatment; and conduct research (Mirror Keane range-wide restoration strategy).	Identify sites that are likely to not be as heavily affected (refugia), and focus on those sites for restoration.
Tactic effectiveness (risks)		
Implementation urgency		
Where can tactics be applied? (geographic)		
Opportunities for implementation		
Cost	Cost of planting is high	
Barriers to implementation	The majority of whitebark pine is in wilderness or other protected areas, or in roadless areas with limited access. Thus, the ability to treat directly is limited. There is a lack of understanding or commitment by personnel. Need comprehensive long term planning and commitment at multiple levels. Funding for climate change adaption implementation is not coming to the ground level.	

Table 6C.11—Adaptation options that address climate change effects on forest vegetation in the Eastern Subregion.

Sensitivity to climatic variability and change: Increased frequency of disturbance, drought, browsing, and livestock trampling may reduce vigor and extent of aspen, even given the unique upward trend of aspen in pine forests that have extensive beetle-caused mortality.

Adaption Strategy / Approach: Maintain and restore/promote the health and vigor of clones (specific key stressors include repeat disturbance, conifer competition, browse/trampling).

Strategy Objective: Maintain the current population trend, promote resilience, reduce stressors/threats, and increase knowledge.

Tactic	**Specific Tactic – A** Actively manage ungulates during regeneration phase through slash barriers, increase in hunting pressure, grazing management and salt block placement.	**Specific Tactic – B** Implement conifer removal on multiple scales and through hand and commercial treatments.	**Specific Tactic – C** Monitor extent and condition of aspen clones to determine the effect of disturbance frequency on aspen survival, effects of sudden aspen decline, and incidence of new clones; potentially implement strategic protection measures for specific clones.
Tactic effectiveness (risks)	High	Highest	Moderate to high
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Wherever aspen regeneration prescriptions are applied	Wherever aspen occurs outside of protected areas	Wherever aspen occurs
Opportunities for implementation	Rocky Mountain Elk Foundation, permittees	Rocky Mountain Elk Foundation	Rocky Mountain Elk Foundation
Cost	Varies by tool Expensive – fencing Inexpensive – grazing management	Inexpensive	Moderate
Barriers to implementation	Some – litigation, scale and timing to be effective (staffing capacity), priority, permittees	Some – litigation, scale and timing to be effective (staffing capacity), priority	None

Table 6C.12—Adaptation options that address climate change effects on forest vegetation in the Eastern Subregion.

Sensitivity to climatic variability and change: Ability of Douglas-fir to develop stands with large, old-growth structure in face of fire, drought, beetles, budworm and limited cone production.

Adaption Strategy / Approach: Establish age class and structural diversity to promote landscape heterogeneity, which could provide appropriate amounts and distribution of large tree structure.

Strategy Objective: Promote resilience, and reduce stressors and threats.

Tactic	**Specific Tactic – A** Manage stand level disturbance through thinning, prescribed fire and natural fire management to accelerate the development of large tree structure.	**Specific Tactic – B** Manage landscape disturbance to achieve heterogeneity in structural diversity.	**Specific Tactic – C** Identify critical stands with high value and large diameter for direct protection from fire and insects; protect using pesticides, stand manipulation, fire protection, and windthrow monitoring.	**Specific Tactic – D** Improve cone production in key seed collection areas through fertilizer, pesticides and stand manipulation.
Tactic effectiveness (risks)	High – thinning Moderate – fire	Moderate–high	High	Moderate
Implementation urgency	Near–mid term	Near–mid term	Near term	Near term
Where can tactics be applied? (geographic)	Throughout species range	Throughout species range	Throughout species range	Throughout species range
Opportunities for implementation	Forest plan; restoration committees	Forest plan; restoration committees	Coordinate with wildlife priorities	Inland Empire Cooperatives
Cost	Inexpensive	Inexpensive	Inexpensive	Inexpensive–moderate
Barriers to implementation	Some – litigation, scale and timing to be effective (staffing capacity), priority	Some – litigation, scale and timing to be effective (staffing capacity), priority	None	None

Table 6C.13—Adaptation options that address climate change effects on forest vegetation in the Eastern Subregion.

Sensitivity to climatic variability and change: Limited ability of limber pine to persist and regenerate in the face of frequent fires, blister rust and pine beetle; challenges include uncertainties in genetic variation and geographically disjunct populations found in the eastern subregion.

Adaption Strategy / Approach: Maintain viable populations of limber pine in suitable environments.

Strategy Objective: Promote resilience, reduce impacts of stressors/threat, increase knowledge, engage coordination.

Tactic	**Specific Tactic – A** Address information gaps on current location, potential habitat and stand condition through coordination with other groups.	**Specific Tactic – B** Address genetic data gaps by establishing a breeding program that includes rust resistance screening, seed zones and drought tolerance through coordination with other groups.	**Specific Tactic – C** Conduct stand treatments to promote resilience over a wide geographic area; protect remaining trees with pesticides and stand thinning, and establish a planting program to achieve scattered, mature individuals.
Tactic effectiveness (risks)	High	High	High at local stand level Moderate at population level
Implementation urgency	Near term	Near term	Near term: improve resilience of existing stands Mid term: planting (answer genetic questions first)
Where can tactics be applied? (geographic)	Forest plans, Region 1 broad scale monitoring strategy	Inland Empire Cooperatives	Forest plans, restoration committees
Opportunities for implementation	All lands – federal, state, districts, communities, universities	All lands – federal, state, districts, communities, universities	All lands – federal, state, districts, communities, universities
Cost	Moderate	Moderate	Inexpensive
Barriers to implementation	None	None	Some – litigation, scale and timing to be effective (staffing capacity), priority

Table 6C.14—Adaptation options that address climate change effects on forest vegetation in the Eastern Subregion.

Sensitivity to climatic variability and change: Small, fragmented populations of eastside ponderosa pine are vulnerable to loss of regeneration capability following repeated disturbance, especially in ecotone sites.

Adaption Strategy / Approach: Maintain genetic diversity, population viability, increase resilience, and promote big-tree structure.

Strategy Objective: Promote resilience, reduce stressors/threats, and facilitate transition.

Tactic	**Specific Tactic – A** Manage stand level disturbance through thinning, prescribed fire and natural fire management to accelerate the development of large tree structure and facilitate the transition to a savanna ecotone.	**Specific Tactic – B** Develop seed collection and reforestation strategies to address potential loss of genetic variability due to disjunct populations and shortened mean return interval of severe disturbances.	**Specific Tactic – C** Identify critical stands with high value and large diameter for direct protection from fire and insects; protect with pesticides, stand manipulation and fire protection.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Low elevation ecotones; suitable ponderosa pine sites	Low elevation ecotones; suitable ponderosa pine sites	Low elevation ecotones; suitable ponderosa pine sites
Opportunities for implementation	Forest management; coordination with fire management	Forest management; Inland Empire Cooperatives	Forest management; wildlife habitat priorities
Cost	Inexpensive	Inexpensive-moderate	Inexpensive
Barriers to implementation	Some – litigation, scale and timing to be effective (staffing capacity), priority	None	Some – litigation, scale & timing to be effective (staffing capacity), priority

Table 6C.15—Adaptation options that address climate change effects on forest vegetation in the GYA Subregion.

Sensitivity to climatic variability and change: Climate change forces us to work across boundaries. Stressors cross boundaries. The public expects coordination.

Adaption Strategy / Approach: Work across jurisdictions at larger scales.

Strategy Objective: Encourage coordination.

Tactic	**Specific Tactic – A** Align budgets/priorities for program of work for neighboring lands (e.g., constrained budget forces cooperation for invasive species strategies).	**Specific Tactic – B** Communicate about adjacent projects and coordinate on the ground; develop memorandum of understanding for adjacent projects.	**Specific Tactic – C** Preserve roads, trails, and access in despite increased fire and flood events.
Tactic effectiveness (risks)	High (if we succeed)	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation	All lands - federal, state, districts, communities, universities	All lands - federal, state, districts, communities, universities	All lands - federal, state, districts, communities, universities
Cost	Inexpensive	Inexpensive	Moderately expensive
Barriers to implementation	Major barriers - politics	Some barriers - politics, time, lack of priority, distance, travel budget	Major barriers – shrinking budget, staffing

Table 6C.16—Adaptation options that address climate change effects on forest vegetation in the GYA Subregion.

Sensitivity to climatic variability and change: Increased fire and disease, and interactions with the wildland urban interface.

Adaption Strategy / Approach: Increase the resilience of forest stands to disturbance, and protect people from potential risks of increased fire.

Strategy Objective: Manage fires in a way to protect the wildland urban interface.

Tactic	**Specific Tactic – A** Create buffer zones between fire and residential development, and implement thinning.	**Specific Tactic – B** Influence development zoning in high risk areas with local government and insurance companies.	**Specific Tactic – C** Increase forest diversity through heterogeneity of species composition, age class and structure.	**Specific Tactic – D** Promote education and communication about responsible land owner tactics.
Tactic effectiveness (risks)	Moderate – intense fires cross boundaries, having unintended impacts on resources and cultural landscapes	High (if we can do it)	Moderate – huge fires, climate change	Moderate
Implementation urgency				
Where can tactics be applied? (geographic)				
Opportunities for implementation				
Cost				
Barriers to implementation	Land designation			

Table 6C.17—Adaptation options that address climate change effects on forest vegetation in the GYA Subregion.

Sensitivity to climatic variability and change: Increased impacts from fire, pests, disease, climate and increased competition.

Adaption Strategy / Approach: Promote resilient whitebark pine communities.

Strategy Objective: Maintain whitebark pine on the landscape.

Tactic	**Specific Tactic – A** Actively remove other dominant tree species, such as lodgepole pine, spruce and fir.	**Specific Tactic – B** Prioritize management for populations with high potential survival.	**Specific Tactic – C** Implement a variety of management strategies/options, such as control sites, fire management, and possibly planting at lower elevations.	**Specific Tactic – D** Replant screened, grafted, genetically-selected seedlings to promote blister rust resistance.
Tactic effectiveness (risks)	Unknown – Not sure if it will work. See barriers.	Moderate – uncertainty, models not considering all factors	Moderate – see barrier	Moderate – see barriers
Implementation urgency	Near term	Near term to long term – more information needed	Near term	Near term
Where can tactics be applied? (geographic)	Where we have access; road, management designation	Greater Yellowstone Area	Greater Yellowstone Area	Where we have access and permission
Opportunities for implementation	Overall whitebark pine strategies, investment strategy niches, Greater Yellowstone Coordinating Committee (GYCC)	Overall whitebark pine strategies, investment strategy niches, GYCC	Overall whitebark pine strategies, investment strategy niches, GYCC	We already have the trees and selected planting locations
Cost	Moderately expensive	Inexpensive	Expensive	Moderately expensive
Barriers to implementation	Major barriers - Limited by wilderness designations, road access, litigation, compliance	Major barriers - Limited by wilderness designations, road access, litigation, cost	Major barriers - - Limited by wilderness designations, road access, litigation, cost	Some barriers – ideal places, access, cost

Table 6C.18—Adaptation options that address climate change effects on forest vegetation in the Western Subregion.

Sensitivity to climatic variability and change: Increased impacts from moisture stress and fire.

Adaption Strategy / Approach: Actively reduce density and maintain low densities.

Strategy Objective: Promote forest resilience through density management.

Tactic	**Specific Tactic – A** Implement precommercial and commercial thinning.	**Specific Tactic – B** Conduct prescribed fires.	**Specific Tactic – C** Influence stand density with planting.
Tactic effectiveness (risks)	High	Moderate – depends on stand conditions	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Be cautious with root disease sensitive species and sites	Applied to maintain fire tolerant conifer species and maintaining structure	Apply where opportunities for thinning are null due to species or stand condition
Opportunities for implementation			
Cost	Inexpensive	Inexpensive	Inexpensive
Barriers to implementation	Some - barriers greater for federal lands. Funding at the landscape scale is less than needed. There are thinning restrictions due to lynx.	Some - barriers greater for federal lands	Some - barriers greater for federal lands

Table 6C.19—Adaptation options that address climate change effects on forest vegetation in the Western Subregion.

Sensitivity to climatic variability and change: Increased frequency and scale of disturbances such as fire and drought.

Adaption Strategy / Approach: Promote disturbance-resilient species, such as ponderosa pine, western larch, western white pine, Douglas-fir, and lodgepole pine.

Strategy Objective: Promote forest vegetation resilience to disturbance.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Promote thinning to favor disturbance-resilient species.	Promote planting of disturbance-resilient species.	Promote resilient species with prescribed fire and/or natural fire use.
Tactic effectiveness (risks)	High	High	Moderate
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Western larch and western white pine on moist sites, ponderosa pine on dry sites, Douglas-fir on extremely dry sites, and lodgepole pine on harsh, difficult to regenerate sites	Western larch and western white pine on moist sites, ponderosa pine on dry sites, Douglas-fir on extremely dry sites, and lodgepole pine on harsh, difficult to regenerate sites	Western larch and western white pine on moist sites, ponderosa pine on dry sites, Douglas-fir on extremely dry sites, and lodgepole pine on harsh, difficult to regenerate sites
Opportunities for implementation	Any place management is feasible and allowed	Any place management is feasible and allowed	Any place management is feasible and allowed
Cost	Inexpensive	Inexpensive	Inexpensive
Barriers to implementation	Scale will vary because of budgetary limitations	Scale will vary because of budgetary limitations	Scale will vary because of budgetary limitations. Natural fire may not occur where or when manageable.

Table 6C.20—Adaptation options that address climate change effects on forest vegetation in the Western Subregion.

Sensitivity to climatic variability and change: Increasing disturbance, moisture deficits, stress due to densities, and longer growing seasons.

Adaption Strategy / Approach: Increase knowledge on current issues, strategies, and future goals.

Strategy Objective: Increase knowledge for agency land managers and stakeholders.

Tactic	**Specific Tactic – A** Address definition of connectivity, including species guilds and scale, and identify existing and historical conditions in order to develop desired conditions.	**Specific Tactic – B** Share knowledge on tree species migration at fine and broad scales, and track regeneration success, species distribution at the fine scale, species transfer zones, habitat type and soil type.	**Specific Tactic – C** Share knowledge on fire regimes in spruce-fir forests and increase collaboration with the Rocky Mountain Research Station.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Landscape	Landscape	Landscape
Opportunities for implementation	All lands – federal, state, districts, communities, and universities	All lands – federal, state, districts, communities, and universities	All lands – federal, state, districts, communities, and universities
Cost	Inexpensive	Inexpensive	Moderately expensive
Barriers to implementation	Funding, lack of understanding	Funding, lack of understanding	Funding, lack of understanding

Table 6C.21—Adaptation options that address climate change effects on forest vegetation in the Western Subregion.

Sensitivity to climatic variability and change: Increasing disturbance, moisture deficits, stress due to densities, and longer growing seasons.

Adaption Strategy / Approach: Increase knowledge on current issues, strategies, and future goals.

Strategy Objective: Increase knowledge for agency land managers and stakeholders.

Tactic	**Specific Tactic – A** Address how to manage conservation areas, such as research natural areas and roadless wilderness. Promote the important components within these areas and desired conditions.	**Specific Tactic – B** Communicate the accurate mapping of important species such as whitebark pine.	**Specific Tactic – C** Address the desired conditions at the landscape level and also for important wildlife habitat by tackling the "how much is enough?" question.
Tactic effectiveness (risks)	Moderate	High	High
Implementation urgency	Mid-term	Near term	Near term
Where can tactics be applied? (geographic)	Program level	Program and forest level	Program and forest level
Opportunities for implementation	Rocky Mountain Research Station, The Nature Conservancy, Wilderness Society, universities, tribes, conservation partners	Universities, conservation partners, state heritage programs	Rocky Mountain Research Station, universities, tribes, conservation partners
Cost	Moderate	Moderate	Moderate
Barriers to implementation	Time	Time	Time

Table 6C.22—Adaptation options that address climate change effects on forest vegetation in the Western Subregion.

Sensitivity to climatic variability and change: Increasing disturbance, moisture deficits, stress due to densities, and longer growing seasons.

Adaption Strategy / Approach: Increase knowledge on current issues, strategies, and future goals.

Strategy Objective: Increase knowledge for agency land managers and stakeholders.

	Specific Tactic – A	**Specific Tactic – B**
Tactic	Increase awareness on the role of root disease in carbon sequestration by publishing Hagles root disease data.	Communicate the need for improved integration between wildlife managers and forest ecologists, and between research and management. Conduct an annual meeting with Rocky Mountain Research Station on management needs for research.
Tactic effectiveness (risks)		High
Implementation urgency		Near term
Where can tactics be applied? (geographic)		Program/Region 1 and Rocky Mountain Research Station
Opportunities for implementation		Program/Region 1 and Rocky Mountain Research Station
Cost		Inexpensive
Barriers to implementation		Lack of time and impetus to do it

Table 6C.23—Adaptation options that address climate change effects on forest vegetation in the Western Subregion.

Sensitivity to climatic variability and change: Increasing disturbance, moisture deficits, stress due to densities, and longer growing seasons.

Adaption Strategy / Approach: Promote resilience in forest vegetation.

Strategy Objective: Promote resilience by reducing stressors and facilitating transitions.

Tactic	**Specific Tactic – A** Reduce forest densities to increase fire resilience in lodgepole pine and whitebark pine sites with precommercial thinning.	**Specific Tactic – B** Reduce forest densities to increase fire resilience in lodgepole pine and whitebark pine sites with commercial thinning.	**Specific Tactic – C** Promote appropriate density conditions and landscape heterogeneity within mapped lynx habitat in spruce-fir forests.
Tactic effectiveness (risks)	High	High	Moderate
Implementation urgency	Near term	Near term	Mid term
Where can tactics be applied? (geographic)	Higher elevations	Higher elevations	Higher elevations
Opportunities for implementation	Whitebark Pine Ecosystem Foundation, Forest Health Protection, programmatic National Environmental Policy Act work, stewardship contracting	Whitebark Pine Ecosystem Foundation, Forest Health Protection, programmatic National Environmental Policy Act work	Rocky Mountain Research Station, state fish and game, U.S. Fish and Wildlife Service, fire management
Cost	Moderate	Moderate	Moderate
Barriers to implementation	Endangered species (lynx), lack of available funding, access and short operating season, management limitations within roadless wilderness, and potential litigation	Endangered species (lynx), lack of available funding, access and short operating season, management limitations within roadless wilderness, and potential litigation	Knowledge gaps in desired conditions

Table 6C.24—Adaptation options that address climate change effects on forest vegetation in the Western Subregion.

Sensitivity to climatic variability and change: Increasing disturbance, moisture deficits, stress due to densities, and longer growing seasons.

Adaption Strategy / Approach: Promote resilience in forest vegetation.

Strategy Objective: Promote resilience by reducing stressors and facilitating transitions.

Tactic	**Specific Tactic – D** Promote legacy trees of western larch, Douglas-fir, western white pine, Engelmann spruce, whitebark pine, and alpine larch.	**Specific Tactic – E** Establish seed collection and seed bank needs for alpine larch, whitebark pine, and high-elevation western larch. Coordinate with other land managers/owners on post-wildfire reforestation and planting of whitebark pine.	**Specific Tactic – F** Promote landscape heterogeneity and create connectivity at multiple scales through strategic placement of treatment units. Increase patch size/treatments and cross-ownership boundary coordination.
Tactic effectiveness (risks)	High	High	Moderate
Implementation urgency	Near term	Near term	Mid term
Where can tactics be applied? (geographic)	Within dense spruce-fir-lodgepole pine sites	Where these species occur	Landscape
Opportunities for implementation	Forest plan desired conditions and project	Whitebark Pine Ecosystem Foundation, volunteers (e.g., backcountry horseman and stakeholders), Forest Health Protection	Forest plan desired conditions and project
Cost	Inexpensive – can be done in conjunction with project	Expensive because of remote location/poor access, but volunteers can help reduce costs	Moderately expensive
Barriers to implementation	None other than lack of these trees in some areas and windthrow risk	Budget (to reduce this barrier, solicit partners); wilderness/roadless policy limitations	Some barriers - knowledge gaps in desired conditions.

Table 6C.25—Adaptation options that address climate change effects on forest vegetation in the Western Subregion.

Sensitivity to climatic variability and change: Increasing disturbance, moisture deficits, stress due to densities, and longer growing seasons.

Adaption Strategy / Approach: Promote resilience in forest vegetation.

Strategy Objective: Promote resilience by reducing stressors and facilitating transitions.

Tactic	**Specific Tactic – G** Promote rapid response and assessment for post-fire reforestation.	**Specific Tactic – H** Implement a triage approach to soil moisture conditions (e.g., loess soil mapping) for prioritizing areas for western white pine and whitebark pine.	**Specific Tactic – I** Protect high value trees (plus other trees, cone producers, and rare species) via management actions, including pheromones and seed orchards.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Throughout zone	Throughout zone	Throughout zone
Opportunities for implementation	Burned area emergency response	Intermountain Forest Tree Nutrition Cooperative, Natural Resources Conservation Service, Rocky Mountain Research Station	Whitebark Pine Ecosystem Foundation, volunteers, Forest Health Protection
Cost	Moderate	Moderate	Moderate
Barriers to implementation	Burned area emergency response does not fund planting; commitment from forests; lack of strategy	Funding; lack of understanding of utility by forests	Funding

Table 6C.26—Adaptation options that address climate change effects on forest vegetation in the Western Subregion.

Sensitivity to climatic variability and change: Accelerated root disease mortality due to climate stressors.

Adaption Strategy / Approach: Reduce dominance of root disease sensitive species (e.g., Douglas-fir and grand fir) on root disease-prone sites.

Strategy Objective: Facilitate transition.

Tactic	**Specific Tactic – A** Regenerate and plant with species less susceptible to root disease.	**Specific Tactic – B** Thin out root disease-susceptible species where less root disease-susceptible species are abundant.	**Specific Tactic – C** Conduct a hot prescribed burn, followed by a re-burn.
Tactic effectiveness (risks)	High	Moderate	Unknown
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Root disease-prone sites with current root disease losses and where management is allowed	Root disease-prone sites; in areas where management is allowed; where adequate, less susceptible species are present and current losses are low	Root disease prone sites and in areas where management is allowed
Opportunities for implementation			
Cost	Inexpensive	Inexpensive	Inexpensive
Barriers to implementation	Where losses are severe and timber value may not cover cost of site preparation	May not be highest priority	5-year regeneration requirement

Table 6C.28—Adaptation options that address climate change effects on forest vegetation in the Western Subregion.

Sensitivity to climatic variability and change: Increasing moisture demands and drought stress in moisture demanding species (western hemlock and western redcedar) on upland sites.

Adaption Strategy / Approach: Minimize the effects to the stand from the affected species (western hemlock and western redcedar).

Strategy Objective: Promote resilience and facilitate transition.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Implement precommercial thinning to limit dominance of these species on drough-prone sites.	Encourage regeneration harvest and planting with a more diverse species mix.	Preserve road and trail access despite increased fire and flood events.
Tactic effectiveness (risks)	Moderate	High	Moderate
Implementation urgency	Near term	Near term	Mid term
Where can tactics be applied? (geographic)			
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 6C.28—Adaptation options that address climate change effects on forest vegetation in the Western Subregion.

Sensitivity to climatic variability and change: Increasing moisture demands and drought stress in moisture demanding species (western hemlock and western redcedar) on upland sites.

Adaption Strategy / Approach: Minimize the effects to the stand from the affected species (western hemlock and western redcedar).

Strategy Objective: Promote resilience and facilitate transition.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Implement precommercial thinning to limit dominance of these species on drough-prone sites.	Encourage regeneration harvest and planting with a more diverse species mix.	Preserve road and trail access despite increased fire and flood events.
Tactic effectiveness (risks)	Moderate	High	Moderate
Implementation urgency	Near term	Near term	Mid term
Where can tactics be applied? (geographic)			
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 6C.29—Adaptation options that address climate change effects on forest vegetation in the Western Subregion.

Sensitivity to climatic variability and change: Western white pine is resilient but underrepresented.

Adaption Strategy / Approach: Increase presence of western white pine.

Strategy Objective: Promote resilience and facilitate transition.

Tactic	**Specific Tactic – A** Implement planting of blister rust resistant western white pine.	**Specific Tactic – B** Implement blister rust pruning.	**Specific Tactic – C** Retain existing natural white pine when thinning, harvesting, and burning.
Tactic effectiveness (risks)	High	High	Thinning/harvest – high Burning – moderate
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Western redcedar, western hemlock and moist grand fir habitat types (and on moister microsites of drier habitat types)	Stands with moderate infection, but low infection above pruning height; may be critical if thinning	Where western white pin is present
Opportunities for implementation			
Cost	Inexpensive	Inexpensive	Inexpensive
Barriers to implementation	Openings are lacking because of limited timber harvest and fire suppression.	Insufficient funds and access	More difficult on steep ground, where fire is needed for site preparation

Table 7A.1—Adaptation options that address climate change effects on non-forested vegetation in the Central Subregion.

Sensitivity to climatic variability and change: Increased susceptibility of vegetation communities (e.g., grasslands) to invasive species. Effects of climate change on grasslands will be amplified by management actions.

Adaptation Strategy / Approach: Increase proactive management actions in order to prevent invasive species

Strategy Objective: Reduce stressors/threats, engage coordination, increase knowledge

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**	**Specific Tactic – D**
Tactic	Conduct integrated weed management (i.e., spraying, chemical, biological, mechanical, manual control, education, targeted grazing).	Develop weed management areas and coordinate with multiple agencies, non-governmental organizations, and public.	Apply early detection rapid response (EDRR) and inventory and mapping.	Update weed risk assessment (WRA) to enhance integrated weed management.
Tactic effectiveness (risks)	High	High (if properly implemented)	High	Moderate
Implementation urgency	Near term	Near term	Near term	Mid term
Where can tactics be applied? (geographic)	Recreation high use areas (roads), administrative areas; Lolo Creek (Missoula District for sheep/goat grazing)	Recreation high use areas (roads); administrative areas	Wilderness protected areas	Multi-scale effort
Opportunities for implementation	Coordinate with multiple agencies, non-governmental organizations, public; opportunity to graze in newly acquired lands (sheep/goats)	Coordinate with multiple agencies, non-governmental organizations, public	Coordinate with multiple agencies, non-governmental organizations, public, employees	Coordinate with federal and state agencies
Cost	Expensive	Inexpensive/moderately expensive (depends on implementation scale)	Inexpensive/moderately expensive	Moderately expensive
Barriers to implementation	Management support; conflict between bighorn sheep and domestic	Community support; social economic barriers (e.g., education, trust, holdouts)	Lack of acceptance that it is a priority	Time, lack of prioritization

Table 7A.2—Adaptation options that address climate change effects on non-forested vegetation in the Eastern Subregion.

Sensitivity to climatic variability and change: Increased temperature and drought will cause more and larger wildfires, leading to mortality of sagebrush and grasslands and increased dominance of fire-adapted herbaceous and non-native species.

Adaptation Strategy / Approach: Maintain intact ecosystems, and increase resilience and resistance of native sagebrush-grass ecosystems**.**

Strategy Objective: Promote resilience, reduce stressors/threats, engage coordination, and increase knowledge.

Tactic	**Specific Tactic – A** Inventory intact/high native cover/weed free areas.	**Specific Tactic - B** Employ preventative measures to reduce the spread and introduction of invasive species into intact/weed free plant communities.	**Specific Tactic – C** Survey for new invasive species.	**Specific Tactic – D** Manage priority invasive species on priority acres.
Tactic effectiveness (risks)	High	Moderate to high	High	Moderate
Implementation urgency	Near term	Near term	Near term	Near term
Where can tactics be applied? (geographic)	On all lands (where access can be granted)	Areas that are currently weed free	On all lands (where access can be granted)	On priority acres
Opportunities for implementation	Work with agencies, counties, state, non-profit and private land owners to share and incorporate current and future inventory data	Work with agencies, counties, state, non-profit and private land owners to partner in weed prevention strategies and practices	Work with agencies, counties, state, non-profit and private land owners to share and incorporate current and future survey data, technology	Work with agencies, counties, state, non-profit and private land owners to collaborate on invasive species management activities
Cost	Moderately expensive	Inexpensive to moderately expensive	Moderately expensive	Inexpensive to moderately expensive
Barriers to implementation	Some to major barriers - staff capacity; budgets; priorities	Some to major barriers - public and internal awareness and perception; funding	Some to major barriers - staff capacity; budgets; priorities	Some to major barriers - budget; plant identification and phenology; capacity

Table 7A.2 (cont.)—Adaptation options that address climate change effects on non-forested vegetation in the Eastern Subregion

Sensitivity to climatic variability and change: Increased temperature and drought will cause more and larger wildfires, leading to mortality of sagebrush and grasslands and increased dominance of fire-adapted herbaceous and non-native species.

Adaptation Strategy / Approach: Maintain intact ecosystems, and increase resilience and resistance of native sagebrush-grass ecosystems**.**

Strategy Objective: Promote resilience, reduce stressors/threats, engage coordination, and increase knowledge.

Tactic	**Specific Tactic – E** Restore to minimize or reverse adverse effects.	**Specific Tactic - F** Manage conifer encroachment.	**Specific Tactic – G** Manage fire for resource benefits.	**Specific Tactic – H** Promote the occurrence and growth of early-season natives.
Tactic effectiveness (risks)	Moderate to high	Low to high	Moderate to high	Moderate
Implementation urgency	Near term	Near term	Near term	Short term
Where can tactics be applied? (geographic)	Degraded non-forest vegetation communities	Priority areas based on current condition and potential response to treatment	Priority areas based on current condition and potential response to fire	Sagebrush-dominated areas where native species have significant populations and non-natives are not dominant
Opportunities for implementation	Collaborate with partners on the design and implementation of restoration activities	Collaborate with partners on conifer encroachment management activities	Collaborate with agencies, counties, state, non-profit and private land owners on fire management	Coordinate with range permittees
Cost	Inexpensive to expensive	Inexpensive to moderately expensive	Inexpensive to moderately expensive	Moderately expensive, depending on work needed
Barriers to implementation	Some to major barriers – awareness and recognition of need	Some to major barriers – litigation; burn windows; awareness and recognition of need	Some to major barriers - Recognition of need; public and internal perception and risk aversion	Some barriers: Some public opposition

Table 7A.2 (cont.)—Adaptation options that address climate change effects on non-forested vegetation in the Eastern Subregion

Sensitivity to climatic variability and change: Increased temperature and drought will cause more and larger wildfires, leading to mortality of sagebrush and grasslands and increased dominance of fire-adapted herbaceous and non-native species.

Adaptation Strategy / Approach: Maintain intact ecosystems, and increase resilience and resistance of native sagebrush-grass ecosystems**.**

Strategy Objective: Promote resilience, reduce stressors/threats, engage coordination, and increase knowledge.

Tactic	**Specific Tactic – I** Reduce grazing in July and August to encourage perennial growth.	**Specific Tactic – J** Manage livestock grazing through planning efforts that serve as livestock movement guides (within-season triggers) and allow for the maintenance and/or enhancement of plant health (end-point indicators).	**Specific Tactic – K** Use targeted grazing to address contemporary vegetation management challenges (e.g., control invasive exotic and noxious weeds and undesirable species, reduce fire risk).	**Specific Tactic – L** Identify and manage (e.g., close, obliterate, re-route) non-system/user created routes (roads and trails).
Tactic effectiveness (risks)	Moderate	Low to moderate	Low to moderate	Low to high
Implementation urgency	Mid term	Near term	Near to mid term	Near term
Where can tactics be applied? (geographic)	Areas with high probability of recovery, primarily moist sites	On all grazed lands	Priority areas based on current condition and potential response to treatment	On priority areas
Opportunities for implementation	Coordinate with range permittees	Livestock managers	Livestock managers	Partner with National Forest Foundation, NGOs
Cost	Inexpensive	Inexpensive to moderately expensive	Inexpensive to moderately expensive	Inexpensive to moderately expensive
Barriers to implementation	Opposition by some permittees	Commitment by managers; compliance by livestock managers; staff capacity	Public perception, National Environmental Policy Act; litigation; logistics and access	Awareness; detection; budget; perception of need (internal and external);

Table 7A.3—Adaptation options that address climate change effects on non-forested vegetation in the Grasslands Subregion.

Sensitivity to climatic variability and change: Phenological mismatch between pollinators and host plants.

Adaptation Strategy / Approach: Maintain and restore natural habitat to ensure pollination.

Strategy Objective: Promote resilience, reduce stressors/threat.

	Specific Tactic – A	**Specific Tactic – B**
Tactic	Restore and enhance habitat (using tools such as grazing, fire, herbicide application, reseeding).	Implement long term monitoring of pollinators (e.g., research, tech transfer, education, citizen science projects, and monitor existing populations).
Tactic effectiveness (risks)	Depends on the combination of tools	Not applicable
Implementation urgency	Near term	Near term
Where can tactics be applied? (geographic)	Use ecological site descriptions to identify priority areas for restoration or enhancement	Look at native and non-native ecosystems, overlap in these ecosystems and the types of pollinators present
Opportunities for implementation	Take advantage of other restoration activities; public involvement	Search for existing information; engage with Natural Resources Conservation Service, Agricultural Research Service, state extensions, North Dakota Department of Agriculture for education on pollinators and agricultural practices; opportunity for citizen science projects to detect broad trends
Cost	Cost varies by tool; shared cost with other restoration projects	Inexpensive with partnerships (i.e., citizen science projects)
Barriers to implementation	Some of the restoration tools may adversely impact the habitat.	

Table 7A.4—Adaptation options that address climate change effects on non-forested vegetation in the Grasslands Subregion.

Sensitivity to climatic variability and change: Encroachment of native species into grasslands (i.e., willow [*Salix*], sumac [*Rhus*], juniper [*Juniperus*], snowberries [*Gaultheria*], ponderosa pine [*Pinus ponderosa*]).

Adaptation Strategy / Approach: Restore natural disturbance regimes in grasslands.

Strategy Objective: Promote resilience, reduce stressors/threats

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Conduct prescribed fires.	Conduct mechanical treatments (chainsaws, mowing, mastication, logging, lop and scatter, haying, grazing).	Use herbicide (use appropriate delivery method).
Tactic effectiveness (risks)	Moderate	Moderate/high	High
Implementation urgency			
Where can tactics be applied? (geographic)	Use ecological site descriptions to determine where to apply prescribed fire		
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 7A.5—Adaptation options that address climate change effects on non-forested vegetation in the Grasslands Subregion.

Sensitivity to climatic variability and change: Encroachment of non-native species into grasslands (i.e., leafy spurge [*Euphorbia esula*], knapweed [*Centaurea*], sulphur cinquefoil [*Potentilla recta*], Canada thistle [*Cirsium arvense*], Russian olive [*Elaeagnus angustifolia*], hounds tongue [*Cynoglossum officinale*], redtop [*Agrostis stolonifera*], cattail [*Typha*], reed canary grass [*Phalaris arundinacea*], paleyellow iris [*Iris pseudacorus*], Japanese brome [*Bromus japonicus*], Kentucky bluegrass [*Poa pratensis*], smooth brome [*Bromus inermis*], crested wheatgrass [*Agropyron cristatum*], cheatgrass [*Bromus tectorum*], sweet clover [*Melilotus*], absinth wormwood [*Artemisia absinthium*], black henbane [*Hyoscyamus niger*], buckthorn [*Rhamnus*]).

Adaptation Strategy / Approach: Maintain and increase resilience of native grassland communities.

Strategy Objective: Promote resilience.

Tactic	**Specific Tactic – A** Use ecological site descriptions to prioritize areas for treatment *(wouldn't apply to all the species listed above).*	**Specific Tactic – B** Apply biological control.	**Specific Tactic – C** Implement prescriptive grazing, fire, herbicide and re-seeding (timing, duration, frequency, kind and class of livestock).
Tactic effectiveness (risks)	Moderate/high	Low-high	Moderate/high
Implementation urgency	Near term	Dependent on research	Near term
Where can tactics be applied? (geographic)	Forest/grassland/sub region level	Where it is likely to be effective and not have unintended consequences	Forest/grassland/sub region level
Opportunities for implementation	Interagency weed working groups	Interagency weed working groups	Interagency weed working groups; US Fish and Wildlife Service; interagency fire program; ranchers
Cost	Varies	Varies by agent	Moderately expensive/ expensive
Barriers to implementation	Lack of knowledge; funding and training	Uncertainty and unintended consequences of using biological control in a changing climate	Social perceptions (e.g., grazing, fire, herbicide use)

Table 7A.5 (cont.)—Adaptation options that address climate change effects on non-forested vegetation in the Grasslands Subregion

Sensitivity to climatic variability and change: Encroachment of non-native species into grasslands.

Adaptation Strategy / Approach: Maintain and increase resilience of native grassland communities.

Strategy Objective: Promote resilience.

	Specific Tactic – D	**Specific Tactic – E**	**Specific Tactic – F**	**Specific Tactic – G**
Tactic	Apply early detection rapid response.	Use best invasive management practices to address vectors; emphasize invasive species education (e.g., teach people how to clean their equipment, boots).	Conduct internal and external education and outreach.	Maintain and increase agency, state and county cooperation on invasive weeds.
Tactic effectiveness (risks)	High	High	High	High
Implementation urgency	Near term	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Wherever new invasions are	Forest/grassland/region level	Forest/grassland/region level	Forest/grassland/region level
Opportunities for implementation	Interagency weed working groups	Interagency weed working groups; field technicians	Interagency weed working groups; field technicians	Interagency weed working groups
Cost	Inexpensive	Inexpensive	Inexpensive	Inexpensive
Barriers to implementation	Plant identification skills	Plant identification skills; turnover of local population	Plant identification skills; turnover of local population	Coordinated action (need mechanism to ensure continued coordination)

Table 7A.6—Adaptation options that address climate change effects on non-forested vegetation in the GYA Subregion.

Sensitivity to climatic variability and change: Increase in fire frequency and intervals, invasive species, herbivory, and species shift (C4)

Adaptation Strategy / Approach: Increase resilience of C3 grassland communities to the above sensitivities, and maintain C3 grassland communities on the landscape.

Strategy Objective: Promote resilience, reduce stressors/threats.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**	**Specific Tactic – D**
Tactic	Allow natural and prescribed fire.	Conduct ecologically based invasive plant management; use herbivory (goats), biocontrol, wildfire, and seeding (e.g., smooth brome).	Conduct inventory of data, including maps and risk assessments; use Early Detection Rapid Response (EDRR) and weed-free policies regarding stock; conduct inventory and monitoring.	Remove conifers with mechanical treatments, prescribed fire, and harvest.
Tactic effectiveness (risks)	Moderate	Moderate	High	High
Implementation urgency	Mid term	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Expand beyond wildland urban interface; apply in areas with healthy vegetation	Prioritize small/new invasions by most critical species; work back to road corridors and developed areas	EDRR for all new findings	Encroached communities
Opportunities for implementation	Implement projects per forest management plan	Effective at local levels; not at landscape scale	Effective at local levels; not at landscape scale	Small watershed or landscape of 1000-1500 acres
Cost	Cost varies by project size and complexity	Moderately expensive	Inexpensive	Moderately expensive
Barriers to implementation	Some barriers: Community acceptance; litigation; risk aversion; lack of non-WUI funding	Major barriers: Community acceptance; capacity; need to scale up to be effective; perceived lack of urgency	Some barriers: Lack of champions; workforce availability; perceived lack of urgency	Some barriers: Staffing; litigation; availability of burn windows; fiscal year limitations; risk aversion

Table 7A.7—Adaptation options that address climate change effects on non-forested vegetation in the GYA Subregion.

Sensitivity to climatic variability and change: Increase in fire severity and frequency, invasive species, and herbivory.

Adaptation Strategy / Approach: Increase resilience of mountain sagebrush community to the above sensitivities, and maintain sagebrush communities on the landscape.

Strategy Objective: Maintain current trend. Promote resilience. Reduce stressors/threats.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Strategically place fuels treatments (thinning, mulching, limited suppression) across the landscape.	Conduct ecologically based invasive plant management (EBIPM); use herbivory (goats), biocontrol, wildfire, and seeding.	Conduct inventory of data, including maps and risk assessments; use Early Detection Rapid Response (EDRR) and weed-free policies regarding stock; conduct inventory and monitoring.
Tactic effectiveness (risks)	Moderate	Moderate	High
Implementation urgency	Near term/mid term	Near term	Near term
Where can tactics be applied? (geographic)	Expand beyond wildland urban interface; apply in areas with existing healthy vegetation	Prioritize small/new invasions by most critical species; work back to road corridors and developed areas	EDRR for all new findings
Opportunities for implementation	Implement projects per forest management plan; be opportunistic when wildfire does strike (crew availability; community acceptance)	Public Lands Day and other volunteer projects; partner with wildlife and other stakeholder groups for habitat improvement	Public Lands Day and other volunteer projects; partner with wildlife and other stakeholder groups for habitat improvement (Trout Unlimited, friends group).
Cost	Moderately expensive; cost varies by project size and complexity	Moderately expensive	Inexpensive
Barriers to implementation	Some barriers: political; community acceptance; litigation; risk aversion; lack of non-wildland urban interface funding	Major barriers: community acceptance; availability of workforce; need to scale up to be effective; perceived lack of urgency	Some barriers: lack of champions; workforce availability; perceived lack of urgency

Table 7A.7 (cont.)—Adaptation options that address climate change effects on non-forested vegetation in the GYA Subregion

Sensitivity to climatic variability and change: Increase in fire severity and frequency, invasive species, and herbivory.

Adaptation Strategy / Approach: Increase resilience of mountain sagebrush community to the above sensitivities, and maintain sagebrush communities on the landscape.

Strategy Objective: Maintain current trend. Promote resilience. Reduce stressors/threats.

	Specific Tactic – D	**Specific Tactic – E**
Tactic	Determine and implement proper grazing; conduct adaptive management that recognizes climate changes will lead to different availability of range; use rest and rotation practices.	Remove conifers with mechanical treatments, prescribed fire, and harvest.
Tactic effectiveness (risks)	High	High
Implementation urgency	Moderate	Near term
Where can tactics be applied? (geographic)	Everywhere	Encroached communities
Opportunities for implementation	Coordinate with range permittees; cultivate management support.	Coordinate with fuels and habitat objectives for interagency and partnership work (and funding; commercial harvest
Cost	Inexpensive	Moderately expensive
Barriers to implementation	Some barriers: Lack of stakeholder support (real or perceived); lack of trust; noncompliance; perceived lack of urgency	Some barriers: Staffing levels; litigation; uncertain availability of burn windows due to climate change; fiscal year limitations; challenges with interagency and/or non-fed implementation and coordinated planning efforts; risk aversion

Table 7A.8—Adaptation options that address climate change effects on non-forested vegetation in the GYA Subregion.

Sensitivity to climatic variability and change: Increase in fire severity and frequency, invasive species, and herbivory.

Adaptation Strategy / Approach: Increase resilience of Wyoming sagebrush community to the above sensitivities.

Strategy Objective: Maintain sagebrush communities on the landscape; **c**reate and maintain a healthy and diverse plant community.

	Specific Tactic – A	**Specific Tactic – B**
Tactic	Strategically place fuels treatments (thinning, mulch, limited suppression) across the landscape.	Conduct ecologically based invasive plant management (EBIPM); use herbivory (goats), biocontrol, wildfire, and seeding.
Tactic effectiveness (risks)	Moderate	Moderate (unless strict adherence to EBIPM, then high)
Implementation urgency	Near term/Mid term	Near term
Where can tactics be applied? (geographic)	Anywhere we can; expand beyond wildland urban interface; apply tactic in areas with existing healthy intact vegetation; avoid degraded areas	Prioritize small/new invasions by most critical species; work back to road corridors and developed areas in non-wilderness.
Opportunities for implementation	Implement projects per forest management plan; be opportunistic when wildfire does strike (crew availability; community acceptance)	Public Lands Day and other volunteer projects; partner with wildlife and other stakeholder groups for habitat improvement (Trout Unlimited, friends groups)
Cost	Moderately expensive; cost varies by project size and complexity	Moderately expensive
Barriers to implementation	Some barriers: Political; community acceptance; management and community tolerance; litigation; risk aversion; lack of non-wildland urban interface funding	Major barriers: Community acceptance; availability of workforce; methodology; public perception; technology; need to scale up to be effective; perceived lack of urgency

Table 7A.8 (cont.)—Adaptation options that address climate change effects on non-forested vegetation in the GYA Subregion

Sensitivity to climatic variability and change: Increase in fire severity and frequency, invasive species, and herbivory.

Adaptation Strategy / Approach: Increase resilience of Wyoming sagebrush community to the above sensitivities.

Strategy Objective: Maintain sagebrush communities on the landscape; **c**reate and maintain a healthy and diverse plant community.

	Specific Tactic – C	**Specific Tactic – D**
Tactic	Conduct inventory of data, including maps and risk assessments; use Early Detection Rapid Response (EDRR) and weed-free policies regarding stock; conduct inventory and monitoring.	Determine and implement proper grazing; conduct adaptive management that recognizes climate changes will lead to different availability of range; use rest and rotation practices.
Tactic effectiveness (risks)	High	High
Implementation urgency	Near term	Moderate
Where can tactics be applied? (geographic)	EDRR for all new findings	Everywhere
Opportunities for implementation	Public Lands Day and other volunteer projects; partner with wildlife and other stakeholder groups for habitat improvement (Trout Unlimited, friends groups)	Coordinate with range permittees; cultivate management support.
Cost	Inexpensive	Inexpensive
Barriers to implementation	Some barriers: Lack of champions; workforce availability; perceived lack of urgency	Some barriers: Lack of stakeholder support (real or perceived); lack of trust; noncompliance; perceived lack of urgency

Table 7A.9—Adaptation options that address climate change effects on non-forested vegetation in the Western Subregion.

Sensitivity to climatic variability and change: Increase in fires, warmer drier conditions, and invasive species, and decline in pollinators. With warmer wetter conditions, conifers are establishing in balds and snow belts because of changes in precipitation from snow to rain.

Adaptation Strategy / Approach: Maintain healthy and intact grasslands.

Strategy Objective: Maintain and increase resilience from perturbation and resistance to invasive species; reduce weed invasion; increased knowledge of the ecology of grasslands.

	Specific Tactic – A	**Specific Tactic – B**
Tactic	Maintain or restore adequate native plant cover, vigor, and species richness; ensure ecologically significant remnant populations of endemics are maintained; tools include appropriate grazing management, focused herbicide use, re-vegetation (with locally adapted and site specific species, forbs and graminoids), appropriate fire management, appropriate travel management, maintaining public land management of ecologically significant remnant plant communities (e.g., rough fescue, Palouse prairie), and conservation easements.	Encourage native pollinators; provide other habitats for pollinators (nesting cover, feeding cover, brooding cover); tools include re-vegetation (with native species), appropriate herbicide and insecticide use, and education for public and within agency.
Tactic effectiveness (risks)	Low/moderate/high	Moderate/high
Implementation urgency	Near term/ongoing	Near term/ongoing
Where can tactics be applied? (geographic)	Throughout current range of grasslands; management activities are species specific	Throughout
Opportunities for implementation	Acquiring remnant populations (partners: The Nature Conservancy (TNC), working with tribes, private landowners, land trusts); conservation easements (TNC, local land trusts)	Xerces Society; native plant societies; local garden clubs; local conservation groups; Idaho Master Naturalists; youth organizations (high schools, 4H)
Cost	Inexpensive/moderately expensive	Inexpensive/ moderately expensive
Barriers to implementation	Multiple land ownership and fragmentation; lack of scientific knowledge; reduced budgets for inventory and monitoring	Farm Bill language; introduction of non-native pollinators; use of insecticides; multiple ownerships

Table 7A.9 (cont.)—Adaptation options that address climate change effects on non-forested vegetation in the Western Subregion

Sensitivity to climatic variability and change: Increase in fires, warmer drier conditions, and invasive species, and decline in pollinators. With warmer wetter conditions, conifers are establishing in balds and snow belts because of changes in precipitation from snow to rain.

Adaptation Strategy / Approach: Maintain healthy and intact grasslands.

Strategy Objective: Maintain and increase resilience from perturbation and resistance to invasive species; reduce weed invasion; increased knowledge of the ecology of grasslands.

	Specific Tactic – C	**Specific Tactic - D**
Tactic	Step 1 - Identify and map soil types (locate molisols); Step 2 - Prioritize restoration based on Step 1; sites that were historically maintained have now shifted to conifer savannas; identify sites that were fire maintained versus snow maintained.	Step 1 - Map risk areas for severe drought, and conduct snow melt risk analysis; Step 2 - Establish targeted areas for monitoring based on step 1 (re-visit and monitor established plots); Step 3 - Work with geneticists to isolate frost and drought hardiness, early emergence; Step 4 - Use seed sources with those traits (step 3) to help vegetate specific sites that were identified in step 1.
Tactic effectiveness (risks)	Step 1/2 moderate	High
Implementation urgency	Near term	Step 1 – near term; step 2 – ongoing dependent on prioritization of areas
Where can tactics be applied? (geographic)	In identified and mapped areas	In identified risk areas
Opportunities for implementation	Partnerships with Natural Resources Conservation Service (NRCS)	Heritage Program (for monitoring); partner with NRCS, National Oceanic and Atmospheric Administration (snow melt data), Rocky Mountain Research Station; local cooperators to help with seed accessions and Forest Service nursery
Cost	Moderately expensive	Moderately expensive
Barriers to implementation	Funding; time and personnel intensive; Requires finer-scale knowledge to be effective; higher priorities (mindset)	Funding; time and personnel intensive; higher priorities? (mindset); sequential process

Table 7A.10—Adaptation options that address climate change effects on non-forested vegetation in the Western Subregion.

Sensitivity to climatic variability and change: Loss of topsoil and invasion of weeds.

Adaptation Strategy / Approach: Maintain and increase montane shrublands.

Strategy Objective: Maintain and increase resilience from perturbation and resistance to invasive species; reduce weed invasion; increased knowledge of the ecology of shrublands.

	Specific Tactic – A	**Specific Tactic – B**
Tactic	Implement fuel reduction projects (i.e., reduce conifer encroachment, brush cutting, slashing/ mastication without burning, targeted browsing); if burning is used, design prescriptions according to requirements of desired shrub species (soil moisture requirements, desired end result conditions).	Maintain adequate shrub cover, vigor, and species richness, and avoid bare ground; create different age classes and compositions of shrubfields (shifting mosaic); no action is a viable alternative dependent on system; tools include removal of timber products, targeted grazing, prescribed burning, and mastication/slashing.
Tactic effectiveness (risks)	Moderate (unintended consequences, higher priorities)	Moderate/high
Implementation urgency	Near term/ongoing	Near term/ongoing
Where can tactics be applied? (geographic)	Throughout; critical areas for restoration	Throughout and across jurisdictional boundaries
Opportunities for implementation	Partners – Rocky Mountain Elk Foundation, sportsmen associations, Idaho Fish and Game, Bureau of Land Management, Idaho Forest Landowner association; forest harvests open up new shrublands	Partners – Rocky Mountain Elk Foundation, sportsmen associations, Idaho Fish and Game, BLM, Idaho Forest Landowner association, Turkey Federation
Cost	Inexpensive/moderately expensive (depends on scale)	Inexpensive/moderately expensive (depends on scale)
Barriers to implementation	Current forest management policies about allowing shrubfields to be maintained rather than reforestation; mindset of current land managers (tradition)	Mindset of current land managers (tradition); lack of equipment; availability of target livestock; road access; inaccessibility (slope); multi-resource objectives

Table 7A.10 (cont.)—Adaptation options that address climate change effects on non-forested vegetation in the Western Subregion

Sensitivity to climatic variability and change: Loss of topsoil and invasion of weeds.

Adaptation Strategy / Approach: Maintain and increase montane shrublands.

Strategy Objective: Maintain and increase resilience from perturbation and resistance to invasive species; reduce weed invasion; increased knowledge of the ecology of shrublands.

	Specific Tactic – C	**Specific tactic - D**
Tactic	Apply early detection rapid response (EDRR), and use ecologically based invasive plant management (EBIPM); tools include biocontrol, herbicides, timing burning prescriptions (to avoid annual brome expansion, and targeted grazing.	Educate fuels specialists, forest ecologists, wildlife biologists and silviculturists on ecology and disturbances affecting shrublands; effects of repeated burns; shifting mosaics (creating a balance of types across landscapes); and weeds (identification, awareness, reporting).
Tactic effectiveness (risks)	Low/moderate	Moderate
Implementation urgency	Near term/ongoing	Near term/ongoing
Where can tactics be applied? (geographic)	Throughout and across jurisdictional boundaries	Throughout and across land management jurisdictions
Opportunities for implementation	Coordinate with private landowners; cooperative weed management areas; partner with Bonneville Power, tribes, private groups such as backcountry horsemen, National Forest Foundation; use volunteer cooperators (for surveys and monitoring)	Revise Forest Service manual; brownbag lunch – weed webinar; educational products such as flyers, posters; ross training and/or internal training for line officers
Cost	Inexpensive/moderately expensive (depends on scale)	Moderately expensive
Barriers to implementation	Multiple jurisdictions; National Environmental Policy Act – not being able to adapt to new chemicals; logistically inaccessible (backpack or on horse); public mindset of using chemicals; budgets are prohibitive.	Tie implementation to performance for achieving objectives (misuse of herbicides, treating non-target native plants); need line officer support; mindset of current land managers (tradition); public mindset of using chemicals

Table 9A.1—Adaptation options that address climate change effects on wildlife in the Central Subregion.

Sensitivity to climatic variability and change: Potential conversion to grassland type; many ponderosa pine forests have converted to Douglas-fir types with fire exclusion and are therefore more susceptible to future fires (putting dry forest cavity nester habitat at risk).

Adaption Strategy / Approach: Restore fire-adapted ponderosa pine stand conditions for dry forest cavity nesters.

Strategy Objective: Promote resilience.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Reduce competition from Douglas-fir and grand fir (thin, burn) in current mature ponderosa pine stands.	Conduct frequent understory burning.	Retain current mature and older ponderosa pine stands and plant where it has been lost.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Low elevations with emphasis on where compatible with wildland urban interface (WUI) objectives; need redundancy across the landscape to buffer against future fire or drought mortality	Has to follow tactic A in the WUI, not necessarily in non-developed areas; need redundancy across the landscape to buffer against future fire or drought mortality	Wherever they occur; need redundancy across the landscape to buffer against future fire or drought mortality
Opportunities for implementation	Collaboration with other landowners	Collaboration with other landowners	Collaboration with other landowners
Cost	Low in places with market size DF, otherwise moderate.	Moderate, depending on location	Low for retaining, moderate for planting
Barriers to implementation	Some	Major	None

Table 9A.2—Adaptation options that address climate change effects on wildlife in the Central Subregion.

Sensitivity to climatic variability and change: Drying of inland maritime forest types that fishers depend on.

Adaption Strategy / Approach: Maintain current, restore historical, and promote potential future fisher habitat. Conserving fisher habitat preserves cool wet forest types that provide habitat for multiple other wildlife species.

Strategy Objective: Promote resilience, facilitate transition

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Conserve current old-growth cedar and larch, but reduce density to increase resilience to drought.	Restore white pine with a cedar understory to create future habitat.	Maintain or create necessary structure in modeled future fisher habitat.
Tactic effectiveness (risks)	Moderate	Uncertain	Unknown (will that be habitat) and uncertain (can the conditions be effectively created)
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Northern ID, Kootenai, Bitterroot divide; where risk of loss is greatest (edge of range); eed redundancy across the landscape to buffer against future fire or drought mortality	Northern ID, Kootenai, Bitterroot divide; need redundancy across the landscape to buffer against future fire or drought mortality	Mission side of Swan; need redundancy across the landscape to buffer against future fire or drought mortality
Opportunities for implementation	Fits with Collaborative Forest Landscape Restoration Program (CFLRP) objectives	Fits with CFLRP objectives	Fits with CFLRP objectives
Cost	Inexpensive	Moderate	Varies
Barriers to implementation	Major	None	Some

Table 9A.3—Adaptation options that address climate change effects on wildlife in the Central Subregion.

Sensitivity to climatic variability and change: Snow melt occurring earlier in the spring creates snowshoe hare pelage mismatch. Lynx adapted to deep soft snow and denser snow could give other predators a competitive advantage. Burn intensity is predicted to increase, and repeat burns can reduce tree seed source; in winter, lynx avoid high intensity burns until tree regeneration allows for branches at snow surface.

Adaption Strategy / Approach: Manage vegetation for long-term lynx and hare habitat and connectivity.

Strategy Objective: Promote resilience, reduce stressors, and facilitate transition.

Tactic	**Specific Tactic – A** Thin some young stands to create a variety of multi-storied hare habitat across the landscape to prevent boom and bust cycles.	**Specific Tactic – B** Maintain forest cover connections between good habitat patches.	**Specific Tactic – C** Maintain current multi-storied forest conditions, prevent large monoculture stand conditions (burning, harvest).	**Specific Tactic – D** Analyze female home ranges to determine necessary mix of habitat patches (distribution and size).
Tactic effectiveness (risks)	Uncertain	Moderate	Moderate	Moderate
Implementation urgency	Near Term	Near Term	Near Term	Near Term
Where can tactics be applied? (geographic)	Anywhere in current range of lynx	Anywhere in current range of lynx	Anywhere in current range of lynx	Anywhere in current range of lynx
Opportunities for implementation	Forest Planning; U.S. Fish and Wildlife Service	U.S. Fish and Wildlife Service	Northern Rockies Lynx Management Direction; critical habitat rule; U.S. Fish and Wildlife Service	U.S. Fish and Wildlife Service; Rocky Mountain Research Station; Collaborative Forest Landscape Restoration Program; Southwest Crown Partnership
Cost	Moderate	Inexpensive	Moderate	Inexpensive
Barriers to implementation	Major	Major	None	None

Table 9A.4—Adaptation options that address climate change effects on wildlife in the Central Subregion.

Sensitivity to climatic variability and change: Townsend's big-eared bat maternal colonies winter hibernacula are sensitive to temperature change, loss of access to habitat, and spread of white-nose syndrome.

Adaption Strategy / Approach: Maintain maternal colony and hibernacula sites, and reduce non-climate stressors.

Strategy Objective: Increase knowledge, promote resilience, reduce stressors, engage coordination

Tactic	**Specific Tactic – A** Identify, and protect current maternal colony sites.	**Specific Tactic – B** Monitor environmental conditions at identified sites, compared to unoccupied sites.	**Specific Tactic – C** Educate the public (caver groups) about spread of white-nose syndrome and stress decontamination procedures.	**Specific Tactic – D** Maintain, or create, open wetland complexes (for insects) near maternal colony sites.
Tactic effectiveness (risks)	High	Moderate, but not an end point itself	Moderate	Unknown
Implementation urgency	Near term	Near term	Near term	Near to mid term
Where can tactics be applied? (geographic)	Range wide	Public land	Range wide	Public land
Opportunities for implementation	Local caving clubs	Local caving clubs	Local caving clubs	Mostly on private lands
Cost	Moderate	Inexpensive	Inexpensive	Variable
Barriers to implementation	Some	Some	None	Some

Table 9A.5—Adaptation options that address climate change effects on wildlife in the Central Subregion.

Sensitivity to climatic variability and change: Increasing winter temperatures reduce snowpack, and snow melt occurs earlier in the spring. Wolverine are obligate snow denners.

Adaption Strategy / Approach: Maintain wolverine female reproductive capacity and core habitat connection.

Strategy Objective: Reduce stressors.

Tactic	**Specific Tactic – A** Map areas with high persistent snow potential; identify protection status and development potential to identify areas of concern and connection between mountain ranges.	**Specific Tactic – B** Identify dispersal habitat requirements.	**Specific Tactic – C** Conduct multi-carnivore genetic monitoring.
Tactic effectiveness (risks)	High	Variable	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Range wide	Range wide	Range wide
Opportunities for implementation			Coordinate existing monitoring, and develop regional monitoring goals.
Cost	Inexpensive	Expensive	Expensive
Barriers to implementation	None	Some	Some

Table 9A.6—Adaptation options that address climate change effects on wildlife in the Eastern Subregion.

Sensitivity to climatic variability and change: Pygmy rabbits are dependent on big-sage, which may be vulnerable to climate change, but range could expand with climate change.

Adaption Strategy / Approach: Increase information on distribution and sensitivities of pygmy rabbit.

Strategy Objective: Increase knowledge.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Produce more accurate sage distribution layer.	Update and expand knowledge of existing pygmy distribution.	Understand climate influences on pygmy rabbits.
Tactic effectiveness (risks)	Moderate	Moderate	Moderate
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Eastern subregion	Eastern subregion	Eastern subregion
Opportunities for implementation		Heritage program.	Wildlife Conservation Society study at the Idaho National Lab; candidate for State Wildlife Grant funding
Cost	Moderate	Moderate	Moderate
Barriers to implementation	Some: funding priority	Some: funding priority	Some: funding priority, not on anyone's radar screen

Table 9A.7—Adaptation options that address climate change effects on wildlife in the Eastern Subregion.

Sensitivity to climatic variability and change: Pygmy rabbits are dependent on big-sage, which may be vulnerable to climate change, but range could expand with climate change.

Adaption Strategy / Approach: Conserve pygmy rabbit habitat.

Strategy Objective: Promote resilience.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Obtain conservation easements in current sagebrush areas.	Lease sagebrush.	Understand succession after fire in sagebrush in the region.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Sagebrush habitat on unprotected private land	Sagebrush habitat on private and state land	Sagebrush habitat
Opportunities for implementation	Land Reliance; partners		
Cost	Inexpensive (cost-sharing and is happening now, even though a lot of money is spent)	Inexpensive (happening now, even though a lot of money is spent)	Inexpensive to moderate
Barriers to implementation	Some: land owner willingness; political consequences	Some	Funding priorities; lack of understanding for the need for the information; difference of opinion about what we already know

Table 9A.8—Adaptation options that address climate change effects on wildlife in the GYA Subregion.

Sensitivity to climatic variability and change: Bat hibernaculum temperature change linked to white-nose syndrome; alternative energy development impacts (wind power).

Adaption Strategy / Approach: Maintain healthy bat populations.

Strategy Objective: Reduce stressors; increase knowledge and coordination.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Consider summer roosting in vegetation management.	Protect hibernaculum from disturbance.	Survey for hibernacula.
Tactic effectiveness (risks)	Uncertain	Moderate	Uncertain
Implementation urgency			
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 9A.9—Adaptation options that address climate change effects on wildlife in the GYA Subregion.

Sensitivity to climatic variability and change: Reduced stream flow, loss of riparian vegetation, incised stream channels due to flood events.

Adaption Strategy / Approach: Maintain healthy beaver populations on the landscape.

Strategy Objective: Promote resilience; reduce stressors; increase public knowledge (slow down the water).

Tactic	**Specific Tactic – A** Inventory current and potential habitat (include multiple factors).	**Specific Tactic – B** Restore riparian habitat (e.g., plant willows, manage grazers, raise water level).	**Specific Tactic – C** Translocate beavers, manage trapping.
Tactic effectiveness (risks)	High	High	High
Implementation urgency			
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 9A.10—Adaptation options that address climate change effects on wildlife in the GYA Subregion.

Sensitivity to climatic variability and change: Habitat shifts and disease transmission in bighorn sheep from direct and indirect effects of climate change (e.g., increase in overlap with domestics, increased disease transmission, shifts in pressure from recreation).

Adaption Strategy / Approach: Maintain healthy bighorn sheep populations.

Strategy Objective: Increase knowledge; reduce stressors; promote resilience.

Tactic	**Specific Tactic – A** Monitor sheep disease trends to determine if there are climate drivers.	**Specific Tactic – B** Identify locations and improve connectivity between seasonal ranges; maintain separation from domestic sheep.	**Specific Tactic – C** Maintain communication among research groups and promote sharing of information and collaboration of research/management efforts.
Tactic effectiveness (risks)	Unknown	High	Moderate
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation	Focus of current attention (state, federal, non-governmental organizations, universities)	Focus of current attention (state, federal, non-governmental organizations, universities)	Focus of current attention (state, federal, non-governmental organizations, universities)
Cost	Inexpensive	Moderately to expensive depending on scale	Inexpensive
Barriers to implementation	None	Some to major (social, legal, jurisdiction)	None

Table 9A.11—Adaptation options that address climate change effects on wildlife in the GYA Subregion.

Sensitivity to climatic variability and change: Loss of mountain sage and grassland habitat for Brewer's sparrow.

Adaption Strategy / Approach: Maintain adequate mountain sage grassland communities for Brewer's sparrow.

Strategy Objective: Promote resilience, reduce stressors, and increase knowledge.

Tactic	**Specific Tactic – A** Manage fire to maintain desired habitat (see sage-grouse conservation strategy).	**Specific Tactic – B** Control invasive vegetation.	**Specific Tactic – C** Restore formerly cultivated land.
Tactic effectiveness (risks)	High	Low to high depending on the invasive species	Low to high depending on site conditions
Implementation urgency			
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 9A.12—Adaptation options that address climate change effects on wildlife in the GYA Subregion.

Sensitivity to climatic variability and change: Water supply; habitat loss; habitat shifts; vegetation phenology shifts; human population expansion and redistribution; snowpack dynamics.

Adaption Strategy / Approach: Maintain connectivity within and through the Greater Yellowstone Area (GYA), including daily, seasonal, dispersal, and range shift connectivity.

Strategy Objective: Facilitate transition; engage coordination; increase knowledge

Tactic	**Specific Tactic – A** Monitor connectivity (genetics, tracking, remote sensing).	**Specific Tactic – B** Compile table of connectivity (daily through range shift) vulnerability by species.	**Specific Tactic – C** Identify and remove barriers.
Tactic effectiveness (risks)	Moderate	High	High
Implementation urgency			
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation	New technologies (e.g., eDNA, remote cameras, GPS collars) make this more accessible		
Cost			
Barriers to implementation			

Table 9A.13—Adaptation options that address climate change effects on wildlife in the GYA Subregion.

Sensitivity to climatic variability and change: Moose prefer colder temperatures; increased disease potential in warmer climates; increased algal growth in warmer ponds; precipitation patterns affect growth of preferred vegetation.

Adaption Strategy / Approach: Maintain healthy moose habitats (e.g., riparian, aspen, spruce-fir) and populations.

Strategy Objective: Reduce stressors; engage coordination.

Tactic	**Specific Tactic – A** Reduce mortality; coordinate with state agencies to reduce hunting quotas; coordinate to reduce highway mortality.	**Specific Tactic – B** Increase knowledge and monitoring of disease and pests.	**Specific Tactic – C** Improve riparian habitat: see beaver sheet.
Tactic effectiveness (risks)	Moderate	Moderate	High
Implementation urgency			
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 9A.14—Adaptation options that address climate change effects on wildlife in the GYA Subregion.

Sensitivity to climatic variability and change: Loss of aspen due to warmer, drier climate and lower water table.

Adaption Strategy / Approach: Maintain adequate habitat structural diversity to support ruffed grouse populations.

Strategy Objective: Promote resilience; increase knowledge.

Tactic	**Specific Tactic – A** Promote disturbance (fire, cutting) in older aspen stands.	**Specific Tactic – B** Protect from grazing (fencing, manage grazing).	**Specific Tactic – C** Reduce conifer competition (fire, cutting) in any age aspen stand.
Tactic effectiveness (risks)	High	High	High
Implementation urgency			
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 9A.15—Adaptation options that address climate change effects on wildlife in the GYA Subregion.

Sensitivity to climatic variability and change: Loss of sage and grassland habitat for greater sage grouse.

Adaption Strategy / Approach: Maintain adequate sage grassland communities, with inclusion of mesic meadows (brood rearing), for greater sage grouse.

Strategy Objective: Promote resilience, reduce stressors, increase knowledge

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**	**Specific Tactic – D**
Tactic	Manage fire to maintain desired habitat (see sage-grouse conservation strategy).	Control invasive vegetation.	Restore formerly cultivated land.	Limit anthropogenic disturbance (e.g., grazing, hunting, infrastructure).
Tactic effectiveness (risks)	High	Low to High depending on the invasive species	Low to high depending on site conditions	High
Implementation urgency				
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation				
Cost				
Barriers to implementation				

Table 9A.16—Adaptation options that address climate change effects on wildlife in the Western Subregion.

Sensitivity to climatic variability and change: Conversion to nonnatives; change in fire frequency; reduction in cover; change of available forage could affect insects, affecting mountain quail habitat.

Adaption Strategy / Approach: Reduce stressors on mountain quail.

Strategy Objective: Promote resilience, reduce stressors

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Reduce high intensity burns using fuel breaks and late winter burning to reduce fuel buildup.	Maintain conifer components, including north face and higher elevation riparian stringers to retain moisture in microsites; replant; protect from burning; avoid harvesting.	Need more information on insect production and the forb component associated with moist areas; how will insects react with phenology changes?
Tactic effectiveness (risks)			
Implementation urgency			
Where can tactics be applied? (geographic)	Western subregion	Western subregion	Western subregion
Opportunities for implementation			
Cost			
Barriers to implementation			

Table 10A.1—Adaptation options that address climate change effects on recreation in the Central Subregion.

Sensitivity to climatic variability and change: Risk to infrastructure with changes in the frequency and severity of natural hazards and disturbances.

Adaption Strategy / Approach: Manage recreation sites to mitigate natural hazards.

Strategy Objective: Increase the resiliency of recreation sites by reducing threats and encouraging coordination with partners.

Tactic	**Specific Tactic – A** Maintain safety by assessing risk factors.	**Specific Tactic – B** Identify flood plains and risks to campgrounds (developed sites) and dispersed recreation sites.	**Specific Tactic – C** Identify effects after disturbance to recreation sites and prioritize treatments or conversions (e.g., relocate, arming, and/or mitigation measures).
Tactic effectiveness (risks)	Moderate–high	Moderate–high	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)	Forest lands or adjacent lands; high risk disturbance areas	Forest wide	National Forest System lands
Opportunities for implementation	Work with other agencies, such as the Federal Emergency Management Agency; use existing data for tree mortality and add species and overlay of use areas	Model risk of storm events, such as rain-on-snow events and flood events (including post-fire floods)	Rapid assessment teams; learn from other agencies, such as the Park Service
Cost	Moderately expensive	Moderately expensive	Moderately expensive
Barriers to implementation	Some - organizational will; leadership commitment; internal resistance, priority setting; integration and interpretation of data and models	Some - external partner support and coordination	Some - forest capacity (resources and funding); public resistance to relocations and closures

Table 10A.2—Adaptation options that address climate change effects on recreation in the Central Subregion.

Sensitivity to climatic variability and change: Changes in demand for warm weather recreation.

Adaption Strategy / Approach: Transition to address extended seasons or changing use patterns.

Strategy Objective: Provide sustainable recreation opportunities in response to changing demand.

Tactic	**Specific Tactic – A** Assess use patterns to understand demand shifts and address recreation niches identified for the area.	**Specific Tactic – B** Identify natural resource impacts and increase coordination with partners and concessionaires.	**Specific Tactic – C** Adjust capacity issues such as enlarging campgrounds and fee opportunities.
Tactic effectiveness (risks)	Moderate	Moderate-high	High
Implementation urgency	Near term	Mid term	Mid term
Where can tactics be applied? (geographic)	National, regional, forest and local levels	Forest level	Local level
Opportunities for implementation	Coordinate with states, local communities; enhance National Visitor Use and Monitoring processes with sub-surveys	Annual operation meetings, meetings with target user groups, special interest groups meetings	Limited opportunities
Cost	Moderately expensive	Moderately expensive	Moderate – expensive
Barriers to implementation	Ability to acquire or predict patterns of use is difficult because demand is difficult to determine; lack of leadership support to engage in studies; low priority in program of work regionally and nationally; declining budgets and staffing	Shifting demographics	Political and environmental justice fees

Table 10A.3—Adaptation options that address climate change effects on winter recreation in the Central Subregion.

Sensitivity to climatic variability and change: Threats to winter recreation

Adaption Strategy / Approach: Transition to address shorter average season and changing use patterns.

Strategy Objective: Provide sustainable recreation in response to changing demand.

Tactic	**Specific Tactic – A** Shift winter use, address safety concerns, and engage partners to implement changes needed in use.	**Specific Tactic – B** Create management areas and direction addressing concentrated winter use areas through forest planning; communicate with partners, cooperators and other agencies and maintain recreation internet sites with access information.	**Specific Tactic – C** Relocate sites as necessary and add signs to guide the public.
Tactic effectiveness (risks)	Moderate	Moderate-high	Moderate
Implementation urgency	Mid term	Near term	Mid term
Where can tactics be applied? (geographic)	Winter recreation sites	Designated management areas	Winter recreation sites
Opportunities for implementation	Nordic clubs; special interest groups; partnerships; increased public interest; impacts as climate changes	Forest Planning – Revision Efforts Project planning Avalanche Centers State Agreements	Integrate projects to include recreation; large landscape efforts; adjusted stewardship law to include recreation
Cost	Moderately expensive	Moderately expensive	Expensive
Barriers to implementation	Our ability to respond	Timing, unclear direction for those not in revision; lacks leadership support to engage	Environmental resources; cultural and political

Table 10A.4—Adaptation options that address climate change effects on recreation in the Eastern Subregion.

Sensitivity to climatic variability and change: Recreation access needs may change with climate change, including change to location, season of use, type of use, and duration of use.

Adaption Strategy / Approach: Ensure that access is adequate for projected recreation use and demand and compatible with resource and climate change conditions.

Strategy Objective: Facilitate transition of recreation access to ensure relevancy and resiliency by season of use and changing use patterns.

Tactic	**Specific Tactic – A** Evaluate and prioritize existing access by season (e.g., trailheads and trails) to ensure consistency with changing recreation opportunity spectrum settings with climate change.	**Specific Tactic – B** Identify new access needs and potential changes to existing access by season.	**Specific Tactic – C** Strategically invest in new and potential changes to existing access by season.
Tactic effectiveness (risks)	High	High	High/moderate
Implementation urgency	Near term	Mid term	Mid term
Where can tactics be applied? (geographic)	Federal lands	Federal lands	Federal lands
Opportunities for implementation	Partners	Partners	Partners
Cost	Moderate	Moderate	Moderate
Barriers to implementation	Some (funding/capacity)	Some (funding/capacity)	Some (funding)

Table 10A.5—Adaptation options that address climate change effects on recreation in the Eastern Subregion.

Sensitivity to climatic variability and change: Recreation settings (recreation opportunity spectrum and scenery), both motorized and non-motorized, during all seasons will be affected by the expected changes in climate.

Adaption Strategy / Approach:
Align our recreation settings with changing landscape conditions and demand.

Strategy Objective: Facilitate transition of recreation settings to achieve flexibility, relevancy and resiliency; maintain those recreation settings that complement our niches.

Tactic	**Specific Tactic – A** Assess existing recreation opportunity spectrum settings and scenic character to determine which are most vulnerable to climate change effects.	**Specific Tactic – B** Develop management strategies to shift or maintain existing recreation opportunity spectrum settings and scenic character in response to climatic change.	**Specific Tactic – C** Develop a sub-regional niche.
Tactic effectiveness (risks)	High	High	Moderate/low
Implementation urgency	Mid term	Mid term	Near term
Where can tactics be applied? (geographic)	Federal lands	Federal lands	Federal lands
Opportunities for implementation	None	None	None
Cost	Moderately expensive	Moderately expensive	Inexpensive
Barriers to implementation	Some barriers	Some barriers	None

Table 10A.6—Adaptation options that address climate change effects on recreation in the Eastern Subregion.

Sensitivity to climatic variability and change: Cultural and heritage resources may be affected by changes in climate, technology, demographics, and culture.

Adaption Strategy / Approach: Protect cultural and heritage sites and the sacred uses of traditional cultural landscapes.

Strategy Objective: Acknowledge the importance of cultural and heritage sites and protect valuable sites.

Tactic	**Specific Tactic – A** Inventory and identify those areas at most risk to climate change and changes in use patterns, and mitigate the effects.	**Specific Tactic – B** Develop interpretation and education opportunities to educate the public in areas or resources most at risk.
Tactic effectiveness (risks)	Moderate	Moderate
Implementation urgency	Near term	Near term
Where can tactics be applied? (geographic)	Greater Yellowstone Area	Greater Yellowstone Area
Opportunities for implementation	Tribes; Tribal Historic Preservation Office; universities, State Historic Preservation Officer; Passport in Time volunteers	Tribes; Tribal Historic Preservation Office; universities, State Historic Preservation Officer; Passport in Time volunteers
Cost	Expensive	Moderately expensive
Barriers to implementation	Some - Forest Service capacity and funding	Some - Forest Service capacity and funding

Table 10A.7—Adaptation options that address climate change effects on recreation in the Eastern Subregion.

Sensitivity to climatic variability and change: Recreation user demand and the shift in recreation activity, amount of use, and patterns of use will be driven by climate change, technology, demographics, and culture.

Adaption Strategy / Approach: Align our recreation opportunities with future demand to commercial (permitted) and non-commercial recreation users.

Strategy Objective: Facilitate transition of recreation opportunities to achieve flexibility, relevancy and resiliency.

Tactic	**Specific Tactic – A** Understand the changes in demand, demographics, and economic trends, both regionally and nationally.	**Specific Tactic – B** Conduct research to clearly identify localized impacts of climate change.	**Specific Tactic – C** Conduct research to understand the latest and upcoming technology that impacts recreation.
Tactic effectiveness (risks)	High	High	High
Implementation urgency	Near term	Near term	Near term
Where can tactics be applied? (geographic)			
Opportunities for implementation	Partners, research, university, non-governmental organizations	Partners, research, university, non-governmental organizations	Partners, research, university, non-governmental organizations
Cost	Moderate	Moderate	Moderate
Barriers to implementation	Some - expertise, agency culture	Some - expertise, agency culture	Some - expertise, agency culture

Table 10A.8—Adaptation options that address climate change effects on recreation in the Eastern Subregion.

Sensitivity to climatic variability and change: The future viability of recreation facilities will be affected by changes in climate.

Adaption Strategy / Approach: Provide recreation facilities that accommodate future demand, and reduce user and natural resource conflicts.

Strategy Objective: Facilitate transition of recreation opportunities to achieve flexibility, relevancy and resiliency.

Tactic	**Specific Tactic – A** Prioritize existing recreation facilities, by season, for viability, investment, and change in services.	**Specific Tactic – B** Invest strategically in developed recreation facilities.	**Specific Tactic – C** Design facilities for flexibility in use.
Tactic effectiveness (risks)	Moderate	Moderate-high	Moderate
Implementation urgency	Near term	Mid term	Mid term
Where can tactics be applied? (geographic)			
Opportunities for implementation	Partners, including permittees, public and non-governmental organizations	None	None
Cost	Moderate	Expensive	Moderate
Barriers to implementation	Some - funding, internal agency	Some - funding	Some - funding and capacity

Table 10A.9—Adaptation options that address climate change effects on recreation in the GYA Subregion.

Sensitivity to climatic variability and change: Archeological sites are susceptible to damage and destruction with increase in wildland fires, erosion and floods, vandalism due to increased recreation activities and longer summer season, and rot from loss of protective snow cover hiding archeological sites.

Adaption Strategy / Approach: Get cultural resources more involved in the climate change discussion.

Strategy Objective: Increase education and reduce stressors.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**	**Specific Tactic – D**
Tactic	Increase pro-active surveys and site recording.	Increase post-fire inventories.	Prioritize site sensitivities and management allocation.	Mitigate adverse effects.
Tactic effectiveness (risks)	High	High	Medium	Medium-high
Implementation urgency	Near term	Near term	Near term	Near term
Where can tactics be applied? (geographic)	High elevation – determine locations by predictive modeling	In burned areas	Unit wide	Site specific
Opportunities for implementation	Section 110 of National Historic Preservation Act; engage with university partners; historical societies; Passport in Time projects	Burned area emergency response; engage with university partners	Forest Service manual	Section 110 of National Historic Preservation Act (when not related to specific undertaking)
Cost	Moderately expensive	Moderately expensive	Inexpensive	Expensive
Barriers to implementation	Forest leadership team may not see benefit, would rather concentrate on support to other functions	Limitation of use of burned area emergency response funds	None	Major costs

Table 10A.10—Adaptation options that address climate change effects on recreation in the GYA Subregion.

Sensitivity to climatic variability and change: Infrastructure location, sizing, safety, and resource protection. Will our infrastructure be able to accommodate the projected future use in a safe manner, considering shorter winters with less snow, increased and earlier runoff, increased erosion, increased hazard trees from insects, disease and windthrow mortality, population shifts to higher elevation, and rapidly growing outdoor recreation locations?

Adaption Strategy / Approach: Proactively determine sites where projected climate change impacts may cause safety, resource or recreation-quality issues.

Strategy Objective: Assess infrastructure and set priorities while considering limited funding and capacity.

	Specific Tactic – A	**Specific Tactic – B**
Tactic	Install appropriately sized culverts; relocate infrastructure; or eliminate infrastructure.	Develop additional restrictions in the permitting process, seasonal closures or allowable uses.
Tactic effectiveness (risks)	Very high	Medium
Implementation urgency	Near to mid term, unless major infrastructure, then 50 years.	Near term
Where can tactics be applied? (geographic)	After catastrophic events using burned area emergency response funds; first priorities from climate analysis	Where needed – site specific
Opportunities for implementation	Department of Transportation, Emergency Relief for Federally Owned Roads	Existing user groups
Cost	Expensive, except when incorporated in already funded projects.	Moderately expensive – staff time
Barriers to implementation	None to major: funding; political and social barriers to road closures	Some barriers: social and political

Table 10A.10 (cont.)—Adaptation options that address climate change effects on recreation in the GYA Subregion

Sensitivity to climatic variability and change: Infrastructure location, sizing, safety, and resource protection. Will our infrastructure be able to accommodate the projected future use in a safe manner, considering shorter winters with less snow, increased and earlier runoff, increased erosion, increased hazard trees from insects, disease and windthrow mortality, population shifts to higher elevation, and rapidly growing outdoor recreation locations?

Adaption Strategy / Approach: Proactively determine sites where projected climate change impacts may cause safety, resource or recreation-quality issues.

Strategy Objective: Assess infrastructure and set priorities while considering limited funding and capacity.

Tactic	**Specific Tactic – C** Develop new opportunities or new recreation sites; be proactive in encouraging use in locations where the use will be sustainable and resources can support the use.	**Specific Tactic – D** Monitor closure and restriction dates and set trigger points to determine changes.
Tactic effectiveness (risks)	Very high	Moderate
Implementation urgency	Near – mid term	Near term
Where can tactics be applied? (geographic)	Urban interface	Site specific
Opportunities for implementation	Any rec site planning process	Unit level; user groups
Cost	Expensive	Moderately expensive – staff time
Barriers to implementation	Some	Some: lack of staff time; lack of priority

Table 10A.11—Adaptation options that address climate change effects on recreation in the GYA Subregion.

Sensitivity to climatic variability and change: Lower snow amounts, earlier snowmelt and a longer summer season.

Adaption Strategy / Approach: Focus on regulation, education, enforcement, and infrastructural changes.

Strategy Objective: Increase education and reduce stressors.

Tactic	**Specific Tactic – A** Adjust dates of orders, as needed, such as extended dates of food storage, travel management, closures and trail shares.	**Specific Tactic – B** Implement social media technology to disperse use, direct users, educate, and promote etiquette.	**Specific Tactic – C** Engage Chambers of Commerce and Development organizations to help deal with the increased pressures on forest and park resources.	**Specific Tactic – D** Install infrastructure as needed (e.g., fences, signs, gates).
Tactic effectiveness (risks)	Medium-high	Medium-high	Low-medium	Moderate
Implementation urgency	Near term	Near term	Mid to long term	Near term
Where can tactics be applied? (geographic)	Anywhere appropriate, but especially in areas with high occurrence of resource-user conflicts	Everywhere – messages can be general or site specific	Starting with the larger urban centers (i.e. Jackson, Bozeman, Cody, Idaho Falls and Billings)	Anywhere appropriate
Opportunities for implementation	Laws; revised travel management	The “GYA app”; National Geographic Magazine	Chambers of Commerce; state departments of tourism; state development councils; regional-scale employers; influential people who settle in the GYA	User groups; businesses
Cost	Inexpensive	Inexpensive to medium	Medium	Inexpensive (with partners)
Barriers to implementation	Small to large, depending on social/cultural opposition from users and communities	Medium to small - lack of coverage in remote areas and seniors not using social media; cost barrier	Medium to high - internal cultural barriers and political differences and external barriers	Low to implement; high to avoid vandalism

Table 10A.12—Adaptation options that address climate change effects on recreation in the GYA Subregion.

Sensitivity to climatic variability and change: Shorter winters with less snow, and wetter or icier snow.

Adaption Strategy / Approach: Consider diversifying permitted activities, assess infrastructure and recreation sites, and develop prioritization process and criteria.

Strategy Objective: Increase knowledge, assess options, and engage industry and community partners.

Tactic	**Specific Tactic – A** Develop options for diversifying snow-based recreation.	**Specific Tactic – B** Use master development plan to determine if we can add uses and extend seasons (or modify the plan).	**Specific Tactic – C** Examine viability of agency snow-based recreation sites, permitted downhill resorts and all permitted winter operations.	**Specific Tactic – D** Monitor snow dates, snow event dates, and snowpack depth.
Tactic effectiveness (risks)	High in the short-term; must consider cost–exclusivity and resource impacts	Low-medium	Low	Moderate
Implementation urgency	Mid term	Mid term	Mid-long term	Near term
Where can tactics be applied? (geographic)	For permitted areas, in and around the existing permitted area, within driving distance of population centers	Within and around permitted area	In and around recreation area	Existing snow telemetry (SNOTEL) sites
Opportunities for implementation				Unit
Cost				Inexpensive (especially with partners)
Barriers to implementation				Low to implement; high to avoid vandalism

Table 10A.13—Adaptation options that address climate change effects on recreation in the Western Subregion.

Sensitivity to climatic variability and change: Increased human exposure to contaminated sediment due to dropping lake levels in the Coeur d'Alene basin and/or increased desire for water-based recreation in higher temperatures in the contaminated areas.

Adaption Strategy / Approach: Avoidance of contaminated areas.

Strategy Objective: Reduce stressors/threat and increase knowledge.

	Specific Tactic – A	**Specific Tactic – B**	**Specific Tactic – C**
Tactic	Cap or harden contaminated areas.	Establish vegetation barriers.	Concentrate use in areas that have been hardened.
Tactic effectiveness (risks)	High in the short-term (requires maintenance)	High	Moderate to low.
Implementation urgency	Near term (but ongoing in long term)	Near term (but ongoing in long term)	Near term (but ongoing in long term)
Where can tactics be applied? (geographic)	Throughout the basin, but focus on priority areas identified in the Coeur d'Alene Basin Restoration Plan Environmental Impact Statement	Throughout the basin, but focus on priority areas identified in the Coeur d'Alene Basin Restoration Plan Environmental Impact Statement	Throughout the basin, but focus on priority areas identified in the Coeur d'Alene Basin Restoration Plan Environmental Impact Statement
Opportunities for implementation	Federal, state, tribal, non-governmental organization partners	Federal, state, tribal, non-governmental organization partners	Federal, state, tribal, non-governmental organization partners
Cost	Moderately expensive	Moderately expensive	Moderately expensive
Barriers to implementation	Issues with sensitive species or other resource concerns	Minimal to none	Social

Table 10A.14—Adaptation options that address climate change effects on recreation in the Western Subregion.

Sensitivity to climatic variability and change: Increased desire for water-based recreation with higher temperatures will lead to increased dispersed recreation sites in riparian areas.

Adaption Strategy / Approach: Limit expansion of sites and pioneering of new sites.

Strategy Objective: Coordinate (e.g., with other agencies and the public); reduce stressors/threat.

	Specific Tactic – A	**Specific Tactic – B**
Tactic	Educate the public and post signs to prevent expansion of dispersed recreation sites in riparian areas.	Design measures for resource protection, such as blocking access to riparian areas, and revegetating impacted areas.
Tactic effectiveness (risks)	Moderate	Moderate
Implementation urgency	Near term (ongoing to long term)	Near term (ongoing to long term)
Where can tactics be applied? (geographic)	Riparian areas on federal lands	Riparian areas on federal lands
Opportunities for implementation	Federal, state, tribal, and private partnerships	Federal, state, tribal, and private partnerships
Cost	Moderately expensive	Moderately expensive
Barriers to implementation	Social	Social; recognizing treaty rights to maintain access to traditional family use areas

Table 10A.15—Adaptation options that address climate change effects on recreation in the Western Subregion.

Sensitivity to climatic variability and change: Cultural/heritage recreation and tourism (e.g., Nimiipuu Trail and Lewis and Clark Trail) and associated scenic driving recreation will likely be affected by increased wildland fire with changing climate.

Adaption Strategy / Approach: Manage vegetation to limit wildfire impacts on recreation and tourism.

Strategy Objective: Promote resiliency.

	Specific Tactic – A	**Specific Tactic – B**
Tactic	Reduce stand density, and vary age class and species composition through vegetation management and/or prescribed fire.	Re-establish native vegetation (e.g., forbs, grasses, and conifers such as whitebark pine); slow spread and reduce populations of invasive species.
Tactic effectiveness (risks)	High to moderate	Moderate to low
Implementation urgency	Near term	Near term
Where can tactics be applied? (geographic)	Within scenic corridors	Within scenic corridors
Opportunities for implementation	Tribal partnerships and collaborative partnerships	Cross-regional genetics improvement programs; federal, tribal, state, and private partnerships
Cost	Moderately expensive	Expensive
Barriers to implementation	Some (opponents to vegetation management as a tool)	Some (difficulty with implementation success)

Table 10A.16—Adaptation options that address climate change effects on recreation in the Western Subregion.

Sensitivity to climatic variability and change: Seasonality of whitewater rafting will likely shift with changing climate and timing of peak flows.

Adaption Strategy / Approach: Increase management (primarily permitting) flexibility.

Strategy Objective: Promote resiliency.

Tactic	**Specific Tactic – A** Vary permit season to adapt to changes in peak flow and duration.	**Specific Tactic – B** Educate the public about changes in peak flows and permitting.
Tactic effectiveness (risks)	Moderate	High to moderate
Implementation urgency	Mid term	Mid term
Where can tactics be applied? (geographic)	Permitted rivers	Permitted rivers
Opportunities for implementation	Agency partnerships	Agency partnerships
Cost	Low	Low
Barriers to implementation	Social	Social

Table 10A.17—Adaptation options that address climate change effects on recreation in the Western Subregion.

Sensitivity to climatic variability and change: Winter recreation (ice fishing, cross-country skiing, snowmobiling) will be at risk with increased temperatures.

Adaption Strategy / Approach: Increase management (primarily permitting) flexibility.

Strategy Objective: Promote resiliency.

	Specific Tactic – A	**Specific Tactic – B**
Tactic	Maintain current infrastructure and expand facilities in areas where concentrated use increases (anticipate additional use as lower elevation areas [Missoula] have reduced snowpacks).	Conduct safety education for increased risk (avalanche potential and thinning ice sheets).
Tactic effectiveness (risks)	Moderate	Moderate
Implementation urgency	Near term	Near term
Where can tactics be applied? (geographic)	Snow play areas and major lakes	Snow play areas and major lakes
Opportunities for implementation	Fees	Partnerships
Cost	Moderately expensive	Low
Barriers to implementation	Social; expense	Social (people do not always listen)

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HISTORICAL AND PROJECTED CLIMATE IN THE INTERMOUNTAIN ADAPTATION PARTNERSHIP REGION

Key messages for the IAP region

For this overview, the projected climate was derived from climate models in the Coupled Model Intercomparison Project version 5 (CMIP5) database, which was used in the most recent Intergovernmental Panel on Climate Change (IPCC) reports. We quantify changes in temperature and precipitation by the 2040 period (average of projections for 2030-2059) and 2080 period (average of projections for 2070-2099).

Over the next 100 years, annual minimum and maximum temperatures are projected to rise by as much as 10 °F. Projections for annual precipitation are highly variable and no clear trend is seen.

Historical spring (March-April-May) mean minimum temperatures in the Middle Rockies, Plateaus, and the Southern Greater Yellowstone subregion have been below freezing. Under the RCP 8.5 scenario, spring minimum temperatures hover around freezing by 2080 for the Middle Rockies and the Southern Greater Yellowstone subregions. For the Plateaus subregion, spring temperatures rise above freezing by the end of the century.

Many of the resource chapters draw from existing scientific literature that used climate projections from the 2007 IPCC reports (the CMIP3 database). In mid-century (2040-2060), CMIP3 and CMIP5 temperature projections are similar. However, CMIP5 precipitation projections appear to be slightly wetter than those in CMIP3.

Climate model projections: CMIP3 and CMIP5

Global climate models have been used to understand the nature of global climate, how the atmosphere interacts with the ocean and the land surface. Scientist can use these models to pose questions about how changes in the atmospheric chemistry would affect global temperature and precipitation patterns. Given a set of plausible greenhouse gas scenarios, these models can be used to project potential future climate. These projections can be helpful in understanding how the environmental conditions of plants and animals might change in the future; how runoff and seasonal flows might vary with precipitation and timing of snowmelt, how wildfire, insects and disease outbreaks might be affected by changes in climate, and how humans might respond in their use of the outdoors and natural resources.

The Coupled Model Intercomparison Project (CMIP) began in 1995 to coordinate a common set of experiments for evaluating changes to past and future global climate. This approach allows comparison of results from different global climate models around the world and improves our understanding of the “range” of possible climate change. The third CMIP modeling experiments, or CMIP3, were used in the International Panel on Climate Change (IPCC) fourth assessment report, whereas CMIP5, the latest experiments, were used in the IPCC fifth assessment report.

A key difference between CMIP3 and CMIP5 is the set of emissions scenarios that drive, or force, the simulations of future climate. The CMIP3 simulations of the 21st century were forced with emission scenarios from the Special Report on Emissions Scenarios (SRES). The CMIP3 scenarios represent futures with different combinations of global population growth and policies related to alternative energy and conventional fossil fuel sources. The CMIP5 simulations of the 21st century are driven by representative concentration pathways (RCPs) scenarios. The RCPs do not define emissions, but instead define concentrations of greenhouse gases and other agents influencing the climate system. RCPs represent the range of current estimates regarding the evolution of radiative forcing, the total amount of extra energy entering the climate system throughout the 21st century and beyond. Projections made with RCP 2.6

show a total radiative forcing increase of 2.6 Wm^{-2} (Watts per square meter) by 2100; projected increased radiative forcing through the scenarios of RCP 4.5, RCP 6.0 and RCP 8.5 indicate increases of 4.5, 6.0, and 8.5 Wm^{-2} respectively.

Assessment methods

For historical data, we drew from and contrasted three common gridded historic datasets PRISM (Parameter-elevation Regressions on Independent Slopes Model), Maurer, and TopoWx. These three gridded historic products are knowledge-based systems that uses point measurements of precipitation, temperature, and other climatic factors to produce continuous, digital grid estimates of monthly, yearly, and event-based climatic parameters. Because of differences in the station data used by these gridded products as well as the models and assumptions used to interpolate to a grid, these models do not always agree on the historical climate or trend for a region. This is especially true in the western mountains where PRISM has been shown to have an artificial amplification in warming trend. For this reason we chose to contrast all historical data products rather than the trend and values produced by a single product.

For an overview of projected climate in the IAP region, we use downscaled CMIP5 projections based on RCP 4.5 and RCP 8.5 scenarios, which represent increases in radiative forcing of 4.5 Wm^{-2} and 8.5 Wm^{-2} above pre-industrial levels by the year 2100. Output from global climate models is at a scale too coarse to represent climate dynamics in subregions and management areas relevant for the IAP. We drew on climate projections that had been downscaled using the bias-correction and spatial disaggregation (BCSD) method. We use projections from 36 climate models for RCP 4.5 and 34 climate models for RCP 8.5. The variables available for each BCSD climate projection include monthly precipitation and monthly surface air temperature for the 1950-2099 period. Spatial resolution of the data is 1/8 degree latitude-longitude and covers the entire IAP region. We use a base period of 1970-2009 for the historical climate, and compare projections for two periods (2030-2059, 2070-2099) with this historical climate. These time periods were selected in an attempt to summarize climate that has influenced the current conditions (base period) and two future periods that will be relevant to long-term management action (such as road construction, hydrological infrastructure, or vegetation planting).

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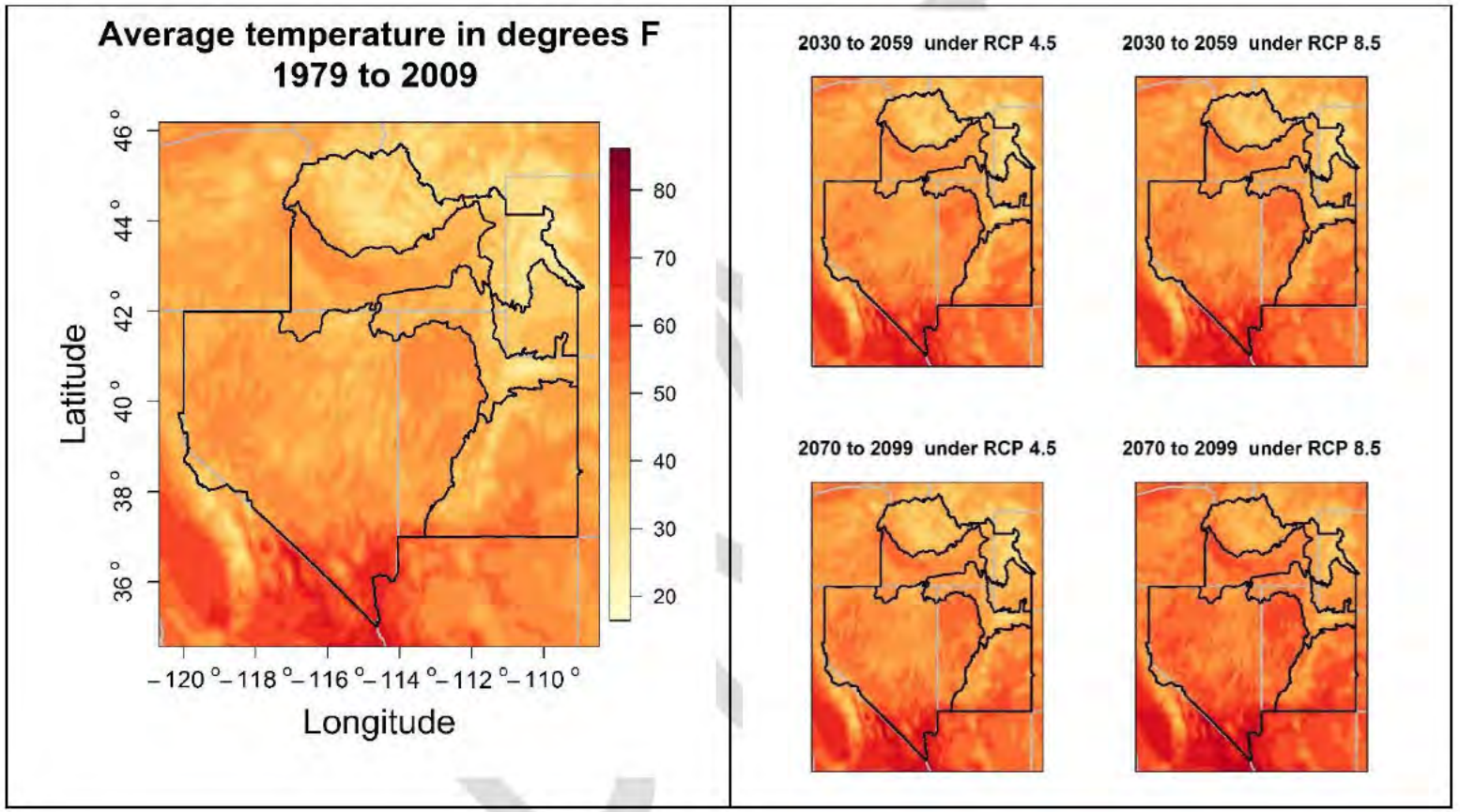
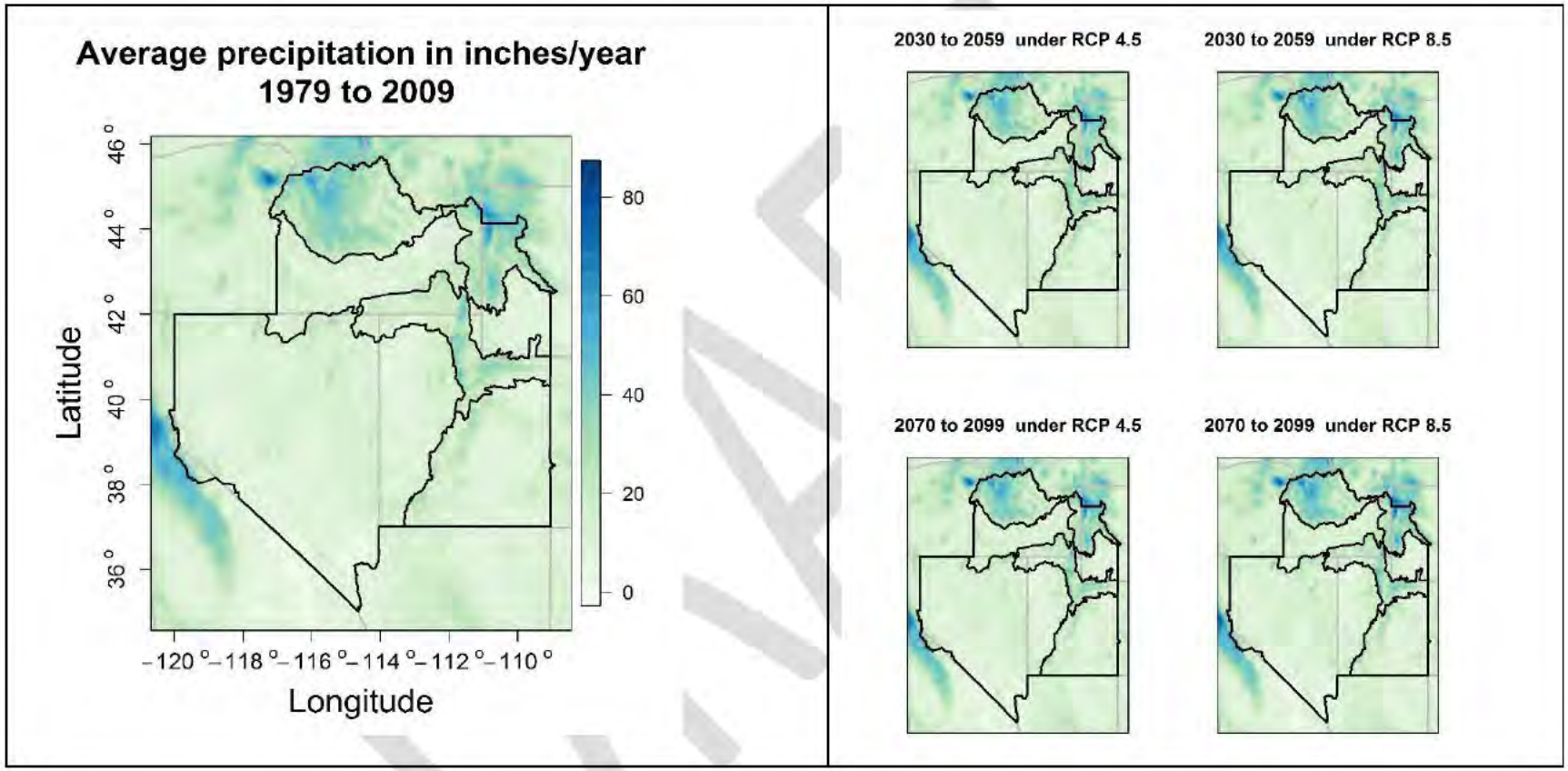
Regional climate projections

Historical (1979-2009) and projected (2030-2059 and 2070-2099) mean annual monthly temperature (°F) under RCP 4.5 and RCP 8.5 scenarios for the entire Intermountain Adaptation Partnership region. Projected climate results are the mean of 36 models for RCP 4.5 and for RCP 8.5. Spatial resolution of the data is 1/8 degree latitude-longitude.



Historical (1979-2009) and projected (2030-2059 and 2070-2099) total annual precipitation (inches) under RCP 4.5 and RCP 8.5 for the entire Intermountain Adaptation Partnership region. Projected climate results are the mean of 36 models for RCP 4.5 and for RCP 8.5. Spatial resolution of the data is 1/8 degree latitude-longitude.



Key messages for the Great Basin and Semi Desert geographic area

- Both minimum and maximum temperature has risen over the last 50 years, but maximum temperature has risen more than minimum temperature during this period. Over the last 30 years, maximum temperature has risen 0.066 °F per year, whereas minimum temperature has increased only 0.032 °F per year.
- By mid-21st century, maximum temperature under RCP 4.5 is projected to rise about 4 °F and minimum temperature is projected to rise similarly. Precipitation projections are highly variable with no discernible trend.
- Maximum daily temperature is projected to increase in all seasons. The greatest departure from historical temperatures occurs in the summer, where average temperatures approach 100 °F by 2100, and in autumn where the mean temperature rises around 10 °F above the historical mean. Minimum spring temperatures, historically around freezing, approach 40 °F by the end of the 21st century.

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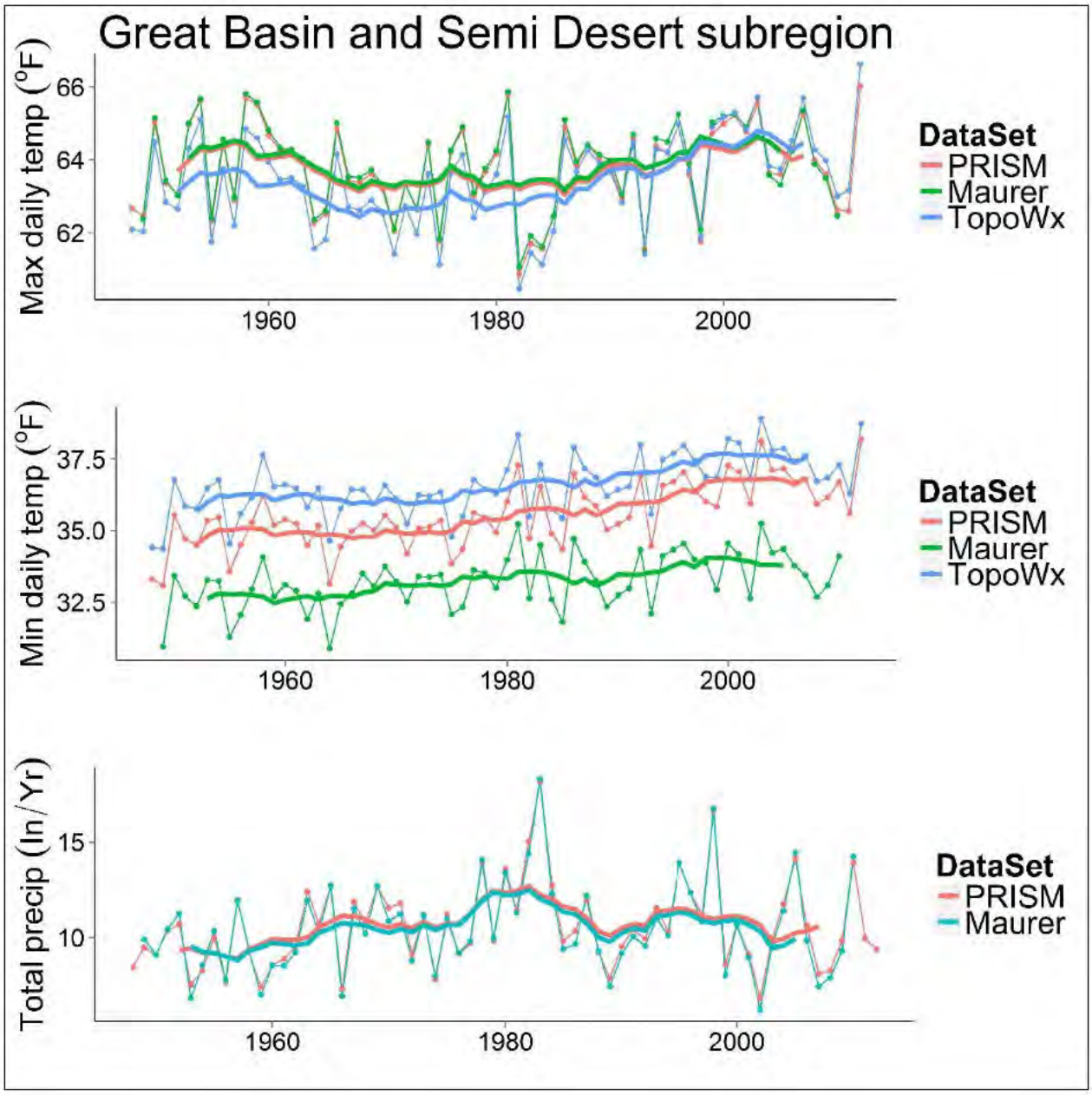
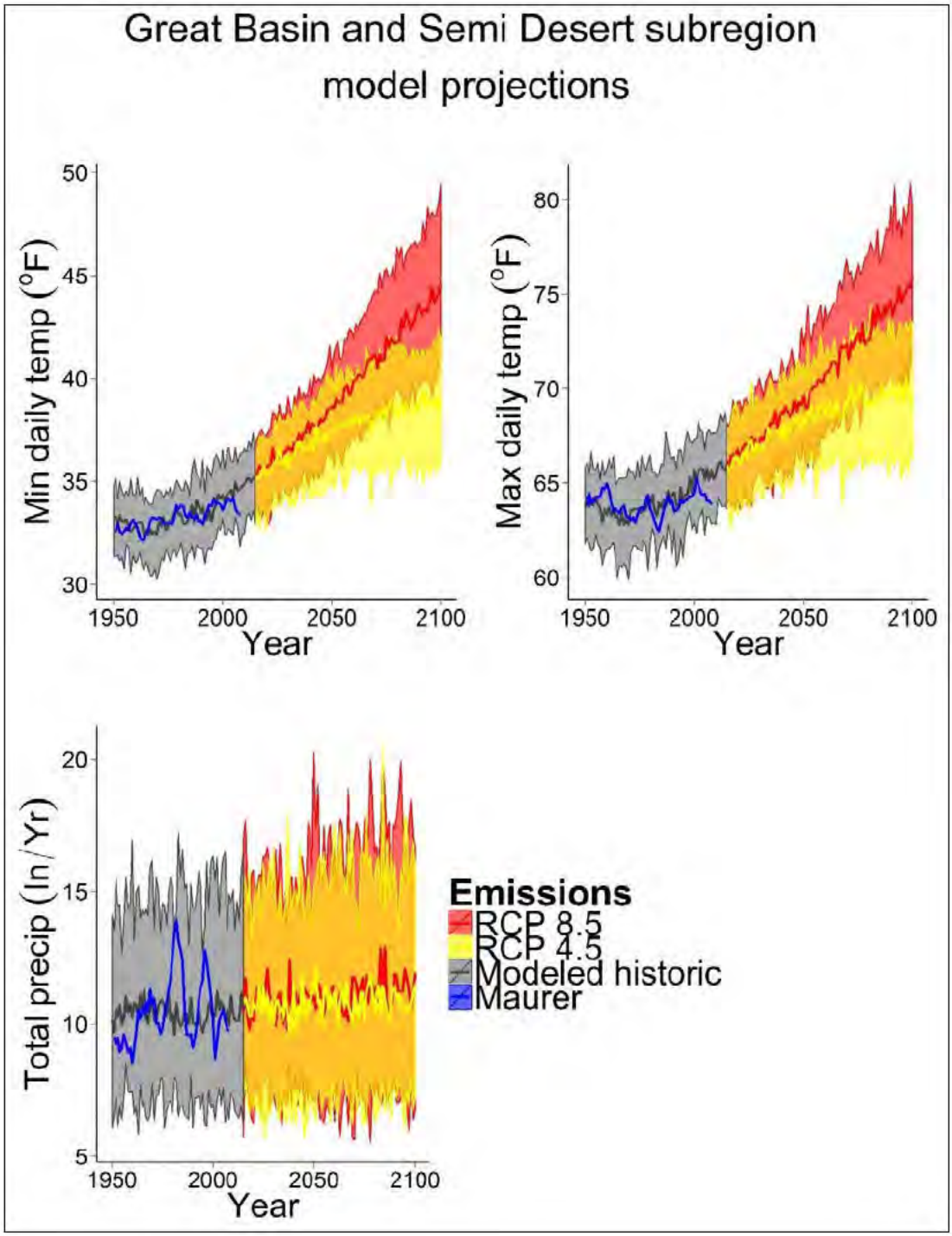
Climate projections for the Great Basin and Semi Desert geographic area

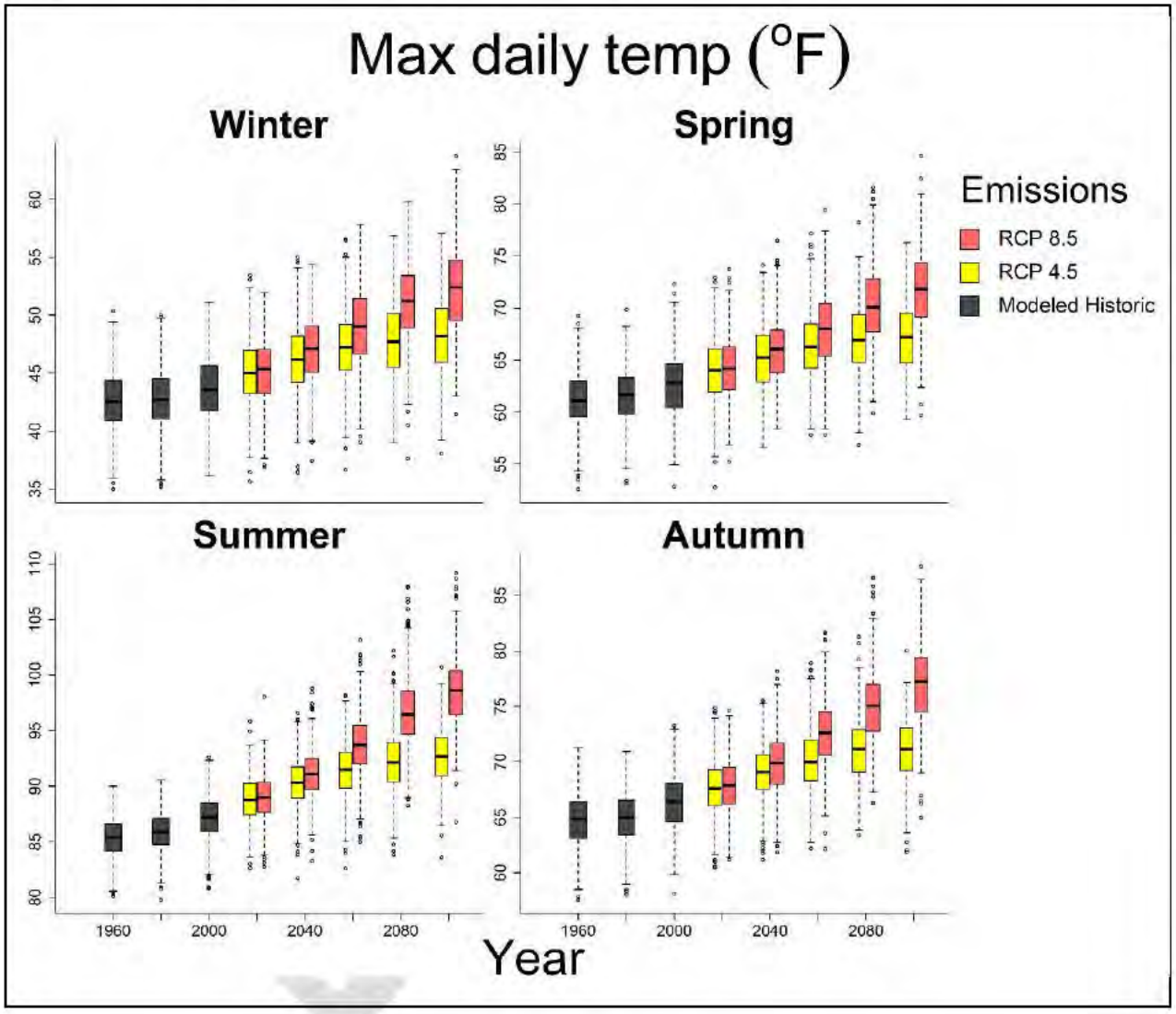
Annual historical mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation from monthly gridded PRISM, Maurer and TopoWx for 1949 to 2010 for the IAP Great Basin and Semi-Desert subregion. The heavy lines are the 10-year rolling average to show short-term trends.



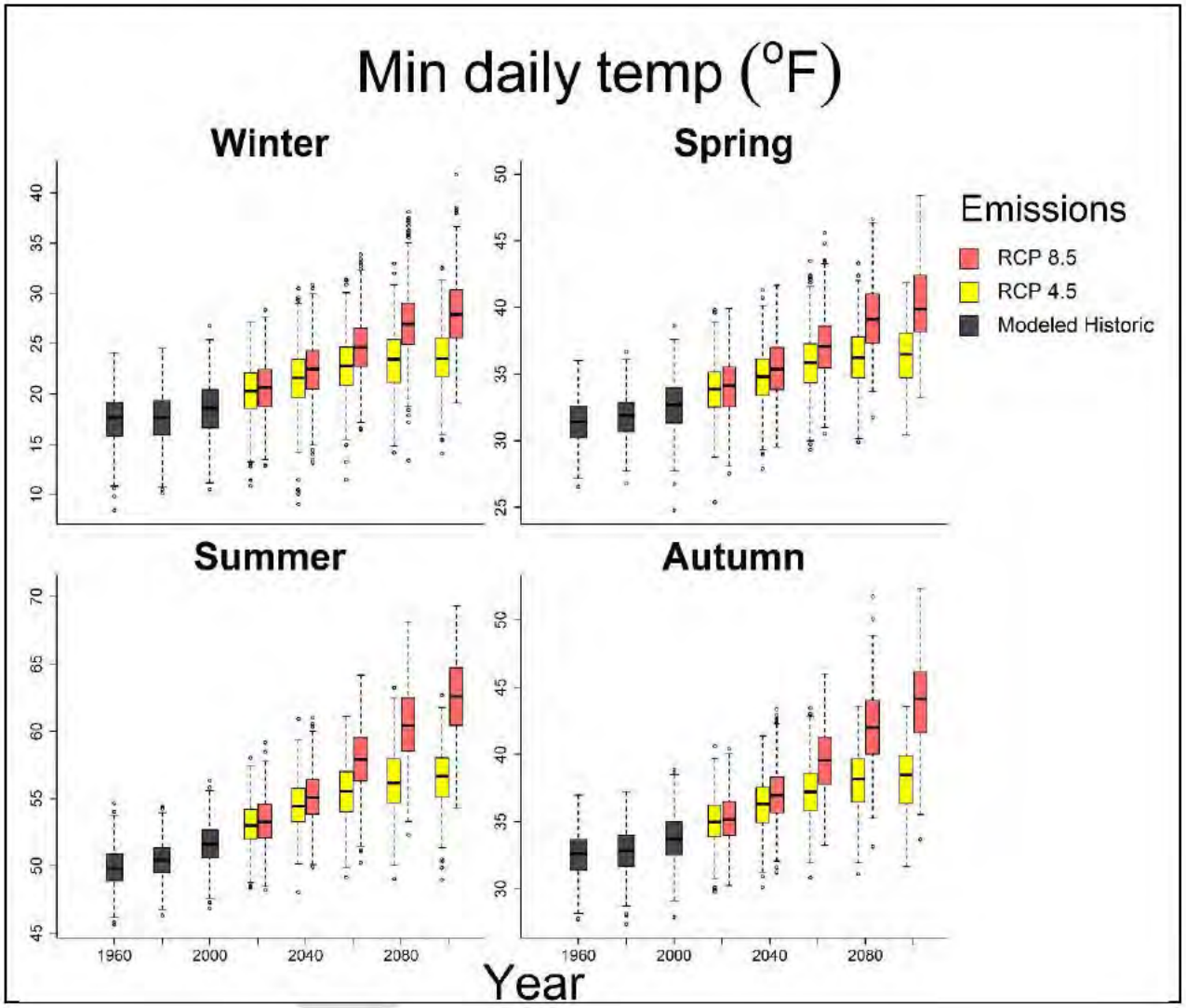
Historical modeled and projected annual mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation for RCP 4.5 and RCP 8.5 emission scenarios based on CMIP5 data for the IAP Great Basin and Semi-desert subregion. Historical modeled results are indicated in gray, projections in colors. The 5th and 95th percent quantiles for all models are shown by the shaded area. The ensemble median is illustrated by the grey, red, or yellow heavy line; the heavy blue line is the gridded historical observed data from Maurer and others (2002).



Seasonal mean monthly maximum temperature for 1950-2100 for the IAP Great Basin and Semi-desert subregion. Each box is an aggregation of 20 years of modeled historical or projected seasonal data centered on the year listed (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.



Seasonal mean monthly minimum temperature for 1950-2100 for the IAP Great Basin and Semi-desert region. Each box is an aggregation of 20 years of modeled historical or projected seasonal data (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.



Key messages for the Intermountain Semi Desert geographic area

- Both minimum and maximum temperature has risen over the last 50 years. Over the last 30 years, maximum temperature has risen 0.064 °F per year, whereas minimum temperature has increased only 0.038 °F per year.
- By mid-21st century, maximum temperature under RCP 4.5 is projected to rise about 5 °F and minimum temperature is projected to rise similarly. Precipitation projections are highly variable with no discernible trend.
- Maximum daily temperature increases in all seasons to the end of the 21st century in both climate scenarios. The greatest departure from historical temperatures by 2100 occurs in the summer, where mean temperatures approach 95 °F, nearly 15 °F above historical temperature, and in autumn where the mean temperature rises around 10 °F above the historical mean.
- Winter minimum temperatures remain below freezing by 2100 (under both RCP 4.5 and 8.5), however the variability includes temperatures above freezing. Minimum spring and autumn temperatures, historically around freezing, rise above 35 °F by the end of the 21st century (RCP 8.5).

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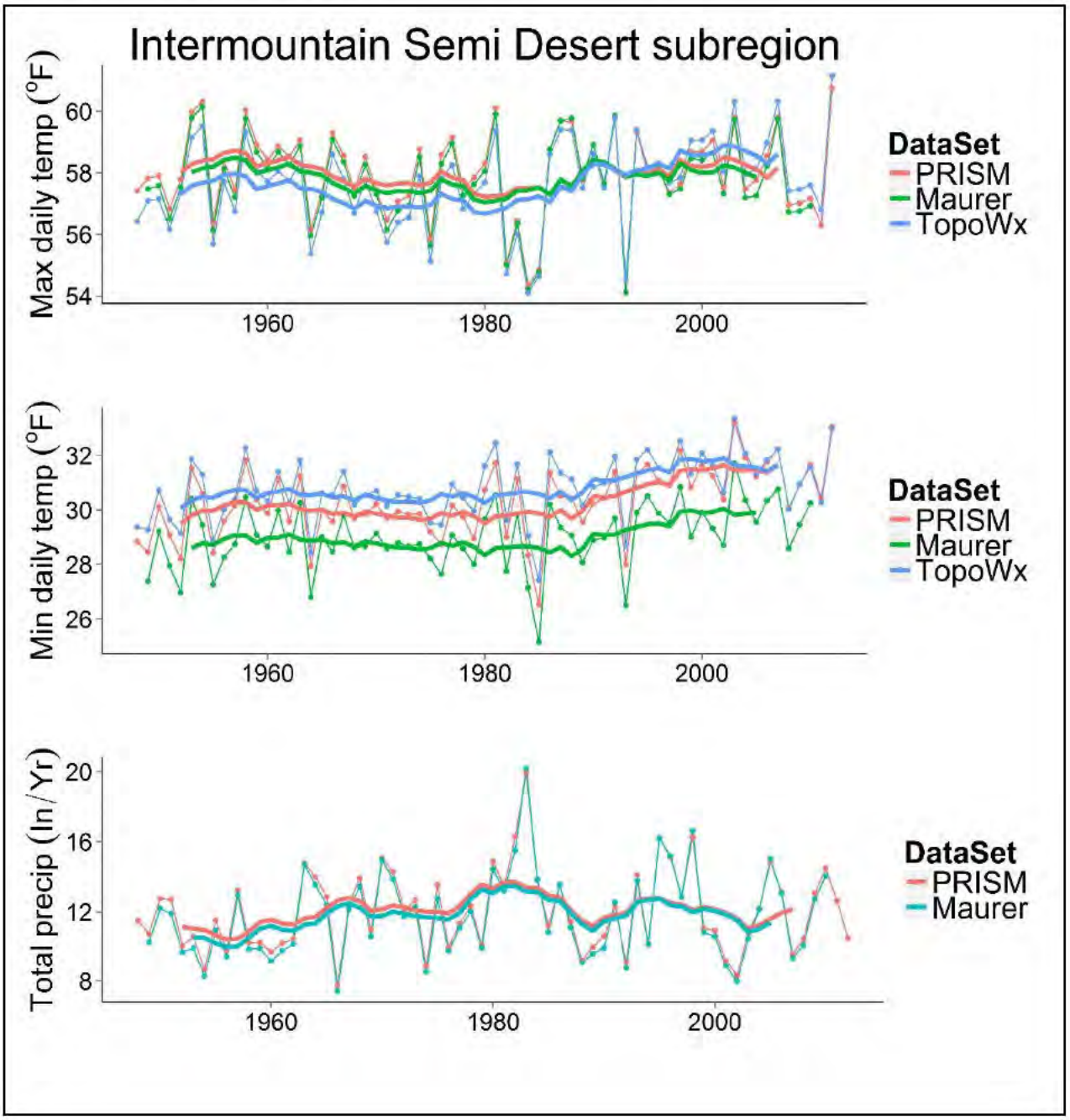
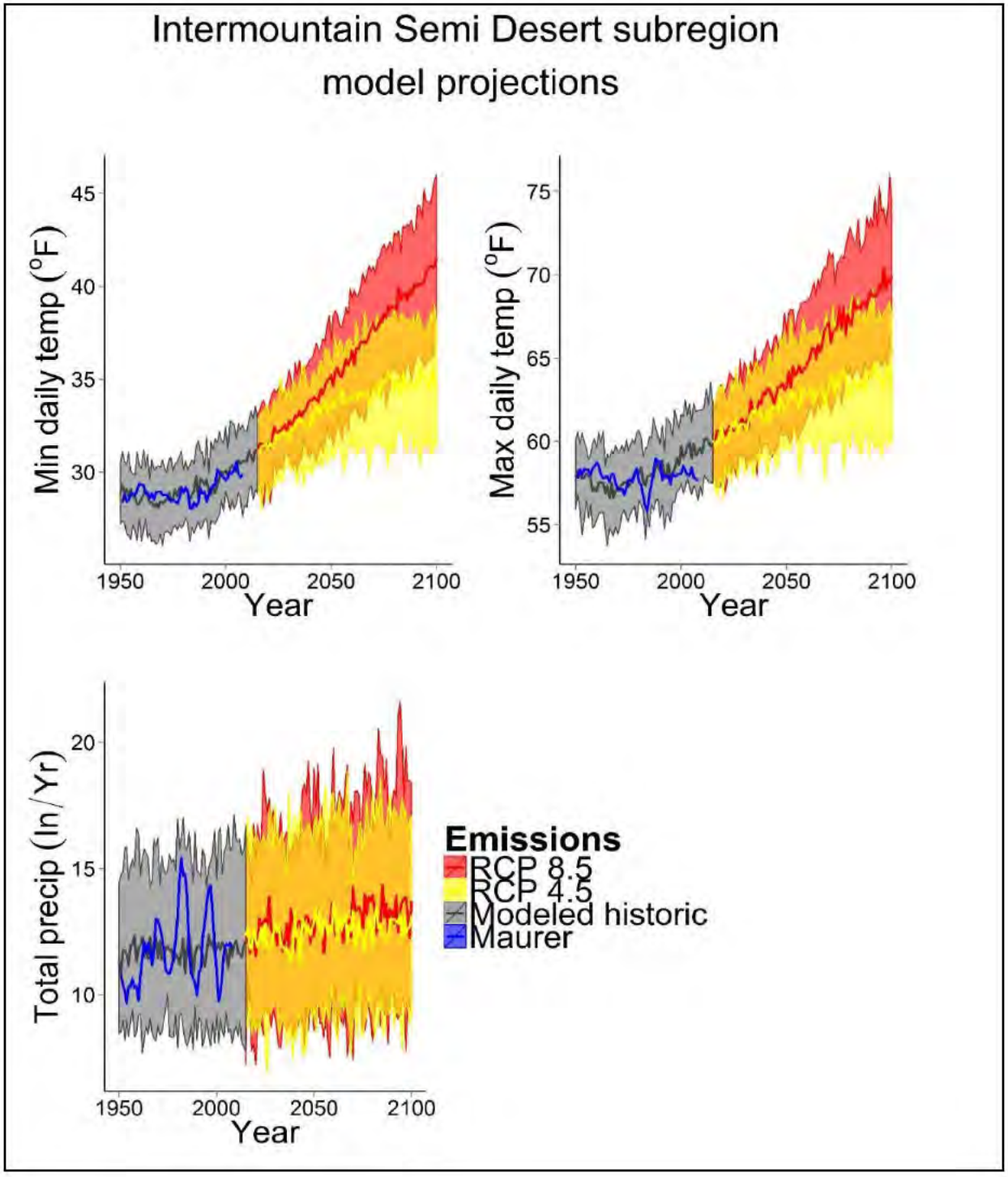
Climate projections for the Intermountain Semi Desert geographic area

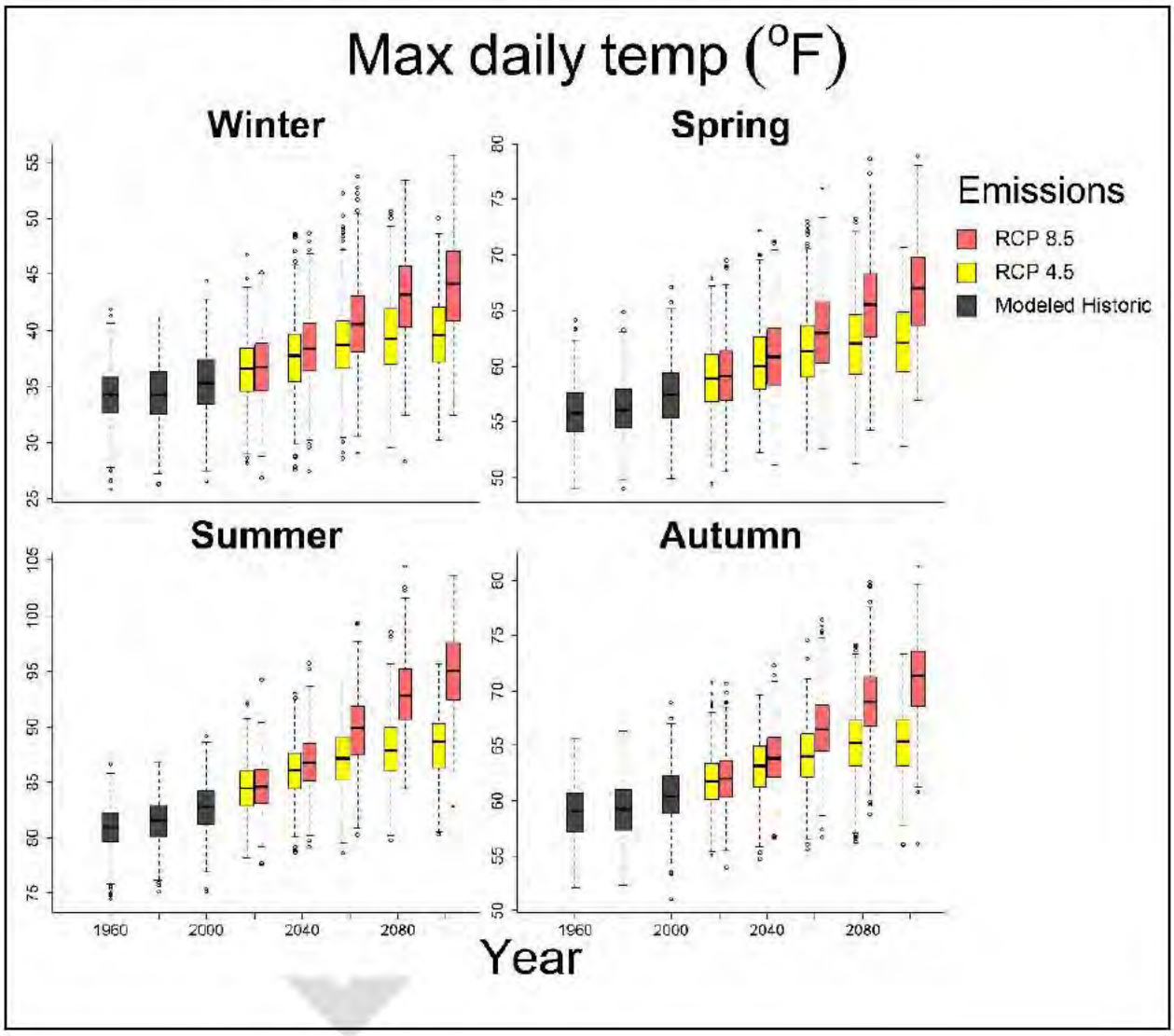
Annual historical mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation from monthly gridded PRISM, Maurer and TopoWx for 1949 to 2010 for the IAP Semi Desert subregion. The heavy lines are the 10-year rolling average to show short-term trends.



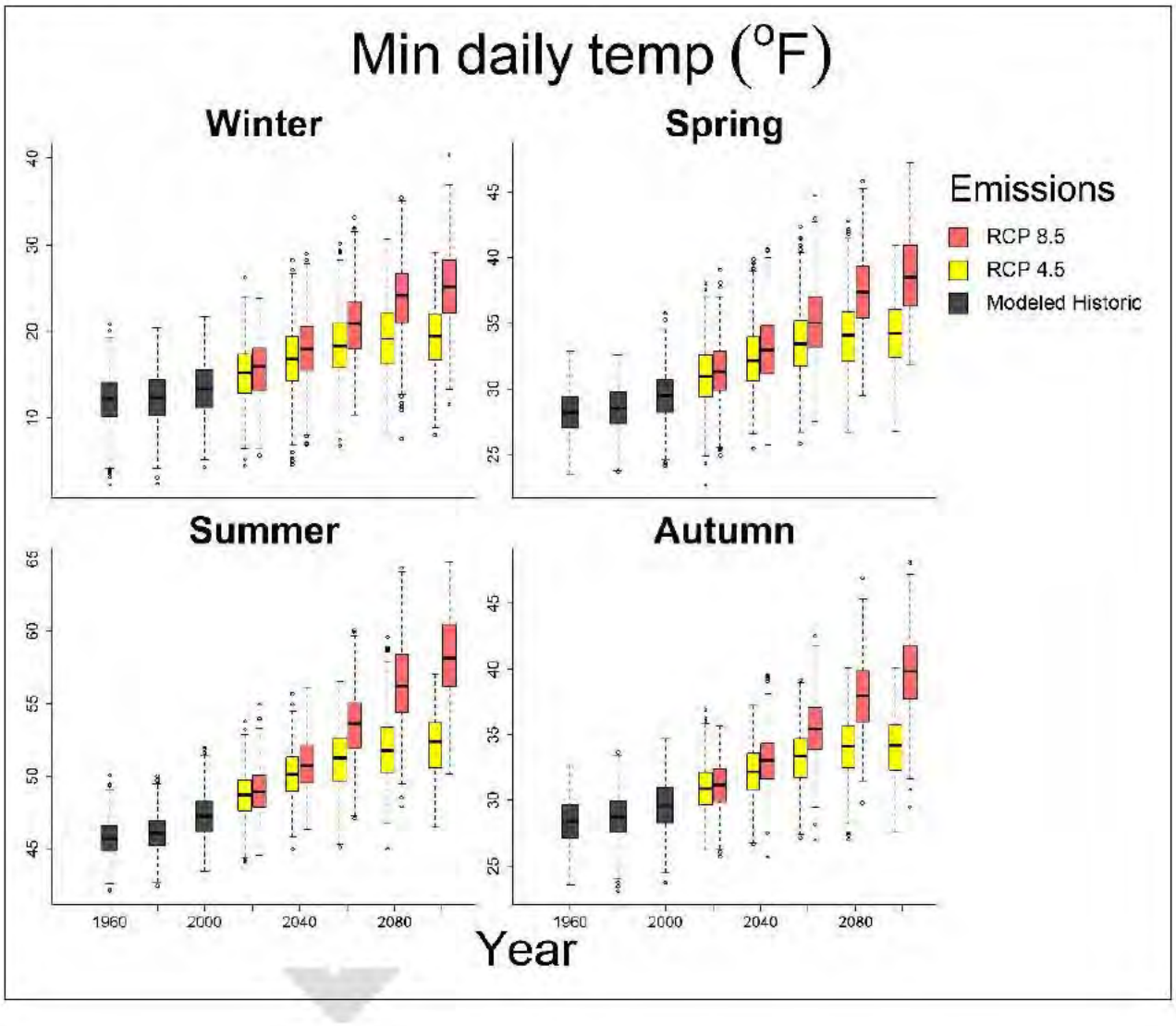
Historical modeled and projected annual mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation for RCP 4.5 and RCP 8.5 emission scenarios based on CMIP5 data for the IAP Intermountain Semi Desert subregion. Historical modeled results are indicated in gray, projections in colors. The 5th and 95th percent quantiles for all models are shown by the shaded area. The ensemble median is illustrated by the grey, red, or yellow heavy line; the heavy blue line is the gridded historical observed data from Maurer and others (2002).



Seasonal mean monthly maximum temperature for 1950-2100 for the IAP Intermountain Semi Desert subregion. Each box is an aggregation of 20 years of modeled historical or projected seasonal data centered on the year listed (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.



Seasonal mean monthly minimum temperature for 1950-2100 for the IAP Intermountain Semi Desert region. Each box is an aggregation of 20 years of modeled historical or projected seasonal data (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.



Key messages for the Middle Rockies geographic area

- In the Middle Rockies geographic area, climate variability is strongly influenced by the interactions with topography, elevation, and aspect.
- Both minimum and maximum temperature has risen over the last 50 years. Over the last 30 years, minimum temperature has, on average, increased 0.039 °F per year, whereas maximum temperature has risen 0.052 °F per year.
- By mid-21st century, maximum temperature under RCP 4.5 is projected to rise nearly 4 °F, and minimum temperature is projected to rise similarly. Precipitation projections are highly variable with no discernible trend.
- Winter maximum temperatures, historically below freezing, rise above freezing in both future scenarios (RCP 4.5 and 8.5). The greatest departure from historical temperatures occurs in the summer season; maximum temperatures rise to near 90 °F by 2100. Historically, mean minimum temperatures in both spring and autumn were below freezing; minimum temperatures in spring and fall rise above freezing by 2100 (under RCP 8.5).

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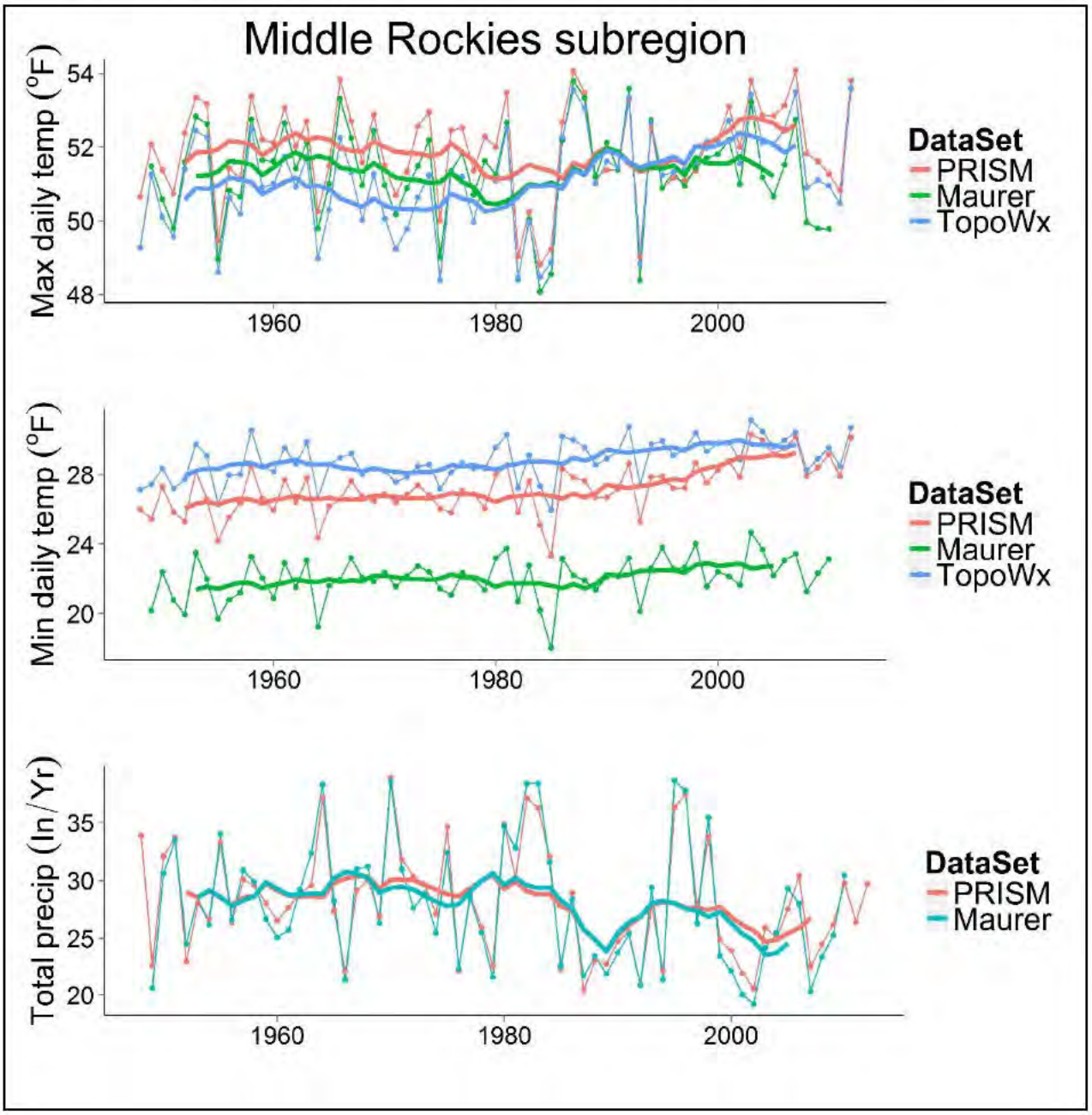
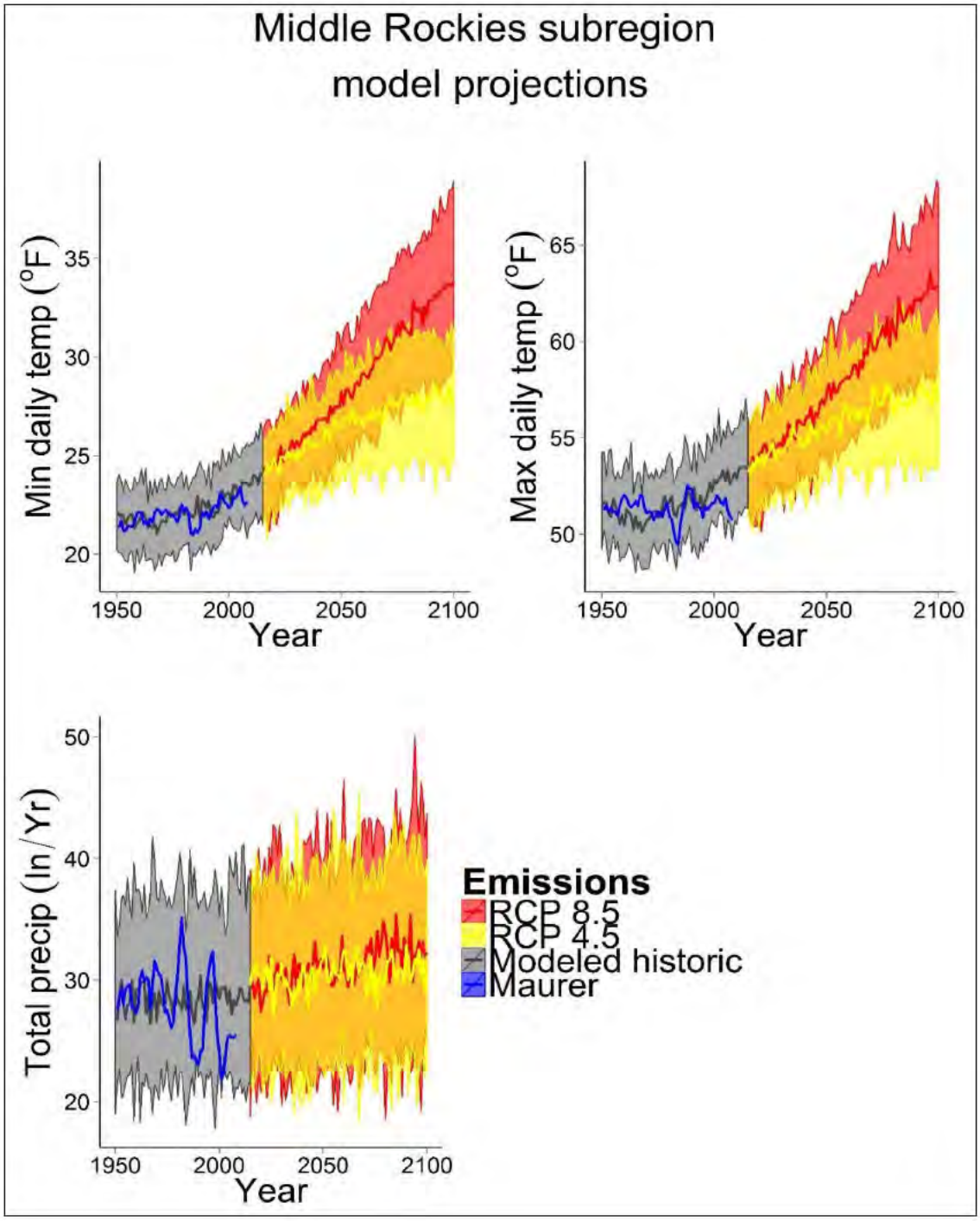
Climate projections for the Middle Rockies geographic area

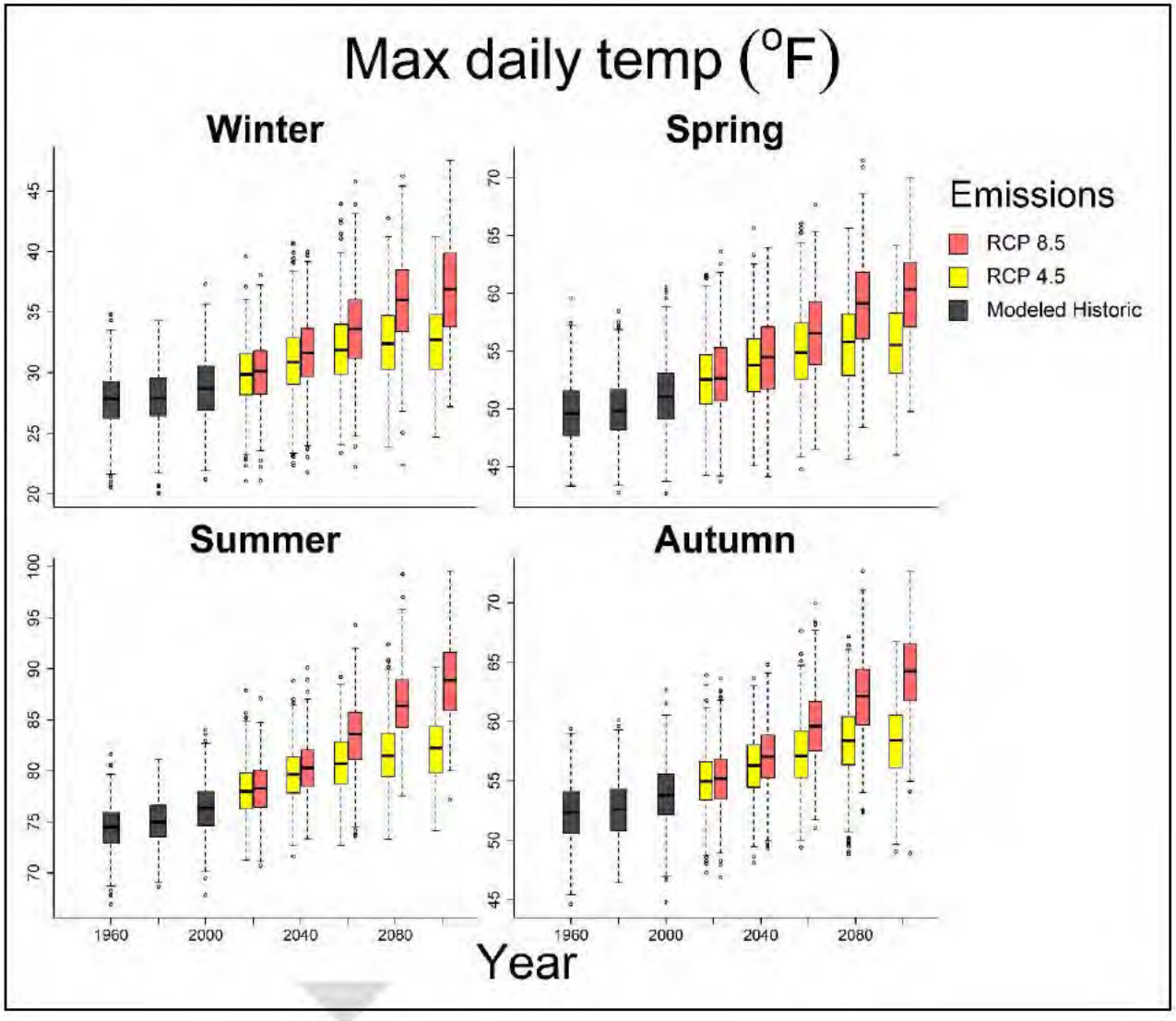
Annual historical mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation from monthly gridded PRISM, Maurer and TopoWx for 1949 to 2010 for the IAP Middle Rockies subregion. The heavy lines are the 10-year rolling average to show short-term trends.



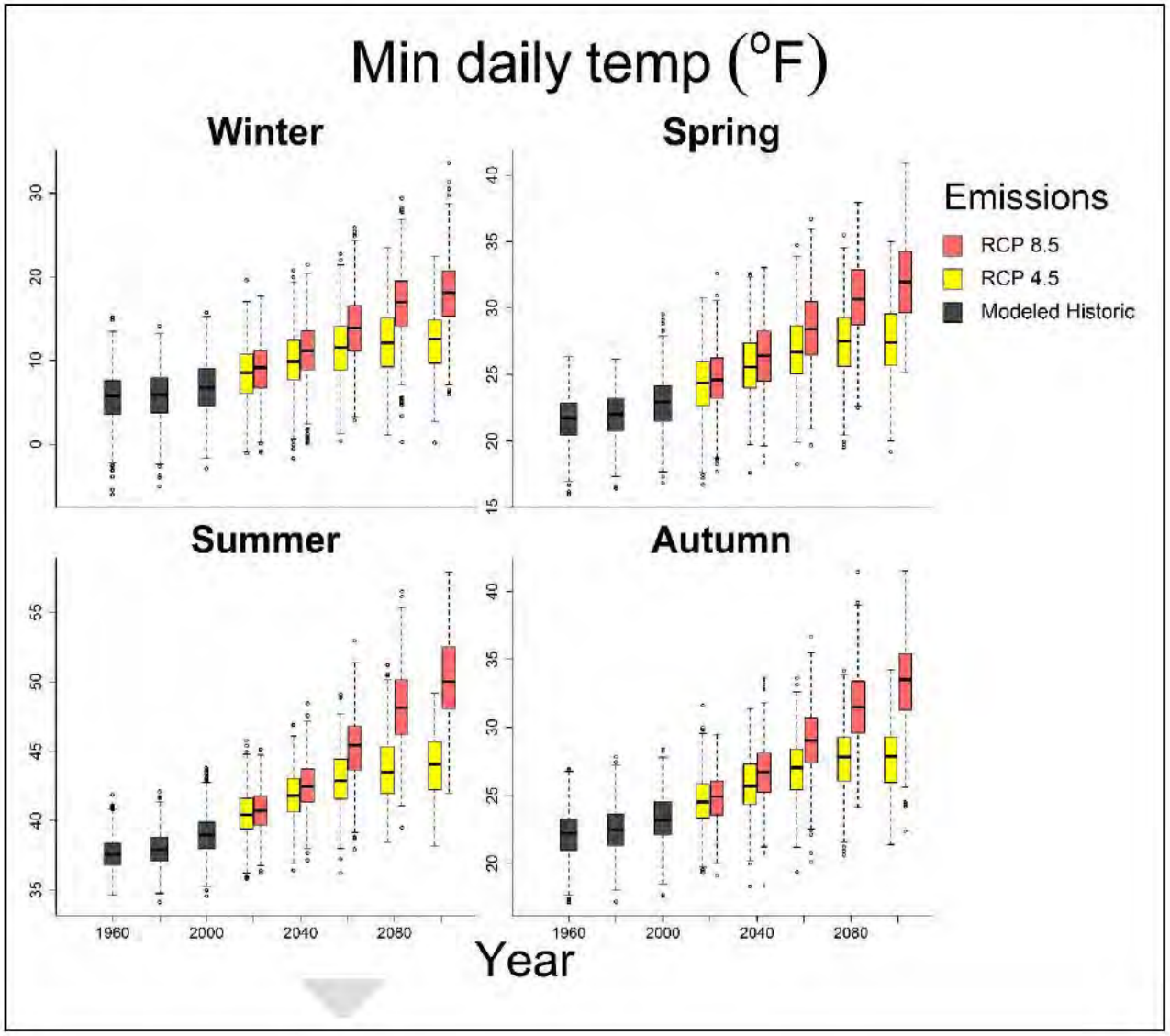
Historical modeled and projected annual mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation for RCP 4.5 and RCP 8.5 emission scenarios based on CMIP5 data for the IAP Middle Rockies subregion. Historical modeled results are indicated in gray, projections in colors. The 5th and 95th percent quantiles for all models are shown by the shaded area. The ensemble median is illustrated by the grey, red, or yellow heavy line; the heavy blue line is the gridded historical observed data from Maurer and others (2002).



Seasonal mean monthly maximum temperature for 1950-2100 for the IAP Middle Rockies subregion. Each box is an aggregation of 20 years of modeled historical or projected seasonal data centered on the year listed (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.



Seasonal mean monthly minimum temperature for 1950-2100 for the IAP Middle Rockies region. Each box is an aggregation of 20 years of modeled historical or projected seasonal data (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.



Key messages for the Plateaus geographic area

- In the Plateaus geographic area, both mean minimum and maximum temperatures have risen around 0.027 °F over the last 50 years. Over the last 30 years, maximum temperature has, on average, increased 0.081 °F per year, whereas minimum temperature has risen only 0.034 °F per year.
- By mid-21st century, under RCP 4.5, maximum temperature is projected to rise nearly 5 °F and minimum temperature is projected to rise similarly. Precipitation projections are highly variable with no discernible trend.
- Maximum temperatures rise in all seasons in both future scenarios (RCP 4.5 and 8.5). The greatest departure from historical temperatures occurs in the summer season; summer maximum temperatures rise above 95 °F by 2100, and autumn maximum temperatures rise to 75 °F.
- Winter minimum temperatures remain below freezing by 2100 (under both RCP 4.5 and 8.5). However, minimum spring and autumn temperatures rise above 40 °F by the end of the 21st century (under RCP 8.5).

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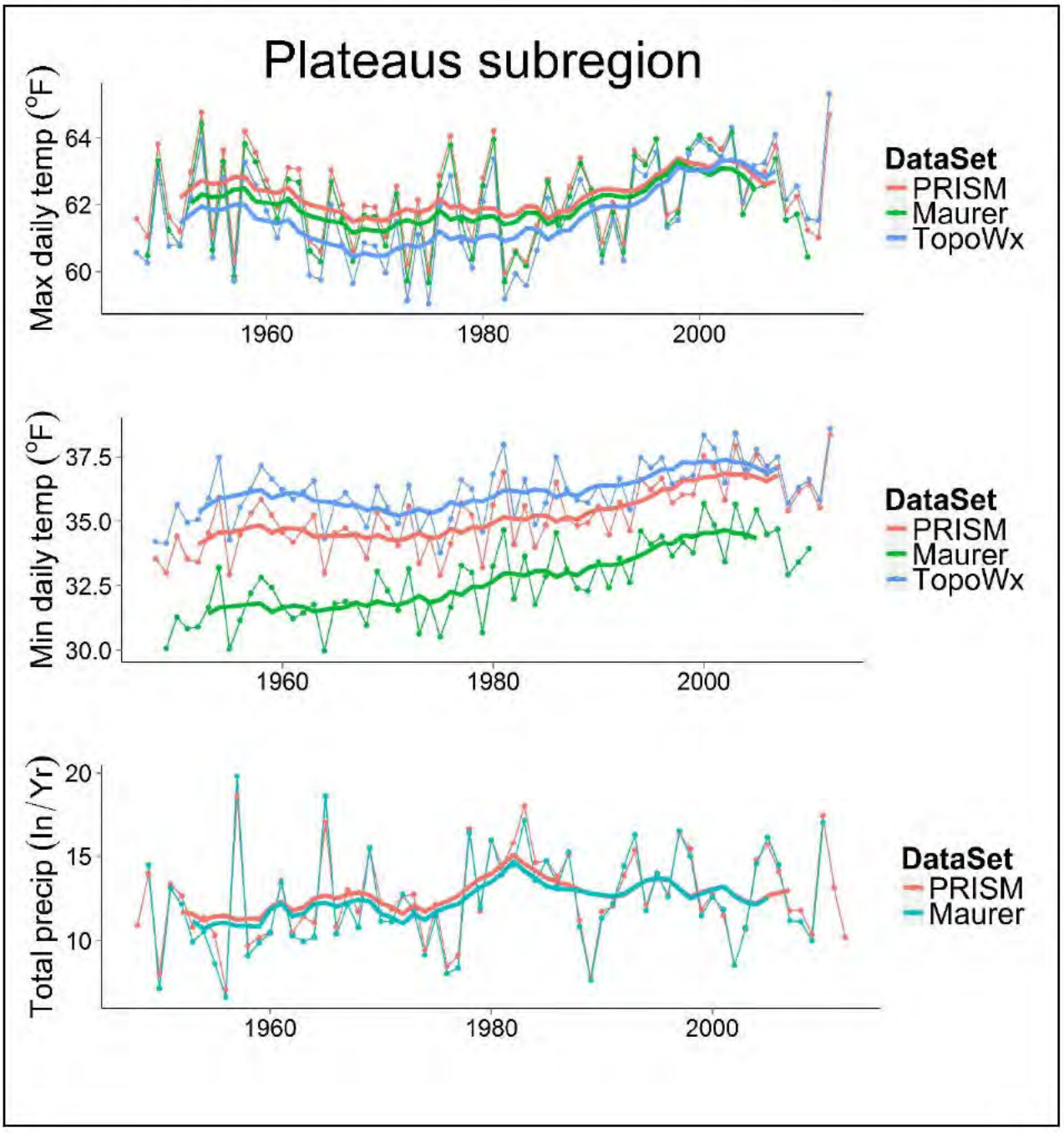
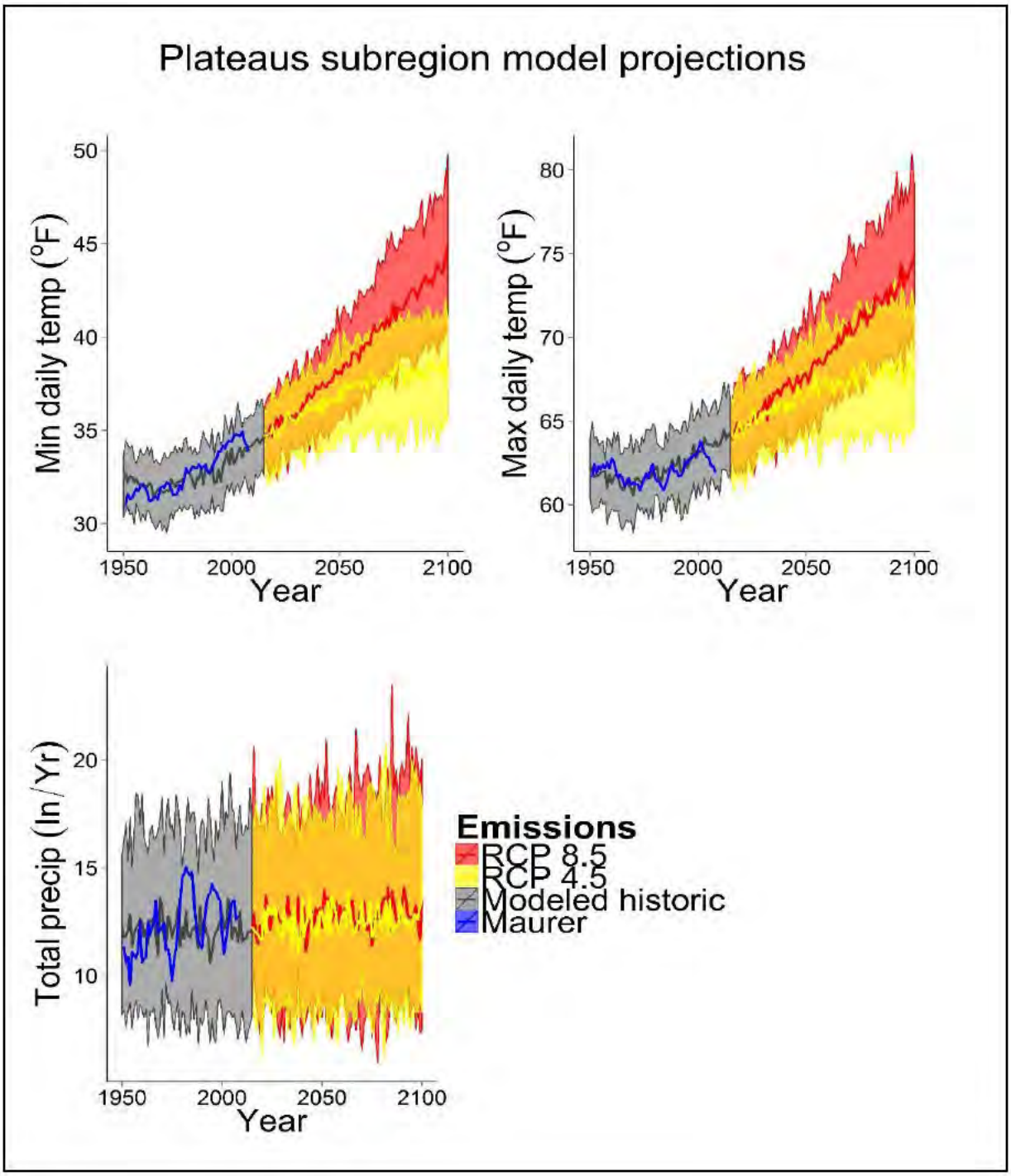
Climate projections for the Plateaus geographic area

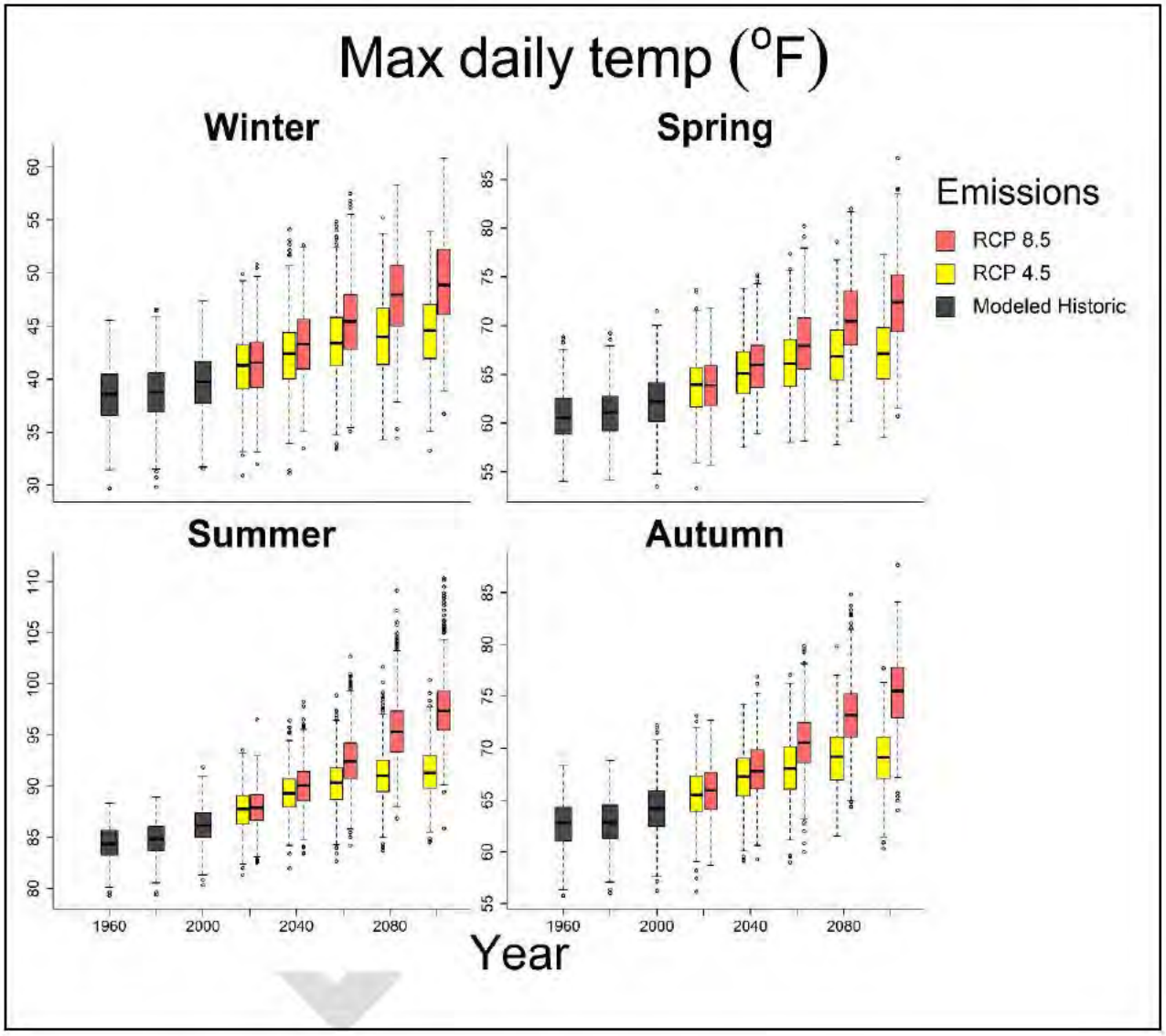
Annual historical mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation from monthly gridded PRISM, Maurer and TopoWx for 1949 to 2010 for the IAP Plateaus subregion. The heavy lines are the 10-year rolling average to show short-term trends.



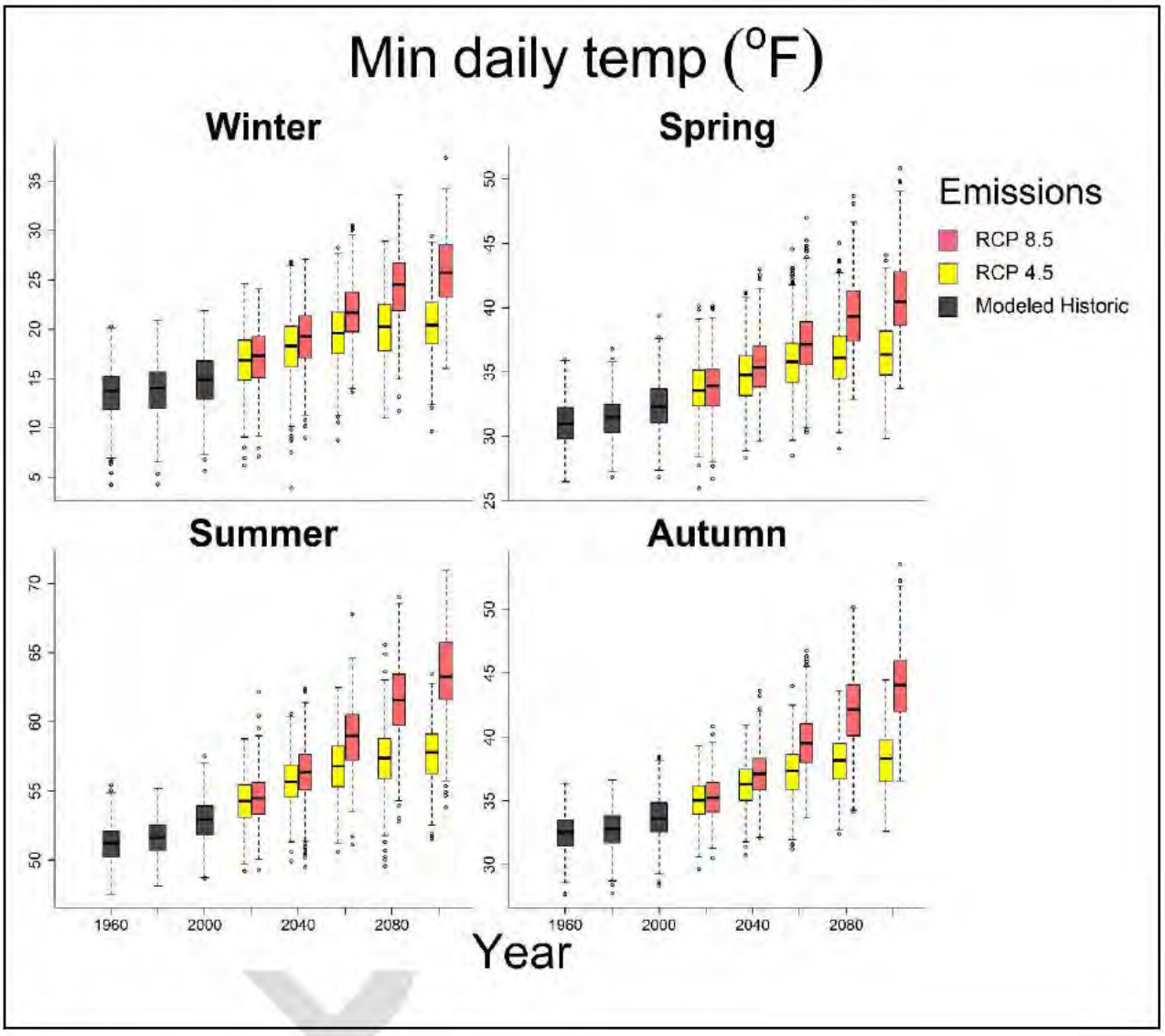
Historical modeled and projected annual mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation for RCP 4.5 and RCP 8.5 emission scenarios based on CMIP5 data for the IAP Plateaus subregion. Historical modeled results are indicated in gray, projections in colors. The 5th and 95th percent quantiles for all models are shown by the shaded area. The ensemble median is illustrated by the grey, red, or yellow heavy line; the heavy blue line is the gridded historical observed data from Maurer and others (2002).



Seasonal mean monthly maximum temperature for 1950-2100 for the IAP Plateaus subregion. Each box is an aggregation of 20 years of modeled historical or projected seasonal data centered on the year listed (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.



Seasonal mean monthly minimum temperature for 1950-2100 for the IAP Plateaus region. Each box is an aggregation of 20 years of modeled historical or projected seasonal data (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.



Key messages for the Southern Greater Yellowstone geographic area

- In the Southern Greater Yellowstone geographic area, climate variability is strongly influenced by the interactions with topography, elevation, and aspect.
- Both mean minimum and maximum temperature have risen over the last 50 years, but maximum temperature has risen more than minimum temperature. Over the last 30 years, minimum temperature has, on average, increased 0.031 °F per year, whereas maximum temperature has risen 0.060 °F per year.
- By mid-21st century, under RCP 4.5, maximum temperature is projected to rise nearly 4 °F, and minimum temperature is projected to rise to nearly 5 °F. Precipitation projections are highly variable with no discernible trend.
- Winter maximum temperatures, historically below freezing, rise above freezing by 2100 (under RCP 8.5). The greatest departure from historical temperatures occurs in the summer season; summer maximum temperatures rise above 85 °F by 2100, and autumn maximum temperatures rise above 60 °F (under RCP 8.5).
- Winter minimum temperatures remain below freezing by 2100 (under both RCP 4.5 and 8.5). However, minimum spring and autumn temperatures, historically below freezing, rise to just under freezing (around 30 °F) by the end of the 21st century (under RCP 8.5).

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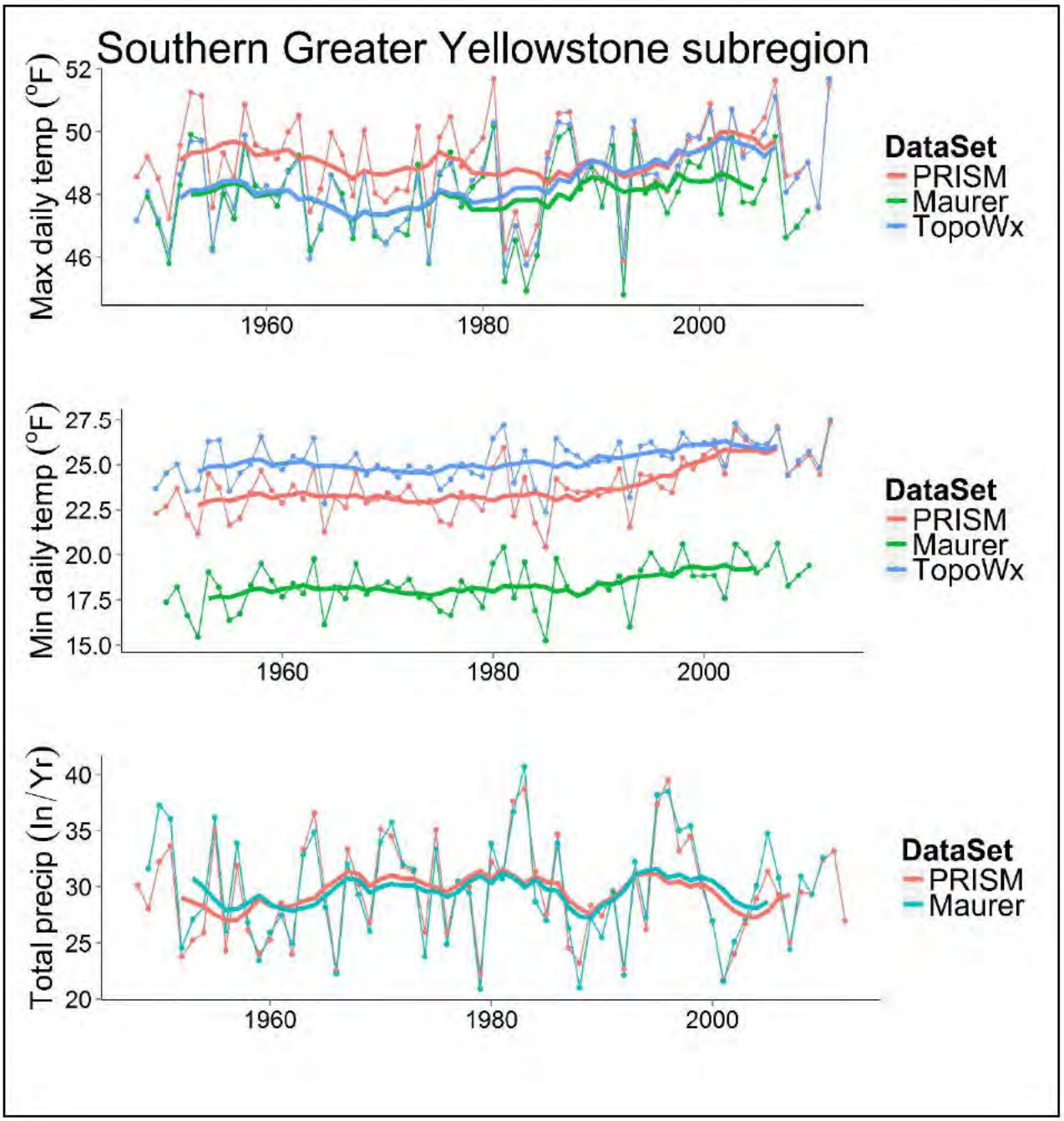
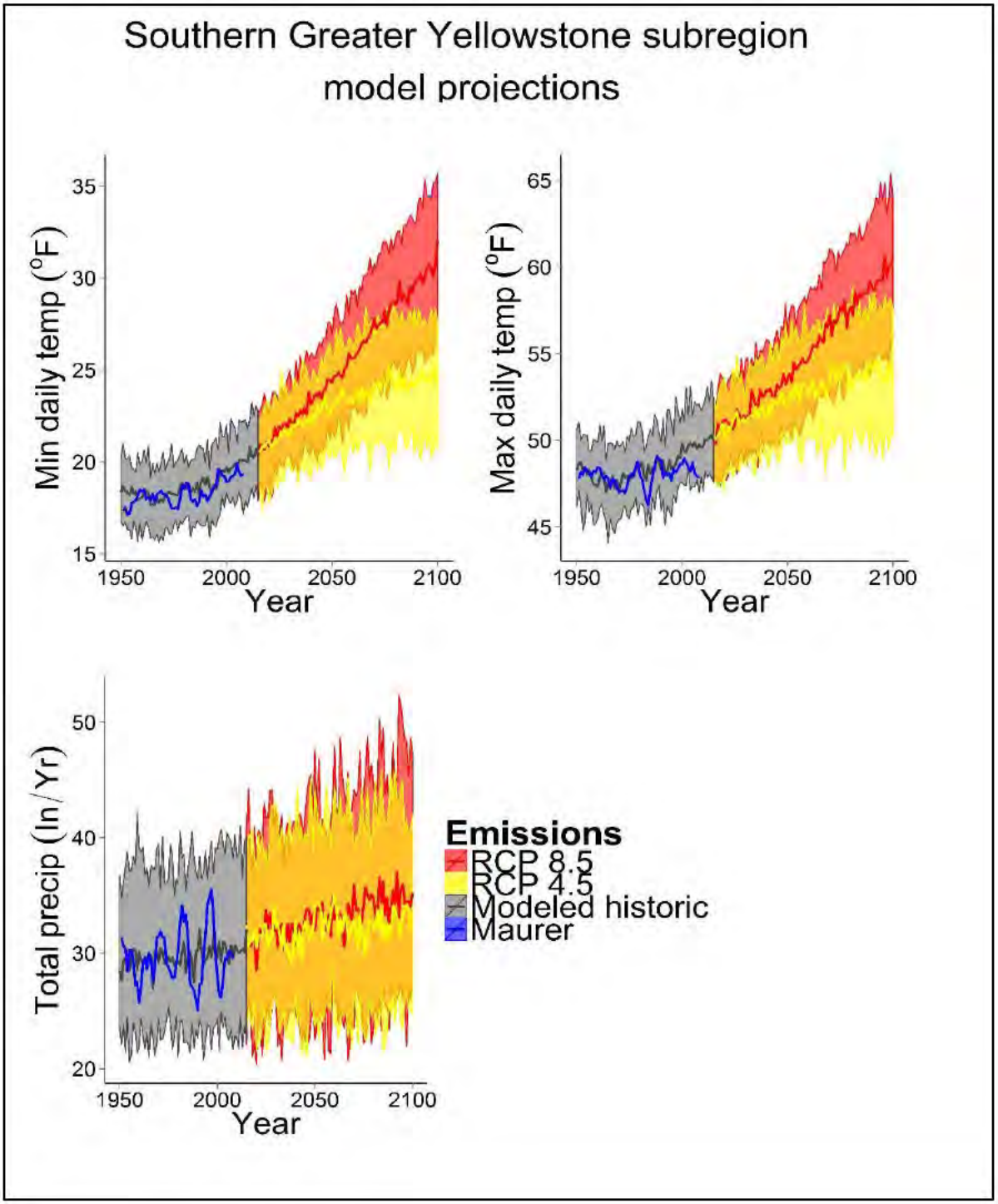
Climate projections for Southern Greater Yellowstone geographic area

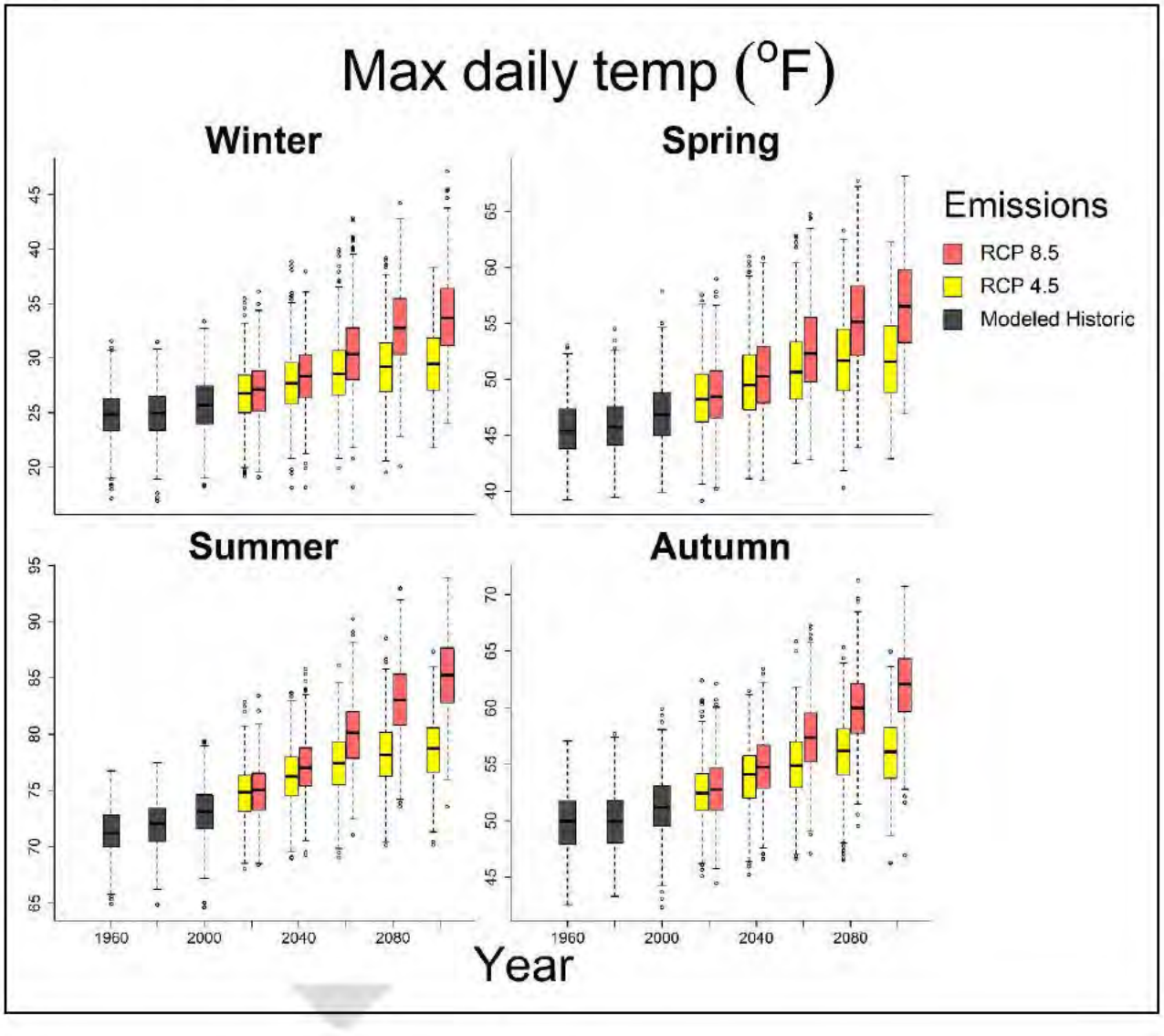
Annual historical mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation from monthly gridded PRISM, Maurer and TopoWx for 1949 to 2010 for the IAP Southern Greater Yellowstone subregion. The heavy lines are the 10-year rolling average to show short-term trends.



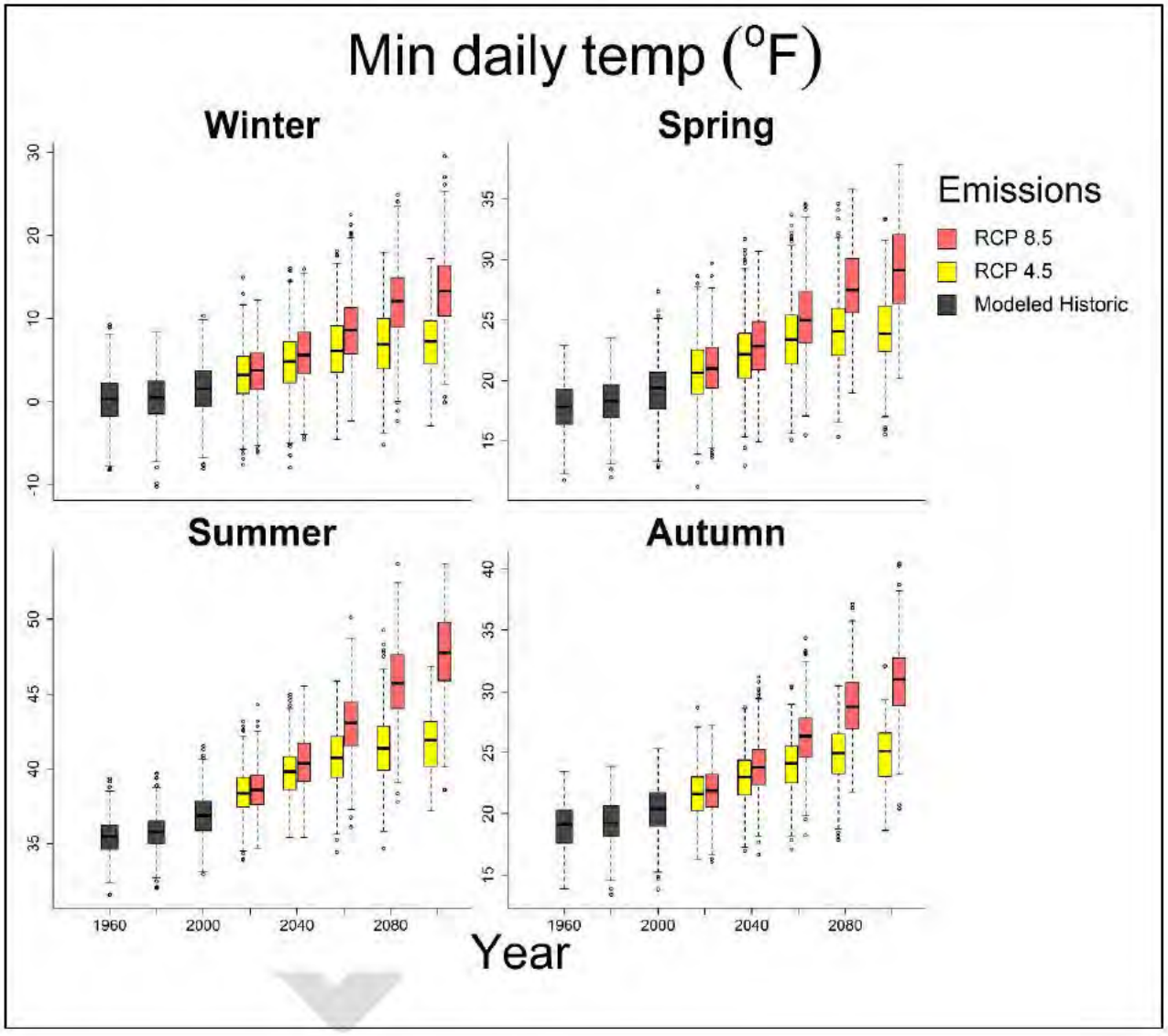
Historical modeled and projected annual mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation for RCP 4.5 and RCP 8.5 emission scenarios based on CMIP5 data for the IAP Southern Greater Yellowstone subregion. Historic modeled results are indicated in gray, projections in colors. The 5th and 95th percent quantiles for all models are shown by the shaded area. The ensemble median is illustrated by the grey, red, or yellow heavy line; the heavy blue line is the gridded historical observed data from Maurer and others (2002).



Seasonal mean monthly maximum temperature for 1950-2100 for the IAP Southern Greater Yellowstone subregion. Each box is an aggregation of 20 years of modeled historical or projected seasonal data centered on the year listed (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.



Seasonal mean monthly minimum temperature for 1950-2100 for the IAP Southern Greater Yellowstone region. Each box is an aggregation of 20 years of modeled historical or projected seasonal data (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.



Key messages for the Uintas and Wasatch Front geographic area

- In the Uinta-Wasatch Front, climate variability is strongly influenced by the interactions with topography, elevation, and aspect.
- Both minimum and maximum temperature has risen over the last 50 years, but maximum temperature has risen more than minimum temperature. Over the last 30 years, minimum temperature has, on average, increased 0.036 °F per year, whereas maximum temperature has risen 0.064 °F per year.
- By mid-21st century, maximum temperature under RCP 4.5 is projected to rise nearly 5 °F and minimum temperature is projected to rise similarly. Precipitation projections are highly variable with no discernible trend.
- Seasonally, the projected spring and fall temperatures, historically well-below freezing, rise above freezing in the warmest future scenario (RCP 8.5).

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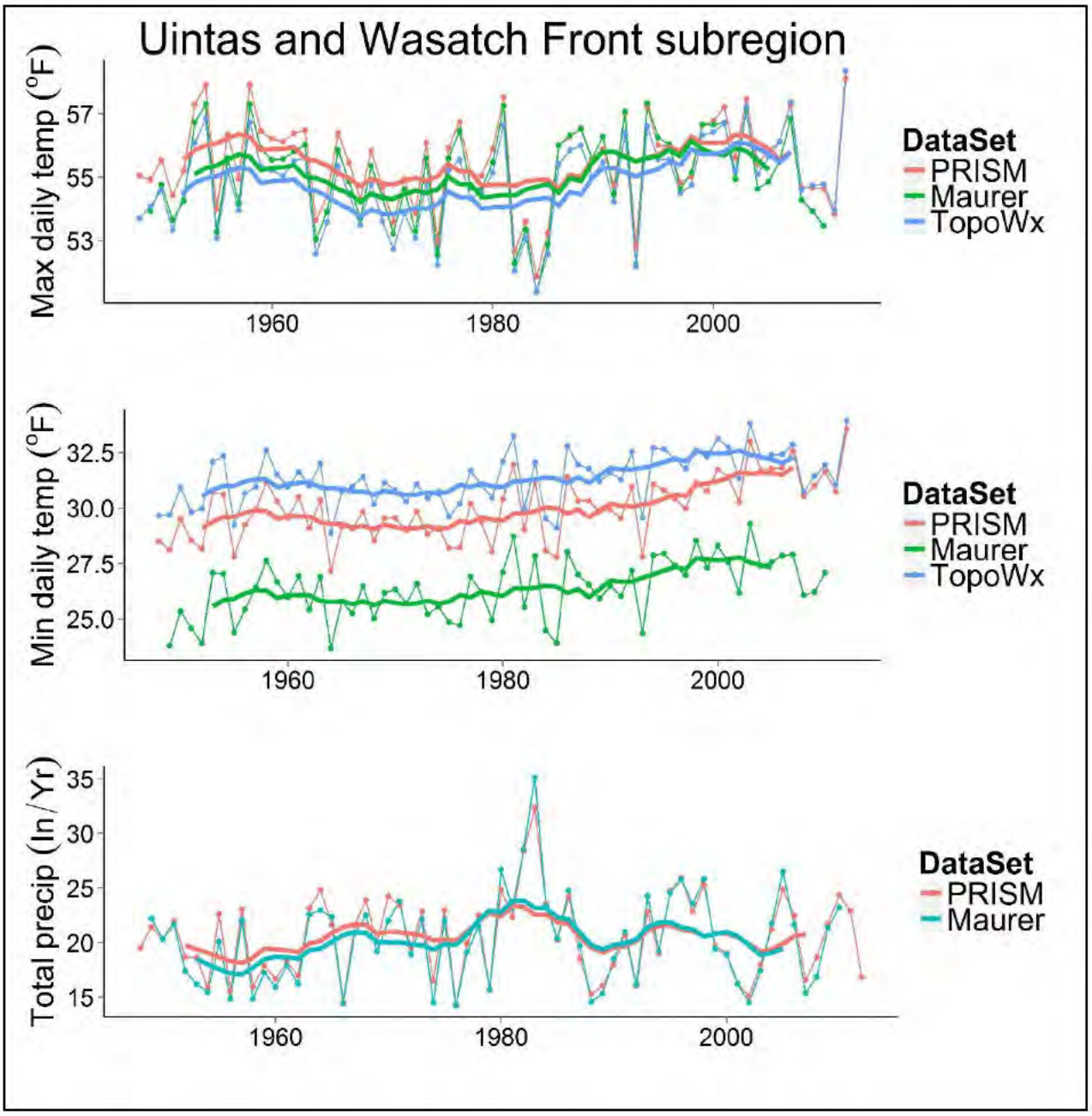
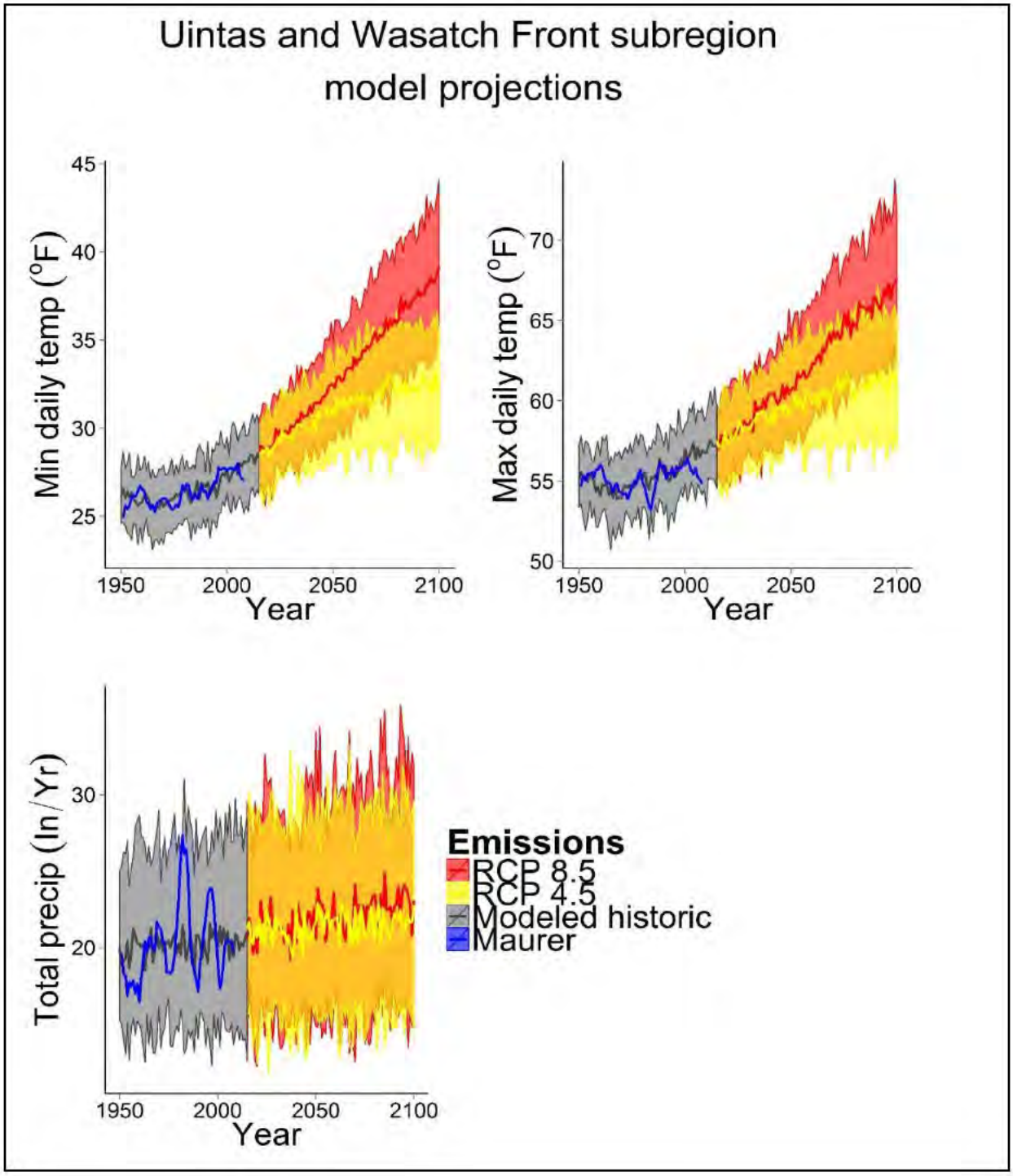
Climate projections for the Uintas and Wasatch Front geographic area

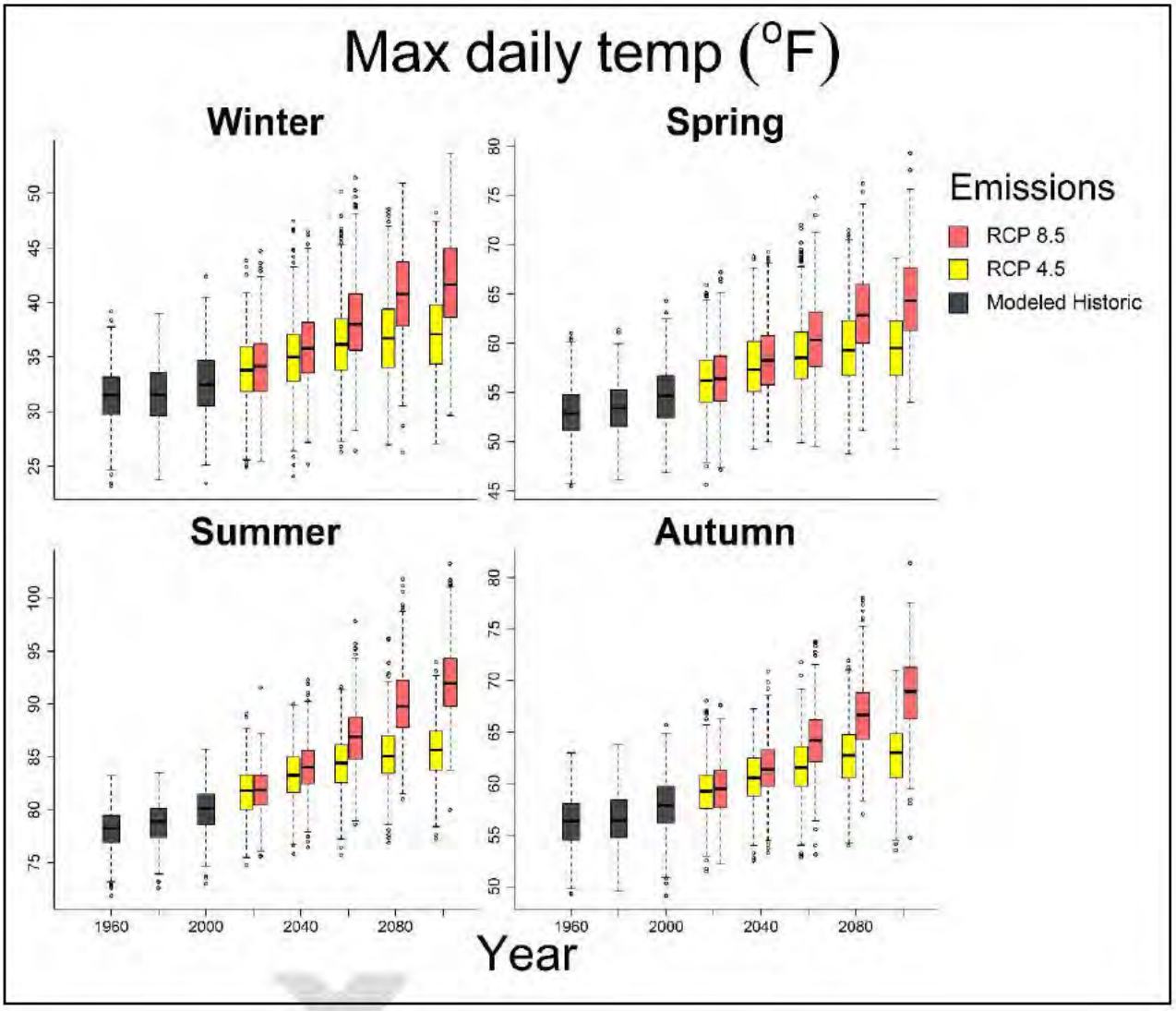
Annual historical mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation from monthly gridded PRISM, Maurer and TopoWx for 1949 to 2010 for the IAP Uintas and Wasatch Front. The heavy lines are the 10-year rolling average to show short-term trends.



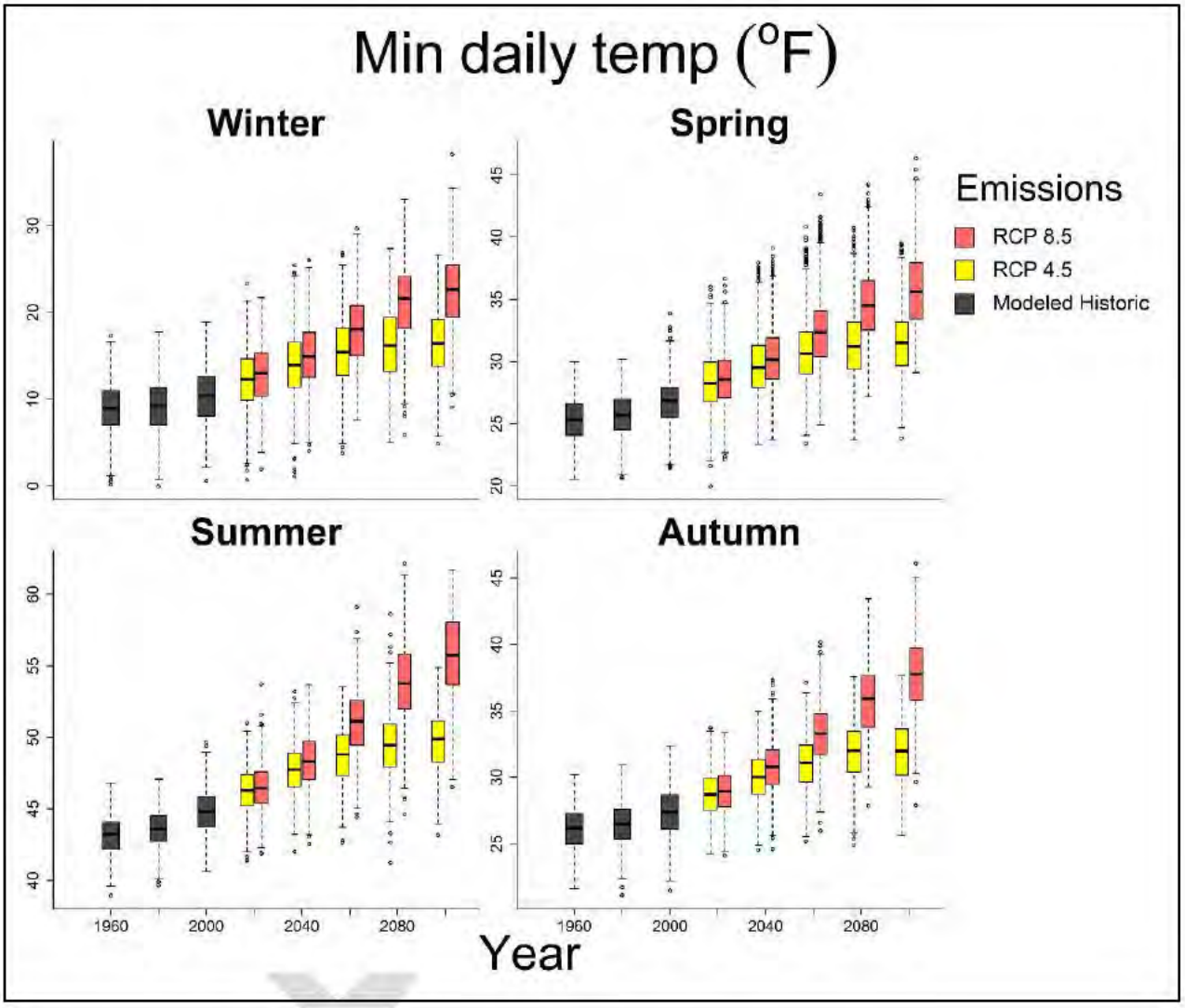
Historical modeled and projected annual mean monthly maximum temperature, annual mean monthly minimum temperature, and total annual precipitation for RCP 4.5 and RCP 8.5 emission scenarios based on CMIP5 data for the IAP Uintas and Wasatch Front. Historical modeled results are indicated in gray, projections in colors. The 5th and 95th percent quantiles for all models are shown by the shaded area. The ensemble median is illustrated by the grey, red, or yellow heavy line; the heavy blue line is the gridded historical observed data from Maurer and others (2002).



Seasonal mean monthly maximum temperature for 1950-2100 for the IAP Uintas and Wasatch Front. Each box is an aggregation of 20 years of modeled historical or projected seasonal data centered on the year listed (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.



Seasonal mean monthly minimum temperature for 1950-2100 for the IAP Uintas and Wasatch Front. Each box is an aggregation of 20 years of modeled historical or projected seasonal data (historical, grey boxes; RCP 4.5, yellow boxes; RCP 8.5, red boxes). For example, 1960 represents the seasonal average of 1950 to 1969. The central line in each box is the median. Hinges or edges of the boxes are the first and third quartiles; whiskers extend past the first and third quartile by 1.5 times the interquartile range (middle 50); points outside of the whiskers are extreme values.



VULNERABILITY ASSESSMENT — WATER RESOURCES

Habitat, ecosystem function, or species
Snowpack and glaciers

Broad-scale climate change effect
Warming winter temperatures, and potential shifts in precipitation (unknown direction)

Current condition, existing stressors
In general, April 1 snow-water equivalent (SWE) has been declining throughout the region since the late-1940s. Where they exist, glaciers have receded to historical lows during the 20th century. Declines in snowpacks have resulted from changes in both temperature and precipitation over this period. Because of the joint forcing, snowpacks at both low and high elevations have seen substantial declines. Low elevation snowpacks are sensitive to temperature variations while mid-to-high-elevation snowpacks have joint sensitivity and consequently greater uncertainty.

Sensitivity to climatic variability and change
April 1 SWE, mean snow residence time (length of time snow sits in the snowpack), and center of timing of snowpack are all sensitive to both temperature and precipitation variations. Warmer (usually low elevation) snowpacks are somewhat more sensitive to temperature variations than are colder snowpacks, although both are temperature sensitive. Colder snowpacks are more sensitive to precipitation, whereas the warmest snowpacks have little sensitivity to precipitation.

Expected effects of climate change
Warming temperatures are consistent among all climate change models projections, but projections for precipitation differ substantially among models. Furthermore, precipitation changes projected by global climate models have high uncertainty in mountain areas.

Places with seasonally intermittent snowpacks will likely see snow more rarely. Some mid-to-low-elevation seasonal snowpacks will likely become intermittent. Higher elevation snowpacks may or may not see substantial changes in April 1 SWE, snow residence time, or center of melt timing, depending on precipitation outcomes. In warmer locations, temperature-dependent changes are relatively robust even if precipitation increases. In colder locations, a precipitation increase within the range of projected possibilities could cancel or even overwhelm the effects of even a relatively large temperature change. Alternatively, a precipitation decrease could exacerbate projected temperature-related declines.

Glacier accumulation zones are at some of the highest elevations of the region, so may respond positively if precipitation increases. Annual dynamics of mass balance with respect to input and output suggest that the equilibrium line (demarcating places where annual snow does not completely melt each summer) will increase in elevation, regardless of precipitation; where that elevation falls on each glacier will influence glacier response. Most glaciers will be reduced in volume and area, and may become small enough to prevent movement. If climate at higher elevations becomes both warmer and drier, the likelihood of glaciers persisting is low.

Increasing soot from forest fires and decreased canopy cover would locally and temporarily increase glacier melt rates. The accumulation of soot over time from increasing fire occurrence could endanger glacier energy balances.

VULNERABILITY ASSESSMENT — WATER RESOURCES

Habitat, ecosystem function, or species
Streamflow

Broad-scale climate change effect
Warming winter and summer temperatures, potential shifts in precipitation (unknown direction), and increased wildfire

Current condition, existing stressors
Annual water yield has been declining throughout the region since the late-1940s. Summer low flows have been declining in concert with declining streamflows. Some locations experiencing declining streamflows have also seen statistically significant declines in the 2-year flood (sometimes termed "bankfull"). Historical precipitation declines as well as temperature increases have both influenced streamflows across the region, affecting both total flows and seasonality of flows. Low flows have historically been more strongly affected by precipitation changes than seasonality shifts, although both are apparent.

Sensitivity to climatic variability and change
Most of the streams in the region depend on snowmelt for runoff, and snowpack changes integrated over the elevation range of a basin strongly dictate the streamflow response. Effects can be classed into seasonality and water yield effects. Most precipitation in the region comes in early winter and late spring, so streamflow is closely tied to snowpack changes. In the southern half of the region, there is a greater influence from summer precipitation. Warmer locations experience more runoff in winter months and early spring, whereas colder locations experience most runoff in late spring and early summer.

Seasonality is most strongly affected by winter snowpack accumulation, which is affected by winter temperature and precipitation. Shallower snowpacks melt earlier than deeper snowpacks, and the sensitivities cited above for snowpack accumulation apply.

In the northern portion of the region, midwinter flooding is common during rain-on-snow (ROS) events. ROS occurs during warm winter storms (rain instead of snow) occurring during winter months after a snowpack has accumulated. The primary effect is rapid melt rates caused by condensation of warm water vapor on the snow. Although these are most commonly restricted to low-mid elevations (warmer and more maritime climates), some atmospheric river related events can yield rapid melt at high elevations. These events are tied more to circulation patterns than "climatic variability," and no trends in their occurrence have been documented. These midwinter floods are typically among the largest in the river basins where they occur.

Annual water yields are affected by annual precipitation totals (heavily influenced by winter and spring precipitation) and summer evapotranspiration. Temperature is commonly used as an index for evapotranspiration, but care needs to be applied in recognizing that warm temperatures can also be caused by low moisture availability, which is caused by low precipitation.

Expected effects of climate change
Warming temperatures will reduce snowpack accumulation and advance snowmelt timing. Despite mixed signals from precipitation and temperature changes in the historical record, future temperature changes are expected to be higher than historical temperature trends, and future precipitation declines are expected to be less pronounced (and increased precipitation is possible). Earlier streamflow center of timing is expected over much of the region, and summer low flows are expected to be lower. Total yields may decrease due to increased evapotranspiration, but precipitation amounts are uncertain. Increasing precipitation could

outweigh evapotranspiration effects on total water yields. Decreasing precipitation could substantially exacerbate annual water yields and low flow declines.

Midwinter flooding is expected to become more common in places where it now occurs and to occur in more locations. Because ROS-driven flood peaks tend to be much higher, flood magnitudes are expected to increase in those locations as well.

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VULNERABILITY ASSESSMENT — WATER RESOURCES

Habitat, ecosystem function, or species
Groundwater

Broad-scale climate change effect
Warming winter and summer temperatures, potential shifts in precipitation, and changes in groundwater recharge and discharge

Current condition, existing stressors
Snowmelt likely contributes the majority of recharge in most mountain regions of the western U.S., either because snow comprises the majority of precipitation, or snowmelt more effectively infiltrates below the root zone than rainwater. Reduced snowpack could decrease water supply to aquifers and potentially reduce productivity in all types of groundwater-dependent ecosystems (GDEs). Changes in temperature and dust on snow events are already shifting snowmelt earlier in the season.

Sensitivity to climatic variability and change
Changes to mountain recharge are difficult to predict because of poorly understood factors such as the hydraulic characteristics of the geology and the spatial distribution and timing of mountain recharge and streamflow generation. Recharge in many mountain areas is permeability-limited rather than recharge-limited because of thin soils overlying low-permeability crystalline bedrock. A decrease in maximum annual snow water equivalent may decrease overland flow of snowmelt to streams but have little influence on recharge because spring snowmelt substantially exceeds the unsaturated zone storage capacity. Conversely, in karst areas where recharge is high and travel time in the aquifer is rapid, timing of groundwater discharges may shift as the snowmelt timing shifts.

Recharge could also increase as a result of a more gradual release of water from the snowpack because of enhanced winter melting. Predicting mountain recharge changes requires knowledge of groundwater flow systems within mountain ranges that is generally unavailable. Effects of changing climate on the ecology of GDEs will depend on changes in groundwater levels and recharge rates, as influenced by the size and position of groundwater aquifers. GDEs supported by small, local groundwater systems tend to exhibit more variation in temperature and nutrient concentrations than regional systems. It is likely that larger systems will be more resilient to climate change.

Expected effects of climate change
Recharge is likely to decrease in the south, but changes in recharge remain uncertain throughout the region given limited understanding of mountain recharge processes and groundwater flow in mountain blocks. Groundwater recharge has been examined in only a few locations, and little is known about groundwater recharge processes in many watersheds. Higher minimum temperatures will reduce the longevity of snowpack, and decrease the length of time aquifer recharge can occur, potentially leading to faster runoff and less groundwater recharge. Some watersheds will be shifting from snow-dominated to rain-dominated, which might result in declines in groundwater recharge. Because many biological processes are temperature-dependent, climate-induced changes in groundwater temperature may negatively affect aquatic communities. However, because the thermal regime of groundwater systems is less dependent on air temperature patterns than surface waters, the effects of rising air temperatures are likely to be less pronounced in groundwater discharges. Wetland plant species can respond to even slight changes in water table elevation, and shifts in composition of both vascular and bryophyte species could occur with lowered water tables.

VULNERABILITY ASSESSMENT — SOIL RESOURCES

Habitat, ecosystem function, or species
Soils

Broad-scale climate change effect
Increased temperatures, increased drought, increased wildfire area burned

Current condition, existing stressors
Soils are created and changed by climate, organisms, parent material, topography, and disturbance. Climate, organisms, and disturbance are active modifiers of soil resources. Human disturbance can have a significant direct effect on soil resources. Climate changes will modify soil resources and processes. However, the interaction of climate change and human disturbances will determine the degree of soil change.

Sensitivity to climatic variability and change
The degree to which soils are sensitive to climate change depends on the soil type, location and degree of climate change, and adaptive management actions to maintain soil processes. The potential changes to soils due to climate change are multifaceted. Changes to chemical, physical, and biological processes in the soil can occur with climate change. These changes can affect other responses such as carbon cycling and vegetation response. Changes to soil properties and processes due to climate change may be viewed as detrimental or beneficial.

Expected effects of climate change
The properties and processes of soils are not independent and a change to one soil property will affect other soil properties and processes. For example, changes to soil temperature and moisture will affect carbon and nitrogen cycles that can affect soil properties such as water holding capacity, cation exchange capacity, soil nutrient content, and aggregate stability. The information below on climate change effects to soils assumes a condition of a warming and drying climate.

Soil temperature and moisture
Soil temperature and moisture are the primary drivers of change for all soil processes. The magnitude of projected change is variable depending on existing soil resources and existing climate. An increase in soil temperature generally will produce an increase in soil biological activity and soil respiration. In the current semi-arid soils of the IAP region, an increase in soil temperature without an increase in soil moisture will likely result in reduced biological activity, increased respiration, and decreased potential to store carbon. In the colder and wetter areas of the IAP region, an increase in soil temperature may lead to greater biological activity, and longer growing seasons if soil moisture is not limiting. Soils derived from coarse textured parent material will transfer heat more efficiently down into the soil profile than fine textured soils. The heat transfer downward can affect soil processes and even groundwater temperatures. Fine textured soils are capable of storing water longer in the soil profile, providing a buffer to warming and higher water demands by plants.

Soil carbon and nitrogen
Changes in soil temperature and moisture will affect carbon and nitrogen cycles. Changes to the carbon and nitrogen cycles may include an increase or reduction in cycling rates or storage of carbon and nitrogen. Globally, there is more carbon stored in the soil than any other terrestrial form of carbon. Soil organic carbon (SOC) may contain more than three times as much carbon

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found in the atmosphere or terrestrial vegetation. The SOC supports many soil processes and functions. These include providing nutrients for plants, binding soil particles together maintaining structure, providing an energy source for microbes, increasing water infiltration and retention, and providing cation/anion exchange for retention of ions and nutrients. Climate change will affect SOC and ultimately the functions and processes supported by SOC. Most of the soils in the IAP region can sequester additional carbon if soil temperatures decrease and soil moisture increases. However, most climate models predict warmer soil temperatures and varied soil moisture changes. The warming temperatures without additional moisture may reduce SOC and capability of soils to store carbon.

Soil physical properties
Changes to SOC with climate change can cause changes to several soil properties that are directly tied to the amount of SOC. These include soil structure, bulk density, and soil porosity. These soil properties affect water infiltration, rooting depth, soil erosional losses, and water holding capacity. These properties are potential indicators that can be used to determine the effects of climate change and where management changes may be needed to adapt to a changing soil environment.

Soil biological activity
Soil organisms perform many functions including decomposition and nutrient cycling. The effects of climate change to soil biology are mixed. Warming of the soil may result in greater microbial activity, releasing more carbon to the atmosphere through increased decomposition. Warming of the soil may also result in slowed microbial growth and less carbon being released through respiration. A greater diversity of soil biology has the greatest adaptive advantage and resistance to climate change.

Soil chemical properties
Potential effects to soil chemical properties with climate change are linked to other biological and physical changes in the soil, all of which are driven by the soil temperature and moisture inputs. Salinization, acidification, pH, and cation exchange capacity are soil processes and properties that will change with changes to climate. In general, the lower elevation, drier rangeland soils are more vulnerable to changes in soil chemical processes and properties.

Adaptive capacity
The fine textured soils in the region will generally have a higher buffering capability to changes in soil temperature and moisture and are expected to see a slower ecological change with changes to climate. Diversity of the soil biological community will likely confer greater capacity to adapt to climate change. Low elevation, drier soils will likely be more vulnerable to changes in soil chemical processes and properties.

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VULNERABILITY ASSESSMENT — AQUATIC ORGANISMS

Habitat, ecosystem function, or species

Bull trout, primarily the interior lineage, are broadly distributed across the northwestern U.S. but are restricted to the northwestern portion of the IAP area in the Sawtooth, Payette, Boise, Salmon-Challis, and Humboldt-Toiyabe National Forests. Populations may exhibit migratory or resident life histories. Migratory fish travel long distances as subadults to more productive habitats and achieve larger sizes and greater fecundity as adults before returning to cold natal headwater habitats to spawn. Fish exhibiting resident life histories remain in natal habitats and mature at smaller sizes, though often at the same age as migratory adults. Adults spawn primarily in September and eggs incubate throughout the winter before juveniles hatch and emerge from stream substrates in late winter or early spring. Reproduction and juvenile growth for the first 2–3 years is almost exclusively in streams with average August water temperatures < 54 °F and flows > than 1.2 ft^3sec^{-1}. Low densities are typical of bull trout populations, even among strong populations in the best habitats.

Cutthroat trout are represented by several subspecies in the IAP area: westslope cutthroat trout, Yellowstone cutthroat trout, Lahontan cutthroat trout, Paiute cutthroat trout, Bonneville cutthroat trout, and Colorado River cutthroat trout. Although there was no historical overlap in the distribution of these subspecies, one or more were distributed throughout all of the national forests across the IAP area except where perennial streams are lacking e.g., southern Nevada. These subspecies have a complex evolutionary history with two major clades. One consists of westslope, Lahontan (including Paiute), and coastal cutthroat trout, and the other includes the rest of the interior subspecies. Moreover, phylogeographic structure in the latter group suggests that another 1–2 taxa may be present, and that the IAP area may also host populations of greenback cutthroat trout. These fish exhibit resident and migratory life history strategies similar to bull trout, but are spring spawners that also occur in smaller streams (0.2 ft^3sec^{-1}) and reproduce in warmer streams (up to 57 °F). Especially cold streams i.e., those with average August temperatures < 48 °F are suboptimal for cutthroat trout because of frequent recruitment failure. Cutthroat trout populations are generally found at higher densities than are bull trout.

Rocky Mountain tailed frogs occur throughout central and northern Idaho, western Montana, and northeastern Oregon but within the IAP area occur only on the Sawtooth, Payette, Boise, and Salmon-Challis National Forests. Populations inhabit steep, cold headwater streams similar to those used by bull trout and cutthroat trout, although Rocky mountain tailed frog distributions may extend upstream past waterfalls and cascades that limit fish distributions. After eggs hatch in late summer, tadpoles grow 1–4 years before metamorphosing into adults that reach sexual maturity after another 4–5 years, and local densities may be quite high. Larval Rocky Mountain tailed frogs are strictly aquatic, but adults often exploit cool, moist riparian zones to forage. Adult body size is 1-2 inches and dispersal is thought to be limited, thus floods and channel disturbances are believed to suppress populations for extended periods. Populations are patchily distributed among headwater streams and show evidence of genetic divergence.

Idaho giant salamanders occur in west-central and portions of northern Idaho south of Lake Coeur d'Alene but within the IAP area occur only on the Payette and Boise National Forests. Populations are patchily distributed and often co-occur with native salmonids in headwater streams, although salamanders also occupy reaches further upstream from which fish are excluded. Giant salamanders may also use lakes and ponds. Neotony, i.e., maturation as a strictly aquatic form with larval characteristics, is common. Uncertainty exists regarding the timing of reproduction, with some literature sources suggesting both spring and fall spawning. Females guard egg masses until hatching occurs and larval stages last several years before

metamorphosing into adults. Adults reach body sizes of 7–12 inches and prey on a variety of aquatic and terrestrial species—including tailed frog tadpoles—in and near streams. Dispersal is presumably limited, and populations often exhibit substantial geographic structure.

Western pearlshell mussel occur in the Columbia River Basin, and internally draining basins such as the Humboldt, the Truckee, and Provo rivers. They have been recorded from all National Forests in the IAP area, though only one population is known in Utah. This sedentary filter-feeder inhabits cold, clear, perennial creeks and rivers at depths of 1.5 to 5 feet, and tends to congregate in stable substrates amid boulders, gravel, and some sand, silt and clay. The species has limited mobility and will not tolerate accumulation of sediment. Western pearlshell larvae parasitize an array of salmonid species (e.g., Chinook salmon, cutthroat trout, rainbow trout, though utilization of bull trout is unknown) and rely on these hosts for recruitment and dispersal. In fact, pearlshells will not successfully reproduce in habitats that do not support their trout or salmon hosts. Female mussels generally release larvae (or glochidia) in spring or early summer, depending on water temperature. Glochidia attach to fish gills and develop for a period of weeks to months. Once metamorphosed, juvenile mussels drop from their host fishes and bury into the substrate.

Springsnails are hydrobiid snails belonging to the genus *Pyrgulopsis* which occur in freshwater habitats throughout much of western North America. Approximately 140 species inhabit the IAP area. These tiny mollusks (shell length 0.04 to 0.30 inches) are widespread and locally abundant (>100 /ft^2) in perennial, groundwater-dependent springs and brooks. Spring habitats may be either ambient temperature or thermal, and springsnails are often concentrated near sources of groundwater discharge with stable water chemistry. *Pyrgulopsis* typically lives on emergent plants and hard substrates and grazes on attached algae and fungi. They are gill breathers and do not tolerate desiccation.

Broad-scale climate change effects

The primary climate change effects are warming air temperatures and potential changes in the amount, timing, and type (snow versus rain) of precipitation. Depending on scale and location, these will generally combine to cause warmer water temperatures, earlier snowmelt runoff, earlier declines to lower summer baseflows, and downstream contraction of perennial flow initiation from headwaters. Depending on watershed elevation, the magnitude of peak flows could increase or decrease. At high elevations where snowmelt drives the flow regime, peak flows may occur several weeks earlier and be smaller than historical averages. At mid-elevations where stream hydrographs are transitional between snow and rain, peak flows may increase and could shift much earlier if rainfall becomes the predominant form of precipitation. More extreme climatic conditions may also occur more frequently and persist over longer periods, including higher peak flows from rain-on-snow events, higher temperatures, and longer, more severe droughts. Increased frequency or severity of wildfires could also cause more extensive debris flows and channel disturbances in headwater streams with steep channels.

Current condition, existing stressors

Bull trout are listed as threatened under the U.S. Endangered Species Act (ESA) and on the R4 sensitive species list. Their recent historical distribution has declined because of water development and habitat degradation (particularly activities leading to water temperature increases, but also cumulative losses of in-channel habitat complexity and fragmentation of some habitats), elimination of migratory life histories by anthropogenic barriers, harvest by anglers, and interactions with introduced non-native fishes. With respect to the latter, this involves wasted reproductive opportunities (with brook trout), competition, and predation (in streams, perhaps with brown trout; in lakes, with lake trout).

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Among **cutthroat trout**, all subspecies are either listed as threatened under the ESA (Lahontan, Paiute, and greenback cutthroat trout) or have been petitioned for listing and found not warranted. Those not listed are on the Forest Service Region 4 sensitive species list (Bonneville, Colorado River, Yellowstone, and Westslope cutthroat trout).The distributions of these subspecies have declined substantially (>50%) in response to the same stressors affecting bull trout. Declines in response to non-native species can be more severe than in bull trout, probably because cutthroat trout historically used warmer habitats where overlap with invading non-native species was more common. Brook trout have replaced cutthroat trout in many waters in the IAP region. These invasions seem influenced by the distribution of low-gradient alluvial valleys that may serve as nurseries for brook trout. Introduced rainbow trout have introgressively hybridized with cutthroat trout at lower elevations (in warmer waters) across their historical ranges, although genetically pure populations often persist in cold headwaters where climatic conditions limit the expansion of downstream hybrid zones.

Rocky Mountain tailed frogs are generally considered to be a conservation concern but do not appear on the Region 4 sensitive species list. Land use practices that warm streams, increase sedimentation and reduce interstitial spaces in substrates, or reduce habitat moisture (through loss of stream and terrestrial canopy cover) are thought to reduce tailed frog habitat quality. Nonnative fish predators, especially brook trout, may increase mortality where distributions overlap. Although occurrence data for Rocky Mountain tailed frogs suggests that the species is widely distributed, monitoring data are not available to determine temporal trends in abundance or distribution.

Idaho giant salamanders are generally considered to be a conservation concern but do not appear on the Region 4 sensitive species list. There is some indication that land use practices may limit their presence, but their patchy distribution limits strong inference about habitat requirements. They are prey for both native and nonnative fish species, but fish species presence is not known to affect their population status. Overall, their distribution is relatively poorly described and monitoring data are not available to evaluate temporal trends.

Western pearlshell mussels occur widely in western North America and range from Alaska and British Columbia south to California and east to Nevada, Wyoming, Utah and Montana. Though vulnerable, they probably do not face an immediate risk of extinction. Many examples exist of the pearlshell's decline or extirpation from streams and rivers across its range, especially in arid areas. Threats include: impoundments, loss of host fishes, channel modification, dredging and mining, restoration activities, pollution, sedimentation, nutrient enrichment, water diversion, thermal pollution, and the introduction of non-native fishes which outcompete host species. Many of these impacts, especially reduction in stream flow and thermal pollution in arid areas, are being exacerbated by climate change.

Springsnails are distributed from southern Canada to northern Mexico, but their habitat specificity and low dispersal ability have contributed to a high degree of endemism, with many species occurring only within a single spring or seep. Springsnails have life history traits that make them vulnerable to extinction. First, they have specialized habitat requirements, typically occurring in pristine, coldwater or thermal springs close to the spring source, where dissolved carbon dioxide and calcium concentrations are high. Slight changes in water chemistry or temperature can quickly impact a population. Second, springsnails are poor dispersers and suitable habitats are generally isolated from each other by arid uplands. Once a springsnail population has been extirpated, there is low probability of recolonization. Threats to springsnails include: groundwater pumping and aquifer drawdown; surface flow diversion for agriculture;

impoundments; channelization of outflows; springhead 'development'; physical alteration of thermal springs for bathing; overgrazing; and invasive species, such as New Zealand mudsnails.

Sensitivity to climatic variability and change

Bull trout evolved in western North America in interior and coastal basins exhibiting a wide array of flow characteristics and natural disturbance at scales from reaches to riverscapes. Nevertheless, large habitats satisfying the restrictively cold thermal requirements for spawning and early juvenile rearing are relatively rare, and little evidence exists for flexibility in habitat use. The length of connected cold-water habitats needed to support a bull trout population varies with local conditions, but current estimates suggest 10–30 miles are needed to ensure a high probability of habitat occupancy (e.g., >0.9), with specifics contingent on water temperature, prevalence of brook trout, and local geomorphic characteristics. Migratory life histories probably conferred greater resistance to extirpation under historical conditions, but may no longer do so. Bull trout may also be sensitive to larger or more frequent winter high flows because eggs incubate in stream substrates throughout the winter.

Cutthroat trout occupy a broader thermal and stream size niche than do bull trout and can persist in smaller habitat patches. Nonetheless, they still require coldwater natal habitat patches exceeding ~2–6 miles to have a high probability of persistence, and this value depends strongly on the prevalence of brook trout, water temperatures, and geomorphic conditions. Temperatures at the upstream extent of cutthroat trout populations in extremely cold streams will become more suitable from climate warming, but flows may become intermittent if precipitation patterns change.

Rocky Mountain tailed frogs have thermal niches similar to cutthroat trout so warming temperatures may increase the suitability of especially cold habitats while decreasing suitability of warmer habitats. Populations rebound slowly from disturbances so anomalous summer/winter flooding or post-fire debris flows in steep channels may threaten persistence of some populations as climate change causes these events to become more common. Tailed frog populations may also be negatively affected by more extreme summer droughts or wildfires that open riparian canopies and make areas adjacent to streams warmer and drier.

Idaho giant salamanders sensitivities are presumed to be similar to Rocky Mountain tailed frogs but may be even more susceptible to disturbance of headwater natal areas given nest guarding behavior by females and multiyear development of larval stages before maturity.

Western pearlshell mussels occupy streams with broad ranges of thermal regimes, but nevertheless require cold water temperatures and perennial flows. Their habitat must also be suitable for salmonid hosts, and the mussel's sensitivity to climatic variability will closely parallel that of their trout and salmon hosts.

Springsnails's limited ability to disperse and narrow environmental tolerances renders them vulnerable to emerging threats associated with climate change. Because they require particular hydrological conditions, specific and stable temperature regimes, and perennial flows, Nevada springsnails, especially, have been rated as 'extremely vulnerable' using the Climate Change Vulnerability Index.

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Expected effects of climate change

Native trout and amphibians: Warming temperatures are expected to shift thermally suitable habitats for trout and amphibian species upstream. Recent estimates suggest those shifts have been occurring at the rate of about 1000-1600 ft/decade over the last four decades. Smaller snowpacks and earlier runoff are decreasing summer flows, with 10-30% declines observed in recent decades and projections for decreases to continue. Declines in summer flows are reducing habitat volume in perennial channels and the largest natal habitat patches will continue to decline in size and may fragment into smaller patches. Invasive trout species more tolerant of warmer temperatures—brook trout, rainbow trout, and brown trout—will expand their distributions upstream and further constrain or replace native trout and amphibians in some stream reaches. Of those invasive species, however, only brook trout are capable of persisting in the coldest headwater streams (e.g., <52 °F mean August temperatures) so refuge habitats and streams will continue to persist in some areas for the foreseeable future. More wildfires may result in more extensive disturbances and debris flows into streams, especially the smallest and steepest channels at the upstream extent of the network.

Less water, hostile environments, and declining fluvial connectivity (e.g., from water development or interactions with road culverts) would favor resident life histories, as would greater separation between spawning and adult growth habitats. Smaller habitats and populations will be more susceptible to extirpation from local environmental disturbances (such as debris torrents following fire, or larger and more frequent floods). In addition, regional weather patterns are likely to synchronize population responses and vulnerabilities; in years of extreme drought and high summer water temperatures, populations in small habitats across the IAP area may be at risk of extirpation.

Western pearlshell mussel. With warming temperatures, shifts in habitat suitable for pearlshells will follow the scenario as for their native trout hosts. Decreases in summer flow and reduced volume of perennial reaches will have greater impact on mussels than fishes because of the mollusk's fixed position in the substrate and inability to move appreciable distances. The pearlshell's ability to parasitize nonnative rainbow trout could, however, allow mussels to persist in reaches where that fish invades. Debris flows or sedimentation triggered by increased wildfire frequency would extirpate local mussel populations.

Springsnails. Warming temperatures, elevation of snowline, and changes in seasonal precipitation will diminish flow to aquifers and lower water tables, thereby adversely affecting groundwater dependent ecosystems. Arid land springs, which provide habitat to most springsnail species, are usually isolated and especially susceptible to desiccation when aquifers draw down. Because of these snails' high degree of endemism, dewatering of a single springhead through the vagaries of climate change could lead to the loss of an entire species.

Adaptive capacity

There is little evidence within the aquatic species considered here of rapid evolutionary adaptation to warmer water temperatures or desiccation. Bull trout and cutthroat trout have good dispersal abilities, so under circumstances in which migration is feasible, may recolonize previously disturbed habitats or those that have been recently restored. Moreover, trout exhibit both migratory and resident life history strategies and their relative proportions may evolve based on how climate change affects fish metabolic rates, water temperature, and stream productivity. The remaining species of concern have limited dispersal abilities and less is known about potential variation in life history strategies. Assisted migration, in the form of translocating populations into suitable habitats, is a human-mediated adaptive strategy that has often been successful for bull trout and cutthroat trout and may also be viable for other species if unoccupied, suitable habitats are identified.

VULNERABILITY ASSESSMENT — FOREST VEGETATION

Habitat, ecosystem function, or species
Subalpine pine forest

Broad-scale climate change effect
Warming temperatures, longer growing seasons, declining snowpack with shorter persistence, increased fire area burned, expansion of mountain pine beetle outbreaks

Current condition, existing stressors
Subalpine pine forest occupies the highest extent of tree species distribution, a relatively small extent of the landscape. Vegetation includes tree islands, ericaceous dwarf-shrubs, forbs, grasses, and wildflowers. Dominant tree species include whitebark pine, limber pine, subalpine fir, white fir, and Engelmann spruce. Whitebark pine is currently threatened by white pine blister rust and mountain pine beetles in some locations.

Sensitivity to climatic variability and change
Subalpine pine forest is typically energy limited, with persistent winter snowpack and a short growing season, except on drier sites. With increasing temperature, lower snowpack, and earlier snowmelt, tree growth may increase, and opportunities for regeneration may increase. However, increasing fire and summer drought could hinder tree establishment in some areas, favoring meadow vegetation.

Expected effects of climate change
Subalpine forests dominated by whitebark pine will be highly vulnerable in a warmer climate, primarily because this species is already subjected to stress from white pine blister rust and mountain pine beetles. As a result, populations are reduced and reproductive capacity is limited, even when germination conditions are suitable. In areas where wildfire has been excluded for many decades, wildfires may be intense, killing mature trees. Subalpine forests in which bristlecone pine is common are in dry locations that could become increasingly stressed by low soil moisture, potentially reducing growth, regeneration, and resistance to bark beetles.

Other subalpine forests are expected to be only moderately affected by a warmer climate. Limber pine, subalpine fir, Engelmann spruce, and white fir may all have increased growth in the upper subalpine zone. These species may (slowly) migrate to higher elevations in some locations. If wildfire increases in the subalpine zone, especially where it has been excluded in the past, crown fires may be prevalent, quickly eliminating mature trees. Biotic stressors are not as great a concern as for other species, except perhaps in old, low vigor stands. Quaking aspen in subalpine pine forests will be minimally affected by a warmer climate, especially compared to aspen at lower elevations.

Adaptive capacity
Suitable climate may decrease in the future, but very slowly, perhaps beyond the 21st century. Decreasing snowpack and increasing temperatures may eventually facilitate expansion of subalpine pine species into the alpine zone, but expansion will be moderated by upslope topographic and soil conditions, wind exposure, and snow distribution. However, the range of subalpine pine may also decrease at its current lower distribution. Although most species in this forest type are adapted to periodic wildfires, adaptive capacity may be overwhelmed if wildfires become frequent.

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VULNERABILITY ASSESSMENT — FOREST VEGETATION

Habitat, ecosystem function, or species
Subalpine spruce-fir forest

Broad-scale climate change effect
Warming temperatures, longer growing seasons, declining snowpack with shorter persistence, potential increase in summer drought stress, increased area burned

Current condition, existing stressors
Subalpine spruce-fir forest covers a large expanse of the higher elevation forest in the IAP region, where Engelmann spruce and subalpine fir are nearly ubiquitous, mixed with Colorado blue spruce and quaking aspen in wetter topographic positions, and Douglas-fir at lower elevation. Lodgepole pine is widespread in drier areas, often on shallow soils, and can be a seral species to spruce and fir. Lodgepole pine has experienced extensive mortality from mountain pine beetle over the past 15 years, a response to higher temperatures. Spruce beetle and spruce budworm are endemic insects with cyclical outbreaks, but their recent occurrence may be unrelated to climate.

Sensitivity to climatic variability and change
Subalpine spruce-fir forest is typically energy limited, with persistent winter snowpack and a short growing season, except in drier and lower elevation sites. With increasing temperature, lower snowpack, and earlier snowmelt, opportunities for regeneration may increase, and tree growth may increase. However, increasing fire and summer drought could hinder tree establishment in some areas, favoring meadow vegetation.

Expected effects of climate change
Spruce-fir forest will be moderately vulnerable to a warmer climate. Subalpine fir, Engelmann spruce, and blue spruce may all have increased growth in the upper subalpine zone because of a longer, snow-free growing season, so overall productivity could increase. These species may migrate to higher elevations where conditions are suitable, although this would be a slow process over many decades. If wildfire increases in the subalpine zone, especially where it has been excluded in the past, crown fires may be prevalent, quickly eliminating mature trees. Biotic stressors are not expected to increase for most species, except perhaps in low-vigor stands.

Lodgepole pine could be more susceptible to mountain pine beetle in a warmer climate. Beetle outbreaks are often severe, and succession could accelerate in areas of high pine mortality. Most subalpine species are susceptible to fire, but because lodgepole pine has serotinous cones and the potential for rapid regeneration, it will probably persist in high-elevation landscapes. Quaking aspen in subalpine forests will be minimally affected by a warmer climate, especially compared to aspen at lower elevations. Where Douglas-fir is a seral species, it could increase in distribution and abundance where sufficient soil water is available. It is more fire tolerant than its associates, so if fire increases, it may become relatively more common.

Adaptive capacity
Suitable climate may decrease in the future, but slowly, perhaps beyond the 21st century. Decreasing snowpack and increasing temperatures may eventually facilitate expansion of subalpine pine species upslope, but moderated by topographic and soil conditions, wind exposure, and snow distribution. Although most species in this forest type are adapted to periodic wildfires, adaptive capacity may be overwhelmed if wildfires become frequent.

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VULNERABILITY ASSESSMENT — FOREST VEGETATION

Habitat, ecosystem function, or species
Mesic mixed-conifer forest

Broad-scale climate change effect
Increased temperatures, increased summer drought stress, increased area burned

Current condition, existing stressors
This forest type is widespread, dominated by ponderosa pine, Jeffrey pine, and Douglas-fir in drier locations; Shasta red fir in the western portion of the IAP region; lodgepole pine at higher elevations; and quaking aspen in wetter landscape positions. Summer droughts are common and are a chronic, periodic stressor. Various insects, root diseases, and mistletoes are common, but not particularly related to stress, with the exception of mountain pine beetle (on lodgepole pine and to a lesser extent ponderosa pine). Forests in the drier portion of the range are increasingly susceptible to wildfire where stands are dense as a result of fire exclusion.

Sensitivity to climatic variability and change
This forest type is generally water limited in the summer, so higher temperatures will increase summer moisture stress, resulting in lower growth and possibly lower regeneration in drier locations. Sensitivity to moisture stress will vary by species and landscape position (e.g., north vs. south aspects). The indirect effects of a warmer climate, primarily through increased wildfire occurrence, will probably greatly outweigh the effects of gradually changing temperature.

Expected effects of climate change
Late-seral forests may become increasingly susceptible to wildfire, especially where fire has been excluded for many decades and fuel loads are elevated. Shasta red fir has some fire tolerance, but other firs and lodgepole pine are subject to high mortality in intense fires. As snowpack decreases and summer temperature increases, growth and productivity will probably decrease, except on north aspects.

Douglas-fir, ponderosa pine, and Jeffrey pine, which are often seral species, have high tolerance to wildfire and can survive moderate-intensity fires. Therefore, if wildfire extent and intensity increase in the future, these species may become relatively more common, and late-seral species may become less common. Although bark beetles may cause some stress, they will probably not have widespread effects. Douglas-fir, ponderosa pine, and Jeffrey pine are all tolerant of dry soils, so they should persist across the landscape, but their growth rates will probably decrease. Lodgepole pine will probably persist because of cone serotiny and rapid postfire regeneration, and aspen will persist through postfire sprouting.

Adaptive capacity
As wildfire becomes more frequent, fire-adapted species will have significant capacity to survive direct fire impacts (ponderosa pine, Jeffrey pine, Douglas-fir), regenerate after fire (ponderosa pine, Jeffrey pine, lodgepole pine, Douglas-fir), and sprout after fire (aspen). Therefore, much of the functionality of this forest type may be retained, although the distribution and abundance of species may shift over time in response to repeated disturbances.

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VULNERABILITY ASSESSMENT — FOREST VEGETATION

Habitat, ecosystem function, or species
Dry mixed-conifer forest

Broad-scale climate change effect
Increased temperatures, increased summer drought stress, increased area burned

Current condition, existing stressors
Located in lower-elevation montane sites, this forest type is often on steep slopes and shallow soils, containing some of the most drought tolerant species in the IAP region. Common seral species include ponderosa pine and quaking aspen, and common woodland species include curlleaf mountain mahogany, Gambel oak, and bigtooth maple. Various insects, root diseases, and mistletoes are common, but not particularly related to climatic stress, with the exception of mountain pine beetle. Forests in the portion of the range dominated by ponderosa pine are increasingly susceptible to wildfire where stands are dense as a result of fire exclusion.

Sensitivity to climatic variability and change
This forest type is generally water limited in the summer, so higher temperatures will increase summer moisture stress, resulting in lower growth and possibly lower regeneration in drier locations. Sensitivity to moisture stress will be higher in conifers than in woodland species, and will vary greatly by landscape position (e.g., north vs. south aspects). Singleleaf pinyon in low-elevation woodlands in northern New Mexico has already experienced significant mortality from prolonged drought and Ips beetles during the past 15 years. The indirect effects of a warmer climate, primarily through increased wildfire occurrence, will probably greatly outweigh the effects of gradually changing temperature in most species.

Expected effects of climate change
Most of the species in this forest type are drought tolerant and are therefore expected to persist, although perhaps with lower growth and productivity. Most species are also well adapted to wildfire through resistance to direct impacts or through regeneration. Limber pine (late seral) is drought tolerant, but may be challenged by mountain pine beetles, white pine blister rust, and increased (usually fatal) wildfire.

Douglas-fir and white fir (late seral) are not as drought tolerant as other mixed conifer species. Their growth will probably decrease in a warmer climate, and although Douglas-fir has relatively high fire tolerance, white fir tolerates fire only when it is very mature. In a warmer climate with more fire, it will be increasingly difficult for these conifer species to compete with early-seral and woodland species that are more tolerant of both drought and fire. Therefore, it is likely that those early seral species will become more dominant in the future, and the late-seral species will become less common and perhaps confined to north aspects and valley bottoms.

Adaptive capacity
As wildfire becomes more frequent, fire-adapted species will have significant capacity to survive direct fire impacts (ponderosa pine, Douglas-fir), regenerate after fire (ponderosa pine, Jeffrey pine, Douglas-fir), and sprout after fire (aspen, bigtooth maple, curlleaf mountain mahogany, Gambel oak). Therefore, much of the functionality of this forest type may be retained, although the distribution and abundance of species may shift over time in response to repeated disturbances. Twoneedle pinyon and singleleaf pinyon are very drought tolerant, and although they are typically killed by intense fire, they can usually regenerate successfully.

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VULNERABILITY ASSESSMENT — FOREST VEGETATION

Habitat, ecosystem function, or species
Aspen mixed-conifer forest

Broad-scale climate change effect
Increased temperatures, increased summer drought stress, increased area burned

Current condition, existing stressors
This forest type has diverse composition, distinguished by the prominent role of quaking aspen as an early-seral species, often in combination with other conifer and woodland species. Various insects and root diseases are common, but not particularly related to climatic stress. Some forests are increasingly susceptible to wildfire where stands are dense as a result of fire exclusion.

Sensitivity to climatic variability and change
This forest type is generally water limited in the summer, so higher temperatures will increase summer moisture stress, resulting in lower growth and possibly lower regeneration in drier locations. Sensitivity to moisture stress will be higher in conifers than in woodland species, and will vary greatly by landscape position (e.g., north vs. south aspects). Singleleaf pinyon in low-elevation woodlands in northern New Mexico have already experienced significant mortality from prolonged drought and Ips beetles during the past 15 years. For most species, the indirect effects of a warmer climate, primarily through increased wildfire occurrence, will probably outweigh the effects of gradually changing temperature.

Expected effects of climate change
Response to climate change will depend on local species composition, ranging from high to low elevation, and from north to south aspects. Increased wildfire frequency and extent will be the primary factor determining future composition and structure of aspen-mixed conifer forests. Most of the higher-elevation, late-seral species in this forest type (firs, Engelmann spruce) are readily killed by wildfire, especially when immature, so if wildfire reaches into the subalpine zone, mature spruce-fir forests will become less common, or will persist only on north slopes and in valley bottoms. Therefore, early-seral species, especially aspen, will attain increasing dominance because of their ability to resist fire or regenerate after it occurs. This will also be true at the lower-elevation range of this forest type, where species such as ponderosa pine can readily survive intense fires, and other species such as aspen and Gambel oak sprout aggressively after fire. Productivity in these systems will probably be lower in a warmer climate with more fire, but the more fire tolerant species will persist, especially in drier locations where they can outcompete species that are susceptible to drought and fire.

Adaptive capacity
As wildfire becomes more frequent, fire-adapted species will have significant capacity to survive direct fire impacts (ponderosa pine), regenerate after fire (ponderosa pine, Douglas-fir), and sprout after fire (aspen). Therefore, much of the functionality of this forest type may be retained, although the distribution and abundance of species may shift over time in response to repeated disturbances.

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VULNERABILITY ASSESSMENT — FOREST VEGETATION

Habitat, ecosystem function, or species
Persistent aspen forest

Broad-scale climate change effect
Increased temperatures, increased summer drought stress, increased area burned

Current condition, existing stressors
This forest type has diverse composition, distinguished by the persistence of quaking aspen for several decades, often in combination with other conifer and woodland species. Persistent aspen forest extends across several thousand feet in elevation, typically in low productivity sites where conifer species do not compete well. Succession proceeds slowly, even in the absence of wildfire, especially at the higher-elevation end of the subalpine zone. Various insects and diseases affect aspen, but they are not particularly related to climatic stress.

Sensitivity to climatic variability and change
This forest type is generally water limited in the summer, so higher temperatures will increase summer moisture stress, resulting in lower growth and possibly lower regeneration in drier locations. Sensitivity to moisture stress will be higher in conifers than in woodland species, and will vary greatly by landscape position (e.g., north vs. south aspects). Singleleaf pinyon in low-elevation woodlands in northern New Mexico have already experienced significant mortality from prolonged drought and Ips beetles during the past 15 years. For most species, the indirect effects of a warmer climate, primarily through increased wildfire occurrence, will probably outweigh the effects of gradually changing temperature.

Expected effects of climate change
The late-seral species in this forest type (firs, spruces) are readily killed by wildfire, especially when immature, so assuming that increasing wildfire reaches into the subalpine zone, it is likely that mature spruce-fir forests will become less common, or will persist only on north slopes and in valley bottoms. Therefore, aspen will maintain and perhaps increase dominance because of its ability to sprout aggressively after fire.

This will also be true at the lower-elevation range of this forest type, where species such as ponderosa pine can readily survive intense fires, and other species such as aspen and Gambel oak sprout aggressively after fire. Douglas-fir will probably persist at some locations on the landscape because it has relatively high drought tolerance and fire tolerance. Productivity in these systems will probably be lower in a warmer climate with more fire, but the more fire tolerant species will persist, especially in drier locations where they can outcompete species that are susceptible to drought and fire.

Adaptive capacity
As wildfire becomes more frequent, fire-adapted species will have significant capacity to regenerate after fire (ponderosa pine, Douglas-fir), and sprout after fire (aspen, Gambel oak). Therefore, much of the functionality of this forest type may be retained, although the distribution and abundance of species may shift over time in response to repeated disturbances.

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VULNERABILITY ASSESSMENT — FOREST VEGETATION

Habitat, ecosystem function, or species
Montane pine forest

Broad-scale climate change effect
Increased temperatures, increased summer drought stress, increased area burned

Current condition, existing stressors
Ponderosa pine is a dominant species in drier montane locations through much of the IAP region. Several other conifer species are included in this forest type, but are rarely as abundant as ponderosa pine, except in wetter locations (north aspects, valley bottoms). Ponderosa pine is persistent in these systems because it is drought and fire tolerant. Periodic drought is a chronic stressor in these forests, as are bark beetles (major) and mistletoe (minor).

Sensitivity to climatic variability and change
This forest type is generally water limited in the summer, so higher temperatures will increase summer moisture stress, resulting in lower growth and possibly lower regeneration in drier locations. Sensitivity to moisture stress in conifers will vary by landscape position (e.g., north vs. south aspects, high vs. low elevation). Because ponderosa pine is so fire tolerant, sensitivity to increased wildfire will be relatively low, except in locations where stem densities and fuel loadings are high.

Expected effects of climate change
Increased frequency and magnitude of drought, and consistently drier soils will cause ponderosa pine (and other co-occurring species) to grow slower, but mortality will be rare unless drought lasts for several consecutive years and bark beetles cause additional stress. The expected increase in frequency and extent of wildfire will favor ponderosa pine over its less fire tolerant competitors, thus ensuring dominance in most forests, although limber pine and bristlecone pine will probably persist at higher elevations where fuel loads are typically low. An exception might be in areas where fire exclusion has increased stand density and fuel loads conducive to crown fires, but even then, regeneration of ponderosa pine will probably be sufficient to maintain dominance after fire. If bark beetles become more prevalent in a warmer climate, they could increase stress and mortality in pine species, especially during drought periods.

Adaptive capacity
As wildfire becomes more frequent, fire-adapted species, mostly ponderosa pine in this case, will have significant capacity to both resist fire-caused mortality and regenerate after fire. Therefore, much of the functionality of this forest type may be retained, as long as ponderosa pine remains the dominant species. Increased wildfire could serve to promote restoration of species composition and the role of periodic fire in many locations.

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VULNERABILITY ASSESSMENT — FOREST VEGETATION

Habitat, ecosystem function, or species
Riparian forest

Broad-scale climate change effect
Increased temperatures, increased summer drought stress, decreased snowpack, increased area burned

Current condition, existing stressors
Riparian forests are distributed at high and low elevation throughout the IAP region, adjacent to lakes, streams, seeps, springs, and high water tables. Vegetation is diverse, including a broad range of conifer and hardwood species, some of which occur only in riparian systems, providing valuable habitats for many wildlife species. In some lower-elevation, drier locations, non-native saltcedar and Russian olive have been present for many decades, displacing native species, reducing available groundwater, and in some cases dominating the forest community. Livestock grazing has caused considerable damage to riparian systems in some locations.

Sensitivity to climatic variability and change
Higher temperatures will accelerate evapotranspiration as soils dry faster, and vegetation takes up water earlier and faster during the growing season. Both surface and subsurface water flows will decrease as snowpack decreases and melts earlier, precluding recharge during dry summers. The co-occurrence of these effects will reduce growth and productivity of existing riparian vegetation, potentially creating stress during late summer

Expected effects of climate change
Riparian forests will be highly vulnerable in a warmer climate because they depend on reliable water supplies. At a minimum, reduced water availability will alter vegetation dominance to species that are more tolerant of seasonal drought, including ponderosa pine and other deep-rooted conifers. Hardwood species that rely on periodic high water levels for regeneration (e.g., cottonwood, willow) could become less common. Riparian forests associated with small or transient water sources (e.g., springs) will be more susceptible than forests near large water sources (e.g., rivers). Low-elevation riparian forests near small water sources will be more susceptible than high-elevation forests that have persistent snowpack. Species composition could change quickly in some areas.

Adaptive capacity
Most riparian tree species have limited capacity to respond favorably to a warmer climate, with the exception of (1) ponderosa pine, which may become more dominant because it tolerates low soil moisture, and (2) saltcedar and Russian olive, which tolerate low soil moisture and are already dominant in many sites. Control of saltcedar with tamarisk beetle, which has proven to be highly effective in many locations, would improve the resilience of native flora to low soil moisture in riparian areas.

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VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Over half of the IAP region is dominated by non-forest vegetation types (table below), and of these, mountain big sagebrush shrublands and pinyon-juniper woodlands and shrublands make up a significant portion.

Percent cover of dominant non-forest vegetation types for each geographic area in the IAP region.

Cover type	IAP Region	Middle Rockies	Southern Greater Yellowstone	Uintas and Wasatch Front	Plateaus	Great Basin and Semi Desert
Forest	49.3	62.0	65.5	55.4	45.6	15.0
Non-forest	50.7	38.0	34.5	44.6	54.4	85.0
Pinyon-juniper shrublands and woodlands	12.6	0.0	0.0	4.9	29.2	37.0
Oak-maple woodlands	2.2	0.0	0.1	9.7	4.4	0.5
Mountain mahogany woodlands	2.1	0.1	0.0	2.3	3.2	6.1
Mountain big sagebrush shrublands	13.0	17.9	12.0	13.4	3.5	11.4
Dry big sagebrush shrublands	6.5	2.3	0.5	5.4	3.3	20.2
Mountain shrublands	2.2	3.7	2.8	1.4	1.4	0.3
Dwarf sagebrush shrublands	1.2	0.7	0.0	0.3	4.3	1.6
Blackbrush shrublands	0.5	0.0	0.0	0.0	0.1	2.2
Salt desert shrublands	0.3	0.0	0.1	0.4	0.3	1.1
Grasslands	4.3	9.9	2.1	1.0	0.7	1.9
Subalpine forb	2.5	1.6	7.9	2.4	1.5	0.6
Alpine	1.6	0.5	5.7	1.6	1.0	0.3
Riparian	1.3	0.5	1.6	1.9	1.5	1.8
Wetland	0.6	0.7	1.6	0.0	0.0	0.2

The following table is a summary of the vulnerability ratings for the non-forest vegetation types that occur within the IAP region. Ratings are based on numerical values given to each of five categories for sensitivity and resilience ratings (low, low-moderate, moderate, moderate-high, and high).

- A value of 5 was given to vegetation types that have high sensitivity to climate change and a value of 1 was given to those with low sensitivity.
- Conversely, a value of 5 was given to vegetation types that have a low resilience to climate change, and a value of 1 was given to those with high resilience.

Scores for sensitivity and resilience were combined to provide a consistent means for determining vulnerability of non-forest vegetation types to the expected effects of climate change. For example, those ecosystems with highest sensitivity score (5) and lowest resilience score (5) to climate change effects, such as alpine and dry big sagebrush shrublands, were given the highest scores and, therefore, the highest vulnerability ratings. At the other extreme, those ecosystems with the lowest sensitivity score (1) and the highest resilience score (1), were given the lowest vulnerability ratings. In the IAP region, the mountain shrublands received the lowest vulnerability rating of low-moderate because of their low to moderate sensitivity and moderate to high resilience ratings.

We feel that this system creates a transparency in this process and a means to assess and evaluate new information as it becomes available in the understanding of how climate change is likely to affect landscapes.

Vulnerability ratings for non-forest vegetation types in the IAP region.

Vegetation cover type	**Sensitivity rating**	**Sensitivity score**	**Adaptive capacity rating**	**Adaptive capacity score**	**Combined score**	**Vulnerability**
Alpine	H	5	L	5	10	Very High
Dry big sagebrush shrublands	H	5	L	5	10	Very High
Low-elevation riparian	H	5	L-M	4	9	High-Very High
Subalpine forblands	H	5	L-M	4	9	High-Very High
Grasslands	H	5	L-M	4	9	High-Very High
Mountain mahogany woodlands	H	5	L-M	4	9	High-Very High
Mountain big sagebrush shrublands	M-H	4	L-M	4	8	High
Persistent pinyon-juniper woodlands	H	5	M	3	8	High
High-elevation riparian	M-H	4	L-M	4	8	High
Salt desert shrublands	M	3	L-M	4	7	Moderate-High
Mid-elevation riparian	M-H	4	M	3	7	Moderate-High
Blackbrush	L-M	2	L	5	7	Moderate-High
Dwarf sagebrush shrublands	M-H	4	M-H	2	6	Moderate
Sprouting big sagebrush	M	3	M	3	6	Moderate
Oak-maple woodlands	L-M	2	M	3	5	Low-Moderate
Mountain shrublands	L-M	2	M-H	2	4	Low-Moderate

VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Habitat, ecosystem function, or species
Pinyon-juniper woodlands

Broad-scale climate change effect
Increasing temperatures and drought

Current condition, existing stressors
Prior to Euro-American settlement, pinyon-juniper (PJ) woodlands were unaffected by fire. They occupied a very small portion of any landscape in the IAP Region, while adjacent ecosystems were maintained as shrublands because of the frequency of fire that kept pinyon and/or junipers from expanding. Through fire suppression and the loss of fine fuels in adjacent shrublands with livestock grazing, PJ communities have expanded greatly at their lower range. Stressors include new proximity to cheatgrass-dominated communities, especially in the southern portion of their range, prolonged droughts, and increasing temperatures.

Sensitivity to climatic variability and change (High)
PJ woodlands are highly sensitive to climate change. Lower elevations of the PJ range will likely be most affected by rapidly increasing temperatures. Climatically-suitable habitat for single-leaf pinyon, western juniper, and Utah juniper will likely contract significantly by the end of the century. Climatically-suitable habitat for two-needle pinyon will also likely contract.

Expected effects of climate change
There is likely to be a great reduction in area dominated by PJ as a result of increased drought and temperatures.

Adaptive capacity (Moderate)
Because of the ability of PJ communities to expand into adjacent shrublands (as a result of fire suppression and loss of fine fuels that once kept this expansion at bay), the amount of land covered by PJ has increase significantly since Euro-American settlement. Woodlands that at one time typically occupied less than 1 percent of the landscape now occupy over 10 percent of the landscape in the IAP region. This expansion of these communities has increased their capacity to r to climate change

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VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Habitat, ecosystem function, or species
Oak-maple woodlands

Broad-scale climate change effect
Increasing temperatures, increasing wildfire area burned

Current condition, existing stressors
More frequent fire could make these landscapes more susceptible to invasive species, of which there are many adapted to these mesic sites with relatively productive soils.

Sensitivity to climatic variability and change (Low–Moderate)
Gambel oak may expand into Idaho and Montana, and possibly Nevada, by the end of the century, but abundance may decrease in its current range. Similarly, bigtooth maple may expand into eastern Idaho and Montana, but decrease in abundance in its current range.

Expected effects of climate change
These woodlands may experience a shift in their locations, but overall should not affected by climate change to the same degree as nearly all other vegetation types in the region.

Adaptive capacity (Moderate)
These ecosystems have moderate adaptive capacity to climate change because: 1) communities are highly diverse with a great number of species associated; and 2) nearly all species resprout following fire.

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VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Habitat, ecosystem function, or species
Mountain mahogany woodlands

Broad-scale climate change effect
Increasing temperatures and drought

Current condition, existing stressors
Mountain mahogany woodlands typically occur in isolated patches on warm, rocky ridges and on other sites with dry, coarse-textured soils, primarily on western or southern exposures. Curlleaf mountain-mahogany is typically killed by fire, and regeneration is only by seedling. Curlleaf has massive, deep roots that enable it to occupy extremely harsh sites and can survive for long periods because of low fuel levels and infrequent fire in its habitat. On sites that have resisted fire disturbance, mahogany trees have been found to be over 400 years old. They are not typically influenced by livestock grazing because of low herbaceous production in the understory, but are important seasonal browse for deer. Invasive species have increased in this type.

Sensitivity to climatic variability and change (High)
Climatically-suitable habitat for curlleaf mountain mahogany will likely decrease with climate change. This type will likely be sensitive to increasing temperatures and drought.

Expected effects of climate change
Curlleaf mountain mahogany woodlands will likely contract in area with rapidly increasing temperatures and ongoing severe droughts. However, this type may be able to occupy similar sites as they become available at higher elevations.

Adaptive capacity (Low–Moderate)
Frequent, low-intensity understory fires and fires on adjacent landscapes prior to Euro-American settlement generally restricted mountain mahogany woodlands to extremely rocky sites where fuels were sparse. The absence of fire has allowed curlleaf mountain mahogany to expand to some degree and occupy new habitats, although not nearly to the extent that PJ has. However, invasive species have become an issue in this type, and curlleaf mountain mahogany does not sprout following fire, thus lowering the adaptive capacity of this type. In addition, these ecosystems generally do not have a high level of diversity in associated species and sites on which they occur.

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VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Habitat, ecosystem function, or species
Mountain big sagebrush shrublands

Broad-scale climate change effect
Warming temperatures, decreasing snowpack and increased area burned

Current condition, existing stressors
Most acres of this cover type are used for domestic livestock grazing because of the palatable herbaceous undergrowth. While most are properly grazed at this time, many acres of this type were overgrazed historically. These landscapes typically have high shrub cover as well as high bare ground, low vigor of native herbaceous species, and as a result, likely have non-native, invasive plant species present in varying amounts. Fire suppression and historical grazing of fine fuels have resulted in a significant number of acres of mountain big sagebrush being converted to pinyon-juniper, particularly at lower elevations, where Wyoming big sagebrush also occurs. In addition, many acres of both mountain big sagebrush and Wyoming big sagebrush have been planted to crested wheatgrass, which has been maintained in near-monoculture states and has resulted in decreased biodiversity and availability of habitat for sage grouse and other sagebrush-dependent species, as well as pollinators. Prolonged improper livestock grazing, native ungulate herbivory, and non-native invasive plants are the primary stressors. Loss of topsoil can occur if vegetation density and cover decline and bare ground increases, primarily because of ungulate impacts (e.g., grazing and mechanical/hoof damage).

Sensitivity to climatic variability and change (Moderate–High)
Increased temperatures, even with additional precipitation, will reduce available soil moisture and increase effective drought for this vegetation type. In addition, mountain big sagebrush is killed by fire. With increased area burned, there will likely be a shift in community composition in favor of fire-adapted herbaceous species or non-native invasive species. Other fire-adapted shrub species may increase, particularly following fire. In addition, more spring and winter precipitation may facilitate establishment of exotic annual grasses (particularly annual bromes, [e.g., cheatgrass] which germinates in the winter/early spring]) because they can set seed earlier than the native perennial grasses, particularly in the lower elevation basin big sagebrush communities. Exotic annual grasses form a continuous fine fuel layer, which can burn easily by late spring/early summer and burn sagebrush and native perennial grasses before they have matured and set seed. In turn, other non-native invasive species (e.g., knapweeds, Dalmatian toadflax, butter-and-eggs, sulphur cinquefoil) respond favorably after fire, and if present, will increase in both cover and density.

Expected effects of climate change
Historically, the fire return intervals for mountain big sagebrush were relatively short (typically less than 25 years) compared to Wyoming big sagebrush (>100 years). Mountain big sagebrush regenerates from seeds shed from nearby unburned plants and typically recovers between 30 and 40 years after fire. With a warmer and drier climate, however, sites may not be as favorable for post-fire vegetation regeneration (from sprouting, regrowth, or from seed). Since there is no viable sagebrush seed bank, if fires burn large areas and there are no live, seed-bearing sagebrush nearby, there may be a type conversion to annual grassland. In addition, with a warmer and drier climate, invasive, non-native species will likely either expand into these communities after fire or increase in abundance. It is possible that mountain big sagebrush distribution may shift to cooler and moister sites (e.g., higher elevation, and/or northeast facing

snowloaded depressions). Understory composition may shift to more xeric grassland species, which are more adapted to warmer and drier conditions.

Adaptive capacity (Low–Moderate)

Mountain big sagebrush is not fire-adapted. With warmer and drier conditions, and increased area burned, mountain big sagebrush may decline in both cover and density, or be eliminated under extreme conditions. Over time, especially if flashy fuels such as senesced cheatgrass are present, more frequent fires may eliminate this species from the community. Mountain big sagebrush communities are typically less invaded by non-native invasive species, and cheatgrass and other annual grasses are not as prevalent as on lower-elevation sites dominated by Wyoming and basin big sagebrush. If, however, these sites become warmer and drier, herbaceous understory composition could shift to more xeric species more adapted to drier, warmer conditions, and bare ground may increase. As a result, invasive species, particularly cheatgrass, could expand into and establish dominance in these altered communities.

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VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Habitat, ecosystem function, or species
Dry big sagebrush shrublands

Broad-scale climate change effect
Increasing temperatures and drought

Current condition, existing stressors
Dry big sagebrush shrublands have been significantly altered in response to historical unmanaged livestock grazing following Euro-American settlement. As a result, this type was highly susceptible to the invasions of annual grasses, primarily cheatgrass, but also by medusahead and jointed goatgrass. Many of the landscapes once dominated by dry big sagebrush have been converted to agriculture and other types of development throughout the western United States.

Sensitivity to climatic variability and change (High)
Climatically-suitable habitat for dry big sagebrush shrublands will likely decline with climate change. Sagebrush establishment will likely be more difficult as years with adequate snowfall will become less frequent. Amount and timing of precipitation control seeding establishment at low elevations, because soil water content primarily controls seedling survival. Thus, these ecosystems are highly vulnerable to drought. Even after seedling establishment, drought and increased summer temperature can affect survival and growth of adult plants, because growth is positively correlated with winter precipitation and winter snow depth. As a result, if drought events increase in frequency and severity, big sagebrush biomass and the abundance and diversity of perennial grasses and forbs may decrease.

Expected effects of climate change
Dry big sagebrush shrublands are expected to decline in area as a result of climate change in the IAP region, perhaps more than any other type. These communities have lost their resilience, and they occur at the lowest elevations of the landscapes, where drought will be severe. These effects will be most pronounced in the southern portion of the region.

Adaptive capacity (Low)
Even without the effects of climate change, the adaptive capacity of dry big sagebrush ecosystems to climate change is low to moderate as a result of the effects of historical grazing on composition and structure. Prior to Euro-American settlement in the west, much of the land occupied by Wyoming big sagebrush was dominated by spatially discontinuous perennial grasses that only carried fires when humidity was low and winds were high, or after several wet years when fine fuels were allowed to accumulate. These fire-free intervals were relatively long (100-200 years, or more). Where annual grasses have invaded, fire return intervals have decreased dramatically to less than half that of native sagebrush steppe in the Great Basin. In addition, much of the dry big sagebrush has been fragmented through conversion to agricultural uses, as well as to oil and gas development, which is prominent in the Uinta Basin of eastern Utah.

Various subspecies of big sagebrush often hybridize and have a high level of polyploidy, providing them with the capacity to undergo selection and adapt to shifting climatic regimes relatively quickly. This characteristic creates a greater level of uncertainty with regard to the future distribution of these species, and the ability of the expected new hybrids to survive in changing habitats under future climates.

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VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Habitat, ecosystem function, or species
Sprouting sagebrush shrublands

Broad-scale climate change effect
Warming temperatures, decreasing snowpack, and increased area burned

Current condition, existing stressors
Many of these shrublands have been heavily grazed, because they are generally highly productive. The more mesic conditions have made them more resilient to the effects of grazing.

Sensitivity to climatic variability and change (Moderate)
Warmer and drier climates will have a greater effect on sprouting sagebrush species, which are adapted to more mesic conditions. While these species have the capability of sprouting following disturbance, like all other sagebrush species, seed viability is short-lived and depends on available spring moisture. Regeneration will thus likely be negatively affected by prolonged droughts, and irregular precipitation patterns.

Expected effects of climate change
While sagebrush species in this type have the ability to sprout, their dependence on higher moisture makes them vulnerable to increasing temperatures and drought. Increased fire frequency and severity (particularly in threetip communities) may cause a shift in community composition to dominance by fire-adapted herbaceous species or non-native species. Other fire-adapted shrubs, such as rubber rabbitbrush and green rabbitbrush, may increase. Non-native invasive species, such as dyers woad, various knapweeds, and Dalmatian toadflax, respond favorably after fire, and if present, may increase in cover and density. Sagebrush species may shift landscape position to sites with more moisture and cooler temperatures (e.g., higher elevation, lower landscape position, and northeast aspects)

Adaptive capacity (Moderate)
Sprouting sagebrush can respond quickly following fire, and silver sagebrush can also spread by underground rhizomes and can, therefore, recover more quickly than other species of sagebrush following disturbance. These factors, when combined with the more mesic habitat conditions, confer higher adaptive capacity to sprouting sagebrush shrublands than non-sprouting sagebrush ecosystems.

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VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Habitat, ecosystem function, or species
Dwarf sagebrush shrublands

Broad-scale climate change effect
Warming temperatures, increased drought, and increased area burned

Current condition, existing stressors
Dwarf sagebrush shrublands occur across a broad elevation range, often on sites with shallow or rocky soils, or on soils with high clay content, which makes them more resistant to cheatgrass dominance, and therefore, more resistant to large or severe fires. Pinyon and/or juniper may invade on more mesic sites in the absence of disturbance. Introduced annual grasses may be present and may alter fire regimes. Various species occupy a wide range of sites and have been subjected to impacts from livestock grazing. Natural fires are rare, because fine fuels are typically low, but when they occur, the grass/forb stage can persist for a long time.

Sensitivity to climatic variability and change (Moderate–High)
All low-growing sagebrush species will be affected by higher temperatures and increased periods of drought. As with all sagebrush species, seed viability is short, establishment is dependent on spring soil moisture, making them susceptible to prolonged droughts and to any changes in timing and amount of spring moisture.

Expected effects of climate change
Climate change is likely to result in shifts in the distribution of dwarf sagebrush species in the region. All low sagebrush species are intolerant to, and do not sprout following, fire. However, because of the inherent low productivity of these sites, they are much less likely to be invaded by cheatgrass and other species that promote high-intensity fires. As a result, these ecosystems are much more likely to resist a significant change in fire regimes. These sites will, however, be exposed to higher temperatures and more erratic precipitation patterns, reducing seedling establishment during unfavorable years.

Adaptive capacity (Moderate–High)
None of the dwarf sagebrush species are capable of sprouting following fire, with the possible exception of hybrids between black and silver sagebrush. Sprouting is thought to be a heritable trait in crosses between non-sprouting and sprouting sagebrush species. As with other sagebrush species, hybridization may also play a role in increasing capacity of dwarf sagebrush species to adapt to climate change. In central Nevada, black sagebrush commonly forms hybrids at all elevations. Lahontan low sagebrush is said to be a stable hybrid between low sagebrush and Wyoming big sagebrush. However, the relatively low productivity characterizing these dwarf sagebrush sites may limit adaptive capacity, especially if other risk factors are present. Of all these low sagebrush species, scabland sagebrush appears to have a much narrower range of elevations in which it occurs and may be the most susceptible to the effects of climate change.

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VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Habitat, ecosystem function, or species
Mountain shrublands

Broad-scale climate change effect
Warmer temperatures, declining snowpacks, and more frequent and severe drought

Current condition, existing stressors
Stressors include fire exclusion and conifer establishment, browsing by both native wildlife and domestic livestock, as well as insects and disease. While these mesic sites are easily occupied by invasive species, they typically have a high diversity and density of native woody and herbaceous species.

Sensitivity to climatic variability and change (Low–Moderate)
Mesic shrubs are well-adapted to frequent fire, and under the right conditions, can actually expand and outcompete regenerating conifers. However, with warmer temperatures, declining snowpack, and more frequent and severe droughts, plants may be stressed and fires may cause greater mortality, depending on site conditions.

Expected effects of climate change
With warmer temperatures and drier soils, some mesic shrub species may shift their distribution up in elevation or to cooler, moister sites (e.g., northeast facing depressions). However, mountain shrublands have high species diversity, broad distribution, and occur across a wide range of elevations, all of which will likely make them more resilient to climate change. Even with increasing temperatures and uncertain precipitation, these species are probably the most capable of expanding into niches at higher elevations and onto adjacent, more mesic portions of the landscapes in which they occur.

Adaptive capacity (Moderate–High)
Most montane shrubs sprout following fires, and mountain shrublands were historically maintained by relatively frequent fire. As noted above, the diversity of species in these communities is often quite high. High diversity, coupled with the broad elevation range over which they occur, adds to the adaptive capacity of these shrublands. However, the potential for more area burned by wildfire moderates this resilience. As sites become drier, there may be a shift away from mesic species to more xeric, fire-adapted, sprouting shrubs, such as rubber rabbitbrush and green rabbitbrush. Non-native invasive plant species often expand into these communities, particularly following fire. Loss of topsoil following frequent, hot fires can lead to loss of these species over time.

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VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Habitat, ecosystem function, or species
Blackbrush shrublands

Broad-scale climate change effect
Increasing temperatures, increasing area burned by wildfire

Current condition, existing stressors
Blackbrush shrublands are very limited on national forest lands in the IAP region, occurring at the lowest elevations on the southern edge of the region in the Spring Mountains National Recreation Area of the Humboldt-Toiyabe National Forest and on the Moab District of the Manti-LaSal National Forest. Two distinct genotypes of blackbrush occur in the region, one in the Plateaus geographic area and the other entering the Great Basin and Semi Desert geographic area from the adjacent Mojave Desert to the south. The populations that occur in the region that are closely allied with the Mojave Desert have seen significant increases of red brome in the understory. These communities have been, and continue to be, at the greatest risk of loss from fire, which historically played an insignificant role in these shrubland communities.

Sensitivity to climatic variability and change (Low–Moderate)
Blackbrush has relatively low sensitivity to the direct effects of climate change. It is an evergreen shrub that is well adapted to high temperatures, and it has a rooting system that allows for access to deep soil water. However, blackbrush shrublands lack resistance to invasion by exotic species and do not sprout following fire.

Expected effects of climate change
With climate change, there may be some expansion of blackbrush communities onto adjacent sites that are currently higher in elevation and/or have somewhat higher available soil moisture. This expansion will be most likely in the Plateaus geographic area where invasive species have had less impact on fire and replacement of existing blackbrush communities. It is much less likely, however, on national forest lands with closer proximity to the Mojave Desert, where replacement of blackbrush is already having a large impact.

Adaptive capacity (Low)
Blackbrush communities have little resistance to the invasion of exotic plant species and have very low resilience to the fires accompanying this invasion. Large areas of blackbrush in the Mojave Desert, where red brome has increased significantly, have burned in the past decade, and because blackbrush is a non-sprouting species following fire, these communities are unable to recover. In addition, there is a very high level of genetic differentiation between populations that occur in the Mojave Desert (those of the Spring Mountains in southern Nevada) and those of the Colorado Plateau (Dixie and Manti-LaSal National Forests), which has implications for population persistence and migration in response to climate change.

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VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Habitat, ecosystem function, or species
Salt desert shrublands

Broad-scale climate change effect
Warming temperatures, increased CO_2, and increased area burned by wildfire

Current condition, existing stressors
Salt desert shrublands are a minor component on national forest system lands. They occur primarily in the Utah and Nevada portions of the region, where their distribution on national forest lands is limited to lower elevations. They are, however, extensive on adjacent lands managed by the Bureau of Land Management in Nevada and Utah.

Sensitivity to climatic variability and change (Moderate)
Many of the species associated with salt desert shrublands have wide ecological distributions and may be well suited to endure a more variable and stressful climate. However, many of the species that characterize salt desert ecosystems evolved in the near absence of fire and are fire intolerant. During the El Nino years of 1983-1985, fine fuels increased significantly, likely the result of introduced annual grasses becoming established in these previously fuel-deficient ecosystems. It was following these years that fire became a critical factor, where historically it had been insignificant, at most.

Expected effects of climate change
While there are a great number of species that can and do occupy salt desert shrubland sites, these communities are becoming more susceptible to invasion by cheatgrass, and fertilization effects of increased CO_2 may result in increased invasion by cheatgrass and red brome. Invasion by these species increases fine fuel levels and fire risk. Because none of the overstory species in salt desert shrubland communities are adapted to fire, they will be vulnerable to increased fire.

Adaptive capacity (Low–Moderate)
Salt desert shrublands are particularly susceptible to invasion by non-native halophytic species such as halogeton and prickly Russian thistle. Halogeton, once established in a salt desert shrubland community, typically prevents regeneration of native shrubs, such as winterfat. Today, halogeton stands are often found adjacent to remnant winterfat communities throughout the Great Basin. Cheatgrass establishment in warm and dry salt desert communities is limited by low and sporadic precipitation, but has been observed to be increasing. With increasing cheatgrass comes the potential for impacts from fire, which was not historically a significant disturbance factor in these communities.

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VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Habitat, ecosystem function, or species
Alpine

Broad-scale climate change effect
Warming temperatures and decreasing snowpack

Current condition, existing stressors
Alpine plant communities are diverse and complex across the IAP region and can include a variety of growth forms, including upland krummholz, shrublands, grassland and herbaceous communities, herbaceous wetlands, as well as sparsely vegetated bedrock and scree communities. Current conditions are highly variable, but the introduction of mountain goats, a non-native species, to nearly every mountain range with alpine habitats in Utah and the Ruby Mountains in Nevada has the potential to impact vegetation, introduce noxious and invasive weeds, and result in a reduction of ground cover and increased erosion.

Sensitivity to climatic variability and change (High)
Alpine plants have adapted to alpine environments through morphological traits (e.g., small leaves, low growth forms), physiological traits (e.g., low thermal requirements for photosynthesis) and life history traits (largely perennial life histories) that facilitate growth and reproduction. The length and depth of snow cover, which are strongly correlated with mean temperature and precipitation, are key factors controlling alpine ecosystems. Snow cover provides frost protection for plants in the winter and water supply in spring. It has been reported that for every degree Celsius increase in air temperature, the snowline is expected to rise by about 150 m. Since about 1950, snowpack has been declining at most monitoring sites in the Great Basin. In addition to direct effects of changing temperatures and precipitation, alpine plants may be affected by new competitors moving into their habitat.

Expected effects of climate change
Alpine ecosystems are sensitive to climatic factors, and climate change effects will depend on the different vulnerability thresholds of the species and the rate and magnitude of the changes over time. Because of the isolation and distance between alpine communities, they often have a relatively high number of endemic species. This isolation means that endemic alpine biota is extremely vulnerable to climate change and has a disproportionately high risk of extinction.

Adaptive capacity (Low)
Plant species in alpine ecosystems are at high risk from the effects of climate change because their habitats are quickly being eliminated, and they have limited geographic space into which they can expand. In addition, the physiological traits that allow their persistence in alpine climates also reduce their ability to adapt to changing climates.

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VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Habitat, ecosystem function, or species
Subalpine forblands

Broad-scale climate change effect
Warming temperatures and decreasing snowpack

Current condition, existing stressors
Subalpine forblands have been lost as a result of historical livestock. Productive top soil has been lost on many sites as a result of heavy grazing, which has altered the ability of many sites to support the establishment and growth of characteristic species. Sites can recover over time once livestock have been removed. This is not always the case, however, as is illustrated by the dense cover of tarweed that remains in place in the Bear River Range years after tall forbs were lost as a result of livestock grazing and loss of topsoil.

Sensitivity to climatic variability and change (High)
Subalpine forb communities occupy a narrow elevation range, limiting the ability of characteristic species to respond to reduced snowpacks and increasing temperatures. These communities respond to summer rainfall, and it is unclear whether or not summer precipitation events will increase or decrease. Higher temperatures, however, will likely lead to reduced soil moisture and will likely alter the conditions necessary to support these unique ecosystems.

Expected effects of climate change
While some subalpine forb communities may be able to move upward in elevation, where alpine environments currently occur, the lack of soil development at these higher elevations may only support lower-growing species. In some areas, such as the Wasatch Plateau in central Utah, which is home to some of the largest stands of this type, these forblands occupy the highest elevations, meaning they cannot shift to higher elevations with changing climate.

Adaptive capacity (Low–Moderate)
Much of the adaptive capacity of subalpine forblands has been lost as a result of historically high levels of grazing. Many sites have lost a significant amount of top soil and are no longer productive. On many less-impacted sites, species composition has shifted to less-palatable species.

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VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Habitat, ecosystem function, or species
Mountain and desert grasslands

Broad-scale climate change effect
Warming temperatures, decreasing snowpack, and increased area burned by wildfires

Current condition, existing stressors
Many low elevation grasslands have been converted to agricultural lands, are used for domestic livestock grazing, and/or are subject to extensive human use and land-use conversion. Those grasslands that remain, particularly in the lower elevations, are typically highly-disturbed and fragmented, and have been invaded by many non-native, invasive plant species. Prolonged improper livestock grazing, native ungulate herbivory, and non-native invasive plants are the primary stressors. Loss of topsoil can occur if cover and density of vegetation decline and bare ground increases.

Sensitivity to climatic variability and change (High)
C_3 grasses are adapted to cool and wet springs, while warm season (C_4) grasses, occur in areas with warm, wet summers, and are more common in the southern extremes of the region where monsoonal influences are the greatest. Most grassland species regrow quickly after fire. Higher temperatures will likely favor C_4 grasses, but C_3 grasses will likely respond positively to increasing CO_2.

Expected effects of climate change
Increasing temperatures early in the spring, especially when combined with elevated CO_2, will likely promote the growth of annual C_3 grasses, such as cheatgrass. Annual C_3 grasses create a continuous fine fuel layer, which can burn easily by early summer and burn native perennial grasses before they have matured and set seed. In turn, other non-native species (e.g., various knapweeds, Dalmatian toadflax, butter-and-eggs, sulfur cinquefoil) respond favorably after fire, and if present, will increase in cover and density. It is likely that with warming and more frequent fires, annual grasslands and invasive forblands will become more dominant landscape components, as perennial grasslands, shrublands and woodlands, are burned and unable to regenerate.

Adaptive capacity (Low–Moderate)
Prolonged improper livestock grazing, native ungulate herbivory, and non-native invasive plants have all reduced the capacity of mountain and desert grasslands to respond to climate change. With climate change, there is an increased risk of invasion by non-native annual grasses, especially at lower elevations, increasing risk of fire and mortality of native perennial grasses.

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VULNERABILITY ASSESSMENT — NON-FOREST VEGETATION

Habitat, ecosystem function, or species
Riparian and wetland ecosystems

Broad-scale climate change effect
Warming temperatures, decreasing snowpack, shifting timing of snowmelt, lower summer streamflows

Current condition, existing stressors
Most riparian and wetland systems have been altered from historical conditions, resulting in changes in stream geomorphic and hydrologic processes, including stream-downcutting and channel straightening, which have decreased water availability to riparian ecosystems. Stream discharge has been reduced as a result of the construction of dams and water diversions. These systems have also been affected by domestic livestock use, concentrated recreation uses, road construction, and non-native invasive species.

Sensitivity to climatic variability and change (Moderate–High)
Water availability will be reduced in a warming climate because of earlier snowmelt and runoff, reduced summer streamflows, and increased drought. Plant community composition and structure will be affected by increased water stress, and drought-tolerant species are likely to replace those riparian and wetland species more dependent on water. Geomorphic and hydrologic processes and dynamics that have been responsible for riparian and wetland ecosystem development at lower elevations have already been affected by construction of dams and water diversions in most places. These existing stresses are likely to be exacerbated by changes in peak and base water flows. Many species are dependent on flooding to transport and deposit sediments and provide bare, moist substrates necessary for seed germination and establishment. Thus, riparian and wetland species will likely be sensitive to any shifts in the timing and magnitude of flooding with climate change.

Expected effects of climate change
Mid-elevation riparian plant species may have the ability to move upward in elevation as sites become warmer. However, because natural resilience has been compromised, these systems will be less able to adjust to changes in environment. Invasive species already dominating many mid-elevation sites will likely expand. As riparian areas become drier, upland species will likely become more abundant.

Adaptive capacity (Low–Moderate)
Riparian and wetland ecosystems have the capacity to respond to the effects of climate change, to the extent that they are able to respond to changes in timing and amount of seasonal flows and recharge. However, because their conditions have been compromised through water diversions, damming, livestock grazing, recreation, road construction, and other forms of development, much of that capacity has been lost.

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VULNERABILITY ASSESSMENT — ECOLOGICAL DISTURBANCE

Habitat, ecosystem function, or species
Wildfire regimes

Broad-scale climate change effect
Increasing temperatures and changing precipitation patterns, including direct effects on fire season length and live and dead fuel moistures, and indirect effects on live and dead fuel amount, distribution, and type

Current condition, existing stressors
Decades of fire exclusion have impeded the ecological benefits that result from fire in many areas, resulting in fuel accumulations in systems that historically burned with high frequency at low severity. At the same time, the human populations in the United States has seen a six fold increase over the past 134 years, and that growth is showing no signs of slowing down. New residential construction continues to push outward from communities into the areas that have a higher risk of fire, often creating a wildland urban interface (WUI). The simplistic equation of more people = more homes results in an increase strain on fire responders and wildland fire management organizations. Fire suppression costs have also increased steadily over the past 20 years.

Sensitivity to climatic variability and change
Climate is a strong driver of wildfires, and its influence on fire regimes varies by forest type and region. For example, very dry forests in the western U.S. are typically fuel-limited, so widespread fires occur during periods of increased productivity and fuel accumulation driven by increased growing season precipitation. Conversely, in more mesic forest types, sufficient fuel is typically available to carry fire, but suitably dry conditions for fire spread occur infrequently.

Expected effects of climate change
Increases in area burned are likely in a warming climate, but fire activity will ultimately be limited by the availability of fuels. Earlier onset of snowmelt and higher temperatures reduce fuel moisture, making a larger portion of the landscape flammable for longer periods of time. This shift may be especially pronounced in middle to high elevation forested systems where fuels are abundant.

Adaptive capacity
The adaptive capacity of a fire-prone ecosystem is strongly influenced by its degree of departure from the historical disturbance regimes under which constituent plant communities have evolved. Areas that are highly departed, such as fire-excluded ponderosa pine forests, may be rapidly and persistently altered by wildfires, especially those that burn under extreme conditions (e.g., hot and dry weather, high winds). Surface and canopy fuels accumulation, homogenous and continuous landscape fuels, and extreme weather acting in combination create the potential for high-severity, stand-replacing fire. Post-fire regeneration of forests may be slowed (e.g., decades to centuries) because of the time required for seed dispersal over large burned areal extents. In addition, the droughty, high temperature conditions associated with anthropogenic climate changes may inhibit seedling establishment and survival.

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VULNERABILITY ASSESSMENT — ECOLOGICAL DISTURBANCE

Habitat, ecosystem function, or species
Bark beetle disturbances

Broad-scale climate change effect
Increased temperatures, increased drought, increased area burned by wildfire

Current condition, existing stressors

Broad-scale climate drivers of bark beetle population outbreaks
All conifer ecosystems in the IAP have at least one bark beetle species that can cause tree mortality (11 species total). Minimum temperatures influence winter survival, and summer/spring/fall temperatures dictate the timing of adult emergence and the number of generations that can be completed. Generally, adding generations produced in a year increases tree mortality. Bark beetles have adapted to local climate, and the number of generations possible in a year is dependent on the species and geographic location. Some species require 2 years for 1 generation, and others can complete 2 or more generations in a single year. Precipitation indirectly affects bark beetle population success through effects on host trees. Increased precipitation can positively influence bark beetles through increased quality and quantity of phloem (the main tree tissue fed on by bark beetles), and short-term severe drought has a positive effect by weakening host tree defenses. Species currently considered secondary (i.e., infest stressed trees), including *Ips* species, could also become primary tree killers as their favored habitat increases.

Landscape characteristics, ecosystem functions, and human systems affected by bark beetles
Each species of bark beetle impacts specific tree species. For example, mountain pine beetle disturbances are only found in pine forests, with the exception of a few species. Generally, bark beetle population outbreaks can be extensive in homogenous host tree forests, often resulting in > 50% tree mortality across thousands of acres. Tree mortality can initially reduce ecosystem carbon productivity, although as surviving and recruited stems grow, carbon productivity and live basal area recover to pre-outbreak levels within a few years or decades. Post-outbreak carbon stocks, however, will depend on pre-outbreak stand structure and composition. In ecosystems affected by mountain pine beetle, post-outbreak conditions for regeneration have been found to be good for lodgepole pine and whitebark pine, although the influence on ecosystem function of high elevation pine ecosystems is less clear. Bark beetle-killed trees of all species can create hazardous conditions in campgrounds, near utility lines, and in the wildland urban interface.

Current status of bark beetle outbreaks within the region
A recent warm and dry period, beginning in 2001, across the western US resulted in extensive bark beetle-caused tree mortality. Within the IAP region, tree mortality caused by pinyon Ips peaked in 2003-04, mountain pine beetle-caused impacts peaked in 2009, and spruce beetle-caused impacts continue to increase in 2014-15. Data taken from forest inventory and analyses (FIA) plots and Forest Health Protection aerial detection surveys (ADS) highlight these impacts. Analysis of FIA plot data suggest that, regionally, insects impacted 2,732,800 acres between 2005 and 2014; this number includes all insects, not just bark beetles. The primary forest type impacted by insects in the region (between 2005 and 2014) was the fir/spruce/mountain hemlock forest type (777,800 acres). Acres of impacted lodgepole pine, Douglas-fir, and pinyon-juniper forest types follow (566,100 acres, 563,000 acres, and 431,100 acres, respectively).

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ADS suggest that, in 2009, at the height of the mountain beetle outbreak, there were 4,707,421 acres of mountain pine beetle-caused mortality. Regional ADS data suggests there were 915,428 acres of spruce beetle-caused mortality in 2014. From 2009 to 2014, the following were the total acres affected by each species: mountain pine beetle: 12,843,912 acres; spruce beetle: 1,571,215 acres; Douglas-fir beetle: 597,055 acres; and Pinyon *Ips*: 17,781 acres.

Sensitivity of bark beetle population outbreaks to climatic variability and change

Temperature is a main driver of bark beetle population survival and population growth. Generally, increasing minimum temperatures will result in increased winter survival for most species. Warming temperatures, however, will not result in a direct and linear response in population. Generation timing must be appropriately timed with the seasons to avoid excess winter mortality, in addition to maintaining synchronized adult emergence that facilitates mass attacks on trees. Changing temperature regimes can either promote or disrupt bark beetle temperature-dependent life history strategies that drive seasonality and length of a generation. Voltinism is the number of generations that can be produced in a single year, and within the IAP region, bark beetle species are multivoltine (more than two generation in a year), bivoltine (two generations in a year), univoltine (one generation in a year), or semivoltine (one generation every two years), depending on the species, location, and annual thermal input. Generally, several consecutive years of favorable temperatures are necessary for population growth, suggesting that high inter-annual variability, which may occur with climate change, may not be advantageous to population outbreaks, although symbiotic associates may benefit. However, severe short-term drought that is associated with warm temperatures can provide a pool of weakened host trees and appropriate thermal conditions for population outbreaks of multiple bark beetle species.

Expected effects of climate change

Warming minimum temperatures are expected to reduce cold-induced mortality of most bark beetle populations, and could result in range expansion northward and upward in elevation. Reduced generation time (i.e., from 1 generation every 2 years to one generation every year) at the highest elevations for both mountain pine beetle and spruce beetle are also predicted. Species already adapted to warm climates (e.g., western pine beetle and *Ips* species) could add extra generations in a year. Generally, adding generations produced in a year will increase tree mortality. However, it is important to consider that changing temperature regimes could also disrupt bark beetle temperature-dependent life history strategies that drive seasonality and length of a generation. Because host tree and stand conditions are also significant drivers of bark beetle outbreaks, the effects of climate change on host tree vigor and stand structure and composition will need to be integrated with predictions of climate effects on bark beetle population success.

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VULNERABILITY ASSESSMENT — ECOLOGICAL DISTURBANCE

Habitat, ecosystem function, or species
Invasive insects

Broad-scale climate change effect
Increased temperatures, changing precipitation patterns, increased area burned by wildfire

Current condition, existing stressors

Broad-scale climate drivers of invasive insect population outbreaks
Invasive insects are often considered non-native, exotic insects that have established on native trees and vegetation and are impacting resource values. Similar to native insects, temperature and precipitation patterns and indirect effects from an increase in severity and frequency of wildfires will affect invasive insect population levels. Escape from specialized predators, parasitoids and pathogens from their home range, and novel interactions with hosts in the invaded range, exacerbated by changes in temperature and precipitation, will likely hasten establishment and impacts by invasive insects, but native generalist natural enemies may also influence invasive insect populations, buffering impacts in some systems.

Current status of invasive insect outbreaks within the region
The current status of invasive insect outbreaks in the IAP region varies from insignificant to significant, with changes in species composition occurring in some ecosystems with invasive insect outbreaks. Larch casebearer has had minimal impacts because of a successful biological control program and native natural enemies. In contrast, balsam woolly adelgid, a non-native piercing/sucking insect, has yet to fully expand to its potential range in western North America and is killing and changing the species composition of some true fir stands by removing subalpine fir of all size classes and affecting growth of some grand fir. There are many more non-native insects on the "watch" list by APHIS and State Regulatory agencies that are being surveyed for and eradicated on occasion, such as European gypsy moth in Utah in the 1990s. If these species establish, we rarely know the degree to which these invasive insects may expand in a newly invaded habitat.

Sensitivity of invasive insects to climatic variability and change
Invasive insects may reduce generation time in a warmer climate. In addition, trees are stressed by changing temperatures and precipitation and will likely be further compromised and more easily attacked by invasive insects with changing climate. The host tree will also have a novel interaction to account for and defend against.

Expected effects of climate change
Balsam wooly adelgid is expected to expand its range to highest elevations of subalpine fir and have impacts on the ecological services those trees provide. Historically, harsh winter conditions may have prevented population establishment or may have limited impacts at the higher elevations. In most invaded systems, additional stress to the vegetation will hasten establishment and magnify impacts.

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VULNERABILITY ASSESSMENT — ECOLOGICAL DISTURBANCE

Habitat, ecosystem function, or species
Forest tree diseases

Broad-scale climate change effect
Increased temperatures, changing precipitation patterns, increased area burned by wildfire

Current condition, existing stressors

Broad-scale climate drivers of forest tree diseases
Climatic variability and change can alter patterns of disease distribution and abundance through (1) direct effects on development and survival of a pathogen; (2) physiological changes in tree defenses; (3) indirect effects on abundance of natural enemies, mutualists and competitors, and (4) interactions with other disturbance agents such as fire, and insects.

Climate change will affect pathogens, hosts, and their interaction; changes in these interactions may become the most substantial drivers of future disease outbreaks. Climate change will have the largest impact on diseases that take advantage of a weakened host. Some diseases may be considered "threshold diseases," meaning they are damaging, but only under certain climatic conditions, and one of the key triggers for this type of disease is the onset of drought stress.

Current status of forest tree diseases within the region
Many forest diseases function as part of the ecosystems they inhabit, and are as widely distributed as the ecosystem itself. In the context of changing climate, the relationships between host and pathogen, and disease and other disturbances could shift.

Only one significant forest disease in the IAP region, white pine blister rust, is an exotic, and the relationships between this disease and its host are still evolving. White pine blister rust is involved in the recent mortality that has driven whitebark pine to near endangered status, and in the long run may be the most consequential damaging agent driving this ecosystem changing event.

Sensitivity of forest tree diseases to climatic variability and change
Some diseases/interactions could be highly sensitive, others will be likely to be unaffected. Sensitive landscapes and ecosystems may experience significantly higher rates of mortality and damage resulting in geographic shifts and contractions of forest vegetation with cascading impacts on other ecosystem components.

Expected effects of climate change
Forest diseases are significant stressors on their ecosystems, and with predicted trends towards warmer, drier climatic conditions, many diseases have the potential to create ongoing synergistic impacts, i.e., the more the climate warms and dries, the more certain diseases will impact ecosystems. However, warmer and drier conditions may be less suitable for some diseases (see table below).

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Summary of expected response of forest tree diseases in the IAP region to climate change.

Disease type or group	Predicted change in impact	Main driver(s) of change	Interacting agent(s)	Likelihood of change
Dwarf mistletoes	Increase	Increased drought stress on hosts	Fire, bark beetles	High
Diebacks and declines	Increase	Increased drought stress on hosts	Fire	High
Root diseases	Increase	Increased drought stress on hosts	Fire, bark beetles	High
Rust diseases	Decrease	Warmer, drier climate may be less suitable for rust infection	Fire, bark beetles	Moderate
Foliar diseases	Decrease	Warmer, drier climate may be less suitable for infection	Limited	Moderate

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VULNERABILITY ASSESSMENT — ECOLOGICAL DISTURBANCE

Habitat, ecosystem function, or species
Invasive plant species (terrestrial and aquatic plants).

Broad-scale climate change effect
Increased temperatures, changing precipitation patterns, increased atmospheric CO_2 concentrations, increased area burned by wildfire

Current condition, existing stressors

Broad-scale climate drivers of invasive plant range expansion
Executive Order 13112 (1999) defines an invasive species as an alien [non-native] species whose introduction causes or is likely to cause economic or environmental harm or harm to human health. Invasive plants are non-native plant species that successfully spread outside their native range causing harm. Temperature and precipitation patterns, atmospheric CO_2 concentration, evolutionary adjustments, human trade activities with direct and indirect introductions, and indirect effects from altered wildfire regimes will drive invasive plant distributions.

Landscape characteristics, ecosystem functions, and human systems affected by invasive plant species
Invasive plant species can affect landscape characteristics, ecosystem functions, and human systems by their economic costs as weeds, reducing native biodiversity and forage, alter ecosystem functions, change nutrient pools, and alter fire regimes.

Current status of invasive plants within the region
The combination of settlement related disturbance prior to 1900, introduction of invasive plants, and subsequent shifts in native vegetation irreparably altered much of the regional vegetation within 50 years. Hundreds of identified invasive plants are established across the IAP region. Currently (2016) many invasive plant species (both annual grasses and perennial forbs) have degraded the non-forested vegetation types of the IAP region by outcompeting native species and by directly affecting the frequency and intensity of wildfires. In contrast, closed canopy forests, in general, act as a physical barrier to plant invasion, as invasive plants are unable to get the sunlight they require to survive in dense forests. Riparian habitats are often most impacted by perennial invasive plant species that displace native vegetation and affect physiographic structure of riparian areas.

Sensitivity of invasive plants to climatic variability and change
It is often assumed that climate change will favor non-native plants over native plants. Although this may be an overgeneralization, attributes associated with successful invaders suggest non-natives could flourish under certain climate change scenarios. For example, many non-natives are fast-growing, early seral species (ruderals) that tend to respond favorably to increased resource availability, including temperature, water, sunlight, and carbon dioxide. Many non-natives respond favorably to disturbances, which can increase resource availability. Despite many native plant adaptations to fire, non-natives may exploit the disturbances associated with post-fire conditions better than many natives. Successful invaders also commonly have strong dispersal strategies and shorter generation times, which can allow them to migrate quickly into freshly disturbed sites. For example in bunchgrass communities, many non-native plants recruit more strongly than do native plants when native vegetation is disturbed, even with equal seed availability.

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Expected effects of climate change

Invasive species are generally inherently adaptable and capable of relatively rapid genetic change, which can enhance their ability to invade new areas in response to ecosystem modifications, including short-term disturbance (fire) or long-term stressors (prolonged drought, increased temperatures, chronic improper grazing). Groups of non-native species can facilitate one another's invasion in various ways, increasing the likelihood of survival and/or ecological impact, and possibly the magnitude of impact, resulting in an accelerating accumulation of introduced species and effects. As more non-native plants establish in the IAP region, and as climate change results in shifts in the environment, certain non-native plants may become more invasive, and the damage to the ecosystems of the IAP region may increase.

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VULNERABILITY ASSESSMENT — ECOLOGICAL DISTURBANCE

Habitat, ecosystem function, or species
Geologic hazards

Broad-scale climate change effect
Warming temperatures will lead to overall decreased water resources because of higher evaporation rates and lower snowpack accumulation. Reduced moisture content in soils will magnify effects of many geologic hazards on forest disturbances and ecosystem functions.

Current condition, existing stressors
Forest disturbances are currently affected by several geologic hazards such as mass wasting processes, including earthquake-triggered mass wasting processes, flooding, snow avalanches, desertification, problem soils and karst terrain. These hazards affect significant areas in many national forests. Many of them are correlated with natural fluctuations in the hydrologic cycle.

Sensitivity to climatic variability and change
Climate change will decrease soil moisture content, significantly increase area burned by wildfires, and in some areas, increase rain precipitation as snow precipitation decreases. These changes will magnify some effects of earthquakes, frequency and magnitude of mass wasting, desertification, and will alter frequency and magnitude of floods. They will also affect problem soils and karst areas.

Expected effects of climate change
Infrastructure, public safety, resource management, and the environment will be affected by increased mass wasting, sediment pollution, and flooding. Maintenance and repair cost will increase. Water use cost will increase because of overall diminishing water resources.

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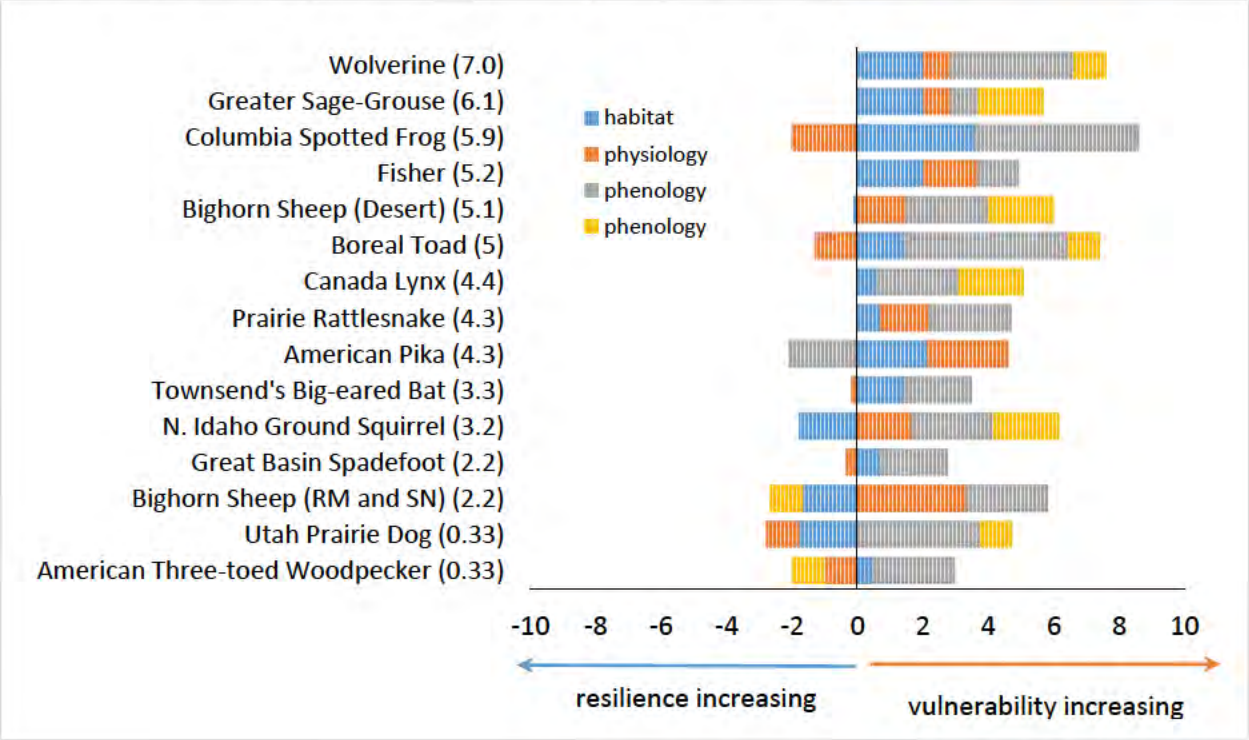
VULNERABILITY ASSESSMENT — WILDLIFE

Vulnerability was assessed for 14 species currently occurring in the IAP region that are of management concern within a time scale of approximately 50 years. Species were chosen to represent a variety of taxonomic groups and a diversity of species' traits responsive to climate change effects.

We used an index-based vulnerability assessment tool to determine how species may respond to climate change. The vulnerability index, System for Assessing Vulnerability of Species to climate change (SAVS) scores species based on predicted response to projected climate change for 21 equally weighted factors. Each factor or species' trait is associated with sensitivity or adaptive capacity in relation to predicted levels of exposure specific to the region of interest. For the purpose of this assessment, we generated scenarios of exposure (e.g., habitat loss) based on future climate and habitat projections within the region. Given the large area encompassed by the IAP region, exposure can be quite variable, and thus vulnerability can also vary for wide-ranging species. We have made note of differences within the region, and in one case (bighorn sheep) provided two sets of scores corresponding to different subspecies.

SAVS divides predictive traits into four categories: habitat, physiology, phenology, and biotic interactions. It is important to consider not just the total scores, but how the scores for individual traits balance. For example, Townsend's big-eared bat and Northern Idaho ground squirrel have a similar overall score of around 3, but that score is made up of stronger opposing predictions for the ground squirrel than for the bat, which tended to be more consistent across all criteria. This implies that the response of the ground squirrel is more uncertain, as it will depend on the strength and interplay of opposing factors.

Species, in order of increasing vulnerability, assessed for the IAP region. Overall scores are presented in parentheses, and categorical scores are indicated with color bars. Overall scores can range from -20 to +20, whereas categorical scores range from -5 to +5.



VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
American pika

Broad-scale climate change effect
Loss of high elevation habitat, increasing barriers to dispersal, increased exposure to heat exceeding physiological threshold, increase exposure to cold exceeding ecological threshold

Interactions with existing stressors
Predicted expansion of cheatgrass at low elevation sites in northern parts of the region may increase vulnerability of resident pika populations.

Sensitivity to climatic variability and change
Pikas are sensitive to both temperature and precipitation changes and they are likely to respond to both indirect and indirect climate change effects. Physiologically, pika are not of tolerate very high or very low temperatures and higher summer temperatures may limit periods when pikas can actively forage. Pika are considered dispersal limited with movements restricted to short distances or along continuous elevational gradients where lowlands do not need to be crossed. Thus, pikas in some locations will have difficulty tracking a geographical shift in habitat. Movements may be facilitated by favorable weather conditions such as years of high precipitation, although the frequency of such conditions in the future is not clear.

Expected effects of climate change
Many consider pikas highly vulnerable to a warming climate as their cool mountain habitats shift upward and occupy less area. Bioclimatic data suggest that if greenhouse gas emissions continue to increase unabated, populations will become increasingly isolated, and pikas may be extirpated in southwest portions of their range, including the Great Basin and Sierra Nevada. Precipitation, particularly during the growing season, has been linked to pika population trends, probably through effects on forage availability. Annual net primary productivity on a broad scale, as a measure of forage quantity, is expected to be enhanced by CO_2 fertilization in more northerly regions, while changes in precipitation will reduce annual productivity in southern regions. Pikas will be the most vulnerable on isolated mountaintops, at lower elevations where pikas may already be near their physiological tolerance, and where primary productivity is expected to decline. Accordingly, populations in the southern Great Basin are likely to be the most vulnerable in the region.

Adaptive capacity
Several areas of potential resilience to climate change have been noted for pika, although the nature of this resilience varies according to landscape context. Pikas have recently been found to occur at lower elevations than previously thought, suggesting a somewhat broader range of temperature tolerance. In warm climates, suitable habitat may be present where temperature is buffered locally in sites with favorable microclimates. At lower elevation sites, pika may not have the same requirements for snow cover, which provides insulation against cold winter temperatures, as is needed to survive at higher elevations. Thus, lower elevation populations may be less vulnerable to reduced snowpack. However, increased summer temperatures are more likely to exceed physiological tolerances in these areas. Additionally, pikas are active year round and can produce more than one litter per year, which may help them take advantage of longer growing seasons. Across the species range, resilient populations are likely to occur in locations that support loosely arranged rocks (rock-ice features, lava tubes), deep rock features, and are in proximity to wetlands or other high quality forage.

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VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
American three-toed woodpecker

Broad-scale climate change effect
Reduced forest area, drier forests, altered timing of beetle development

Interactions with existing stressors
Three-toed woodpeckers appear to be sensitive to salvage logging practices that reduce favored snag species or that occur in mesic areas that are favored by this species.

Sensitivity to climatic variability and change
Climate-induced shifts in the distribution of different tree and bark beetle species could have a negative impact on this species, especially if there are large scale shifts to non-forested habitats. Three-toed woodpeckers could also be sensitive to timing mismatches between breeding events and beetle outbreaks.

Expected effects of climate change
Three-toed woodpecker's diet consists primarily of bark beetles, coinciding with the woodpecker's high mobility and attraction to forest die-offs with bark-beetle outbreaks, fires, pollution, and windthrow. Bark beetle populations in most of the region are not expected to increase from direct effects of warming, because in contrast to Canada, current conditions already favor rapid development and low winter mortality. However, indirect effects of climate change on tree vigor and mortality caused by increased heat and drought is likely increase bark beetle populations and thereby an important food source for the woodpecker. In addition, outbreaks are expected to be more severe and cover larger areas. Woodpecker populations in turn affect beetle populations, because during outbreaks, woodpeckers eat large numbers of beetles and can ameliorate the overall impact of an outbreak. However, potential benefit of increases in forest disturbances must be considered within the broader set of predictions related to forest persistence and tree range shifts. Forests are expected to shift upward in elevation, and fire frequency and size is expected to increase. Disturbance events can speed forest transition to new vegetation types, particularly under altered climate regimes, that may no longer be suitable for three-toed woodpeckers. Thus, favorable landscapes for three-toed woodpeckers will be dynamic, will vary with disturbance events at both a small and large scales, and over time as snags fall, fuel structure changes, and forests regenerate or are replaced by other vegetation types.

Adaptive capacity
Woodpeckers, which are highly mobile and engage in irruptive movements to take advantage of bark beetle outbreaks, are likely to benefit from increased forest die-offs and disturbance. Management of salvage logging following disturbance will likely be an issue of importance in order to ensure the retention of favored snag species and avoidance of more mesic areas that are considered important for three-toed woodpeckers.

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VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Bighorn sheep

Broad-scale climate change effect
Bighorn sheep (Desert) - Prone to dehydration, drought mortality, loss of water sources, reduced activity under high temperatures, timing of high nutrient availability, reduced plant growth, higher disease risk.
Bighorn sheep (Sierra Nevada and Rocky Mountain) - Prone to dehydration, drought mortality, reduced activity under high temperatures, timing of high nutrient availability, increased plant growth, higher disease risk.

Interactions with existing stressors
Bighorn sheep regularly experience large mortality events that counter recovery efforts to reverse declining population trends. Endemic and introduced diseases are important drivers, but complex interactions with livestock, habitat quality, weather, predation, and infectious agents make it difficult to identify a single cause of these die-offs. Parasites that cause scabies and lungworm may expand with warmer temperatures as suitable habitats expand and parasite and host populations develop more rapidly. Potential climate-related changes in the prevalence of scabies and predation within winter ranges are of particular concern for bighorn sheep populations within the Sierra Nevada. Drought, severe weather, and vegetation changes can increase contact with infected individuals and facilitate transmission of pathogens.

Sensitivity to climatic variability and change
Desert bighorn sheep will be more sensitive to increasing drought and high temperatures that reduce forage and standing water. Those populations in the most arid, low elevation areas and without access to dependable springs are most vulnerable. Disease may become or continue to be an issue for all subspecies, because disease transmission might be enhanced under warmer temperatures, and many bighorn populations in the region are small.

Expected effects of climate change
We calculated vulnerability for the desert (*Ovis canadensis nelsoni*) and Sierra Nevada/Rocky Mountain (*O. c. sierra*/*O. c. canadensis*) bighorn sheep subspecies. Different parts of the region, and thus different bighorn subspecies, will be subject to differential changes in climate that are linked to bighorn sheep population dynamics. Fluctuations in precipitation that affects spring forage availability and timing may have significant impacts on Rocky Mountain bighorn sheep populations. Climate changes are likely to facilitate the invasion of more arid vegetation types and reduce primary productivity within the southern portions of the region that are occupied by the desert subspecies. Forage quality might decline in mountainous habitats where warmer springs encourage faster green-up. Changes in snowpack, in conjunction nitrogen deposition, can also reduce forage content of selenium resulting in deficiency and population declines.

Adaptive capacity
Expected reductions in snowpack could increase winter range for the Sierra and Rocky Mountain subspecies. A longer growing season in mountainous areas may benefit bighorn sheep by allowing them to maintain their proximity to escape terrain occurring at higher elevations for a greater proportion of the year. Shifts in winter range could also potentially reduce contact with domestic livestock and competing ungulates. In general, areas with more topographic relief and fewer barriers may be more resilient to negative impacts affecting year-round forage availability.

VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Boreal toad

Broad-scale climate change effect
Loss of wetlands, stream and pond drying, desiccation risk in terrestrial habitats, altered breeding timing, increased risk of chytridiomycosis in some locations

Interactions with existing stressors
Recent population declines have occurred throughout the boreal toad range, including unaltered habitats, and coincide with the introduction of the chytrid fungus *B. dendrobatidis*, although chytridiomycosis may be just one of many drivers of decline. Warmer temperatures are associated with spread of *B. dendrobatidis* in cooler, high elevation habitats, but precipitation and humidity are also important, with more limited infections in warmer drier areas. Seasonality of prevalence and intensity of infection is also affected by temperature, with high severity in winter for tropical climates or summer for temperate climates. Warmer and drier climates have been associated with a lower occurrence of chytrid in Australia and Costa Rica, but die-offs of the Arizona lowland leopard frog illustrate that chytrid can impact amphibians in dry climates as well. Although the mechanism is unclear, boreal toads appear to respond positively to fire, at least in the short term, and may benefit from climate-driven increases in fire frequency.

Sensitivity to climatic variability and change
Like all amphibians, boreal toads are sensitive to water availability and changes in rainfall, high temperatures, and drought. These factors can interact in important ways that affect when and where the toads can be active.

Expected effects of climate change
Boreal toads of the region encompass considerable genetic diversity, with eastern populations in Utah and southeastern Idaho considered distinct from western populations in Nevada and California. A study in Idaho projected significant reductions in activity periods and growth under warmer conditions, especially in more open habitats where desiccation risk is higher. Another study found toads selected refugia within a landscape that possessed favorable microclimates with relatively high relative humidity as compared to surrounding habitats. Juvenile toads are more diurnal and thus may be at an increased risk of reduced growth because of decreased activity under warmer drier conditions. Warmer temperatures may increase rate of metamorphosis but can reduce pond longevity causing tadpole mortality. Warmer temperatures also lead to increased livestock activity at water bodies and increase the risk of trampling and loss of vegetative cover in breeding habitats. Timing and duration of water availability along with the availability of sufficient refugia to avoid predation, cold, or desiccation will be important factors in determining locally vulnerable or resilient populations.

Adaptive capacity
Some seasonal drying of habitats within levels the species can tolerate may benefit toad populations where it discourages the establishment of chytrid fungus, predatory fish, and bullfrogs, which are predators as well as carriers of chytrid. Boreal toads are explosive breeders, a characteristic associated with increased resilience to resource variation.

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VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Canada lynx

Broad-scale climate change effect
Loss of mature forest, reduced snowpack, mismatched timing with snowshoe hare cycles, more variable prey, greater predation risk for kits, increased competition

Interactions with existing stressors
Fire and drought are likely to exacerbate the rate of habitat loss for Canada lynx. Reductions of trees and shade will also accelerate loss of snow from their winter range. Habitat fragmentation and lynx hybridization with bobcats are also threats which could increase as habitat quality declines and changing conditions induce dispersal.

Sensitivity to climatic variability and change
The Canada lynx is a specialized predator dependent on snowshoe hares as a primary food source, although a variety of prey species are taken, particularly in the summer. Lynx and snowshoe hare populations are linked and fluctuate with climate, and thus the magnitude and timing of climate events are important. Alternate prey species such as grouse or tree squirrels are smaller in size and may not compensate for reduced snowshoe hare populations. Lynx will also be vulnerable with reductions in snowpack that will reduce its competitive advantage over other predators during winter months.

Expected effects of climate change
Canada lynx are specialist predators and are expected to be vulnerable to climate change impacts through a variety of mechanisms. Predicting overall change to lynx habitat for the region is difficult because of the complexity of interactions between climate, wildfire, and insect outbreaks across a diverse landscape. Drought-related mortality will impact fir species and late seral stage forests used for breeding by the lynx. Non-breeding habitats, which typically contain a variety of seral stages and well-developed understory, may increase in more mesic areas with mixed severity fires, but decline in drier areas where more extensive wildfires will favor homogeneity. Homogenization of forests will likely reduce understory vegetation favored by the lynx's preferred prey, the snowshoe hare. Recent evidence suggests lynx tolerance for effects of insect outbreaks.

Adaptive capacity
Lynx are highly mobile, which will allow them to transition to new habitats. Lynx might experience increased hunting success where white-coated snowshoe hares are unable to accelerate and match molting cycles to more rapid and earlier snowmelt. However, this short-term advantage is unlikely to compensate for the negative impacts of increasingly variable hare populations. Lynx are expected to be more resilient where dense understory vegetation and large forest patches are maintained, whereas more vulnerable populations will be found where forests are drying and at high risk for wildfire or insect outbreaks.

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VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Columbia spotted frog

Broad-scale climate change effect
Loss of wetlands, stream and pond drying, uses disjunct breeding/winter habitats (some populations), altered breeding timing, increased risk of ranaviruses

Interaction with existing stressors
Climate change will likely exacerbate the major cause of historical declines in this species: alteration and fragmentation of aquatic habitats. Chytridiomycosis, caused by chytrid fungus *Batrachochytrium dendrobatidis*, has not been clearly linked to population declines, and there is no clear evidence that infection rates and pathology would increase in this species with climate change. Columbia spotted frogs appear susceptible to malformations due to infections by larval trematodes which are transmitted by birds, fish and snails. Host snail populations are known to increase with shrinking water sources and eutrophication, and are often associated with artificial waters, which may become more predominate under drier conditions. Because stressors such as pollution, UV-B radiation, and habitat change can interact with pathogens, disease outbreaks can cause rapid widespread mortality. Livestock grazing, which was also implicated in recent declines, may have an increased impact on this species as drier and warmer conditions concentrate livestock at water sources.

Sensitivity to climatic variability and change
Although able to disperse relatively long distances, previous habitat changes have left some populations isolated. Fragmentation of habitats will likely be intensified by drier conditions, particularly in southern portions of the region.

Expected effects of climate change
Drought, warmer temperatures, altered precipitation regimes and reduced snowpack will alter the timing of peak flows in streams, reduce permanent and increase ephemeral water channels, and reduce duration of temporary waters for breeding. Warmer temperatures may increase suitability of some oviposition sites, but greater evaporation can increase reproductive failure that occurs when ponds become desiccated before metamorphosis is complete.

Adaptive capacity
Warmer winters may improve overwinter survival. A shift to more ephemeral water sources will reduce exposure to fish predators. This species engages in explosive breeding, a characteristic associated with increase resilience to resource variations. Another source of resilience includes potential habitat expansions as high elevation areas become more suitable to frogs under warming winter conditions. Overall, Columbia spotted frogs will be more resilient where water sources are more reliable, dispersal corridors are intact, and they coexist with fewer fish and *Planorbella* snails.

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VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Fisher

Broad-scale climate change effect
Loss of forests, loss of denning and resting sites, increased predation with more open habitats

Interactions with existing stressors
Fishers appear to rely on the physical structure of forest habitats rather than specific forest type. Human activities that reduce the areal extent of these structures may act as stressors. The largest emerging threat to the fisher is almost certainly increasing frequency, extent and severity of wildfire, driven in large part by climatic change. Increases in area burned by wildfire will likely result in a reduction in late successional forest area, increase the fragmentation of late successional forest, and lead to larger proportions of the landscape in non-forest and early successional age classes.

Sensitivity to climatic variability and change
Fishers are patchily distributed in the Northern Rockies and may consist of several disjunct populations. Historical fragmentation of western fisher populations indicates that they have very specific habitat requirements, and therefore will be sensitive to climate related disruptions in habitat. Fishers have also been shown to avoid dry habitat types. There are no clear trends for an overall increase or decrease in availability of prey species, but they may experience increased predation within more open habitats.

Expected effects of climate change
Recent analyses project declines in habitat quality in virtually all areas where fishers currently exist within the U.S., but increased habitat quality in areas to the east and south. However, it is unlikely new areas will develop the old-forest structure currently associated with fisher presence in time to replace losses within its current range, particularly in the West. A more specific analysis projected current and future distribution of fisher across western Montana and northern Idaho using a suite of vegetative, topographic, and climatic (but not fire) variables and showed the greatest probability of fisher occurrence within mesic forest types with tall trees, high annual precipitation, and mid-range winter temperatures. This analysis showed an increase in area of high-probability habitat. However, given the expected effects of fire regime change on the extent and pattern of late seral forests, it is likely that the extent, quality and connectivity of fisher habitat will decrease in response to climate change, driven largely by increasing area burned in wildfires, which will reduce the extent, quality and connectivity of late seral forest habitats favored by fisher.

Adaptive capacity
In eastern North America, fishers have urbanized and have become extremely common, indicating some ability to adapt to new conditions. Fishers are probably not dispersal limited and appear to favor forested areas with low monthly snowfall. There is direct evidence that fishers avoid deep snowpack and that deep snow can limit fisher dispersal.

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VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Great Basin spadefoot

Broad-scale climate change effect
Loss of wetlands, reduced activity, altered breeding timing, increased competition for breeding habitats, desiccation risk, altered hibernation timing

Interactions with existing stressors
Cheatgrass, which is projected to expand in northern Nevada, grows best on the same sandy soils used by burrowing spadefoots and may degrade habitats. Fibrous roots of cheatgrass remove soil moisture, reduce permanency of water sources, and restrict burrowing activity.

Sensitivity to climatic variability and change
Breeding spadefoots will be most vulnerable to climate effects on the availability and longevity of pools and ponds. Changes in hydrology will vary across the region, with expected increases in winter precipitation in all but the most southern part of the region. Summer and monsoon precipitation amounts are expected to decrease. The collective impact of reduced summer precipitation, more variable precipitation patterns, and higher temperatures may reduce the number and duration of ephemeral ponds typically used for breeding, with potential negative impacts for spadefoot populations. Spadefoot populations will likely be more vulnerable in parts of the region where they are more reliant on ephemeral over permanent pools and in the south where less precipitation and more frequent drought will have the greatest impact on the availability of breeding ponds.

Expected effects of climate change
The Great Basin spadefoot occurs in a wide variety of vegetation types, which lends it some resilience to changing climate, but its reliance on temporary and permanent ponds for breeding makes this species vulnerable to changes in precipitation and increased evaporation rates. Long-distance dispersal by spadefoots is irregular and limited by presence of ponds and habitat fragmentation. Movement in response to climate-induced habitat shifts will be further limited by the occurrence of friable soils and burrows. Biotic interactions with other species are poorly known. Competitive interactions with other amphibians may increase where pond availability is reduced, but an accompanying shift to more ephemeral water sources could decrease predation by fish.

Adaptive capacity
Explosive breeding capacity, rapid tadpole development, and flexible breeding seasons improve the likelihood that this species will be able to successfully respond to changes in pond availability. Spadefoots are more resilient during non-breeding periods because of their generalist diet and ability to aestivate in burrows for long periods. Competitive interactions with other amphibians may increase where pond availability is reduced, but an accompanying shift to more ephemeral water sources could decrease predation by fish.

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VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Greater sage-grouse

Broad-scale climate change effect
Reduced plant cover (sagebrush, herbaceous), more frequent fires, needs to migrate (some populations), increased West Nile virus

Interactions with existing stressors
Lower elevations are particularly prone to invasion by non-native grasses, which can fuel frequent fires and encourage rapid transition from shrubland to grassland. The Great Basin is expected to experience a substantial increase in large wildfires, which will threaten isolated sage-grouse populations. Higher elevation sagebrush habitats are prone to conifer encroachment, particularly in northern parts of the region. Climate change may also increase disease risk among sage-grouse. West Nile virus is an emerging infectious disease, which is highly virulent in sage-grouse. Because mosquitoes transmit the virus, transmission of the virus and its prevalence are related to local temperature and precipitation. Warmer summer temperatures increase infection rates by favoring mosquito vectors and accelerating virus replication. Lower annual precipitation and increased drought can increase transmission of the virus by increasing contact between individuals who congregate in remaining mesic habitats and by creating more ephemeral water sources that cannot support mosquito predators. Increased presence of West Nile virus is predicted for California, where the bi-state sage-grouse population occurs, as well as northern Nevada and Idaho where stronghold sage-grouse populations currently occur. Probability of West Nile virus presence in Utah may decrease, but artificial waters such as stock tanks and ponds associated with coal-bed natural gas extraction further enhance West Nile virus transmission and sage-grouse vulnerability.

Sensitivity to climatic variability and change
In addition to habitat loss, drought is expected to reduce forb cover and arthropod abundance and increase the likelihood of heat stress, particularly for chicks and juveniles. The availability of insects is important for chick survival, and there is the potential for timing mismatch if insect population cycles decouple with breeding events in response to weather cues.

Expected effects of climate change
The vulnerability of greater sage-grouse is linked with the future of sagebrush. Invasion by cheatgrass and tree species (e.g., juniper), both influenced by climate, degrade sagebrush habitats and result in habitat loss for the sage-grouse. Under warmer and drier conditions, sagebrush is expected to decline throughout much of Nevada and Utah.

Adaptive capacity
Sage-grouse are able to disperse to new sites. Sage-grouse can renest in the event of nest failure, which could reduce their sensitivity to timing mismatches.

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VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
North American wolverine

Broad-scale climate change effect
Loss of alpine and high elevation forest, reduced annual snow, altered timing and depth of spring snow, reduced caching longevity, increased competition for food

Interactions with existing stressors
Strong avoidance of human disturbance, including roads, may limit the wolverine's ability to respond to change, particularly in southern parts of their range where habitats are more restricted. For this reason, the currently narrow corridors available for dispersal in Wyoming and Utah are likely to be extremely important as climate leads to changes in the distribution of associated habitats.

Sensitivity to climatic variability and change
More precipitation falling as rain rather than snow and earlier spring snow melt will have a number of negative consequences: restricted wolverine movement across the landscape, more fragmented habitat, increased competition with other predators, and reduced availability of cold food-caching and denning sites. Wolverines have low reproductive rates, and these may decline further with loss of spring snow that is associated with preferred den sites. Loss of snow cover may also expose kits to increased predation. Despite a few resilient traits (next section), wolverines are likely to decline in the region given the very low populations in the contiguous U.S. and the number of anticipated negative impacts from climate change.

Expected effects of climate change
Climate-induced changes that reduce suitable habitat and alter annual snowpack are expected to have negative impacts on wolverine populations in the region. Wolverine response to these changes, however, is uncertain because information is limited. Wolverines depend on high elevation forests and alpine habitats, which are likely to contract as habitats shift upwards. Wolverine range is closely tied to snow levels where their large feet allow them to travel more easily than many other species. Reduction in snow, although predicted throughout North America, may be less severe in the Sierra Nevada than in the Rockies, but very little is known about Sierra Nevada populations, as wolverines were only detected there in 2009 after a long period of extirpation.

Adaptive capacity
The wolverine may be fairly resilient to food resource fluctuations because of its relatively broad diet and food caching behaviors, but only within those areas that otherwise remain suitable under future climates. Ungulates are an important scavenging item, thus ungulate populations and hunting success of predators will affect food availability. Reductions in the depth and duration of snow cover may benefit certain ungulate species, and thus may increase prey, but could also increase competition with other predators and scavengers.

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VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Northern Idaho ground squirrel

Broad-scale climate change effect
Less snow insulation during hibernation, cold spring weather, altered hibernation and growing season timing, increased plague risk, short breeding season

Interactions with existing stressors
Declines in the northern Idaho ground squirrel have been partially attributed to encroachment of young trees, facilitated by fire suppression and livestock grazing. Increased area burned by wildfire is predicted for this part of the region and could increase the quantity of suitable habitat and the availability of dispersal corridors. Short-term events such as drought, cold spring weather, or disease are likely to increase for this species and exacerbate ongoing non-climate threats, such as overgrazing, recreational shooting, and land development. Plague is a potential threat, but has not been recorded in these populations, though climate is expected to become more favorable for plague transmission in Idaho.

Sensitivity to climatic variability and change
Remaining ground squirrel populations within the IAP region are small and isolated and highly vulnerable to additional stress related to climate or other factors. Ground squirrels have a long hibernation period that requires the accumulation of fat stores and hibernacula that are insulated by snowpack. Grounds squirrels are sensitive to winter mortality when snow is not deep enough to provide insulation.

Expected effects of climate change
Suitable or associated habitat may increase under increasing fire pressures. Several important questions are raised, however, about the future quality of habitat for the ground squirrel. Given current climate model projections for reduced in snow within the Rocky Mountains, overwinter mortality may increase, particularly for juveniles. Primary productivity is expected to increase across the current range of this ground squirrel, which may increase seed production, but potentially at the cost of plant species diversity, which could reduce the availability and timing of preferred forage species. Earlier snowmelt, longer growing seasons, invasion of non-natives, increasing fires, and alterations to pollinator populations all affect plant species composition and seed set. The timing and overall availability of fat-laden seeds is likely to be an important determinant of ground squirrel response, but we lack adequate research on the interplay of factors that would allow us to predict future food sources.

Adaptive capacity
Individual squirrels are capable of dispersing to new areas in pace with habitat change, but small populations and anthropogenic barriers will constrain movement. Although climate change may lead to improved habitat over time through increased productivity, short-term events such as drought, cold spring weather, or disease are likely to increase for this species and exacerbate ongoing non-climate threats such as overgrazing, recreational shooting, and land development.

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VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Prairie rattlesnake

Broad-scale climate change effect
Loss of cover for refugia, increased temperature, changes in active periods, altered hibernation timing, loss of conspecifics for denning, low reproductive rates

Interactions with existing stressors
Sensitivity to anthropogenic factors such as human predation and roads limits this species' ability to adapt to change.

Sensitivity to climatic variability and change
Rattlesnakes time several important activities to temperature conditions, including hibernation, breeding, basking, and foraging, which can lead to mismatched timing of those activities with favorable conditions. The potential for timing mismatch and the outcome for populations is difficult to predict, as relevant information is limited.

Expected effects of climate change
Rattlesnakes in far eastern Idaho have been recently grouped as part of the eastern clade along with Hopi rattlesnake, which occurs in southeastern Utah and may itself be a distinct subspecies. For this assessment, we focused on projected changes for prairie rattlesnakes in Idaho, which likely includes more than one subspecies. In general, rattlesnakes are likely to be vulnerable to climate changes due to low fecundity, long generation times, and low dispersal ability. Climate envelope models indicate that suitable climate for the prairie rattlesnake will shrink considerably overall, but should persist in Idaho to 2100. Note that these projections do not include effects of fire or biotic interactions, which could be significant. Extreme events such as flooding can reduce prey and damage habitats. Refugia under downed woody debris or shrubs provide favorable microclimates and would be reduced by frequent fires.

Adaptive capacity
Warmer temperatures could reduce time spent in hibernacula (decreasing time needed to build fat stores), shorten digestion time, and positively influence reproductive. Projections of increased primary productivity in Idaho may increase rodent populations depending on habitat, which would benefit rattlesnakes in the area. Prairie rattlesnakes may be more resilient where microclimate refugia remains (e.g., low fire risk, rocky terrain) and habitats are not heavily fragmented.

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VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Townsend's western big-eared bat

Broad-scale climate change effect
Reduced surface water, timing of hibernation, timing of prey peaks

Interactions with existing stressors
Although many shrub habitats are expected to remain or expand, increasing fires and proliferation of invasive grasses could degrade habitats and lead to reduced prey availability. Northern portions of Nevada may be especially prone to cheatgrass invasion. Spread of white-nose fungus into the region is expected by the 2020s, with earlier arrival in the north than south. Warmer weather and torpor characteristics in big-eared bat species are associated with frequent arousal, which may reduce negative effects of fungal infection. Disturbance at roost sites is considered an important threat.

Sensitivity to climatic variability and change
These insectivorous bats need access to surface water to meet physiological requirements, especially during lactation. Expected changes in snowpack and higher evaporation rates will likely reduce water availability, especially in summer. Unfortunately, little is known about how the quality of various habitats relate to bat survival and reproduction, but it is likely that changes in proximity of suitable roost sites to foraging grounds will be a source of vulnerability for all bats, including the Townsend's bat.

Expected effects of climate change
Two subspecies of this poorly known bat species may occur in the region, and shifts in the distributions of subspecies are likely to occur under climate change. Although big-eared bats specialize on moths, which are sensitive to climate-induced change, there is no evidence that generalist and specialist moth populations would decline synchronously across all species. Still, rising temperatures will affect phenology related to foraging, breeding, torpor, and movements in bats while also affecting moth life cycles and distributions, which could lead to a mismatch in prey availability and bat energy requirements.

Adaptive capacity or areas of resilience
Big-eared bats use a wide variety of forest, shrub, and woodland habitats, and thus may have some resilience to habitat change. This species may experience an increase in winter foraging with more mild winter conditions. Because of its relatively sedentary nature and cave-roosting habits, this bat species is less likely than others to be vulnerable to wind turbine collisions. Bats may be more resilient in landscapes where more roosts are available, surface water is available year round, and cheatgrass invasion risk is low.

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VULNERABILITY ASSESSMENT — WILDLIFE

Habitat, ecosystem function, or species
Utah prairie dog

Broad-scale climate change effect
Fewer moist swales, altered hibernation timing, change in growing season, short breeding season

Interactions with existing stressors
Increasing fires and invasive grasses will play a role in local habitat change although the ultimate outcome for prairie dogs is unclear. Plague transmission is not expected to change in Utah based on past climate relationships, but future climate relationships are unclear, considering the complex dynamics of outbreaks, which will include climate effects on short-term reservoir and flea species.

Sensitivity to climatic variability and change
Prairie dogs will be vulnerable to changes in resource timing such as availability of forage during lactation and before the onset of hibernation. Drought is of particular concern for prairie dogs, as it has been implicated in past population declines through limitations related to food availability and water balance.

Expected effects of climate change
Predicting prairie dog response to climate change is made difficult by the lack of climate-related research and a range of traits associated with both increased vulnerability and increased resilience to climate change. For example, contraction of forests and woodlands with drier conditions may expand grassland habitats, but given projected drying in southern Utah, habitats may be less productive and lack moist swales that provide critical moisture. Areas of suitable climate for prairie dogs are expected to shift considerably over the next century. By 2100, suitable climates are projected to shift into Wyoming and Nevada, outpacing dispersal. Prairie dog response to climate change is important because their presence on the landscape has ramifications for closely associated species.

Adaptive capacity
Specialized traits of prairie dogs related to colonial living such as communal nursing, predator evasion, and habitat manipulation may offer some resilience to changing conditions. Expansion of shrub steppe and grassland habitats are likely to benefit prairie dogs, and prairie dogs are able to disperse to new areas. More resilient populations will be those that are near persistent moist swales and with few barriers to dispersal.

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VULNERABILITY ASSESSMENT — RECREATION

Habitat, ecosystem function, or species
Warm weather recreation activities, including hiking and walking on trails, viewing natural features, camping at developed sites, bicycling, and other non-motorized activities

Broad-scale climate change effect
Participation in these activities generally depends on the availability of snow- and ice-free sites, dry weather with non-extreme daytime temperatures, and the ability to select sites where air quality is not impaired by smoke.

Current condition, existing stressors
This broad category represents the most common recreation activities on federal lands in the IAP region. Summer recreation accounts for 43% of all visits (9 million, of which over 70% are for hiking/walking and nature viewing).

Sensitivity to climatic variability and change
Sensitive to the length of appropriate season, depending on the timing of spring snow melt and availability of snow- and ice-free trails and sites, and the timing and number of days with temperatures within minimum and maximum comfortable range (which may vary with activity type and site).

Expected effects of climate change
Overall demand for warm-weather activities is expected to increase, especially during shoulder seasons. Climate change is expected to lengthen the expected season for warm-weather activities due to early availability of snow- and ice-free sites, and overall warming of spring and autumn months that increase the number of warm-weather days. Extreme summer temperatures can dampen participation during the hottest weeks of the year, shift demand to cooler weeks at the beginning or end of warm-weather season, or shift demand to alternative sites that are less exposed to extreme temperatures (e.g., lakes, higher elevations). Potential increases in likelihood of extreme wildfire activity may reduce demand for warm-weather activities in some years due to impaired air quality from smoke or limited site access due to fire management activities.

Adaptive capacity
Adaptive capacity among recreationists is high due to the large number of potential alternative sites, ability to alter the timing of visits, and ability to alter capital investments (e.g., appropriate gear). However, some alternative sites may involve higher costs of access (due to remoteness or difficulty of terrain), and increased demand may place pressure on sites that currently have limited capacity. There may be some limits on ability to alter seasonality of visits due to the timing of scheduled academic breaks.

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VULNERABILITY ASSESSMENT — RECREATION

Habitat, ecosystem function, or species
Snow-based recreation activities that occur during winter, including downhill skiing, cross-country skiing, and snowmobiling

Broad-scale climate change effect
Availability of winter snow-based recreation depends on the timing and amount of precipitation as snow, and cold temperatures to support consistent snow coverage and snowmaking at developed (downhill skiing) sites.

Current condition, existing stressors
The IAP region has a large number of winter recreation sites that contain a wide range of site characteristics and attract local, regional, and national visitors. Winter recreation accounts for 19% of all recreation visits (3.9 million total, of which 70% are for downhill skiing). Snow-based recreation is inherently sensitive to climatic variability and interannual weather patterns. For downhill ski areas, snowmaking ability can provide a buffer against low-snowfall years given water availability and appropriate temperatures.

Sensitivity to climatic variability and change
Snow-based recreation is highly sensitive to variations in temperature and the amount and timing of precipitation as snow.

Expected effects of climate change
Climatic warming is expected to reduce expected season length and the likelihood of reliable winter recreation seasons. Some areas, especially at lower elevation, may become unsuitable for snow-based recreation due to warmer temperatures or increased likelihood of precipitation as rain. Higher elevation sites (including several of the downhill ski resorts) may not experience as large a transition to more precipitation as rain, but may experience more variability in season length. Warmer temperatures and increased precipitation as rain may increase availability of water in the near term during winter, but warmer temperatures may also reduce the number of days per season when snowmaking is viable.

Adaptive capacity
Snow-based recreationists have moderate capacity to adapt to changing conditions given the relatively large number of winter recreation sites in the region. For non-developed or minimally developed site activities (e.g., cross-country skiing, backcountry skiing, snowmobiling, snowshoeing), recreationists may seek higher elevation sites with higher likelihoods of viable seasons. Although developed downhill skiing sites are fixed improvements, potential adaptations include snowmaking, higher elevation development, and new run development. Changes to sites in the IAP region relative to other regions may also be important; if snow-based recreation is affected more negatively in other regions, recreationists may view sites in the IAP region as a substitute.

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VULNERABILITY ASSESSMENT — RECREATION

Habitat, ecosystem function, or species
Wildlife-related activities, where animals are a significant and necessary input into the recreation experience, such as hunting, fishing, and wildlife viewing

Broad-scale climate change effect
Changes in temperature and precipitation may affect suitable habitat for terrestrial and aquatic species due to changes in vegetation cover, productivity of food sources, water quantity and temperature (for aquatic species), and species interactions. Climate-related changes to disturbance regimes, including wildfire, invasive species, and insect and disease outbreaks, may affect the amount and spatial distribution of suitable habitat.

Current condition, existing stressors
Wildlife activities account for 18% of all recreation visits (1.9 million total, of which 52% are for hunting and 37% are for fishing). Encroaching development and habitat fragmentation are reducing the quality and availability of wildlife activities in some locations.

Sensitivity to climatic variability and change
Wildlife activities are sensitive to expected "catch rates" (likelihood of catching or seeing the target species), and to the existence of valued target species. Hunting for terrestrial game species is sensitive to temperature during the allotted hunting season (i.e., colder temperatures preferred for dressing and pack-out of harvested animals) and the timing and amount of precipitation as snow (to reduce costs of tracking). Fishing catch rates are dependent on stream flows and temperatures to support target species. Increased water temperatures in main-stem rivers and streams limit site access due to closures.

Expected effects of climate change
-- Increased incidence of disturbances due to climate change is likely to be neutral or slightly beneficial for terrestrial game species populations and thus catch rates for targeted species. Potential decreases in overall vegetative productivity similarly likely have neutral effect on game species populations. Desirability of hunting during established seasons may decline as warmer weather persists later into the fall and early winter and the likelihood of snow cover decreases.
-- Higher temperatures will decrease populations of native cold-water fish species and favor increases in populations of warm-water (often non-native) species. Decreased snowpack is expected to increase the incidence of low flows and stress fish populations.

Adaptive capacity
-- Hunting: Hunters can in some cases adapt by altering the timing and location of hunts; state rules on hunting season dates impose a constraint on this behavior unless states change hunting seasons based on altered climate.
-- Fishing: Anglers may adapt by choosing different species (e.g., shift from cold-water to warm-water species) and sites less affected by climate change (e.g., high-elevation streams). Some anglers may place high value on certain species and have a lower willingness to target warm-water species that may thrive in place of cold-water species.

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VULNERABILITY ASSESSMENT — RECREATION

Habitat, ecosystem function, or species
Water-based recreation activities that involve non-angling use of surface water bodies, including swimming, boating and floating on rivers, lakes, or reservoirs

Broad-scale climate change effect
Warming temperatures and increase in season length. Higher interannual variability in precipitation affects flows and water levels.

Current condition, existing stressors
Separate from angling, water-based activities comprise a small portion of primary recreation (320,000 visitors in national forests, BUT 7 million visitors in Lake Mead NRA). Upper reaches of streams and rivers are generally not desirable for boating and floating. Lakes and reservoirs provide opportunities for both motorized and non-motorized boating and swimming, although boating may commonly be paired with fishing. Existing stressors include the occurrence of drought conditions that reduce water levels and site desirability in some years. Disturbances can alter water quality (e.g., erosion events following wildland fires).

Sensitivity to climatic variability and change
The availability of suitable sites for water-based recreation is sensitive to reductions in water levels due to warming temperatures, increased variability in precipitation, and decreased precipitation as snow. Demand for water-based recreation is also sensitive to temperature increases as recreationists may increasingly seek out water-based activities during extreme heat and increase overall demand as the season lengthens.

Expected effects of climate change
Increasing temperatures, reduced storage of water as snowpack, and increased variability of precipitation are expected to increase the likelihood of reduced water levels and greater variation in water levels in lakes and reservoirs, which is associated with reduced site quality and suitability for certain activities. Increased demand for surface water by downstream users may reduce water levels in drought years. Warmer temperatures are expected to increase demand for water-based recreation as the season lengthens and people seek relief from extreme heat.

Adaptive capacity
Water-based recreationists may adapt to climate change by choosing different sites that are less susceptible to changes in water levels (e.g., by seeking out higher-elevation natural lakes) and changing the type of water-based recreation activity they engage in (e.g., from motorized boating on reservoirs to non-motorized boating on natural lakes).

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VULNERABILITY ASSESSMENT — RECREATION

Habitat, ecosystem function, or species

Gathering forest products for recreational and personal uses, including foraging for food (e.g., huckleberries, mushrooms), gathering firewood, and cutting Christmas trees

Broad-scale climate change effect

Climate change may alter species composition and vegetative cover for target species. Periods of drought may reduce productivity in the near term and reduce extent of target species in current locations in the medium to long term. Changes in disturbances (e.g., wildland fire, invasive species, insect and disease outbreaks) may place additional stress on target species and alter the availability of target species (positive and negative) in current locations.

Current condition, existing stressors

Forest product gathering accounts for a small portion of recreation visits (1.5%), although it is relatively more common as a secondary activity. A small but fervent population of enthusiasts for certain types of products supports a small-scale but steady demand for gathering as a recreational activity. Small-scale commercial gathering likely competes with recreationists for popular and high-valued products (e.g., huckleberries, pinyon nuts), although resource constraints may not be significant at current participation levels.

Sensitivity to climatic variability and change

Forest product gathering is primarily sensitive to the climatic and vegetative conditions that support the distribution and abundance of target species. Participation in forest product gathering is also akin to warm-weather recreation activities, depending on moderate temperatures for and the accessibility of sites where products are typically found.

Expected effects of climate change

Vegetative change due to warming temperatures may alter the geographic distribution and productivity of target species. Increased incidence and severity of wildland fires may eliminate sources of forest products in some locations in the short term (e.g., berries), but in some cases may encourage short- or medium-term productivity for other products (e.g., mushrooms). Long-term changes in vegetation due to climate that reduces forest cover may reduce viability of forest product gathering in some areas if a transition to other vegetation types occurs.

Adaptive capacity

Recreationists engaged in forest product gathering may select different gathering sites as the distribution and abundance of target species changes, although these sites may increase the costs of gathering. Those who engage in gathering as a secondary or tertiary activity may choose alternate activities to complement primary activities. Commercial products serve as an imperfect substitute for forest product gathering in some cases (e.g., Christmas trees).

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Summary of climate change assessment ratings for recreation by activity category.

Activity category	Magnitude of climate effect	Likelihood of climate effect	Direct effects	Indirect effects
Warm-weather activities	Moderate (+)[a]	High	Warmer temperature (+) Higher likelihood of extreme temperatures (-)	Increased incidence, area, and severity of wildfire (+/-) Increased smoke from wildfire (-)
Snow-based winter activities	High (-)	High	Warmer temperature (-) Reduced precipitation as snow (-)	
Wildlife activities	Terrestrial wildlife: low (+) Fishing: moderate (-)	Moderate	Warmer temperature (+) Higher incidence of low streamflow (fishing -) Reduced snowpack (hunting -)	Increased incidence, area, and severity of wildfire (terrestrial wildlife +/-) Reduced cold-water habitat, incursion of warm-water tolerant species (fishing -)
Gathering forest products	Low (+/-)	Moderate	Warmer temperature (+)	More frequent wildfires (+/-) Higher severity wildfires (-)
Water-based activities, not including fishing	Moderate (+)	Moderate	Warming temperatures (+) Higher likelihood of extreme temperatures (-)	Lower streamflows and reservoir levels (-) Increase in algal blooms (-)

Note: Positive (+) and negative (-) signs indicate expected direction of effect on overall benefits derived from recreation activities.

VULNERABILITY ASSESSMENT — INFRASTRUCTURE

Habitat, ecosystem function, or species
Streamflow

Broad-scale climate change effect
Warming temperatures will lead to decreased snowpack accumulation and earlier melt out, resulting in shifts in the timing and magnitude of streamflow. Increases in the occurrence and magnitude of winter and spring peak streamflows are likely.

Current condition, existing stressors
There are many roads near streams on federal lands within the IAP area, and these roads have high value for public access and resource management. With decreasing budgets, there is decreased capacity to maintain these roads, and there is a backlog of deferred maintenance.

Sensitivity to climatic variability and change
Roads in near-stream environments are periodically exposed to high flows. Midwinter flooding is expected to become more common in places where it now occurs and to occur in more locations. Because rain-on-snow (ROS) driven flood peaks tend to be much higher, flood magnitudes are expected to increase in the ROS zone as well. Increased peak flow makes infrastructure more vulnerable to effects ranging from minor washout to complete loss of road prism, with effects on public safety and access for resource management, and the environment.

Expected effects of climate change
Infrastructure, including roads near perennial streams, which are valued for public access and resource management, are likely to be impacted by higher winter and spring peak streamflows. Maintenance and repair costs will increase with increased damage to infrastructure. Damage to roads near streams often has ecological effects on stream water quality and aquatic habitats. Water use infrastructure (e.g., head gates) may also see an increase in storm damage and maintenance needs/cost due to the increase in high streamflow events, particularly in those areas where the likelihood of rain-on-snow (ROS) events are projected to increase.

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VULNERABILITY ASSESSMENT — CULTURAL HERITAGE

Habitat, ecosystem function, or species
Cultural and heritage values (tribal belief systems, historic properties, heritage tourism, culturally valuable sites)

Broad-scale climate change effect
Increased temperatures, drought, area burned, and flooding

Current condition, existing stressors

Native American resources
Archaeological research supports that North America was colonized by the ancestors of Native Americans sometime in the range of 14-15,000 years ago. These dates remain variable due to fluctuations in radiocarbon dating, corrected radiocarbon dates, genetic research, and the ongoing discovery of new archaeological information.

Currently, the oldest well-dated archaeological sites located within the area that encompasses the IAP, which include Danger Cave, Smith Creek Cave, and Bonneville Estates Rockshelter (all located on the western shores of the then freshwater Lake Bonneville), date to around 12,800-10,600 years ago.

Over thousands of years, successive groups of Native Americans either created or adopted different subsistence strategies adapted to the ecology of the area the group inhabited. Although these adaptations ranged from hunting and gathering, foraging, horticulture, and agriculture, the one salient characteristic of all them is that no matter what strategy was employed, they were all intrinsically tied to the local ecology and locally procured resources. Even if a group was highly mobile or nomadic, and maintained trade networks with other groups, they were still reliant on the local resources they procured in any given area.

With the degradation of organic material over millennia, the bulk of the archaeological record left behind by people consist of stone tools and the debris left over from making stone tools, as well as pottery from different time periods. In rare cases, buried archaeological deposits, especially those found in protected rock shelters and caves, contain organic material such as wood, antler, bone, leather, textiles, basketry, and charcoal. Common features that remain on the landscape include rock art, architecture, food storage features, and stone alignments such as teepee rings and pinyon nut storage features. Less common, and dating to the proto-historic and historic period, are animal drive lines created from brush/timber, wikiup structures made from branches, brush houses, and culturally modified trees. Not all of these resources are ubiquitous throughout the region, and some of the spatially unique resources are found in only in specific geographic areas.

The legacy of indigenous lifeways still in practice
Native Americans have an active relationship with the lands in the IAP region. We must also acknowledge that all cultures change with time, and we must be cognizant that aspects of the active relationship that indigenous people have with the land may change as well. Land managers should be sensitive to the fact that current relationships are as culturally valid as historic ones. Native American cultures and their relationship to the land are dynamic.

Historic era resources
Multiethnic exploration of the areas that now include the IAP region began in the late 1700's, followed by more intensive settlement in the mid-1800's. Thereafter, settlements of people of European, Asian, and African descent expanded quickly in terms of both population size and

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settlement extent. In addition, Native American peoples increasingly participated in the new agricultural and industrial economies brought by the newcomers to the West.

The visible footprints from these new economies take primarily three forms. First, there are the remains of the work and residential locations associated with agricultural and industrial activities. These generally take the form of archaeological sites and include homesteads, mines, towns, trash scatters and campsites. Second, this wave of settlement created landscape features such as roads, dams, railroads, and canal systems. Third, there are the remains of changes to landscapes brought on by agricultural and industrial activities. These include stream channel alteration caused by hydraulic mining, stump fields associated with tie cutting, and field clearing associated with farming.

The physical evidence of past activities inform us about not only what happened in the past 150+ years, but how these activities have affected current human, plant and animal communities, and how these changes set the stage for future management of the region. They also offer our visitors an unparalleled opportunity to see the full extent and effect of the industrialization of the American West. As a result, we need to consider the potential effect of climate change to all of these types of evidence, and at multiple scales. These scales includes individual archaeological sites and the larger landscapes in which particular activities were carried out, such as a mining district or homesteading area. An even broader landscape could be affected by a suite of activities, such as the watersheds around the Comstock Lode in western Nevada affected by mining, the logging that supported the mining, and the transportation systems associated with both of these activities.

Expected effects of climate change

Climate change has the potential to accelerate on-going effects to cultural resources. Warming temperatures are currently influencing the scale and severity of wildfires across the American West. Wildfire has a direct effect on cultural resources since they are broadly distributed throughout forest and grassland ecosystems. Sources of wildfire impacts are three-fold. First, wildfires readily burn cultural resources made of wood and other combustible materials, such as ancient aboriginal pole and brush shelters and wood game drives, or historic homesteads, mining ruins, and administrative buildings. Emergency wildfire suppression tactics, including fire line construction with heavy equipment, also affect standing structures and archaeological sites buried in forest soils and duff. Finally, post-wildfire flooding and debris flows threaten cultural resources exposed on fire-charred landforms and soils.

Seasonal aridity and prolonged drought, which are expected to increase with climate change, accelerate soil deflation and erosion, and expose archaeological sites once buried in prairie or mountain soils. Wind and water roil across archaeological sites, blowing or washing away ground cover, revealing ancient artifacts and features such as cooking hearths and tool-making areas. This new ground exposure leaves artifacts highly vulnerable to artifact collecting and illegal digging. These effects are intensified in areas where livestock grazing, recreation, mining or other activity is focused and the ground is already impacted.

At the same time, a projected increase in winter precipitation, coupled with earlier and more intense spring run-off, poses another threat to cultural resources. In this context, archaeological and historic sites will be increasingly vulnerable to flooding, debris flows, down-cutting, and mass wasting of their underlying landforms. This scenario is now common in the aftermath of large-scale wildfires.

Cultural resources not only include places of specific archaeological, cultural or historic significance but also larger landscapes (which are typically designated as National Register of Historic Places “districts” on National Forest lands). The cultural and historical integrity of these landscapes is contingent on the component cultural resources and their surrounding environmental context.

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Cultural sites and landscapes are also recognized for their traditional and continuous relationship with descendant communities, including American Indian tribes (these places are called “traditional cultural properties” in historic preservation parlance). Some provide foods, medicinal and sacred plants, paints and other resources important to tribal peoples today. Other areas used for religious or ceremonial purposes are designated as tribal Sacred Sites under a federal executive order. Climate change effects to the environments of these specially-designated areas, particularly shifting, shrinking or disappearing vegetation resources, not only diminish the viability of these designations, but more importantly, the on-going historical and traditional use of these areas by local communities and indigenous peoples.

Adaptive capacity

Because this ecosystem service is largely about preserving the past, adaptive capacity is low.

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VULNERABILITY ASSESSMENT — ECOSYSTEM SERVICES

Habitat, ecosystem function, or species
Livestock grazing

Broad-scale climate change effect
Warming temperatures and increased frequency of wildfires will affect the health of the rangelands and non-forest vegetation on which grazing depends (see the section on non-forest vegetation).

Current condition, existing stressors
Grazing is an important economic driver, tied to a cultural heritage in the West. Livestock was among the first industries in the West, existing alongside Spanish missions during the first periods of settlement and playing an important role in the westward expansion of America. By the late 1800s, must of the Intermountain West was completely stocked. Unmanaged competition for free land and resources led to devastating impacts on the landscape. In the early 1900s, forest reserves were created in the area to manage livestock grazing, decreasing conflict in the area related to grazing areas (range wars) and beginning an era of scientific range management.

Today, livestock grazing is still the most widespread commercial use of land in western North America and a large force in economic development in the region. Public lands held primarily by the Bureau of Land Management and the US Forest Service are an important source of forage for western ranchers, both as primary places to graze and to supplement grazing on private lands.

Livestock use on national forests and grasslands are given by the annual Grazing Statistical Summary. The table below shows the 2015 values for national forests in the IAP region. The number of goats and sheep exceeds that of cattle and horse and burrows, but cattle account for over 78 percent of total animal unit months (AUMs).

Grazing statistics for Bureau of Land Management holdings come from the Public Land Statistics for 2014, shown in the second table below. BLM statistics are given by state, so do not match up with the IAP area for Idaho and Wyoming. Nevertheless, the trends are informative for what occurs across the landscape. Some permittees run more than one type of livestock and may be included in more than one column for type of grazing. The authorization count, therefore, is not necessarily the sum across the rows. Cattle, yearling, and bison make up the majority of both authorizations of AUMs.

Changes in public perception and the way we value public lands has changed management of rangelands to one of primarily focusing on livestock to one of focusing on multiple uses of the land. Current threats include declining profitability, urbanization, concern over endangered species, and spread of invasive species. Total production in the area across all land types is in decline. In Utah, record beef production occurred in 1983, and record land production occurred in 1930.

Sensitivity to climatic variability and change
Grazing occurs in some of the most sensitive vegetation regions (e.g., alpine, subalpine forblands, dry sagebrush shrublands, low-elevation riparian and wetland ecosystems), amplifying other natural disturbances. The primary concern directly related to climate is that of drought, which has already plagued much of the region. Declines in productivity of the range increase costs of production and decrease operator profitability. Typical rates of return on livestock in the West are around two percent. Such thin margins decrease the likelihood of new investments in the industry and adversely affect those whose livelihoods and sense of self are

closely tied to ranching. These industry trends have led to increase fragmentation of rangelands through conversion of private rangeland to ranchettes and suburban developments.

The cycle between fire and spread of invasive species has already altered areas formerly suitable to grazing. These impacts are expected to worsen with climate change, leading to both decreased access to rangeland and decreased productivity of those that remain open.

Expected effects of climate change

Climate change will amplify the effects of social pressures on grazing, including increased urbanization and fragmentation of rangelands, out-migration of the younger generation, and changes in land management priorities that emphasize conservation and recreation over livestock. Profitability is likely to decline as rangelands become less productive and competition for other uses of the land increase.

Livestock use (numbers and animal unit months, or AUMs) on National Forests System (NFS) lands in the IAP region.

	Number of permittees	Cattle		Horses and burros		Sheep and goats		Total	
		Number	AUMs	Number	AUMs	Number	AUMs	Number	AUMs
NFS permitted commercial livestock	1693	309,759	1,441,944	1,517	5,823	549,874	463,542	861,150	1,911,309
NFS authorized commercial livestock	1670	294,476	1,236,510	1,221	4,583	512,649	329,521	808,346	1,570,614
NFS authorized livestock use	20	500	110	70	296	0	0	570	406
NFS total authorized	**1690**	**294,976**	**1,236,620**	**1,291**	**4,879**	**512,649**	**329,521**	**808,916**	**1,571,020**
Private lands	50	1,311	6,277	0	0	2,183	1,716	3,494	7,993

Livestock authorizations and animal unit months on BLM Lands.

	Cattle, yearlings, bison	Horses and burros	Sheep and goats	Authorization count
Number of authorizations:				
Idaho	1,549	93	99	1,632
Nevada	509	30	59	551
Utah	1,174	40	157	1,278
Wyoming	2,420	249	267	2,568
Animal unit months authorized				
Idaho	806,580	3,945	69,778	880,303
Nevada	970,467	2,167	87,056	1,059,690
Utah	635,705	1,441	149,353	786,499
Wyoming	1,075,021	11,219	174,708	1,260,948

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VULNERABILITY ASSESSMENT — ECOSYSTEM SERVICES

Habitat, ecosystem function, or species
Water quality and quantity

Broad-scale climate change effects
Water yield, timing, and quality are particularly important for municipal drinking water suppliers, and are expected to be uniquely impacted across the IAP region by climate induced changes. Increased atmospheric temperatures and loss of vegetation along stream banks will raise the temperature of streams and influence invasive and disease threat. Stream temperatures are predicted to rise about 12% on average for municipal users in the region by the end of the century. Stream temperature impacts water solubility and governs the organisms that can survive in water. Increased number and severity of wildfires will also deposit more sediment into streams, lakes, and reservoirs, causing further concerns for water quality. Changes in vegetation affect the rate of flow and influence the landscape's ability to filter and purify water.

Earlier stream runoff is expected over much of the region and summer flows are expected to be significantly lower for most users. By the end of the century the median flow date is expected to be over 21 days earlier and summer flows are predicted to decline over 30% on average. In extreme cases the median flow date is over a month earlier and summer flows are projected to decline over 80% for some users. Total water yield, measured by mean annual flow, is expected to slightly increase on average in the northern part of the region, but decline over 10% in the warmer southern and western parts of the region. Groundwater levels and recharge rates are also impacted by climate change. During the summer a high water demand coupled with low water supply already forces many municipal water suppliers to utilize groundwater intakes in order to meet local water demand, and in some cases even to help out neighboring communities. Changes in temperature and population growth will further increase the demand and stress on water resources in the region. This is especially true in Utah where there is heavy development and agricultural use, making the threat of population growth and development a key concern for water resources.

Current condition and existing stressors
Many of the region's sub-watersheds are already impaired or at risk. Both water quantity and quality conditions are currently classified as impaired or at risk for most of Nevada, and generally as impaired in the heavily populated parts of Utah. This heavy development also makes road and trail conditions in Utah a major concern. Riparian and wetland vegetation conditions are classified as impaired for nearly all of Nevada, while Utah and parts of Idaho and Wyoming have a mix of well-functioning and at risk riparian systems, again with some impaired conditions near the heavily developed parts of Utah. Soil condition is most impaired in Nevada, but also a concern for much of Utah. The aquatic habitat is classified as impaired in much of Nevada, and again in Utah where development is prevalent.

Sensitivity to climatic variability and change
The most sensitive watersheds are those which are already impaired or at risk, based on conditions discussed in the last section, such as vegetation, soil, and habitat condition. Watersheds that have a high threat of wildfire or disease are also more sensitive to climate change, as are heavily developed areas. Developed land alters the shape of the landscape, influencing everything from water flow, timing, and quality. Sensitivity to climate change therefore depends on current watershed conditions and future threats to those conditions.

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Expected effects of climate change

Riparian systems and vegetated areas are likely to be affected by changes in temperature, precipitation, evapotranspiration, flow, runoff timing, and extreme weather events. As surface water runoff is altered, riparian zones experience reduced abundance and diversity of many organisms including algae, invertebrates, amphibians, and fishes. Any resulting reductions in water quality will lead to increased treatment costs, compounded by increased frequency and severity of wildfires that lead to increased sediment delivery. Extreme weather and increased rain rather than snow can also increase runoff from agricultural fields and add pesticides and fertilizers to streams. Changes in timing and summer flow are expected to cause shortages of surface water in many regions, especially during the warm summer months when demand is high. Many municipal systems will likely experience increased treatment costs and greater dependence on groundwater intakes in order to meet demand.

Vulnerability Assessment

The following table gives a brief overview of municipal drinking water vulnerability in the region at both the water system scale and national forest scale. The analysis utilizes municipal drinking water intake locations and nearby spatial characteristics in order to identify drinking water vulnerability for the several users that depend on national forest lands within the region. Vulnerability measures are based on stream channel and sub-watershed characteristics and the final measures are then mapped at the water system and national forest level. Vulnerability is measured based on indicators of exposure, sensitivity, and adaptive capacity. The final components for each system are standardized so that they can be compared to other water systems within the region. Exposure is measured according to projected changes in annual stream flow, summer stream flow, stream temperature, and runoff timing from downscaled climate scenarios for the 2040s (2030-2059) and the 2080s (2070-2099). Sensitivity and adaptive capacity are measured according to current sub-watershed land cover, use, conditions, and threats.

Change in runoff timing is closely related with change in summer flow, and there is a stark difference in the expected changes when comparing the north part of the region to the south. Interestingly, mean annual flow appears to move in the opposite direction for many systems, implying that earlier runoff and lower summer flow corresponds with higher annual flow on average. This is again apparent when comparing the northern and southern parts of the region. Stream temperature change is highest in Utah, especially near highly developed areas.

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Average municipal water system vulnerability by nearby national forest.

National Forest	Municipal systems	System intakes	Population served	Exposure 2040 (2080)	Sensitivity less adaptive capacity	Vulnerability 2040 (2080)
Ashley	10	17	40,725	Moderate (High)	Moderate	**Moderate**
Bridger	20	35	9,107	Low	Moderate	**Very low**
Cache	71	242	277,830	Low	High	**Moderate**
Caribou	15	69	58,268	Very low	High	**Low**
Curlew	1	1	250	Moderate	Very high	**High**
Dixie	39	96	118,601	Moderate	Moderate	**Moderate**
Eldorado	4	53	63,410	Very high	Moderate	**Very high**
Fishlake	33	96	25,661	Moderate (Low)	Moderate	**Moderate (Low)**
Gallatin	1	1	10,234	Very high	Very low	**High (Moderate)**
Humboldt	7	19	14,122	Very low	Very high	**Moderate**
Inyo	1	2	70	Moderate (Very high)	Very low	**Low (Moderate)**
Manti-La Sal	20	76	26,747	Moderate	Moderate	**Moderate**
Payette	1	2	170	Very high	Very low	**High (Moderate)**
Tahoe	6	34	12,695	Very high (High)	Very high	**Very high**
Targhee	2	6	160	Low	Low	**Very low**
Teton	22	52	13,452	Very low	Very low	**Very low**
Toiyabe	71	258	471,668	Moderate	Very high	**High**
Uinta	44	168	446,833	Moderate	Moderate	**Moderate**
Wasatch	38	199	887,098	Moderate	High	**High**

**These estimates are based on water systems and populations which rely directly on water resources from sub-watersheds with some fraction of NFS land. The measures of exposure, sensitivity less adaptive capacity, and vulnerability are relative to the average municipal water system in the region. Very high = Std Dev > 1; High = 1 > Std Dev > 0.5; Moderate = 0.5 > Std Dev > -0.5; Low = -0.5 > Std Dev > -1; Very Low = -1 > Std Dev.*

VULNERABILITY ASSESSMENT — ECOSYSTEM SERVICES

Habitat, ecosystem function, or species
Native plant materials and pollination

Broad scale climate change effect
Increasing temperatures, increasing drought, altered wildfire regimes, shifting distribution of native plant species

Current condition, existing stressors
Pollinators are crucial members of various ecosystems, from farmland to wilderness. As such they are critical to the Nation's economy, food security, and environmental health. Honey bee pollination alone adds more than $15 billion in value to agricultural crops each year, and helps ensure that our diets include ample fruits, nuts, and vegetables. The value of pollinators in natural systems is much more difficult to discern, given that the maintenance of natural plant communities through pollination contributes to a variety of valuable ecosystem services, including carbon sequestration, water filtration, and erosion control.

Simultaneous declines in native and managed pollinator populations globally, with highly visible decreases in honey bees, bumble bees, and monarch butterflies, have brought into focus the importance of pollinator conservation. This tremendously valuable ecosystem service is provided to society by honey bees, native bees and other insect pollinators, birds, and bats.

As such there is an increasing demand for seeds to restore plant communities on both public and private lands across the U.S. Our ability to repair these damaged lands and stem the loss of cultural and economic benefits to society largely depends upon the reliable availability of genetically appropriate seed, including advancing the availability and use of pollinator-friendly seed mixes in land management, restoration, and rehabilitation actions nationwide. The focus is on making available the most appropriate seed for a given location by using seed zones, seed transfer guidelines and genetically appropriate materials that have a high likelihood of success when planted. Origin of seed collections and genetic foundation are often overlooked in revegetation projects. However, these are key factors to help ensure survival of the plants and protect local genetic resources. Plant populations in native plant communities must be genetically variable to be able to adapt to new stresses. Collection and propagation procedures need to conserve sufficient genetic diversity to buffer environmental changes in both the short term (years) and long term (decades or centuries).

Sensitivity to climate variability and change
Changes in temperature and precipitation are likely to alter suitable ranges of native plant species and pollinators.

Expected effects of climate change
Drought will increase stress to plants and increase the likelihood of adverse impacts from invasive species, habitat fragmentation, and overuse.

VULNERABILITY ASSESSMENT — ECOSYSTEM SERVICES

Habitat, ecosystem function, or species
Carbon sequestration

Broad-scale climate change effect
Increased fire, increased drought, forest productivity gains and losses

Current condition, existing stressors
The forests that comprise the IAP contain varied ecosystem carbon reservoirs, ranging from near zero (Desert Range Experiment Station) to over 160 Tg (see figure below). Wildfire, drought, and insect outbreaks all pose significant threats to the stability and long term storage of these reservoirs.

Sensitivity to climatic variability and change
Carbon sequestration is very sensitive to changing climate in direct and indirect ways. Rates of carbon storage will largely depend on wildfire and insect activity, along with drought frequency and potential changes in productivity via direct physiological changes to trees. Potential productivity changes need to be evaluated at large spatial and temporal scales in order to understand potential trends in future carbon storage.

Expected effects of climate change
Wildfire and insect outbreaks will cause short term losses to carbon sequestration. Increased disturbance size and frequency will cause greater carbon losses. Mortality and growth declines associated with drought events will also increase, impacting the carbon storage potential of the landscape. Drier sites might experience steady declines in productivity with higher temperatures, while more mesic sites might experience increases in productivity.

Adaptive capacity
All ecosystems have an inherent capability to store carbon. The rate and capacity of carbon storage depends on plant productivity and disturbance, with the maximum levels of productivity dependent on climate, while the instantaneous levels of productivity are dependent on successional stage or time since disturbance. Though many areas within the IAP region have the capacity for long term, stable increases in carbon storage, the balance of disturbance, climate, and management actions will ultimately determine carbon sequestration. Carbon storage is one of many ecosystem services provided by the forests and grasslands of the IAP region, and the adaptive capacity of carbon sequestration is affected by protection of existing stocks and building resilience in stocks through adaptation, restoration and reforestation.

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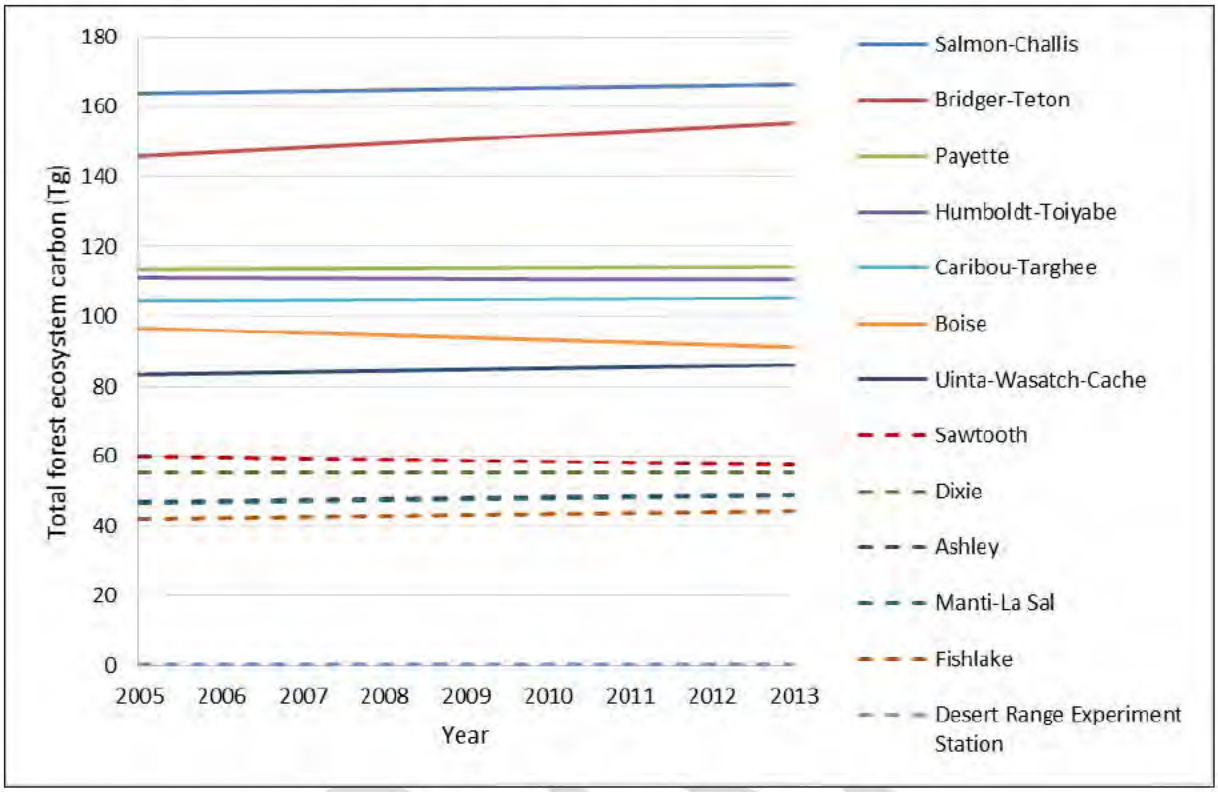
Total ecosystem carbon (Tg) for the national forests in the IAP region from 2005 to 2013.



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VULNERABILITY ASSESSMENT — ECOSYSTEM SERVICES

Habitat, ecosystem function, or species
Building materials/wood products and biomass

Broad-scale climate change effect
Wildfire, drought, and insect outbreaks can cause significant levels of tree mortality, decreasing potential timber outputs, and having a deleterious effect on forest health in general. For non-timber forest products, those same stressors can reduce gathering levels through reduced access.

Current condition, existing stressors
Much of the Intermountain West has been under drought conditions for the last several years. Drought, regardless of any other conditions, increases stress. That stress is amplified when there is excess biomass in the forest from lack of harvest activity and active forest management. More trees competing for less water stresses the ecosystem and leaves trees increasingly vulnerable to attack by insects and disease.

Sensitivity to climatic variability and change
Changes in productivity caused by increased temperatures and CO_2 could be significant. Productivity may increase at higher elevations and decrease in lower more moisture-limited areas. Disturbance regimes, particularly wildfire and insect outbreaks, are highly sensitive to climatic shifts and can change significantly from year to year. Combined, these effects reveal high sensitivity of timber and non-timber forest products to climate change.

Expected effects of climate change
The effects of climate change are complex, and effects can compound and build on other effects. Increased temperatures and shorter, warmer winters have resulted in two generations of bark beetles being observed in a single year, for example. Those more "insect friendly" conditions, combined with the increasingly stressed trees in the forest, amplify vulnerability to insect infestation and its related impacts. Increases in other disturbances such as wildfire, blowdowns, and outbreaks of disease made more likely by changes in climatic conditions will cause losses to merchantable timber and non-timber forest products. Potential increases in productivity, particularly in higher elevation areas, could offset those losses to some extent.

Adaptive capacity
Forest ecosystems can adapt to changes in climatic conditions by evolving to different mixes and distribution of species that thrive in the changed conditions. Perhaps more relevant to adaptive capacity to climate change are social actions and policy changes. Increased utilization of woody biomass, for example, can make fuels reduction and other silvicultural treatments more economically feasible and thus, more likely to be accomplished. More such treatments on the ground promote a healthier and more robust forest, less vulnerable to insect infestation and less prone to the extremely large and intense wildfires seen under conditions of high fuel loads.

There is a social component to this adaptive capacity as well. Part of the social action and policy change that could bring about adaptations in forest use and management results from adaptive capacity in social communities. Infrastructure and labor capacity facilitate and are complementary to accomplishing on the ground forest treatment activity. Forest treatment and restoration activity facilitate economic activity, and provide incentives for technological advances that can lead to more and diverse uses of woody biomass.

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From:	Kuennen, Reed -FS
To:	Grizzle, Betty
Subject:	wolverine section of Flathead NF biological assessment
Date:	Monday, September 18, 2017 5:03:44 PM
Attachments:	image002.png image003.png Wolverine_FNF_BA_excerpt_2017.docx

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Hi Betty it was good talking with you on the phone last week. I have attached the wolverine section from our updated BA. Please let me know if you have any questions or if I have written anything that conflicts with the species status assessment you are working on.

Thanks!

M. Reed Kuennen
Wildlife Biologist

Forest Service
Flathead National Forest

p: 406-758-5256
c: 406-862-6716
f: 406-758-5367
rkuennen@fs.fed.us

650 Wolfpack Way
Kalispell, MT 59937
www.fs.fed.us

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Wolverine

When the Forest's assessment was published (April 2014), the USFWS had published a proposed rule to list the North American wolverine distinct population segment (DPS) in the contiguous United States (USFWS, 2013a). However, on August 13, 2014, the USFWS withdrew its previous proposal (USFWS, 2014b). On April 14, 2016, the Court remanded the matter to the U.S. Fish and Wildlife Service for further consideration consistent with order CV 14-246-M-DLC (Consolidated with Case Nos.14-247-M-DLC and 14-250-M-DLC). The wolverine is now listed as a proposed threatened or endangered species for the Flathead National Forest, pending completion of a status review by the USFWS. The USFWS is currently preparing a Species Status Assessment (SSA) report that will incorporate additional information about the species from several new studies, as well as new climate modeling results for Glacier National Park (adjacent to the Forest) that includes a fine-scale assessment of snow extent and depth.

Affected environment

Population, life history, and distribution

Wolverines are year-round residents across Alaska and Canada. The southern portion of the species' range extends into high-elevation alpine portions of Washington, Idaho, Montana, Wyoming, California, and Colorado. Wolverines occur at low densities, range widely, inhabit remote and rugged landscapes away from human populations, and are difficult to detect, so conducting research on wolverines is challenging (IDFG, 2014). Wolverine populations in Montana were heavily trapped in the early 1900s and were near extinction by 1920. However, numbers increased in the western part of the state from 1950 to 1980 (Hornocker & Hash, 1981). Wolverine population growth and expansion has been documented in the North Cascades and northern Rocky Mountains (USFWS, 2013a). The Western Association of Fish and Wildlife Agencies is currently conducting a multi-state occupancy study to address conservation of the wolverine including restoring, connecting, and monitoring wolverine populations and their habitat in the U.S. Rocky Mountains and Cascade Mountains. Preliminary results for the 2016/17 monitoring season indicate there were 157 detections of wolverine in grid cells across Montana, Idaho, Wyoming, and Washington, but genetic identification of individuals has not yet been completed.

According to the USFWS (2013a), "Wolverine records from 1995 to 2005 indicate that wolverine populations currently exist in the northern Rocky Mountains and that the bulk of the current population occurs here. Within the area known to currently have wolverine populations, relatively few wolverines can coexist due to their naturally low population densities, even if all areas were occupied at or near carrying capacity. Given the natural limitations on wolverine population density, it is likely that historic wolverine population numbers were also low" (p. 7868).

Wolverine populations fluctuate in response to prey availability, juvenile dispersal, and mortality of adult females. The USFWS stated that the northern Rocky Mountains portion of the North American wolverine distinct population segment is thought to be the largest subpopulation and the most genetically resilient of the current subpopulations within the United States (USFWS, 2013a). Inman and others (2013) estimated the current population as well as the population capacity for regions of the western U.S. The Forest is in the Northern Continental Divide region. Inman and others (2013) estimated that current population in the Northern Continental Divide region is at its capacity, with the highest capacity in the Bob Marshall Wilderness.

Current information for wolverine occurrence on the Forest is based on (1) reported trapping records; (2) non-invasive monitoring, including remote cameras and DNA analysis of hair or scat; and (3) observations/sightings of either the species or tracks recorded in Forest or State databases (USDA, n.d.).

Wolverine detections are distributed across suitable habitats on the Forest (USDA, n.d.). No recent research that would estimate population levels has been conducted for wolverine on the Forest. The Forest and other cooperators detected a minimum of 13 individual wolverines within Forest geographic areas (based upon genetic analysis of samples collected during non-invasive carnivore monitoring in areas accessible by snowmobile from 2012-2015) (Curry et al., 2016; Pilgrim & Schwartz, 2015; Ruby et al., 2016; Swanson, 2017; SWCC, 2014, 2015).

Hornocker and Hash conducted telemetry research on 24 individual wolverines over a five-year period within a study area making up about 1,300 square kilometers of the Flathead National Forest (Hornocker & Hash, 1981). Their study area was primarily located in the South Fork of the Flathead River watershed and, secondarily, portions of the Sun, Swan, and Middle Fork of the Flathead River watersheds. About one half of the study area had timber harvest and a wide variety of types of recreation, and the other half was wilderness. Hornocker and Hash found wolverines at relatively high densities in the South Fork of the Flathead River watershed, and they concluded the population was stable (Hornocker & Hash, 1981). Research on wolverines has been conducted in the last decade or so in Glacier National Park (adjacent to the Forest)(Copeland & Yates, 2006; J. R. Squires, Copeland, Ulizio, Schwartz, & Ruggiero, 2007). Wolverines are constantly on the move and are known to make long-distance movements that are not impeded by topography or deep snow (Copeland & Yates, 2006; J. R. Squires et al., 2007). Copeland and Yates estimated that adult female wolverines have home ranges averaging 55 square miles. Adult males ranged over an even larger area, including lands outside the park, with home ranges that averaged 193 square miles (Copeland & Yates, 2006). Home range boundaries are dynamic, as are population demographics.

Habitat

For wolverine habitat across the western U.S., Inman and others reported that in general, wolverines are distributed in areas of higher elevation, where there is steeper terrain, more snow, fewer roads, less human activity, and in areas closer to high elevation talus, tree cover, and snow cover persisting to April 1 (Inman et al. 2013). Year-round habitat includes rocky alpine habitats, glacial cirque basins, and avalanche chutes that provide food sources such as marmots, voles, and carrion (Copeland et al., 2007; Hornocker & Hash, 1981; Robert M. Inman et al., 2007; Magoun & Copeland, 1998). Wolverines appear to rely on the cold and snow to cache carrion (Robert M. Inman, Magoun, Persson, & Mattisson, 2012). Wolverines also travel through the area where snow persists and they minimize travel through low-elevation habitat (McKelvey et al., 2011). Persistent spring snow cover is also correlated with gene flow because this is where the wolverine's within-home-range movements and dispersal occurs year-round (M. K. Schwartz et al., 2009). The area modeled by Inman and others (2013) as providing for male dispersal encompasses the whole Forest, while the area modeled as providing for female dispersal is more limited.

Magoun and Copeland (1998) described two types of reproductive dens: natal dens where young are born and maternal dens where the mother may move the kits if conditions are no longer suitable at the natal den. Abandonment of natal and maternal dens may be a preemptive strategy that confers an advantage to females if prolonged use of the same den makes a den more evident to predators (USFWS, 2013a). Sites used for maternal dens are often close to the natal den and have a similar structure. Prior to the Glacier National Park study, not much was known about the den sites of reproductive female wolverines in Montana because den sites are often in remote terrain that is very difficult to study. During the first three years of the study, data was collected for 19 wolverines, and information about reproductive dens was obtained for two adult females that raised four offspring (kits). Copeland and others found that dens were excavated in the snow and were on upper slopes in sparse timber beneath downed woody debris or rocks. Dens are typically used through late April or early May. Females used two to three different dens prior to the weaning of kits at six to seven months of age. Kits gather at rendezvous sites that are primarily in

boulder, talus, and cliff areas (Copeland et al., 2010). Survival of young was low, even in the national park setting where trapping is not allowed and motorized disturbance does not occur in winter or spring. Wolverine den sites may not occur in the same exact spot year after year, and specific maternal and/or natal den sites on the Forest are unknown.

Primary wolverine habitat is also characterized by low levels of human development (Copeland, 1996; Hornocker & Hash, 1981; Krebs, Lofroth, & Parfitt, 2007; USFWS, 2013a). This negative association with frequent human presence is sometimes interpreted as active avoidance of human disturbance, but it may reflect the wolverine's preference for cold, snowy, and high-elevation habitat that humans do not often develop. The USFWS assessed the effects of a variety of human activities that can affect wolverines and their use of habitat. The USFWS stated:

> Few effects to wolverines from land management actions such as grazing, timber harvest, and prescribed fire have been documented. Wolverines in British Columbia used recently logged areas in the summer and moose winter ranges for foraging (Krebs et al., 2007, pp. 2189-2190). Males did not appear to be influenced strongly by the presence of roadless areas (Krebs et al., 2007, pp. 2189-2190). In Idaho, wolverines used recently burned areas despite the loss of canopy cover (Copeland, 1996). . . .
>
> Intensive management activities such as timber harvest and prescribed fire do occur in wolverine habitat; however, for the most part, wolverine habitat tends to be located at high elevations and in rugged topography that is unsuitable for intensive timber management. . . . Wolverines are not thought to be dependent on specific vegetation or habitat features that might be manipulated by land management activities, nor is there evidence to suggest that land management activities are a threat to the conservation of the species. (USFWS, 2013a, p. 7879)

The USFWS also stated that it is unlikely that wolverines avoid the type of low-use forest roads that generally are found in wolverine habitat. Based on the best available science, the USFWS concluded that wolverines do not avoid human development of the types that occur within suitable wolverine habitat and that there is no evidence that wolverine dispersal is affected by infrastructure development (USFWS, 2013a).

Krebs and others (2007) modeled male vs. female wolverine habitat selection in British Columbia, hypothesizing that food, predation risk, and human disturbance affected habitat selection. Krebs and others based their model on 39 adult wolverines (23 females and 16 males) that were located a total of 2,125 times within two study areas. These authors modeled selection in two time periods: winter and nonwinter. The winter season was defined as the period when there was persistent snow cover at treeline. Human use variables included in the models they tested included those associated with winter recreation activity, roads, and timber harvesting. Winter recreation data included estimates of snowmobile primary use sites, locations of runs for two helicopter skiing companies in the Columbia Mountains study area, and backcountry ski use centered on the Trans-Canada Highway corridor within and adjacent to Mount Revelstoke and Glacier National Parks. These authors stated that extensive timber harvesting had occurred within a large portion of the study area. Krebs and others (2007) concluded that male wolverines were most closely associated with food availability in both summer and winter. Moose winter ranges, valley bottom forests, and avalanche terrain were positively associated with winter male wolverine use. The authors stated:

> Habitat associations of females were more complex; combinations of variables supporting food, predation risk, or human disturbance hypotheses were included in most supported models from both summer and winter in both study areas. Females were associated with alpine and avalanche environments where hoary marmot and Columbia ground squirrel prey are found in summer.

> Roaded and recently logged areas were negatively associated with female wolverines in summer. In the Columbia Mountains, where winter recreation was widespread, females were negatively associated with helicopter and backcountry skiing. Moose winter ranges within rugged landscapes were positively associated with females during winter. Our analysis suggests wolverines were negatively responding to human disturbance within occupied habitat. The population consequences of these functional habitat relationships will require additional focused research. Our spatially explicit models can be used to support conservation planning for resource extraction and tourism industries operating in landscapes occupied by wolverines. (abstract)

Recreational use in wolverine habitat

The threshold for the amount of human activity that can occur before it affects male and female wolverine habitat selection is unknown. Some scientists have expressed concern about the effects of human activities on female wolverines with young kits during the mid-February to mid-May time period because food resources are scarce for foraging females. As the kits mature, the mother will leave them for longer periods of time to find food, but until the kits are at least 10 weeks old, they cannot travel with their mother. If a female needs to move kits to a new location, or to another den, she must carry them in her mouth. If the female needs to move the kits very far, the probability of kits dying increases. Reproductive females and kits are at risk of predation (Magoun & Copeland, 1998), and, according to Persson in 2005, females are most vulnerable to energetic pressures due to the high cost of lactation during this period (Krebs et al., 2007). The predominant activity in some portions of wolverine habitat during this time period is backcountry recreation.

Winter backcountry recreation opportunities in the northern Rocky Mountains include snowshoeing, snowboarding, skiing, snowcat- or trackster-assisted skiing and snowboarding, snow bikes, and snowmobiling. Heinemeyer and Squires (2015) are investigating winter recreational use (primarily skiing, snowboarding, and snowmobiling) in wolverine habitat in central Idaho and the Yellowstone region of Idaho, Montana, and Wyoming. Heinemeyer and Squires stated that wolverines appear to tolerate many types of winter recreation in their home ranges. Wolverines have been documented to persist and reproduce in habitats with high levels of human use and disturbance, including developed alpine ski areas and areas with motorized snowmobile use (Heinemeyer, 2012; Heinemeyer & Squires, 2013). Heinemeyer and Squires (2014) stated, “Wolverines appear to tolerate winter recreation in their home ranges, including denning females. Based on our preliminary findings, potential wolverine habitats that have even high levels of winter recreation may support resident wolverines despite the potential human disturbance” (p. 4). This suggests that wolverines can survive and reproduce in areas that experience human use and disturbance; however, there is uncertainty with respect to the amount, type, and timing of human recreational use and its effects on female wolverines.

Heinemeyer and Squires (2014) indicated there may be increasing avoidance of winter recreation areas as the amount of an individual wolverine’s home range affected by winter recreation increases. They also noted that the reproductive status of the females may affect their potential response to winter recreation, with reproductive females having higher movement rates when in a high-use recreation zone. In their 2015 annual report, Heinemeyer and Squires (2015) stated that the field data collection for the wolverine winter recreation project was completed and they were focused on analyzing the responses of wolverines to winter recreation (p. 12). The response of individual wolverines to human disturbance is still being analyzed.

The Flathead National Forest has approximately 1.4 to 1.7 million acres of modeled wolverine habitat, depending upon which model is used (USFWS, 2013a, 2014b; Woods, Morey, & Mitchell, 2014). The majority of the modeled habitat occurs in the Bob Marshall Wilderness Complex in the South Fork and Middle Fork geographic areas, with lesser amounts in the Swan and Mission Mountain portions of the

Swan Valley geographic area as well as the Whitefish Range portion of the North Fork and Salish Mountains geographic areas. On the Forest, about 59-64 percent of modeled wolverine habitat is in designated wilderness, where motorized uses (including snowmobiling, helicopter-assisted skiing or snowboarding, and trackster-assisted skiing or snowboarding) are not allowed. Nonmotorized uses such as backcountry skiing are not restricted, but because much of the wilderness area on the Forest is large and remote, it is also difficult to access for nonmotorized winter recreation. Wilderness areas provide habitat where the risk of human disturbance to wolverines is very low during the time period when females have dependent young. In addition, about 25 percent of modeled wolverine habitat is in inventoried roadless areas, where road building is not allowed and timber harvest is restricted. Glacier National Park, adjacent to the Forest, provides over 1 million acres that is closed to motorized over-snow vehicle use. In combination with wilderness areas on the Forest to the south, there are over 2 million acres of habitat available to wolverines where there is no motorized over-snow vehicle use allowed and where ungulates are present to provide sources of carrion. I

Some of the modeled wolverine habitat on the Forest has developed recreation and motorized access. Much of Whitefish Mountain Resort is in modeled wolverine habitat and skiers riding the lift observed a wolverine as it fed on carrion. Outside wilderness areas, restrictions on motor vehicle and motorized over-snow vehicle use provide habitat for wolverines with a low risk of human disturbance during time periods when wolverines may be sensitive—particularly in the North Fork geographic area, where use of motorized over-snow vehicles is restricted to specific routes in much of the area. In areas open to motorized over-snow vehicle use, the amount of use has likely increased over the last few decades due to technical advances in motorized over-snow vehicles and human population growth in the Flathead Valley. Backcountry skiing has also increased in popularity.

Connectivity and wolverine habitat

Inman and others (2013) reported that the Northern US Rockies include most of the major core areas, the majority of the current population, and connections to larger populations in Canada. They identified six regions that can likely function as major population cores where primary habitats exist as large blocks of relatively contiguous, publically-owned lands that include significant portions of designated wilderness or national park and are capable of supporting 50 or more wolverines; these were the Northern Cascade, Northern Continental Divide, Salmon-Selway, Greater Yellowstone, Southern Rockies, and Sierra-Nevada Regions. Recent research in Glacier National Park has demonstrated that habitat connectivity between Glacier National Park, the Forest, and Canada currently provides for wolverine movement (Copeland & Yates, 2006).

Effects of the Framework Programmatic Action

For assessing effects to wolverine habitat, we used models which incorporated the work of two groups of scientists (Copeland et al., 2010; R. M. Inman et al., 2011)for wolverine habitat across the United States (USFWS, 2013a, 2014b) (Figure B-19), as refined by Inman and others (2013).

As described in the affected environment section above, research results suggest that wolverines are generally tolerant of human disturbance associated with recreation developments and activities (Heinemeyer & Squires, 2014, p. 4). The thresholds for the amount of development or human recreational use that individual wolverines will tolerate in their home ranges is unknown but is being investigated. Plan components would support key ecosystem characteristics for wolverines because about 59-64 percent of modeled wolverine habitat is in designated wilderness (the range varies based upon which model is used). In designated wilderness, the risk of human disturbance is low because motorized uses and mechanized transport such as snowmobiling, helicopter-assisted skiing or snowboarding, and snow bikes are not allowed. Nonmotorized and non-mechanized transport on the Forest are not restricted, but

because much of the designated wilderness area on the Forest is remote, it is difficult to access for nonmotorized and nonmechanized winter recreation.

To assess effects of the risk of human disturbance to female wolverines with young, the Forest used the model developed by Copeland and others to model maternal denning habitat (2010). Modeled maternal denning habitat encompasses about 655,000 acres or about 27 percent of all Forest lands. In comparison with the environmental baseline, there would be a slight net decrease in modeled maternal denning habitat that is suitable for motorized over-snow vehicle use. The proposed action, alternative B modified, would change an area in Big Creek to suitable for motorized over-snow vehicle use, but the majority of the area added is not in modeled maternal denning habitat. An area in Sullivan Creek would become unsuitable and is in modeled maternal denning habitat.

The revised forest plan also includes guidelines that would benefit the wolverine by limiting the risk of human activities that might cause disturbance in modeled maternal denning habitat in the future. FW-GDL-WL-04 states, "New projects or activity authorizations involving low-altitude helicopter flights or landings in areas of modeled wolverine maternal denning habitat (identified in cooperation with USFWS and the USFS Rocky Mountain Research Station) should not occur from February 15 to May 15 unless they include strategies or design features to mitigate disturbance to wolverines. Exceptions to this guideline may occur for public health and safety, emergency activities, or other approved administrative activities, such as site maintenance." FW-GDL-REC-04 states, "To limit the risk of cumulative impacts to female wolverines with dependent young, there should be no net increase in percentage of modeled wolverine maternal denning habitat where motorized over-snow vehicle use would be suitable on NFS lands at a forestwide scale. Specific locations of routes or areas suitable for motorized over-snow vehicle use are specified in figure B-11."

Under alternative B modified, about 15 percent of modeled wolverine maternal denning habitat is in recommended wilderness (management area 1b) and it would not be suitable for motorized uses or mechanized transport. In summary, scientific information about the effects of human disturbance indicates that wolverines are generally tolerant of many types of human recreational developments and use, as described in the affected environment section. The thresholds for levels of human disturbance in habitats where female wolverines give birth to and raise dependent offspring are unknown at this time, but plan components for all alternatives would limit the risk of human disturbance.

Plan components support habitat connectivity for the wolverine by: 1) designating management areas that form large contiguous blocks of habitat with low levels of human development to provide for potential range shifts of this species, 2) providing for ecological conditions that meet subsistence and movement needs in connectivity areas, 3) limiting mortality risk through management of motorized access, 4) working with adjacent landowners and other interested parties to improve connectivity and linkage opportunities across multiple jurisdictions (e.g., cooperative agreements, highway approaches/ crossings, and land consolidations, exchanges, acquisitions, easements). Some of the key plan components include:

- Infrastructure standard FW-STD-IFS-02 limits increases in motorized access, and guideline FW-GDL-IFS-12 specifies that within areas specifically identified as being important for wildlife connectivity across highways (see table 18), the Forest should cooperate with highway managers and other landowners to design approaches and crossings that contribute to wildlife and public safety.

- Energy and minerals standards FW-STD-E&M-08 and 09 contribute to connectivity. For example, new leases for leasable minerals in the grizzly bear recovery zone/primary conservation area shall include a no surface occupancy stipulation and development is not allowed in areas withdrawn from mineral entry.

- Desired condition FW-DC-LSU-01 specifies that land ownership adjustments, through purchase, donation, exchange, or other authority, improve national forest management by consolidating ownership, reducing wildlife-human conflicts, providing for wildlife habitat connectivity, improving public access to public lands, and retaining or acquiring key lands for wildlife and fish and lands within wild and scenic river corridors.

- Desired condition FW-DC-P&C-01 specifies that the Forest work towards an all-lands approach to management, in cooperation with other land managers, such as by mitigating threats or stressors, providing for wildlife and fish habitat connectivity, and providing social, economic, and ecological conditions that contribute to mutual objectives.

- Several geographic area plan components provide for connectivity, incorporating areas where connectivity across highways is emphasized in several models: GA-HH-DC-03, GA-MF-DC-04, GA-NF-DC-06 and 07, GA-SM-DC-03, and GA-SV-DC-09, GA-MF-OBJ-01, GA-NF-OBJ-03, and GA-SM-OBJ-04.

- Management area suitability also contributes to connectivity. For example, management areas 1a, 1b, 2a, 2b, 4a, 5a, and 5c are not suitable for permanent road construction, wheeled motor vehicle use, or timber production (see revised forest plan table 34 for more details).

Cumulative effects on the wolverine

Cumulative effects under the Endangered Species Act include state, tribal, local, or private actions that are reasonably certain to occur in the action area. Future site-specific Forest Service activities are subject to future section 7 consultation requirements and are not included in the cumulative effects analysis in this biological assessment.

The wolverine trapping harvest during the 30 years prior to 2007 was considered stable, with a statewide average of 10.5 wolverines taken annually during this time period (Giddings, 2009, pp. 35-39). Then, based on research findings by Squires and others (J. R. Squires et al., 2007), wolverine trapping quotas were adjusted downward for the two large ecosystems in the state; the Northern Continental Divide Wildlife Management Unit (WMU 1) and the Greater Yellowstone (WMU 3). Further analysis tied to the genetic make-up of the Montana wolverine population, the issue of maintaining population connectivity, and recognizing the core population areas of three major ecosystems (now including the central Idaho wilderness area) led to additional regulation changes in 2008. These adjustments included delineating four wildlife management units and reducing quotas to a statewide total of five animals, with a central Montana wildlife management unit quota of 0, to promote population connectivity among the three major ecosystems in the state where harvest is allowed (Giddings, 2009, pp. 35-39). In December 2012, a state district court judge in Helena granted a temporary restraining order that blocked the opening of Montana's 2012–13 wolverine trapping season, and it remained closed with a quota of "0" in 2013–14 and 2014–15. The future of wolverine trapping is unknown. The Forest is within wolverine management unit 1 (WMU 1) (northwest Montana), which had a quota of three wolverines (with a maximum of one female) in 2010 and has had a quota of 0 since then (MTFWP, 2015). Since trapping was suspended in 2011, there has been one wolverine trapped accidentally (T. Thier, MFWP, personal communication, 2016). Glacier National Park, encompassing about one million acres adjacent to the Forest, is closed to trapping. Any cumulative effects to the wolverine resulting from trapping and winter recreation access on all lands are highly uncertain at this time, but investigations are ongoing. Management on the Forest has supported wolverine populations in the past and is expected to continue to do so in the future.

Lands managed by the Confederated Salish and Kootenai Tribes include the Mission Mountains Tribal Wilderness Area and the South Fork Jocko Primitive Area. Cumulative adverse effects to the wolverine are not expected as a result of management actions on tribal lands.

Private lands do not generally occur in modeled wolverine habitat on the Flathead National Forest. The human population in northwest Montana has grown at a relatively high rate during the past few decades, and growth is expected to continue. Increasing residential development along highways that cross wolverine habitat and demand for recreational opportunities can result in disturbance or habitat fragmentation,

With respect to connectivity and highways on the Forest, there is one high-elevation paved highway along the border between the Forest and Glacier National Park. Since 2011, there have been two wolverines killed by vehicles in MFWP Region 1 (T. Thier, MFWP, personal communication, 2016). Squires and others concluded that wolverine movements are unpredictable and are not well suited for planning structural highway mitigation projects. They suggested that connectivity for wolverines may be facilitated by limiting permanent developments through conservation easements and land purchases (J. R. Squires et al., 2007). The Forest and Montana DNRC recently completed the Legacy land acquisition in the Swan Valley geographic area of the Forest. This acquisition and other conservation easements on private lands may benefit wolverines in the future by limiting the density of permanent human developments and facilitating movement between mountain ranges.

From:	Shoemaker, Justin
To:	Marjorie Nelson
Subject:	Fwd: draft wolverine SSA comments
Date:	Monday, December 4, 2017 8:48:45 AM
Attachments:	image002.png image004.png image003.png image001.png Wolverine draft SSA comments.docx Yates_edits_11_17Draft Wolverine SSA Report_Oct 23 2017.pdf

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FYI

Justin Shoemaker
Classification and Recovery Biologist
U.S. Fish and Wildlife Service, Region 6
Phone: 309-757-5800 x214
Email: justin_shoemaker@fws.gov

---------- Forwarded message ----------
From: **Grizzle, Betty** <betty_grizzle@fws.gov>
Date: Mon, Dec 4, 2017 at 9:33 AM
Subject: Fwd: draft wolverine SSA comments
To: "Shoemaker, Justin" <justin_shoemaker@fws.gov>, John Guinotte <john_guinotte@fws.gov>

From USFS.

---------- Forwarded message ----------
From: **Jackson, Scott -FS** <sjackson03@fs.fed.us>
Date: Fri, Dec 1, 2017 at 5:20 PM
Subject: RE: draft wolverine SSA comments
To: "Grizzle, Betty" <betty_grizzle@fws.gov>
Cc: "Jodi_Bush@fws.gov" <Jodi_Bush@fws.gov>

Hi Betty,

Please accept this email as the USFS comments on the FWS's draft Species Status Assessment for the North American Wolverine (v. 1.0, Oct. 23, 2017). I've attached a Word document that provides comments primarily pertaining to the North Cascades, and a pdf of the draft SSA that includes comments in track changes, with a focus more on the Northern Rockies.

In addition, I've included the following from a USFS commenter, which summarizes some of the comments in the attached pdf file.

> Attached are my comments on the Wolverine SSA. I appreciate the opportunity to comment and I do hope my comments are helpful in perpetuating the conservation of wolverines in the lower 48 states.
>
> As you are aware, much of the SSA climate change discussion was based on specific data from our Glacier National Park wolverine study between 2002 and 2007. I feel it is my obligation as a wildlife biologist to provide comments on the proper use and interpretation of those data, and once again, I appreciate the opportunity to do so. I made comments throughout the document, including editions for grammatical errors. However the Glacier Climate Change analysis, as it relates to den site habitat and persistent snow cover, is the section of the document I had the most comments on. The other issue was how Copeland et al. 2010 was presented. Here are a few summary highlights.
>
> Snow pack at active wolverine den sites in Glacier averaged 2.6m in depth at the end of April and in to early May. I know this because I visited these sites and did the measurements. This metric is not based on a model. For some reason, the depth used as the standard for the SSA models was 0.5m. If snow depth diminishes from an average of 2.6m to 0.5m and we call that "no change", because it is still "snow cover", it is not the same thing where a wolverine is concerned. Not all snow cover is the same, ask any hydrologist. Our den sites had a deep snow pack at the time of use. A half meter is not deep.
>
> The model for the changes in snow cover in Glacier used years 2000 to 2013 as the "historic average". I have a real problem with this. 2012 was the hottest year ever recorded, and 13 of the 14 hottest years occurred during this supposed "historic" period. Using this average and projecting 40 years into the future produced little change in the snow cover in Glacier. I believe this is a misrepresentation of what is occurring on the ground.

Finally, Copeland et al. 2010 was a seminal work that correlated persistent spring snow cover with wolverine den sites (n=562), across the Northern Hemisphere. It was not intended to be the final word on wolverine reproductive denning habitat or temperature conditions. The model Copeland used explained 96% of the relationship between wolverine dens and persistent spring snow. There are, of course, exceptions/outliers. That is not surprising. However, the SSA goes to great lengths to suggest that wolverines can den in areas that do not show persistent spring snow as a habitat feature. There may be reasons for this that are explained by the limitations of the models. But, to use a sample size of 8, at a different scale, to refute a hemispheric model of 562 den sites seems rather capricious. There is no doubt that wolverine reproductive denning ecology is in need of further study. Perhaps wolverines can adapt to increases in temperature and to losses of snow cover (den substrate), perhaps not.

Thank you, Betty, for providing the USFS the opportunity to review and comment. You've done a nice job of assembling a lot of good information and I very much appreciate the effort that went into this document. As managers of the majority of wolverine habitat in the lower 48, the USFS very much supports the use of the best science available, in the most accurate way possible, to help conserve this rare species and its habitat.

Scott Jackson
National Carnivore Program Leader
Forest Service

Northern Regional Office

p: 406-329-3664
f: 406-329-3171
sjackson03@fs.fed.us

26 Fort Missoula Road
Missoula, MT 59804
www.fs.fed.us

Caring for the land and serving people

From: Grizzle, Betty [mailto:betty_grizzle@fws.gov]
Sent: Wednesday, November 29, 2017 5:00 PM

To: Jackson, Scott -FS <sjackson03@fs.fed.us>
Subject: Re: draft wolverine SSA comments

Hi Scott - As much as it would make it easier to have everything in one document, given our time constraints, it's probably best just to send everything and we will sort through them.

Thanks to you and others for your review,

Betty

On Wed, Nov 29, 2017 at 3:54 PM, Jackson, Scott -FS <sjackson03@fs.fed.us> wrote:

> Hi Betty,
>
> I've collected some USFS comments on the draft wolverine SSA and would like to provide them to you. Do you have a preference for the format? Some of what I've received are written out in a Word doc and some are in track changes within the document. Would it work for you if I just forward them to you? Or do you need a summary of comments?
>
> Thank you for the chance to comment. I appreciate the work that went into the draft SSA report.

Scott Jackson
National Carnivore Program Leader
Forest Service

Northern Regional Office

p: 406-329-3664
f: 406-329-3171
sjackson03@fs.fed.us

26 Fort Missoula Road
Missoula, MT 59804
www.fs.fed.us

Caring for the land and serving people

Dear Wolverine Conservation Partners:

Attached please find the DRAFT Species Status Assessment (SSA) for the North American Wolverine. As you may be aware, the draft report is currently undergoing peer review.

We are providing this draft to your agency for review by members of your organization with expert knowledge of the species and its habitat. Your review will help us ensure that we have appropriately considered the best scientific and commercial information when evaluating the current status and future viability of the North American wolverine. We request your independent scientific perspectives on the comprehensiveness and logic of the document, as well as how well the technical conclusions are supported by the data and analyses.

As the literature cited is lengthy, if you need a copy of any document cited in the draft report, please contact Betty Grizzle at the email address below.

The Draft SSA is not intended to solicit public comment and will be revised after this scientific review. The SSA does not predetermine any future agency decision under the Endangered Species Act.

In general we ask that your comments on the Draft SSA report focus specifically on whether the best available information was used, the quality of the scientific information, and our interpretation and analyses of the data with regard to the species' viability in the contiguous United States. We request that you direct your review to the scientific issues and assumptions related to your expertise.

General Information about SSAs:

The Species Status Assessment framework is a new tool the U.S. Fish and Wildlife Service is using to improve transparency while conducting listing determinations and other Act actions, and peer review of our analyses of the viability of species is part of that new process. The attached draft SSA report is a rough draft; we are seeking comments at this stage to ensure that we have time to incorporate any substantial comments as we finalize the report.

In reviewing the document, please note that this draft SSA report does not result in or predetermine a decision by the Service on whether the Canada lynx warrants protections of the Act. This document is strictly a characterization of the viability species' viability in the contiguous United States. As a reminder, all reviews and comments submitted to the Service will become public documents and part of our administrative record for this document.

We welcome consolidated comments from your organization by November 30, 2017. Please send comments by that date to Betty_Grizzle@fws.gov. Thank you for your interest and assistance. JB

Jodi L. Bush

Office Supervisor

Montana State Ecological Services Office

585 Shepard Way, Suite 1

Helena, MT 59601

(406) 449-5225, ext.205

Jodi L. Bush

Office Supervisor

Montana State Ecological Services Office

585 Shepard Way, Suite 1

Helena, MT 59601

(406) 449-5225, ext.205

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Betty J. Grizzle, D.Env.

Fish and Wildlife Biologist

U.S. Fish and Wildlife Service

Carlsbad Fish and Wildlife Office

2177 Salk Ave, Suite 250

Carlsbad, CA 92008

760-431-9440, ext. 215

760-431-5901 fax

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Betty J. Grizzle, D.Env.
Fish and Wildlife Biologist
U.S. Fish and Wildlife Service
Carlsbad Fish and Wildlife Office
2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

Comments, as requested, on
***Draft* Species Status Assessment for the North American Wolverine; USFWS; Version 1.0**

Page 17; Figure 3 – The title for this figure seems to be misleading, "Current range of North American wolverine". The map delineates areas in Oregon, California, Utah, and Colorado implying that wolverines are distributed throughout these areas, which does not seem to be an accurate reflection of current data. Using the presence of one male wolverine in Colorado to illustrate that the entire southern Rocky Mtn range is inhabited seems to be a stretch. Same thing for California and all of Oregon except the NE corner. There have been numerous track and baited camera station surveys in the Oregon Cascades in recent years that have targeted wolverine, with no detections.

Page 27; paragraph 3 – This section seems to be making the case that wolverines give birth in late February/early March because that is when food resources are most available. I do not think that is the case, especially in the North Cascades of Washington and, from what I've read, not in the Rocky Mtns either. The 2 known natal den sites in the North Cascades (Aubry et al. 2016) were at approximately 5500 ft elevation. Both those sites had 7-8 ft of snow at them when discovered and into early May when we inspected them. Food resources at that elevation at that time of year are minimal; snowshoe hares, red squirrels, and hibernating rodents. From Dec through May, wolverine food resources in the form of ungulate carrion are most available on winter ranges, about 3000 – 4000 ft lower in elevation than the den sites. The wolverines collared and monitored during the 10 year North Cascades Wolverine Study (Aubry et al. 2016) never went to these lower elevations, in winter or summer. We documented over 2400 telemetry locations on 11 different wolverines and 91% of those fell within the area modelled by Copeland et al (2010) for persistent spring snow cover. At the den sites elevation, it would seem wolverine food resources are most available from late June through September, when rodents aren't hibernating and ungulates are using those high elevation areas.

Page 48; paragraph 4 – "*and a member of the public reported wolverine tracks within Grand Teton National Park in March 2017, while skiing* . . . " Seems like you would want to limit wolverine sightings that you include in this assessment to those that are verified with a carcass, photograph or DNA sample. I would not categorize a report of wolverine tracks in the snow from a member of the public as a verified sighting without a good photo of the tracks. Based on my 27 years as a wildlife biologist and the numerous follow-ups I have done on reports of rare carnivores, I have found reports by members of the public to often be unreliable.

In general, there seem to be inconsistencies between some of the final conclusions and some of the information presented in the assessment:
Page 92; paragraph 2 – "Although the persistence of spring snow has not yet been evaluated as critical to wolverine survival in North America . . . ." Yet on page 32; paragraph 5 – ". . . indicated that most panelists allocated points to an obligate relationship of wolverines with deep snow at the den-site scale."
And on page 10; paragraph 1 – "The wolverine is a snow-adapted, cold climate animal in its physiology, morphology, behavior, and habits." But on page v, ". . .we have no indication that this species is unable to adapt or adjust to changing conditions."

Page 93; paragraph 4 – " . . both direct and cumulative effects of climate change may affect the resilience of the wolverine by creating an environment that is less favorable to its physiological and ecological needs." Yet on page 95; paragraph 2 – " . . we do not predict a significant loss of individual and population resiliency to the species in the future within its North America range, including the

contiguous United States." And page 95; paragraph 3 – "We do not expect a reduction in representation of the wolverines in the contiguous United States in the future."

In regards to the 2 statements with conclusions regarding the population in the contiguous U.S.:
page 95; paragraph 2 - " . . we do not predict a significant loss of individual and population resiliency to the species in the future within its North America range, including the contiguous United States." And page 95; paragraph 3 – "We do not expect a reduction in representation of the wolverines in the contiguous United States in the future."
Known wolverine natal dens in the contiguous US are in deep snow areas. New data from northern Canada, Russia, and Scandinavia doesn't change that. Wolverines seem to be made for occupying deep snow; their large feet, frost-resistant fur, powerful jaws for eating frozen meat, foot-load, threshold of thermoneutrality all indicate that they are adapted to a deep-snow, cold environment. Their global distribution is largely restricted to areas that are snowy and cold. In the contiguous US they are currently only found in northern, high mountain ranges. They live in the snow, they give birth to altricial young in the middle of winter at elevations with deep snow. And they seem to be able to do that by caching food items in snowbanks that last year round (Inman et al. 2012). The conclusions in the Draft SSA seem to be based on the assumption that wolverines don't need deep snow and can survive/adapt to areas without snow because there is no data showing exactly why deep snow is needed by wolverines, or because there is no data that precisely proves that wolverines cannot survive in areas without snow. Wolverines in the North Cascades only used high elevations year-round (Aubry et al. 2016) despite the fact that one of their reportedly primary food sources, ungulate carrion, is much more abundant at lower elevations. The Draft SSA does not make a compelling argument that this population is secure into the future, especially with a changing climate that will reduce and constrict the amount of deep snow habitat in the Cascade and Rocky Mtn ranges.

Thank you for the opportunity to comment.

DRAFT
SPECIES STATUS ASSESSMENT
FOR THE
NORTH AMERICAN WOLVERINE
(*Gulo gulo luscus*)

Wolverines in southwestern Montana. *Photo credit: Mark Packila; used with permission.*

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Executive Summary

The North American wolverine (*Gulo gulo luscus*; wolverine) is a medium-sized carnivore found across the west-northwestern contiguous United States, Alaska, and Canada. The most recent estimate of wolverine populations in the contiguous United States based on resource function modeling is 318 individuals, with a range from 249 to 949; however, systematic monitoring across the wolverine's North American range has not been conducted given the difficulty in surveying this highly mobile species, and its occupation across large and remote areas. A multi-state effort to determine wolverine occupancy in Montana, Idaho, and Washington was conducted in winter of 2016–2017 and in Wyoming for the winters of 2015 and 2016–2017. Results from this study are still being analyzed, but photographic detections of wolverines were found across all States, including areas where wolverines have not recently been observed. In Canada, the population is estimated to exceed 10,000 mature individuals and has been stable over the last two decades. Recent density estimates indicate no declining trend for wolverines in Alaska. Wolverine populations in Alaska are considered to be continuous with populations in the Yukon and British Columbia provinces of Canada. Wolverines that occupy the North Cascades region are known to move from Washington into British Columbia.

Wolverines are highly mobile, capable of moving and dispersing over great distances over short periods of time. Wolverine populations are also characterized by naturally low densities in North America. The species is highly territorial, with very little overlap between same-sex adults. Wolverines occupy a variety of habitats, but are generally found in remote locations, away from human settlements. Wolverines consume a variety of food resources and seasonal switching of prey likely allows for adjustment for nutritional needs throughout their life history. As observed in other arctic mammals, wolverines have the ability to dissipate body heat to balance the heat loss from 30°C to −40°C (86°F to −40°F), due in large part to vasodilatation and rise of skin temperature, and rapid and seasonal adjustments in fur insulation. Wolverines can also adapt to both cold and warm temperatures by movement and, relatedly, micro- and macro-habitat selection. Further, wolverines have been observed near and in lakes and other water bodies.

Wolverine reproduction includes the following characteristics: polygamous behavior (i.e., male mates with more than one female each year), delayed implantation (up to 6 months), a short gestation period (30–40 days), denning behavior, and an extended period of maternal care (3.5 months). The reproductive behavior in wolverines is temporally adapted to take advantage of the availability of food resources, limited interspecific competition, and snow cover in the winter.

Since the publication of the Service's 2013 proposed rule to list the distinct population segment of the North American wolverine in the contiguous United States (78 FR 7864; February 4, 2013), several new wolverine studies have been published, which has added to our understanding of wolverine biology while also highlighting new insights into identifying key species' needs and their interactions with both abiotic and biotic factors. In particular, wolverine populations and wolverine dens have been observed outside previously modeled projections of spring snow cover. Our evaluation of snow cover at previously recorded natal den site locations in the western United States indicated that 'melt-out' dates at these locations extend well past the May 15 date used in persistent spring snow cover models.

Overall, the best available information indicates that within the contiguous United States the wolverine's physical and ecological needs include:

(1) large territories in remote landscapes; at high elevation (1,800 to 3,500 meters (5,906 to 11,483 feet));
(2) access to a variety of food resources, that varies with seasons; and
(3) physical/structural features (e.g., talus slopes, rugged terrain) linked to reproductive behavioral patterns.

In this Species Status Assessment (SSA) Report, we provide a discussion of the ecological needs of the wolverine, its current conditions, and projected future conditions. We evaluate potential stressors to the species, with a particular focus on the impacts associated with projected effects of climate change.

In our analysis, we applied the conservation biology principles of redundancy, resiliency, and representation (collectively known as the "3Rs") to evaluate the current and projected future condition of the wolverine and its ability to sustain itself (as one or more populations) in the wild over time (Carroll *et al.* 1996, entire; Wolf *et al.* 2015, entire). This evaluation considers the unique demographic, distribution, and diversity characteristics unique to the species. After applying the framework of the 3Rs, we determined the following:

(1) Redundancy: The wolverine occurs across the contiguous United States within a metapopulation structure. The best available information indicates that the species continues to expand into historical, previously occupied areas in the contiguous United States following decades of hunting and trapping.
(2) Representation: The wolverine is currently found across the west-northwestern United States, as well as much of Canada, and Alaska. The best available information indicates that the species is found across a wide range of habitats. Modeled primary habitat for the wolverine in the contiguous United States has been estimated at 164,125 square kilometers (km^2) (63,369 square miles (mi^2).
(3) Resiliency: The wolverine appears resilient within its contiguous United States range. The species exhibits physiological (e.g., seasonal changes in fur) and behavioral plasticity in its life history (e.g., reproduction, feeding, movement and use of habitat). Estimated population size and growth rates across its North American range are uncertain, but the best available information does not suggest that abundance is declining in the contiguous United States, or in North America. The most significant stressor currently and in the future appears to be the effects of climate change, such as warming temperatures and loss of snowpack. However, based on the best available information, we have no indication that this species is unable to adapt or adjust to changing conditions.

Demographic risks to the species from either known or most likely potential stressors (i.e., effects from roads, disturbance due to winter recreational activities, effects of wildland fire, and overutilization) are low based on our evaluation of the best available information as it applies to current and potential future conditions for the wolverine and in the context of the attributes that affect its viability. We analyzed the potential effects of climate change to wolverine habitat, including snow persistence in the Northern and Southern Rocky Mountains. The future

timeframe evaluated in this analysis is approximately 40 to 50 years, which captures the range of time periods for proposed projects within the species range, as well as our best professional judgment of the projected future conditions related to climate change, wildland fire conditions, or other potential cumulative impacts. While population information is lacking for this subspecies in some parts of its range, the best available information does not indicate that, winter recreational activities, infrastructure features, mortality from road crossings or trapping (authorized and incidental), currently or in the future will result in a decline in the subspecies across its range. Our evaluation of climate change indicates that snow cover is projected to decline in response to warming temperatures and changing precipitation patterns, but this varies by elevation, topography, and by geographic region. In general, models indicate higher elevations will retain more snow cover than lower elevations, particularly in early spring (April 30/May1). Further, significant snow persistence (greater than 0.5 meters (20 inches)) is projected at high elevations.

Legal protections include State listing in California and Oregon (as threatened), as endangered in Colorado, as a candidate species in Washington, and protection as a non-game species in Idaho and Wyoming. In Canada, provincial designations range from endangered to threatened in eastern provinces, and sensitive/special concern to no ranking in other provinces. Legal trapping or hunting of wolverines is currently prohibited in the contiguous United States. Trapping effort along the U.S.–Canada border does not represent a significant barrier to wolverine movement and dispersal along the international border.

Within the contiguous United States, approximately 96 percent of modeled wolverine primary habitat is located on Federal lands, with 41 percent located in designated wilderness areas. Management actions, including State Wildlife Action Plans, the Idaho Wolverine Conservation Plan, and USDA Forest Service Land and Resource Management Plans, and other Federal and Tribal partners, include winter road closures, fire management, land acquisition or conservation easements.

Abbreviations and Acronyms Used

ADF&G = Alaska Department of Fish and Game
BLM = Bureau of Land Management
°C = degrees Celsius
CDFW = California Department of Fish and Wildlife
CNDDB = California Natural Diversity Database
COSEWIC = Committee on the Status of Endangered Wildlife in Canada
cm = centimeter
DNA = deoxyribonucleic acid
EIS = Environmental Impact Statement
EPA = U.S. Environmental Protection Agency
°F = degrees Fahrenheit
ft = feet
GCMs = Global Climate Models
GHG = Greenhouse gas
GPS = Global Positioning System
IDFG = Idaho Department of Fish and Game
in = inch
IPCC = Intergovernmental Panel on Climate Change
IUCN = International Union for Conservation of Nature and Natural Resources
kg = kilogram
km = kilometer
lb = pound
m = meter
mi = mile
MODIS = Moderate-Resolution Imaging Spectroradiometer
Montana FWP = Montana Fish, Wildlife, & Parks
NRC = National Research Council
NRIS = Natural Resource Information System
ODFW = Oregon Department of Fish and Wildlife
RCPs = Representative Concentration Pathways
Service = U.S. Fish and Wildlife Service
SSA = Species Status Assessment
SCA = Snow Covered Area
SGCN = Species of Greatest Conservation Need
SWCC = Southwestern Crown of the Continent
SWE = Snow Water Equivalent
WAFWA = Western Association of Fish and Wildlife Agencies
WDFW = Washington Department of Fish and Wildlife
WGFD = Wyoming Game and Fish Department
WRCC = Western Regional Climate Center
WSWCP = Western States Wolverine Conservation Project
YBP = Years Before Present

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Introduction

The wolverine (*Gulo gulo*) is the largest member of the Mustelidae family (weasels, mink, marten, and others) and resembles a small bear with a bushy tail (Hash 1987, p. 575). Wolverines have a Holarctic distribution that includes the northern portions of Europe, Asia, and North America. In North America, they are found in Alaska, much of Canada, and the western-northwestern United States. The wolverine is important to the culture of Native Americans and Aboriginal Peoples in North America, as is its conservation status in aboriginal territory (Cardinal 2004, p. iv; Edmo 2016; pers. comm.; Miles 2017, pers. comm.).

Wolverines possess a number of morphological and physiological adaptations that allow them to travel long distances and they maintain large territories in remote areas (Pasitschniak-Arts and Larivière 1995, p. 6). They have been described as curious, intelligent, and playful, but cautious animals (e.g., Krott 1958, p. 241; Krott 1960, pp. 25–26; Magoun 1985, p. 94; Cardinal 2004, p. 7–8; Woodford 2014; entire), though their social behavior and social organization has not been well-studied.

During the late 1800s and early 1900s, the wolverine population declined or was extirpated in much of the conterminous United States (lower 48 States), which has been attributed to over-trapping and habitat degradation (Hash 1987, p. 583). Similar range reductions and extirpations of some wolverine populations were observed in parts of Canada during this time period (van Zyll de Jong 1975, entire; Committee on the Status of Endangered Wildlife in Canada (COSEWIC) 2014, p. iv), attributed largely to human exploitation and availability of food (e.g., decline in caribou (*Rangifer tarandus*)), not climate or habitat changes (van Zyll de Jong 1975, pp. 434, 436). Habitat loss (historic vs. current range) for the North American wolverine (i.e., Canada and United States) has been estimated at 37 percent (Laliberte and Ripple 2004, p. 126). Wolverine numbers have recovered to some extent from this decline; in the United States, wolverines are currently found in parts of Washington, Oregon, Idaho, Montana, Wyoming, and California, and, as recently as 2012 in Colorado and 2016 in Utah, though not all of these areas contain resident, reproductive populations.

Species Status Assessment Methodology

In preparing the Species Status Assessment (SSA) Report for the wolverine, we reviewed available reports and peer-reviewed literature, incorporated survey information, and contacted species experts to collect additional unpublished information for the North American subspecies (*Gulo gulo luscus*), including Canada and Alaska. We identified uncertainties and data gaps in our assessment of the current and future status of the species. We also evaluated the appropriate analytical tools to address these gaps and conducted discussions with species experts and prepared updated maps of the known species' range and denning areas across North America. In some instances, we used publications and other reports (primarily from Fenno-Scandinavia) of the Eurasian subspecies (*Gulo gulo gulo*) in completing this assessment.

Importantly, we note here that, since the publication of the 2013 proposed listing rule (78 FR 7864; February 4, 2013), many new wolverine studies have been published, which has added to our understanding of wolverine biology while also highlighting new insights into identifying key

species' needs and their interactions with both abiotic and biotic factors. This is particularly relevant for a difficult to study animal like the wolverine.

Using the species, individual, and population needs identified for the wolverine and location results from surveys and studies, we conducted a geospatial analysis to estimate the North American wolverine's current range. We then evaluated this range and previous estimates of potentially suitable habitat in the west-northwestern United States to assess the species' current conditions within that region. Our future condition analysis includes the potential conditions that the species or its habitat may face, that is, the most probable scenario if those conditions are realized in the future. This most probable scenario includes consideration of the sources that have the potential to most likely impact the species at the population or rangewide scales in the future, including potential cumulative impacts. Potential future impacts associated with climate change (probabilistic estimates for temperature and precipitation) were based on downscaled climate model projections, including a detailed study of two regions in the western United States (Glacier National Park and Rocky Mountain National Park).

For the purpose of this assessment, we generally define viability as "consisting of self-sustaining populations that are well distributed throughout the species' range," and where "[s]elf-sustaining populations are those that are sufficiently abundant and have sufficient genetic diversity to display the array of life history strategies and forms that will provide for their persistence and adaptability in the planning area over time" (Committee of Scientists 1999, p. 38). We use a timeframe of approximately 40 to 50 years because it is within the range of the available modeling efforts related to climate change. We believe this is a reasonable timeframe to consider as it includes the potential for observing these effects over several generations of the wolverine.

Using the SSA framework (Figure 1), we consider what the species needs to maintain viability by characterizing the status of the species in terms of resiliency, redundancy, and representation (Wolf *et al*. 2015, entire).

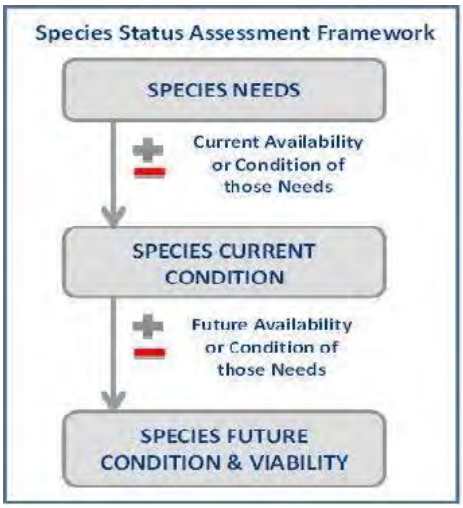

Figure 1. Species Status Assessment Framework.

- **Resiliency** is having sufficiently large populations for the species to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health; for example, birth versus death rates and population size. Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities.
- **Redundancy** is having a sufficient number of populations for the species to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk and can be measured through the

duplication and distribution of populations across the range of the species. The greater the number of populations a species has distributed over a larger landscape, the better it can withstand catastrophic events.

- **Representation** is having the breadth of genetic makeup of the species to adapt to changing environmental conditions. Representation can be measured through the genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics within the geographical range.

Species Description

Taxonomy

The taxonomic relationship between North American and Eurasian wolverines has been a debated topic (Pasitschniak-Arts and Larivière 1995, p. 1). Most authorities consider all wolverines to belong to a single species, *Gulo gulo* (Rausch 1953, p. 114; Kurten and Rausch 1959, p. 19; Wozencraft 2008 [in *Wilson and Reeder's Mammal Species of the World*, online publication]). Some also further consider the New World and Old World wolverines to be two subspecies, *Gulo gulo luscus* and *G. g. gulo,* respectively, based on morphological measurements. Degerbøl (1935, pp. 35–43) noted slight color differences and very slight, if any, cranium differences, based on 10 North American (Hudson Bay) specimens examined, and regarded the North American and Old World wolverines as conspecific, but identified two subspecies. This reference also cites Coues (1877, p. 43), who, based on observations of a slight similar cranium difference, had posited that the wolverines of the Old World and New World were the same species (Degerbøl 1935, p. 35).

In their *Checklist of Palaearctic and Indian Mammals* (1st and 2nd editions) Ellerman and Morrison-Scott (1951, p. 251; 1966, p. 251) identified one species of wolverine, but listed several subspecies. A comparative analysis of various measurements from 1 wolverine skull collected from the northern Ural Mountains to 41 Alaskan skulls by Rausch (1953, entire) reported "no appreciable differences," noting the highly variable skull characteristics for the Alaskan specimens. Additionally, Krott (1960, p. 20) found no distinct differences between Old World and New World wolverines, and that pelt size and quality were not distinguishable. However, using biometric measurements of both newly collected and previously published cranial measurements (e.g., Degerbøl 1935; Rausch 1953), Kurtén and Rausch (1959, p. 19) reported that the North American and European wolverine were significantly different in several quantitative characters related to the size and shape of the skull size and teeth size. They concluded that the two wolverine populations represented two distinct subspecies, but were the same species, *Gulo gulo*.

The International Union for Conservation of Nature and Natural Resources (IUCN) states that "Most recent accounts [citing Jones *et al*. 1992, Pasitschniak-Arts and Larivière 1995, Wozencraft 2005] treat *luscus* as a subspecies of *Gulo gulo*, following Degerbøl (1935) and

Kurtén and Rausch (1959)" (Abramov 2016, p. 1). We reviewed the references cited by IUCN. Jones *et al*. (1992, p. 17) only considers *Gulo gulo*. Pasitschniak-Arts and Larivière (1995, p. 1) state there are differences in the taxonomic treatment, and that, while *Gulo gulo* is now considered by most to be the extant *species*, others (including the above-cited Kurtén and Rausch (1959) and Rausch (1953)) have considered two *subspecies*. The Wozencraft (2005) citation is from Wilson and Reeder's previous 2005 publication, which was updated as of 2008. That account lists several "offspring" of *Gulo gulo*, but does not provide citations for the subspecies identified there, and at least two of those listed are not considered to be subspecific entities (e.g., *G. g. vancouverensis* and *G. g. luteus* (see Banci 1982, p. ii; Banci 1994, p. 104)). Finally, the COSEWIC Assessment and Status Report on the Wolverine (*Gulo gulo*) in Canada indicated that taxonomists recognize only a single subspecies (*Gulo gulo luscus*) in North America *or* consider *G. gulo* as single Holarctic taxon (COSEWIC 2014, p. 4).

Genetic analyses for the North American wolverine populations have primarily focused on genetic structure and variation of wolverine populations or subpopulations (see Kyle and Strobeck 2001; Kyle and Strobeck 2002; Zigouris *et al*. 2012, Zigouris *et al*. 2013). However, Frances' (2008, pp. 20–21) assessment of wolverine spatial genetic structure and demographic history (using mitochondrial DNA) indicated incomplete lineage sorting between North American and Eurasian populations, though comprehensive sampling has not been conducted for some areas (e.g., eastern Asia). A study by Tomasik and Cook (2005, entire) also concluded that reciprocal monophyly (i.e., distinct *species*) had not been attained between Eurasian and North American wolverine populations. Until additional studies are published, including robust genetic analyses in conjunction with additional sampling, the Service recognizes the North American wolverine as *G. g. luscus*.

Physical Appearance

Detailed descriptions of the wolverine are described in Novikov (1962, pp. 196–202), Hash (1987, p. 575), Pasitschniak-Arts and Larivière (1995, pp. 1–2), and Wilson (1982, pp. 644–646), among others. Key distinguishing features are summarized here.

Wolverines are a medium-sized (about 1 meter (m) (3.3 feet (ft)) in length) carnivore, with a large head, broad forehead, and short neck (Pasitschniak-Arts and Larivière 1995, p. 1). Males are larger than females (Hall 1981, p. 1,007; Banci 1987, p. 35). Wolverines have heavy musculature and relatively short legs, and large feet with strong, curved claws for digging and climbing (Hash 1987, p. 575). Their feet are well-adapted for travel through deep snow and, during the winter, dense, stiff, bristle-type hairs are found between the toes and around the foot pad (Grinnell *et al*. 1937, pp. 265–266; Hash 1987, p. 575); this characteristic becomes diminished in the summer (Hash 1987, p. 575).

Adult wolverines are sexually dimorphic, with females weighing from 7 to 13 kilogram (kg) (15.4 to 29 pounds (lbs)) and males weighing between 10 to 18 kg (22 to 40 lbs) (North America) (Rausch and Pearson 1972, p. 264; Magoun 1985, pp. 19–21; Banci 1994, p. 99; Copeland 1996, p. 20; Cardinal 2004, p. 8; Lofroth 2001, p. 11; Inman 2013, pers. comm.; Magoun 2013, pers. comm.; Aubry *et al*. 2016, pp. 17–18). The skulls of wolverine are large and heavy, and the strong jaw structure allows animals to feed on frozen flesh and crush bone

(Haglund 1966, p. 269; Hash 1987, p. 575). Some geographic variation and sexual differences in skull morphology have been reported (Pasitschniak-Arts and Larivière 1995, p. 2). Wolverines have small, wide-set eyes, and are reported to have excellent hearing (Grinnell *et al*. 1937, p. 265; Krott 1960, p. 25; Bevanger 1992, p. 8).

Wolverine fur is short, thick, and uniform in thickness on the head and becomes longer towards the rear of the body (Hash 1987, p. 1). The coat consists of dense, woolly underfur (2-3 centimeters (cm) (0.8-1.2 inches (in) long) and coarse, stiff guard hairs, 6-10 cm (2.4-4 in) in length (Hash 1987, p. 1). The rich glossy coat can vary from medium brown to black (Banci 1994, p. 99; Pasitschniak-Arts and Larivière 1995, p. 1). Seasonal and individual variation in pelt color has been described (Degerbøl 1935, pp. 38–42; Grinnell *et al*. 1937, p. 252). In general, the head, tail and legs are darker than the face (Pasitschniak-Arts and Larivière 1995, p. 1). An upper body stripe, which varies from creamy, pale buff to light brown or reddish in color (Pasitschniak-Arts and Larivière 1995, p. 1), extends from the nape of the neck, along the sides of the body, to the base of the bushy tail (Banci 1994, p. 99). White or orange patches are commonly found on the throat or chest (Pasitschniak-Arts and Larivière 1995, p. 1; Magoun *et al*. 2008, p. 24; Figure 14). The unique property of wolverine fur to shed frost (Hardy 1948, p. 330; Quick 1952, pp. 492–493), along with its rarity, has made wolverine pelts valuable for trade (Hash 1987, p. 575).

Various accounts state that wolverines have a strong sense of smell (Grinnell *et al*. 1937, p. 265; Bevanger 1992, p. 8) that allows them to locate carrion from great distances (Hornocker and Hash 1981, p. 1,297; *in litt.* Bevanger 1992, p. 8, citing Røskaft 1990; Copeland 1996, p. 100; Cardinal 2004, p. 8); however, experiments with young wolverines indicated a poor sense of smell, and that wolverines may locate food (areas where previously located or cached) based on their memory skills (Magoun 2013, pers. comm.) or learning abilities (e.g., Krott 1958, p. 241).

Scent-marking is used by mammalian carnivores for chemical communication (Hutchings and White 2000, p. 160). For wolverines, this behavior commonly includes urination (e.g., trees, stumps, snow) (Copeland 1996, p. 115; Magoun 1985, p. 105), but also includes scat, and scratches and bites on trees (Haglund 1966, pp. 225, 277; Copeland 1996, p. 115). Scent rubbing (see review by Rieger 1979) of the ventral (abdomen/stomach) area and anal rubbing have also been observed in wolverines (Pulliainen and Oyaskainen 1975, pp. 268–269; Rieger 1979, p. 22, *in litt.* Goethe 1964; Magoun 1985, p. 105). Scent marking by wolverines may also be an important chemical communication signal for potential wolverine prey. Field experiments conducted by Sullivan *et al*. (1985, pp. 928, 930) and Sullivan (1986, p. 388) found that black-tailed deer (*Odocoileus hemionus columbianus*) and snowshoe hares (*Lepus americanus*) avoided feeding on seedlings that were marked with wolverine urine.

Life History and Ecology

In this section we provide a summary of the individual and population needs (collective, species needs), including its life history, physiology and behavior, resource functions necessary for each life stage (i.e., breeding, feeding, sheltering, dispersal), demographic information (abundance and distribution) and ecological setting.

Overview

Wolverines are active year-round and have been considered as primarily nocturnal (Iversen 1972b, p. 319; Pasitschniak-Arts and Larivière 1995, p. 7, and references cited therein). In his observational studies, Krott (1958, p. 168; 1960, p. 25) described periods of 3-4 hours of activity followed by 3-4 hours of sleep for wolverines in Scandinavia, a pattern also observed in Idaho (Copeland 1996, p. 77).

A study of body temperatures of caged wolverines, along with direct observations of animals obtained from Alaska and Sweden and previous studied animals (Alaska), suggested that wolverines were a day-active species, being very active in the morning, with periods of sleep during the night, a pattern that persisted in both winter and summer (Folk *et al*. 1977, p. 233). However, crepuscular activity (period just after dawn and just before sunset) may be a more accurate description for wolverine behavior (McCue *et al*. 2007, pp. 98–99). Others have remarked that wolverines exhibit a plasticity in their behavior (i.e., different behavior under different conditions) (Krott 1960, p. 26), a result attributed, in part, to their being a scavenging carnivore covering large areas (Stewart *et al*. 2016, pp. 1,495, 1,497). Several aspects of this plasticity are described below.

Wolverines are wide-ranging animals and known for traveling great distances in a short period of time (Krott 1960, p. 21; Gardner *et al*. 1986, p. 603; Woodford 2014, entire) (see Movement section below). This is due, in part, to their unique body structure. As described by Krott (1960, p. 20), they are "lumbrosacrally overbuilt" with heavy musculature and legs that are acutely angled when walking. Wolverine gait is characterized as either a 2X pattern (when patterns of two footprints repeat), used primarily in deep snow, and the more common 3X lopes (patterns of three footprints), for covering long distances over more compacted snow (Halfpenny *et al*. 1995, p. 104). The latter is described as a bouncing gait where all four feet may leave the ground at the same time (Halfpenny *et al*. 1995, p. 104).

As noted in our Species Description section above, in winter, the dense hairs on the foot pad and its body structure supports a low foot load, which has been estimated at 22 gram/cm^2 (Knorre 1959, p. 26) and 27–35 gram/cm^2 (Novikov 1962, pp. 22–23 (citing Dulkeit 1953)). This foot loading is believed to provide an advantage for wolverines preying on ungulates and other large mammals whose movements become restricted in deep snow (Knorre 1959, p. 26; Formozov 1963, pp. 40–41; van Zyll de Jong 1975, p. 435; Banci 1994, p. 113). However, a study of wolverines in boreal forest habitat in Canada present a differing interpretation of the wolverine foot adaptation based on tracking wolverines in snow over three winters (Wright and Ernst 2004a, pp. 58–59), in which they observed wolverines in their study area continuously selected for a path of least snow cover, where practicable, and only traveled in upland areas (Wright and Ernst 2004a, p. 59). They concluded that the low foot load is advantageous when snow crusts form, but, in deep snow, wolverines shift to an inefficient walking gait, which increases energy demand (Wright and Ernst 2004a, p. 59). They hypothesized that traveling in deep snow during winter in search of food may increase the risk of starvation due to the greater energy expenditure (Wright and Ernst 2004a, p. 59).

Physiology

The wolverine is a snow-adapted, cold climate animal in its physiology, morphology (Telfer and Kelsall 1984, p. 1,830), behavior, and habits. The wolverine was considered by Formozov (1963, p. 65) as one of several "chioneuphores," or those vertebrates who tolerate snow but have no special adaptations; however, wolverines could also be considered as a "chionphile" or those animals with adaptations for snow (e.g., increased surface area on feet, pelt characteristics) (see definitions in Pruitt 1959, p. 172; Cathcart 2014, p. 22).

In general, mustelids weighing more than 1 kilogram (kg) (2.2 pounds (lbs)) have a basal metabolism (defined as the minimum metabolic rate for maintaining a comfortable warm temperature; Irving 1972, p. 121) that is about 20 percent higher than other mammals (Iversen 1972a, p. 343). For the wolverine, Young *et al*. (2012, p. 222) estimated a basal metabolic rate for a 15 kg (33 lbs) adult at 669.4 kcal/day, using Iversen's derived equation [Metabolic rate (M)=84.6*Weight (W, in kg)$^{(0.78)}$ ± 0.15] (Iversen 1972a, p. 343). By comparison, the estimated basal metabolic rate for a 53 g (1.9 ounce (oz)) least weasel (*Mustela nivalis*) is about 40 kcal/day, and approximately 250 kcal/day for a 3.8–5.5 kg (8.4–12 lbs) Arctic fox (*Vulpes lagopus*) (both sampled from Barrow, Alaska) (Irving 1972, p. 115; Figure 9.1).

Experimental studies by Iversen (1972, pp. 320–321; Figure 4) found that during their first 2½ months, the basal metabolic rate for young wolverines was substantially higher than rates reported for other mammals ($W^{1.41}$ vs. $W^{1.0}$), then declined after 3 months, and declined again after 8 months. Because the early period coincides with weaning, Wilson (1982, p. 646) suggested that the observed peak may be related to changes in food consumed as well as improved thermoregulation since the mother is leaving the young for longer periods of time.

Energy expenditure during pregnancy is relatively low for mustelids (Oftedal and Gittleman 1989, p. 374); however, energy requirements for lactation in mammals can be over 4 to 7 times basal metabolic rates (Allen and Ullrey 2004, p. 478). Thus, estimates of energetic requirements (e.g., less than 1 kg prey/day annually) may be too low to support reproductive activity (Young *et al*. 2012, p. 226). Wolverines are known to consume a variety of food resources and seasonal switching of prey likely allows for adjustment for nutritional needs throughout their life history (Krebs *et al*. 2007, p. 2,187 (Canada); Koskela *et al*. 2013a, pp. 103–104 (Finland); Yates and Copeland *in prep* (Montana)). Additional details on diet and feeding behavior for wolverines are provided below.

Relatedly, Casey *et al*. (1979, p. 335) evaluated metabolic and respiratory responses of eight terrestrial Arctic mammals to ambient temperature during summer months. For wolverines, they found that the frequency of respiration was generally constant (15-20 per minute), but their tidal volume (air moved per breath) increased nearly constantly with *decreasing* ambient temperature, unlike Canada lynx (*Lynx canadiensis*), which is similar in body mass (Casey *et al*. 1979, p. 335). The researchers inferred that the increased ventilation of wolverines at low ambient temperatures was the result of an increased energy metabolism (Casey *et al*. 1979, p. 336).

Thermal neutrality (or **thermoneutrality**) is the temperature range at which resting metabolism is at minimum (Barnett and Mount 1967, p. 468) and animals produce heat at a minimum rate in

a thermal neutral environment (Barnett and Mount 1967, p. 413). For a resting mammal at thermal neutrality, body temperature is primarily maintained by "physical thermoregulation," that is, control of circulation in the skin and by sweating (Barnett and Mount 1967, p. 413). The body temperature of wolverine (measured by an implanted temperature transducer) at thermoneutrality has been reported at 38°C (100.4°F) (Folk *et al*; 1977, p. 231; Casey *et al*. 1979, pp. 332–333). The **critical temperature** is the point at which the metabolic rate starts to rise; thus, animals with lower critical temperatures are able to better conserve their energy expenditure (Barnett and Mount 1967, p. 413). Studies of arctic mammals defined a zone of thermoneutrality in Eskimo dogs (*Canis lupus familiaris*) and Arctic foxes that extended to at least −40°C (−40°F), with an estimated critical temperature between −45°C (−49°F) and −50°C (−58°F) (Scholander *et al*. 1950a, p. 254).

Arctic mammals, including wolverine, Arctic fox, and wolf (*Canis lupus*), have a threshold of thermoneutrality of between −30°C to −40°C (–22°F to –40°F) (Iversen 1972b, p. 322; citing studies by Scholander *et al*. (1950b) and Hart (1956)). Relatedly, Casey *et al*. (1979, p. 340) estimated a critical temperature for wolverine (14 kg (31 lb)) in *summer* pelage of 5°C (41°F) based on an observed increase in oxygen uptake at air temperatures below this temperature. For comparison, measurements of metabolic rates for the red fox (*Vulpes vulpes alascensis*) (Alaska) observed critical temperatures of 8°C (46°F) in summer (Irving *et al*. 1955, p. 184). These Arctic mammals therefore have the ability to dissipate heat to balance the heat loss from 30°C to −40°C (86°F to −40°F), due in large part to vasodilatation and rise of skin temperature (Scholander *et al*. 1950a, p. 251).

Arctic mammals, particularly small mammals, also adapt behaviorally to cold temperatures by creating burrows and building nest sites under the snow. Wolverines are known to dig holes in snow for shelter (Pruitt 2005, p. 120), and wolverine reproductive den sites located under deep snow may provide a thermoneutrality advantage for newborn cubs (Magoun and Copeland 1998, p. 1,313). This topic is discussed in more detail below under Use of Dens and Denning Behavior.

Wolverines can also adapt to both cold and warm temperatures by movement and, relatedly, micro- and macro-habitat selection. Wolverines have been observed near and in lakes and other water bodies and are good swimmers, easily crossing lakes and rivers (Seton 1909, p. 950; Krott 1960, p. 23; Magoun 2017, pers. comm.). They likely use these areas more frequently during warmer months both for cooling and hydration, or possibly for hygienic reasons (Krott 1960, p. 23).

Changes in endocrine (hormone) function can also represent a physiological adaptation to cold by acting on organs to generate energy (Barnett and Mount 1967, p. 428). The best available information does not indicate that these functions have been evaluated in wolverines. However, one veterinarian reported an enlarged thyroid in a wolverine during a necropsy procedure (Copeland 2017, pers. comm.), which is suggestive of a high metabolism.

In addition to these physiological processes, rapid and seasonal adjustments of fur insulation provide an additional mechanism for mammals to overcome large seasonal changes in temperature (Casey *et al*. 1979, p. 340) and have been described for wolverine and other mammals in Alaska (Henshaw 1970, p. 522). The seasonal increase in fur depth for captive

wolverines was reported to be 65 percent (Henshaw 1970, p. 522). That study identified a metric termed seasonal insulative advantage (or SIA) as a measure of the degree to which insulative compensation changes seasonally in response to ambient temperature (Henshaw 1970, p. 522). For wolverines, this advantage was found to be less than unity; that is, the increase in fur did not fully compensate for average winter cold, and therefore other compensating mechanisms were needed (Henshaw 1970, p. 522).

Similarly, an evaluation of the seasonal change in the insulation of fur of wolverine (pelts from Canada) found a 41.2 percent change in mean insulation values (measured as °C/cal/m^2/hr) from winter to summer (Hart 1956, p. 56). A single annual molting (between August and December) was noted in Grinnell *et al*. (1937, p. 251) (California), but twice yearly was described by Novikov (1962, p. 201) (Russia). The large seasonal change in insulation observed for wolverine and other larger mammals is, in large part, due to changes in fur depth, and can be interpreted as an adaptation to both high summer temperatures and low winter temperatures (Hart 1956, p. 57). The reported seasonal decrease in wolverine fur thickness also correlates with experimental results of Casey *et al*. (1979, p. 337) who indicated that a seasonal shift in oxygen consumption below critical temperature was likely due to an increased rate of heat loss in summer.

Range and Habitat Use

Historical Range and Distribution

Phylogeography/Phylogenetics

Results from a molecular study of phylogenetic relationships of the Mustelidae family suggest at least six radiation episodes within this family since the Early Eocene Epoch (approximately 50 million years before present (YBP)) (Marmi *et al*. 2004, pp. 488, 492). The split of the marten (*Martes*, *Gulo*) and weasel (*Mustela*) lineages occurred in the Early Middle Miocene Epoch (14 to 11 million YBP), with the separation of Old World and New World lineages (*Martes*, *Gulo*) occurring in the Late Miocene Epoch (8.6 to 5.8 million YBP) (Marmi *et al*. 2004, p. 488). The *Gulo* genus appears in the fossil record in the mid-Pleistocene in both Europe and North America (Bryant 1987, p. 659).

The dispersal of *Gulo* across Beringia (land mass that extended from Siberia into interior Alaska during the Pleistocene) is believed to have produced contemporaneous records for the species in Europe and North America (Bryant 1987, p. 659). Genomic data was examined using a molecular dating technique to estimate an approximate age of the *G. gulo* ancestor (Malyarchuk *et al*. 2015, entire). The researchers estimated a relatively recent origin of the species *Gulo gulo* at about 181,000 to 234,000 YBP (Malyarchuk *et al*. 2015, pp. 1,115–1,116). They note that this latter time period corresponds to the Riss glaciation period (187,000 to 230,000 YBP), a time of genetic divergence of amphi-Beringian (both sides of Beringia) species and speciation events (Hope *et al*. 2013, p. 426). Their results, along with fossil information, also indicate the divergence of the *Gulo* branch and the other *Martes* taxa occurred during the Late Miocene-Early Pliocene (5.6 million YBP), and lends support for strong evolutionary processes in the northern Siberian ecosystems in the Pliocene and Pleistocene Epochs (Malyarchuk *et al*. 2015, pp. 1,116–1,117).

An evolutionary trend was described in which *Gulo* increased in size from the mid- to late-Pleistocene, with a subsequent reduction in size post glaciation, as well as small changes in selected teeth, and a possible shift to colder habitats (Bryant 1987, p. 660). The Late Pleistocene and the Pleistocene-Holocene transition represent the end of prolonged period that was characterized by climate fluctuations followed by rapid warming (Post 2013, p. 28). This analysis also indicated that both the mid-Pleistocene European *Gulo schlosseri* and the early North American *Gulo* appear to be adapted to a warmer climatic environment, but are likely to have also occupied colder climates (Bryant 1987, p. 660). Other factors such as competition (Guilday 1971, p. 237), predator avoidance, and prey abundance may also have been important in creating significant shifts in geographic ranges for certain species during glacial cycles.

Wolverines are believed to have migrated to North America during the late Pleistocene, although fossil evidence from the Pleistocene Epoch for wolverine is limited (Anderson 1977, p. 15; Bryant 1987, p. 660), and most fossil material is either cranial or dental fragments (Bryant 1987, p. 660). A summary of records for both Pleistocene and extant *Gulo* (Bryant 1987, p. 659; Table 3) includes findings in the United States from Colorado, Idaho (e.g., White *et al*. 1984, p. 248 (lava tubes)), Alaska, Maryland, and Pennsylvania, and Canada (primarily the Yukon region) ranging from the Irvingtonian Age (1.8–2.4 million YBP) to Late Wisconsinan-Holocene (15,000 YBP to present day).

Genetic studies can provide an understanding of the postglacial recolonization of wolverines following the Last Glacial Maximum, a period of rapid cooling, and movement patterns due to changed climatic conditions (Frances 2008; Zigouris *et al*. 2013; McKelvey *et al*. 2014). Following the Last Glacial Maximum, beginning about 21,000 YBP, was a period of rapid warming, resulting in a second wave of extinction events, particularly of large mammalian megafauna that were cold-adapted (Post 2013, pp. 29, 31).

During the late Wisconsin period (10,000 to 25,000 YBP), approximately 60 percent of North America was covered by glacial ice (Rogers *et al*. 1991, p. 624). However, several ice-free refugia existed at that time including the Beringian refugium, which included eastern Siberia, most of Alaska, areas of northwestern Canada, and areas of the Bering Sea shelf that were exposed by lower sea levels, and this refugium harbored a number of mammalian species including wolverine (Rogers *et al*. 1991, pp. 624, 626). Analyses by Frances (2008, entire) and Zigouris *et al*. (2013, entire) supported a wolverine colonization of North America in which individuals "followed retreating glaciers" (Zigouris *et al*. 2013, pp. 10–11), beginning about 21,000 YBP, following the Last Glacial Maximum, when a period of rapid warming occurred that resulted in additional extinction events, particularly large mammalian megafauna (Post 2013, p. 29)

A phylogeographic analysis presented by McKelvey *et al*. (2014, p. 331) proposed that a unique haplotype (Cali 1) observed in historical wolverine samples from California was reflective of an independent evolutionary history resulting from isolation (i.e., southern ice-free refugium) of wolverines during glacial retreat. However, Zigouris *et al*. (2013, p. 10, Supplemental Table S5) found the Cali 1 haplotype described by Schwartz *et al*. (2007, p. 2,173; Tables 2 and 4) (relabeled as Haplotype 21) also occurred in historical wolverine samples from the eastern region

of Canada (Quebec-Labrador). In addition, as noted by Zigouris (2014, pp. 232–233) the historical samples analyzed by McKelvey *et al*. (2014, p. 327; Table 1) were primarily those from locations at the southwestern edge of the wolverine's North American range (e.g., California, Colorado, Idaho, Montana, Wyoming, Utah, Washington). Without additional sampling, it is unclear if this particular haplotype distribution from two of the most peripheral North American wolverine populations is a reflection of a skewed dispersal after post-glacial colonization, or was a more widely distributed haplotype that declined or was lost due to hunting and trapping pressures (beginning in 18th century) or fragmentation (late-20th century) (Zigouris *et al*. 2013, p. 10).

Additional discussion of our current understanding of wolverine genetic structure and diversity is provided in the *Population Structure* section below.

Historical Range

In North America, wolverines were historically distributed in much of the northern portion of the continent, extending southward to the northernmost region of the United States (Maine to Washington) or approximately north of the 38th parallel (Hash 1987, p. 576; Banci 1994, p. 102).

An estimate of wolverine observations and distribution in the contiguous United States was prepared by compiling 901 verifiable or documented records of wolverine occurrence dating from 1801 to 2005 from 24 states in the contiguous United States (Aubry *et al*. 2007, entire). This included a total of 809 verifiable or documented records for the Rocky Mountain and Pacific Coast mountains (west-northwestern United States) for this time period (Aubry *et al*. 2007, p. 2,151).

The historical population size of wolverines in Canada is not known (Fortin 2005, p. 4). Its historical distribution, as depicted by Seton (1909, p. 947; Map 51) and also later by van Zyll de Jong (1975, p. 435; Figure 9) shows a broad range across much of Canada. Examples of early descriptive accounts include de Puyjalon (1900, pp. 126–144), who described wolverines as inhabiting Labrador, Canada (de Puyjalon, p. 101), and extending in range to the 66th parallel and perhaps further (de Puyjalon 1900, p. 144); reports of both trapped and live wolverines in Labrador in the late 1700s (Townsend (ed.), 1911, pp. 73, 93, 228, 255); and reports of wolverines as "common" in Canada's Nunavut Territory (Hudson Bay region) during a 1920s Danish excursion (the Fifth Thule Expedition) to Arctic North America (Freuchen 1935, p. 101). The 2014 COSEWIC report presents a historical range distribution for Canada based on personal accounts and interpretation of the fur trade (COSEWIC 2014, pp. 12–13; Figure 3).

Current Range

We created a map depicting wolverine observations for the west-northwestern United States by requesting all available wolverine records from State agencies (e.g., wildlife agencies, natural heritage programs) and the Forest Service Natural Resource Information System (NRIS) Wildlife Database. We found a total of 4,215 records (1800s to 2017) for this portion of the United States (*cf*. 809 records from Aubrey *et al*. 2007; Table 1). Figure 2 presents a map of these compiled

observations, overlaid with the habitat suitability model results presented by Inman *et al*. (2013, p. 281). We acknowledge that some of these records may be in error or inaccurately located, and although wolverines have been reported from the Central Great Plains, Great Lakes region, Upper Midwest, or Northeast (Wilson 1982, p. 650), we did not create a historical range for these regions given the very low number (92) reported by Aubry *et al*. (2007, p. 2,151) from the 1880s to 2005, and to present day, and an incomplete historical record of trapping. We also found a few additional historical records that do not appear in Aubry *et al*. (2007, p. 2,151). For example, Nead *et al*. (1985, entire) identified several positive and probable reports of wolverines in Colorado in the late 1970s. A wolverine was reported from the Squaw Valley region of California in the summer of 1953 (Ruth 1954, pp. 594–595). Our intent in creating this map was to present an overall geographical depiction of the wolverine's estimated range only for the west-northwestern United States, and is not intended to represent an estimate of population numbers.

Using the best available information, we also created a current North American range based on results presented by COSEWIC (2014, p. 12) for Canada and Alaska, Forest Service NRIS data, and more recent observations (e.g., telemetry, camera traps, mortality reports) reported from California, Washington, Colorado, Wyoming, Utah, and North Dakota (e.g., California Natural Diversity Database (CNDDB); Forest Service NRIS; Idaho Department of Fish and Game; Utah Division of Wildlife; Wyoming Game and Fish Department). This range is illustrated in Figure 3.

We recognize that this depiction does not necessarily represent current areas where reproducing populations of wolverines are found, nor does it capture unverified accounts from New Mexico, described in Frey (2006, pp. 20–21) for the Sangre de Cristo Range, and visual observations reported by two individuals (2005 and 2016) in response to our *Federal Register* notice (81 FR71670; October 18, 2016) requesting information for our status review. In addition, we did not incorporate the Central Great Plains, Great Lakes region, Upper Midwest, or Northeast. However, we note here that a female wolverine was observed over several years (2004–2010) in the lower peninsula of Michigan, and genetic testing after her death in 2010 suggested she was more closely associated with eastern Canada wolverine populations (i.e., Manitoba and Ontario) (*in litt* Zigouris 2013, pers. comm.). It's unclear how this individual came to occupy this region, but given the long distant movements reported for this species (e.g., male wolverine that traveled from Wyoming into Colorado and then back to North Dakota), dispersal from Canada is plausible. Wilson (1982, p. 650) reported that wolverines on occasion may enter Minnesota from Canada. Jackson (1961, pp. 359–360) also reported several authentic records of wolverine in Wisconsin and in areas in Minnesota, along the Wisconsin-Minnesota border. However, the wolverine was likely never abundant in Wisconsin, even before trapping and hunting in the late 19th and early 20th centuries (Jackson 1961, p. 359).

We provide a discussion of wolverine population abundance and distribution in more detail in the *Biological Status–Current Condition* section below.

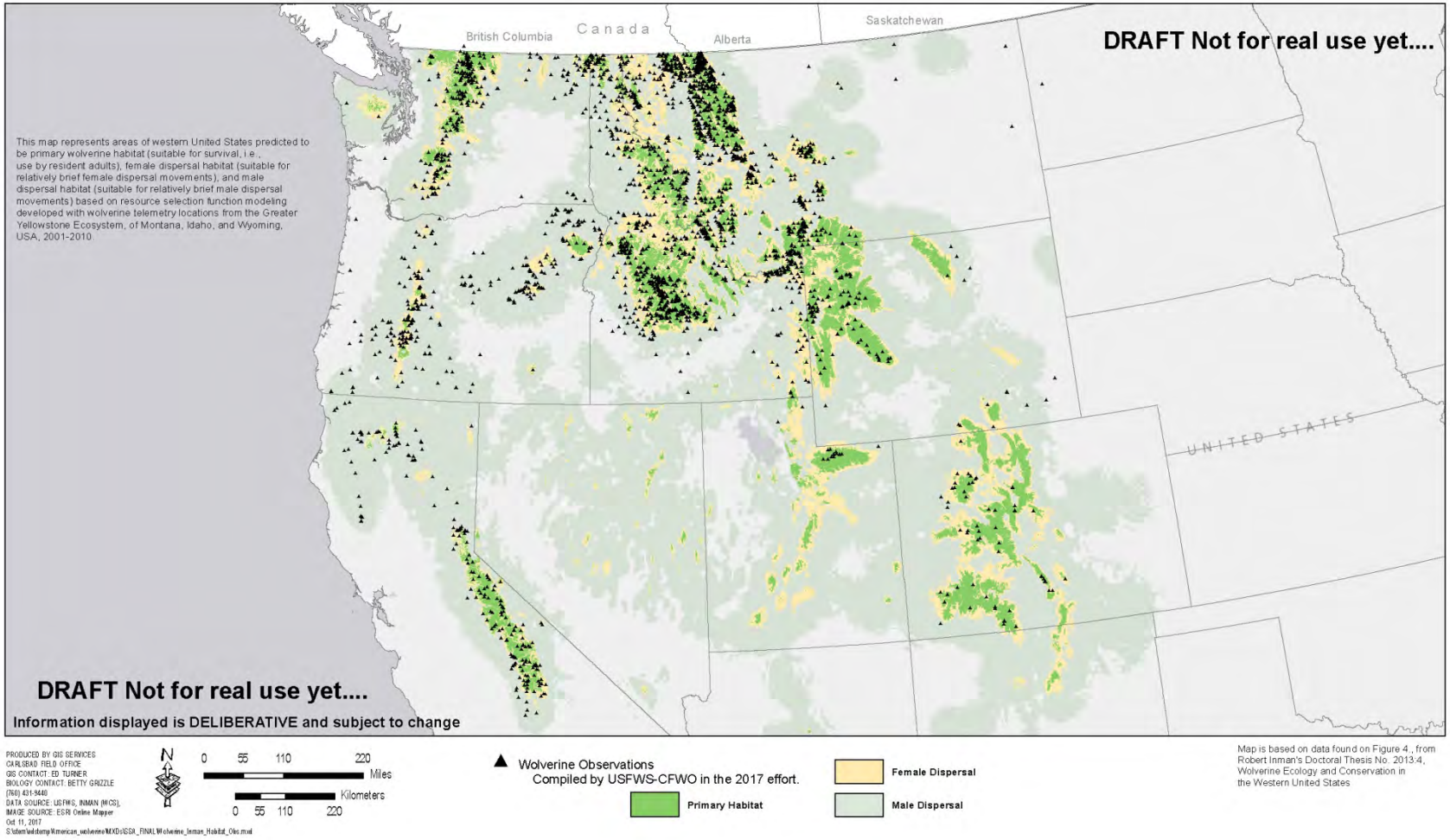

Figure 2. North America wolverine observations within the west-northwestern United States (1800s to 2017); shown with Inman *et al.* (2013) modeled habitat.

Figure 3. Current range of North American wolverine. Adapted from COSEWIC (2014), EPA (2010), Inman *et al.* (2013), records from CNDDB; Forest Service NRIS; Idaho Department of Fish and Game; Utah Division of Wildlife; Wyoming Game and Fish Department, and den records from CNDDB, Inman, and Copeland.

Habitat Use

Wolverines occupy a variety of habitats within their current range, including Arctic tundra, subarctic-alpine tundra, boreal forest, mixed forest, redwood forest, and coniferous forest (Banci 1994, p. 114). However, these broad, landscape-scale vegetation associations can obscure other habitat variables important for wolverines, including features found within peripherally occupied areas or areas of high elevation (Banci 1994, p. 114). In Canada, wolverines use a wide variety of forested and tundra vegetation, at all elevations (COSEWIC 2014, p. 18).

When viewed by ecoregion (U.S. Environmental Protection Agency (EPA) 2010), in general, wolverine observations in the contiguous United States are most commonly found in the Northwestern Forested Mountains ecoregion. In Canada, our estimate of current range includes Northwestern Forested Mountains, Northern Forests, Marine West Coast Forest, Hudson Plain, Taiga (Boreal Forest), Tundra, and parts of the Arctic Cordillera (northeastern fringe of Nunavut and northern Labrador); in Alaska, Marine West Coast Forest, Northwestern Forested Mountains, Taiga, and Tundra are represented. **Appendix A** provides an illustration of these ecoregions of North America in relationship to our Current Range map presented in Figure 3.

Studies of wolverines in central Idaho found that montane coniferous forests comprised two-thirds of available habitat (Copeland 1996, p. 120). Wolverines in this region also exhibited a seasonal preference, with subalpine rock habitats used in summer and montane coniferous forests used most often in winter (Copeland 1996, p. 120). In addition, individuals within this study population commonly crossed natural openings and those areas with little cover, including burn areas, meadows, or open mountain-top areas (Copeland 1996, p. 124).

Observations of summer movements of wolverines in northwestern Montana indicated that both males and females moved to higher, cooler elevations and remained there throughout the summer (Hornocker and Hash 1981, p. 1,299). In the Greater Yellowstone Ecosystem, wolverines selected areas that contained steep terrain with tree cover, high elevation meadows, boulder or talus fields, and avalanche chutes (Inman *et al*. 2012a, p. 785). In this region, wolverines selected elevations at and above the treeline during summer, moved slightly lower during winter, but avoided low-elevation winter ranges occupied by potential prey (e.g., elk) or areas with little human activity (Inman *et al*. 2012a, p. 785). The avoidance of these areas may be the result of lack of tree or talus field cover at these low elevations, in combination with presence of potential predators (e.g., wolf, mountain lion (*Puma concolor*) or competitors (e.g., coyote (*Canis latrans*), bobcat (*Lynx rufus*) (Inman *et al*. 2012a, p. 785).

Several habitat association-type models have been developed for both North American and European wolverines. In the northern Rockies (including Canada and the United States), Carroll *et al*. (2001, p. 975) found that elevation and north-facing cirque habitat variables (i.e., alpine areas), when incorporated into empirical habitat models, were significantly correlated with wolverine occurrence; however, results from multiple regression analyses of these and other habitat variables indicated a high degree of unexplained variance for predicting wolverine habitat relationships, and underscores the inherent difficulty in identifying appropriate metrics to represent difficult to measure underlying factors, or other unrecognized limiting variables (Carroll *et al*. 2001, pp. 971, 973–974). Copeland *et al*. (2007, entire) also evaluated habitat

associations for wolverines in central Idaho. Wolverines were found to be associated with high elevations (2,200 to 2,600 m (7,218 to 8,530 ft)) with a slight downward shift in summer (Copeland *et al*. 2007, p. 2,207). These movements correspond with a shift in cover types, from high-elevation whitebark pine (*Pinus albicaulis*) communities in summer to mid-elevation Douglas fir (*Pseudotsuga menziezii*) and lodgepole pine (*Pinus contorta*) in winter (Copeland *et al*. 2007, pp. 2,207–2,208). Results from a study of wolverines in Scandinavia suggested that topography may be important in providing refugia from predators and may therefore facilitate the co-existence of wolverines with larger carnivores such as wolves (Khalil *et al*. 2014, p. 636).

In interior Alaska, wolverines were also found to be positively associated with high elevations (Gardner *et al*. 2010, p. 1,901). The authors concluded that wolverines avoided human influences based on observations that both elevation and human influence were found to have significant effects on wolverine occurrence probabilities, but were not correlated (Gardner *et al*. 2010, p. 1,901). However, they indicate that their sampling design was not able to determine which human activities influenced wolverine behaviors; a combination of intensity of development and harvest activities was suggested (Gardner *et al*. 2010, p. 1,901). Current studies are underway in the North Slope region of Alaska to evaluate fine-scale habitat selection of wolverines related to denning, caching, day bed use, and snow holes (Dorendorf 2016, p. 6). Day beds were also described by Haglund (1966, p. 268) for wolverines studied in Sweden.

A study also found that habitat associations, at least for females, are more complex, and include combinations of several modeled variables that supported hypotheses related to food (prey distribution), predation risk (based on a ruggedness index), or human disturbance (winter recreation activity, roads, and forest harvesting) for both summer and winter in two study areas located in northcentral and southeast British Columbia (Krebs *et al*. 2007, pp. 2,186–2,187). Wolverines in the Rocky Mountains of Alberta, Canada, were found to more likely occupy areas with increasingly rugged terrain (Fisher *et al*. (2013, pp. 710–712).

Camera trapping was used to study wolverine behavior in varying habitat in the Rocky Mountains of Alberta, Canada (Stewart *et al*. 2016, entire). That study found that wolverine behavior differed in landscapes that had been significantly modified by human activities as compared to those with light modifications or in protected areas (Stewart *et al*. 2016, p. 1,499). They concluded that wolverine occurrence in their study areas varied more strongly with linear features (seismic lines created from oil and gas exploration, pipelines, transmission lines, roads, and rail lines) than with the degree of snowpack, and supports the idea that human "footprint" as a driver of habitat suitability for wolverines; that is, if snowpack conditions was the only driver for suitable habitat, then a behavioral signal would not be expected (Stewart *et al*. 2016, p. 1,501).

Aboriginal knowledge holders (the knowledge Aboriginal Peoples have accumulated about wildlife species and their environment) in Canada have reported that while wolverines appear to avoid human habitation and developed areas, some wolverine will visit these areas if they do not appear to be threatened or if development activities cease (Cardinal 2004, p. 22). Wolverines have also been described as occupying deserted snow huts (Nunavut Territory, Canada) during winter months (Freuchen 1935, p. 98).

A negative association with roads and wolverine (and caribou) occurrence in boreal forest habitat was reported in northwestern Ontario, Canada, and wolverines in that study area avoided deciduous forests (Bowman *et al*. 2010, p. 464). However, a study of wolverines in upland boreal forests of Canada found that wolverines followed open linear corridors that offered compact snow conditions, including winter roads, recent seismic lines, snowmobile trails, and all-terrain vehicle tire tracks for travel of distances up to 3 kilometers (km) (1.86 miles (mi)) (Wright and Ernst 2004b, p. 59). In central Idaho, wolverines were reported using snowmobile winter access (unmaintained) roads for travel (Copeland *et al*. 2007, p. 2,210).

A study of wolverine selection patterns in boreal forests in northwestern Alberta using resource selection function (RSF) modeling techniques[1] and data from telemetered wolverines found that, for the winter season, both male and female wolverines selected for streams, forested areas (broadleaf, coniferous, and mixed) and bogs or fens, while avoiding active oil and gas well sites and low-traffic winter roads (Scrafford *et al*. 2017, pp. 31, 32). That study also found that wolverines did not avoid older seismic lines, likely due to the intermediate stage of regeneration found in their study area as well as availability of small prey in conjunction with minimal risk of human or wolf presence (Scrafford *et al*. 2017, p. 34).

RSF-based modeling was used to quantify the relationship between the observed distribution of the wolverine and variables representative of habitats and human disturbance in the taiga and tundra ecoregions (shown in Appendix A) of the Canadian central Arctic (Nunavut and Northwest Territories) (Johnson *et al*. 2005, p. 10). Using a range defined by previous studies of collared wolverines, researchers identified two seasons for wolverines, based on presence or absence of barren-ground caribou (*Rangifer tarandus groenlandicus*) (Johnson *et al*. 2005, p. 8). They found that, in winter, the occurrence of wolverines was correlated with patches of heath rock and rock association, and areas dominated by sedge (Johnson *et al*. 2005, pp. 23–25). Results for models for summer season were less clear, but models that included grizzly bear (*Ursus arctos*), caribou, and wolf were found to be positively associated with wolverine, likely due to the scavenging opportunities and hunting of caribou provided by these other carnivores (Johnson *et al*. 2005, p. 24). In Finland, the presence of wolves was found to be one of the most important variables influencing habitat selection of wolverines (Koskela 2013, p. 35) likely due to the increased scavenging opportunities provide by wolf kills (Koskela 2013, p. 36).

A RSF model was also used to develop a predictive map of wolverine habitat for the western United States (Inman *et al*. (2013, p. 281), as shown in the background of our Figure 3. Their best fit model found that, in general, wolverine were most likely to be distributed at high elevations, with steeper terrain, more snow, fewer roads, and reduced human activity, but also in proximity to high elevation talus, tree cover, and areas that had snow cover on April 1 (Inman *et al*. 2013, pp. 280–281). Primary habitat for the wolverine in the western United States was estimated at 164,125 km^2 (63,369 mi^2) (Inman *et al*. 2013, p. 281). Additional information

[1] RSF is any mathematical function that is proportional to the probability of use of a resource unit (Manly *et al*. 2002, p. 15). A RSF contains several coefficients that quantify the selection for or avoidance of an environmental feature, and the sign/strength of those coefficients represents a differential variation in the distribution of each environmental feature measured at a sample of locations to a comparable set of random sites. Thus, when an animal's observed use of a resource is greater than those random sites, selection of that feature is inferred (Johnson *et al*. 2005, p. 10).

related to the results of this modeling effort is discussed in the *Population Distribution and Abundance* section below.

Movement

Wolverine movements are related to both territoriality (within home ranges) and dispersal (adults and young). Movement within home ranges by adult male and female wolverines is extensive. For example, wolverines monitored in the Greater Yellowstone Ecosystem traveled a distance that was equivalent to their average home range diameter in less than 2 days, which is also about the size of their home range circumference in less than 1 week (Inman *et al*. 2012a, pp. 782–783). This study also found that, for a 24-hour period, the average minimum distance traveled was 15.5 (km) (9.63 (mi) for males and 7.5 km (4.66 mi) for females (Inman *et al*. 2012a, p. 783). Telemetry studies of wolverines in south-central Alaska indicate an average distance traveled per day of approximately 12 km (7.46 mi) for females and 8–21 km (4.97–13 mi) for males (Woodford 2014, no page number). Observations from snow tracking studies have found instances where two individual wolverines traveled together (Wright and Ernst 2004b, p. 63).

A study of female Fennoscandinavian wolverines found that most (86 percent) females remained stationary in their established territories, with 8 percent vacating and 6 percent expanding their territory (Aronsson 2017, p. 40). In addition, this study of 42 female wolverines in 122 territories reported that females with established territories only moved to available territories that were higher than average in quality (Aronsson 2017, p. 41). In central Norway, a study of spatial and temporal patterns in wolverines using noninvasive genetic sampling methods also found that individuals tended to stay in the same general area from one year to the next (Bischof *et al*.'s 2016, p. 1,533).

A number of factors can affect wolverine movements within territories, such as availability of food, temperature, and breeding activity. Seasonal shifts in elevation have also been observed for wolverines in the contiguous United States. An ecological study of wolverines in southcentral Alaska found significant movement up in elevation during late winter and early spring as well as significant movement down in elevation during the late fall and winter (Gardner 1985, p. 21). Wolverines were also observed moving to and occupying higher and presumably cooler elevations in summer months in northwestern Montana (Hornocker and Hash 1981, p. 1,299). In Central Idaho, wolverines exhibited a preference for higher elevation areas containing rock and talus cover in summer months, but moved to lower elevations in winter; this was likely the result of an increase in availability of carrion related to the fall hunting season (Copeland 1996, p. iv). Two aboriginal knowledge holders in the Kivalliq region (Nunavut, Canada) reported that wolverines will move closer to communities during caribou migration in the fall, likely attracted by the large number of caribou carcasses left by hunters (Cardinal 2004, p. 22).

A study of wolverine movement in boreal forest habitat in Canada (northwestern Alberta and northeastern British Columbia) during winter months found that wolverines chose the most direct travel route with the least snow cover (Wright and Ernst 2004a, pp. 58–59). Woodford's (2014, no page number) account of wolverine observations from studies in Alaska indicated that, when pursued, wolverines will run uphill, which may represent a predator-avoidance adaptive behavior.

As discussed in more detail below (*Diet and Feeding*), several studies have shown that wolverines exhibit a seasonal shift in diet, and Hornocker and Hash (1981, p. 1298) concluded that food availability was the primary factor determining both movements and home ranges for wolverines studied in northwestern Montana. Movement patterns of adult males during the summer months are also likely influenced by breeding activity (Magoun 1985, p. 66).

Males and females maintain large territories with very little overlap between same-sex adults (Magoun 1985, p. 38; Banci 1994, p. 118; Inman *et al*. 2012a, p. 783; Bischof *et al*. 2016, pp. 1,532–1,533; Regehr and Lacroix 2016, p. 249), but breeding pairs have overlapping territories (Copeland 1996, pp. 55–61; Hedmark *et al*. 2007, p. 19; Dawson *et al*. 2010, p. 413; Persson 2010, p. 52; Inman *et al*. 2012a, p. 787). However, ranges of young males, who have not yet dispersed, can overlap with resident adult male home ranges (Alaska) (Magoun 1985, p. 64). Studies of wolverines in the Greater Yellowstone Ecosystem found a mean percent overlap of 12.7 percent for same sex, adult–sub-adult pairs and about 24 percent for opposite sex, adult–sub-adult pairs (Inman *et al*. 2012a, p. 787). In addition, Inman *et al*. (2012a, p. 783) found that when a resident adult wolverine died, same-sex adults (not known to be located within the dead wolverine's home range) would begin using (within 3–7 weeks) areas of the unoccupied home range, or same-sex subadults would expand into and then occupy most or all of the dead wolverine's former home range. A study of territoriality of wolverines in central Norway (using scat analysis) indicated that within their study population, wolverines were also more likely to choose a home range area that was previously used by a neighboring same sex individual after that individual's death (Bischof *et al*. 2016, p. 1,533).

Table 1 below presents a summary of annual home ranges of resident wolverines.

Table 1. Home Range Size for Adult, Resident Wolverines.

Region	Female, km^2 (mi^2)	Male, km^2 (mi^2)	Reference
Central Idaho	384 (148)	1,582 (610)	Copeland 1996
Central Idaho / Yellowstone Region	357 (138)	1,138 (439)	Heinemeyer and Squires 2015
Greater Yellowstone Ecosystem	303 (117)	797 (308)	Inman *et al*. 2012a
Glacier National Park (MT)	139 (54)	521 (201)	Copeland and Yates 2008
Alaska (Northwestern)	53-232 (20-89.6)	488-917 (188-354)	Magoun 1985
Canada Northwest Ontario	50-400 (19-154) 423 (163)	230-1,580 (89-610) 2,563 (990)	COSEWIC 2014 Dawson *et al*. 2010
Central Norway	331 (128)	757 (292)	Bischof *et al*. 2016
Southern Norway	274 (106)	663 (256)	Landa *et al*. 1998
Northern Sweden	170 (66)	669 (258)	Persson *et al*. 2010

Home range use is smaller for female wolverines during the reproductive period. For a parturient (about to bear young) female, estimates of home range size in the Greater Yellowstone region were significantly smaller, with a minimum of 100–150 km^2 (39–58 mi^2) (i.e., during year raising young) (Inman *et al*. 2012a, p. 782). The average home range size for lactating females rearing young was estimated at 70 km^2 (27 mi^2) from March through August (Alaska) (Magoun 1985, p. 36). In northwestern Ontario, researchers reported a home range of 262 km^2 (101 mi^2) for a lactating female (Dawson *et al*. 2010, pp. 141–142). In general, the distance traveled by female wolverines depends on the location of the reproductive den site within the home range, the areas used for locating food/prey, and the territory border (Myhr 2017, no page number).

In summary, habitat diversity, food availability, and competition for resources can collectively or individually influence home range sizes of wolverines (Magoun 1985, p. 63; Inman *et al*. 2012a, p. 785), which affects wolverine densities and population structure. Home range sizes of male wolverines are likely influenced by the density and reproductive condition of female wolverines (Magoun 1985, p. 63).

Dispersal relates to the successful establishment of a breeding territory, generally by juveniles, at a location removed from the natal denning area, and can be confused with long-range movements of wolverines and other carnivores (Ruggiero *et al*. 1994, pp. 4–5).

Based on telemetry studies, wolverines have been observed to disperse over very long distances. Both male and females can move long distances (Flagstad *et al*. 2004, pp. 684–686), but young (yearling) females tend to establish home ranges closer to their natal ranges than do young males (COSEWIC 2014, p. 24), which supports a male-biased dispersal pattern (from natal range) for wolverine populations. Vangen *et al*. (2001, p. 1,647) indicated that dispersal patterns of females were likely determined by competition for resources (that is, high quality territories) while male dispersal patterns were likely determined by competition for mates.

As noted above, wolverines readily cross water bodies such as rivers, and can cross rugged terrain (COSEWIC 2014, p. 24; Woodford 2014, entire). Dispersing wolverines in Idaho traveled over 200 km (124 mi) following routes across isolated subalpine habitat (Copeland 1996, p. 130). Inman *et al*. (2012a, p. 784) recorded dispersal-related movements of wolverines in the Greater Yellowstone Ecosystem and found that the maximum dispersal distance of subadults from the home range of their mothers was 170 km (106 mi) for males and 173 km (108 mi) for females, with an average maximum distance per dispersal movement of 102 km (63 mi) for males and 57 km (35 mi) for females (Inman *et al*. 2012a, p. 784). In the Ontario, Canada, region a juvenile male reportedly dispersed 100 km (62 mi) (COSEWIC 2014, p. 24, citing unpublished data from Dawson *et al*. 2013).

Two recent examples illustrate the extensive dispersal capability of wolverines. A male wolverine apparently dispersed (2008 or earlier) from the western edge of the Rocky Mountain region to the Sierra Nevada region of California (Moriarty *et al*. 2009, p. 160). Another male wolverine (designated as M56), whose natal area was the Greater Yellowstone Ecosystem (northwest Wyoming), moved south to Colorado (about 500 miles), where it remained for about 3 years (2009–2012), when its tracking signal was lost. In April 2016, M56 was legally shot and

killed by a rancher in western North Dakota, about 1126.5 km (700 mi) from where it was last seen (Wyoming Game and Fish Department (WGFD) 2016, pers. comm).

Additional discussion of population distribution and density estimates is provided below (see Biological Status–Current Conditions).

Reproduction and Growth

Wolverine reproduction includes the following characteristics: polygamous behavior (i.e., a male mates with more than one female each year), delayed implantation (up to 6 months), short gestation period (30–40 days), denning behavior, and an extended period of maternal care (Rausch and Pearson 1972, pp. 255–256; Pasitschniak-Arts and Larivière 1995, p. 5; Magoun and Copeland 1998, pp. 1,315–1,316; Hedmark *et al*. 2007, p. 19; Persson *et al*. 2017 *in prep*).

Table 2 below presents a summary of wolverine reproductive chronology (extent and peak of reproductive events) based on a review of the literature and personal knowledge from field studies (Inman *et al*. 2012b, entire), and studies from Scandinavia (Aronsson 2017; Persson *et al*. 2017 *in prep*).

Table 2. Chronology of wolverine reproductive events (adapted from Inman *et al*. 2012b).

Reproductive Biology Event	Time Interval
Mating Season	May – August; *peak in* ***June***
Nidation (implantation of embryo)	November – March; *peak in* ***late December–early February***
Gestation (45 days)	November – April; *peak in* ***January–mid-March***
Parturition (birth of young)	late January – mid-April; *peak in* ***February–mid-March*** (**Sweden**: *peak in* ***mid-February***, range from end of January to early March)[a]
Reproductive Den Use	late January – end of June; most commonly, ***early February–mid-May***
Lactation	About 10 weeks; generally February–June
Weaning	April – June; most commonly, ***late April–May***
Rendezvous Sites	April – June; peak in ***early May***
Independence	August – January; *peak in* ***September–December***
Dispersal	Peak period at ***10–15 months of age***; February–mid-April

[a] Persson *et al*. (2017, *in prep*).

Wolverine mating is generally assumed to occur in May, June, and July (Pulliainen 1968, p. 341; Rausch and Pearson 1972, p. 249). A review of both the literature and personal observations by Inman *et al*. (2012, p. 636) indicated that June represented the peak in a wolverine mating season, but began in at least May and extended into early August. Female wolverines have been reported as not breeding in their first summer (under 1 year of age) based on examination of reproductive tracts from wolverine carcasses obtained from trappers (Yukon) (Banci and Harestad 1988, p. 268) and ages of pregnant female wolverines were estimated at 1 to 11-plus years of age (Banci and Harestad 1988, p. 266). In another study of wolverine carcasses (also in Yukon), some female wolverines were said to be mature at about 1 year (about 15 months), but first litters were not produced until 2 years of age (Rausch and Pearson 1972, p. 253). In Scandinavia, the mean age of first reproduction for female wolverines was 3.4 years, based on

monitoring of telemetered animals (Persson *et al*. 2006, p. 76). Breeding ages were reported at 2 to 13 years of age for wolverines in Sweden (mean age of first birth was 3.4, range of 2 to 5 years), based on monitoring/observations of female wolverines (Rauset *et al*. 2015, p. 3,157).

A genetic-based wolverine study in Scandinavia found that "females often reproduced with the same male in subsequent breeding years" (Hedmark *et al*. 2007, p. 18). However, this study also found (with some assumptions regarding sampling and paternity) that 8 of 13 female wolverines bred with different males, and, based on telemetry results, 2 females bred with a new male even though their previous breeding partner was still alive (Hedmark *et al*. 2007, p. 18). This shift in partners may have resulted from a change in the resident male wolverine in the area (Hedmark *et al*. 2007, p. 19).

The reproductive rate of wolverines is relatively low. An early study of 31 wolverine dens in Finland, as reported by hunters, found an average of 2 young per den (range 1–4) (Pulliainen 1968, pp. 338–341). Average litter size for northern Europe (161 litters) was 2.5 (range 1–4) (Pulliainen 1968, p. 343). In Alaska, average litter size was reported as 1.75 young, with a reproductive rate of 0.69 young per adult female per year (Magoun 1985, p. 28). A summary of average litter size for earlier studies of New World and Old World wolverines, based on method of determination, was presented in Magoun (1985, p. 29), indicating a range of 2.2 to 3.5. Anderson and Aune (2008, entire) evaluated pregnancy rates based on presence of corpora lutea (CL) and fetuses in trapper-harvested wolverines from western Montana. That study found median CL counts for pregnant adults ranging from 1.6 to 3.0, depending on the subpopulation (Anderson and Aune 2008, p. 22), with a mean litter size based on number of fetuses for pregnant adult females of 2.6 (Anderson and Aune 2008, p. 23). Studies of telemetered female wolverine in Scandinavia, from 1993 to 2002, reported a mean litter size of 1.88, with a range of 1 to 4 young, with a mean annual birth rate of 0.74 young per female (Persson *et al*. 2006, pp. 76–77). More recently, the average number of young per female per year reported for wolverines in Sweden was 0.84 (range 0–3); however, for those animals with recorded denning behavior, this value increased to 1.38 (range 0–3) (Rauset *et al*. 2015, p. 3,157).

Results from studies of telemetered female wolverines indicate that studies of wolverine reproductive tracts are likely to overestimate wolverine productivity (Persson *et al*. 2006, p. 77). Their findings suggest that young are either lost during pregnancy and/or shortly after birth, and are not likely to occur before implantation due, in part, to presumed delayed implantation (Persson 2006, p. 77). Delayed implantation (or reabsorption) of fetuses has been observed in other mustelids, including mink (Hansson 1947, p. 62; and references cited therein, pp. 65–66). However, the factors that contribute to the observations that female wolverines do not give birth during some years are not well understood, and could be due to failure to breed, pseudo-pregnancy (as demonstrated by Mead *et al*. 1993, entire), failure of a fetus to implant, absorption of implanted fetus, stillbirth, or mortality before emerging from den (e.g. infanticide, etc.) (Magoun 2013, pers. comm.).

Carnivorous mammals generally have altricial young (poorly developed and dependent young (Derrickson 1992, p. 58)), and prepare shelter in dens where the mother can feed their young and keep them warm (Irving 1972, p. 174). Young wolverines (kits or cubs) weigh about 0.1 kg (3.5 oz) at birth and are blind until about 4 weeks of age (Krott 1960, p. 23). Newborns are covered

with whitish to yellow hair (Krott 1958, p. 87; Mehrer 1976, p. 570), 4.5 millimeters (mm) (0.18 in) in length (Shilo and Tamarovskaya 1981, p. 147), with unerupted teeth (Mehrer 1976, p. 570; Pasitschniak-Arts and Larivière 1995, p. 5) and closed ear canals (Shilo and Tamarovskaya 1981, p. 147). They are generally not left alone at the den during the first 3-4 weeks (Krott 1958, pp. 88, 108). A study of telemetered wolverines in Scandinavia found that, on average, a female wolverine spends most of her time within 1,000 m (3,281 ft) of the reproductive den during the denning period (Myhr 2017, no page number).

Mustelids, in general, have a short period of growth (Iversen 1972b, p. 317). As noted above, the metabolism of young wolverines is highest during the first 2.5 months, and individuals are almost two-thirds grown by the fall (at about 6 months) (Krott 1960, p. 25). As described by Shilo and Tamarovskaya (1981, p. 146), 45-50 day old cubs (Norway) have woolly coats, are muddy grey in color, with teeth beginning to erupt at this age. At about 150 days, all permanent teeth have been established (Shilo and Tamaovskaya 1981, p. 147). After 2.5 months, young wolverines replace their juvenile coat with the adult summer coat (Shilo and Tamarovskaya 1981, p. 147). With growth ending at about 8 months (Iversen 1972b, p. 320; Magoun 1985, p. 23), cubs are generally full grown by October or November.

Use of Dens and Denning Behavior

Dens and breeding burrows of animals are, in general, carefully constructed, well-camouflaged, and located in areas not easily accessible (Novikov 1962, p. 25). Wolverines use both natal dens (used for birthing) and maternal dens (used subsequent to natal den and before weaning) for rearing young (Magoun and Copeland 1998, p. 1,314). The average relocation distance to maternal den sites for active wolverine den sites studied in Norway was 268 m (879 ft) (95% confidence interval: 40–497 m (131–1,631 ft)) (May *et al*. 2012, p. 199). The young remain at the natal den site for 6 to 8 weeks (Krott 1960, p. 24), and are weaned at 9 to 10 weeks (Copeland 1996, p. iv (Central Idaho); Koskela *et al*. 2013a, p. 101 (Finland)) (*cf*. 7 to 8 weeks reported by Myhre and Myrberget, 1975, p. 754 (Norway)). After weaning, the young are dependent on the mother and begin to travel with her by late April (Koskela *et al*. 2013a, p. 101 (Finland)). Observations of wolverines in central Idaho reported that females traveled up to 17.9 km (11 mi) from maternal dens to forage (Copeland 1996, p. 97).

The exact timing of when females abandon natal dens and begin using maternal dens is difficult to establish (Inman *et al*. 2012b, p. 638). In general, studies have found that den abandonment (natal) occurs before May (Magoun and Copeland 1998, p. 1,315; Table 1; Inman *et al*. 2012b, p. 637; Figure 2). A study by Aubry *et al*. (2016, p. 24) reported that a female wolverine moved her single young (estimated to be at least 9 weeks old) from a natal den in *late April* in the North Cascades region of Washington. More recently, a comprehensive study of wolverines in Scandinavia found that females begin to shift den locations more frequently beginning in *late April* as young are more mobile and are more reliant on solid food brought to them by the mother (Aronsson 2017, p. 46). Natal den abandonment in Alaska and Idaho reportedly "coincided with a period when maximum daily temperatures rose above freezing for a number of days for the first time since denning commenced" (Magoun and Copeland 1998, p. 1,316). Factors other than temperature can influence shifts in the locations of these den, including intraspecific predation, parasites, or other disturbances (Inman *et al*. 2012b, p. 638). In central Idaho, Copeland (1996, p.

iv) concluded that human disturbance at maternal den sites resulted in den abandonment, but not *abandonment of young*.

Rendezvous sites are locations in which the female leaves young while she hunts for food, and from which they will not leave without her (Magoun 1985, pp. 16, 77). These areas provide security to young (Copeland 1996, p. 94) and serve as locations at which females bring food to the young, or from which she will guide them to a food source (Inman *et al*. 2012b, p. 638). Rendezvous sites of wolverines studied in central Idaho consisted of large boulder talus or riparian areas associated with mature overstory and dense timber deadfall (Copeland 1996, p. iv). Magoun (1985, p. 76) reported that rock caves and hilltops containing boulders without large snowdrifts were used as rendezvous sites in Alaska. Females may move their young to new rendezvous sites several times over a two month period (Magoun 1985, p. 73), and distances between consecutives sites have been reported as far away as 8.5 km (5.3 mi) (Magoun 1985, p. 76).

Studies of adult female wolverines in Scandinavia (northern Sweden) have provided additional details regarding the temporal patterns of reproductive behavior and den site use. Aronsson (2017, p. 45) (see also Persson *et al*. 2017, in prep) found that, in general, most births occurred in mid-February. Females spend very little time outside the natal den for the first 2 weeks (Aronsson 2017, p. 45). During the first period of den site use, or approximately 2 to 2.5 months from mid-February (when females generally give birth and are lactating), females will move short distances and do not need to bring food to young (Aronsson 2017, p. 46). This time period generally coincides with snow cover and favorable conditions for food caching, and dens offer protection from predators and the environment (Aronsson 2017, p. 46). In addition, during the first 1.5 months of the denning period, females rarely changed den sites, but begin to move outside the den in early March (Aronsson 2017, p. 45). In the later denning period (after April 15), females begin to move more frequently and at greater distances between den sites (Aronsson 2017, p. 45). By late April, the young are more active and also begin to rely more on solid food that is brought back to them by their mother (Aronsson 2017, p. 46). This also corresponds to a time period when prey are more available (reindeer migration and calving period in Sweden) and expected shorter distance movements by the mother back to denning or rendezvous sites (Aronsson 2017, p. 46). These observations are consistent with Inman *et al*.'s (2012b, entire) proposed cold, low productivity niche for wolverines based on studies of wolverines in the Greater Yellowstone Ecosystem. That is, reproductive chronology in wolverines is considered to be adapted to take advantage of the availability of food resources, limited interspecific competition, and snow cover in the winter (Inman *et al*. 2012b, p. 635).

In summary, as described by Inman *et al*. (2012b, entire) and Persson *et al*. (2017, in prep), reproductive behavior of wolverines reflect seasonal shifts in resource abundance within the wolverine's range; that is, adaptation that matches the time of birth and development of young to changes in the availability of resources and foraging strategies (Persson *et al*. 2017, in prep). We present in Figure 4 a visual summary of wolverine feeding strategies relative to resource availability from time of birth to post-weaning.

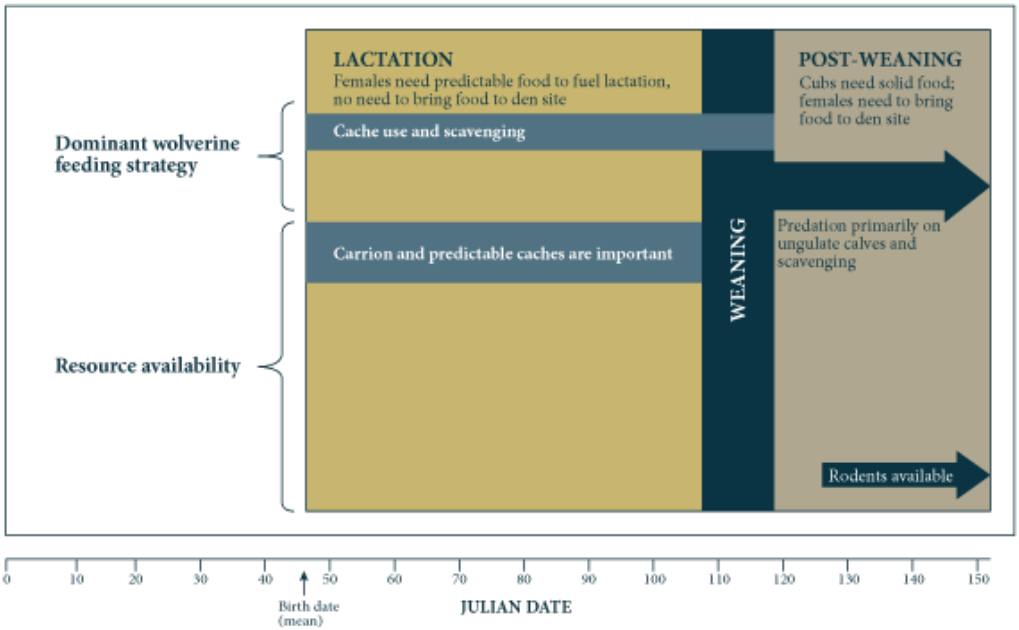

Figure 4. Wolverine feeding strategies relative to resource availability. Adapted from Persson *et al.* 2017, in prep.

Denning Habitat

Given the wolverine's observed association with snow, we provide in **Box 1** a summary of the importance of snow, in general, for ecological systems. This summary provides a detailed perspective of how various physical properties of snow can influence ecological systems occupied by snow-adapted wildlife, including insulating properties, differences in snow cover in mountainous vs. forested habitat, and changes in snow cover due to wind and slope/aspect. However, we also emphasize here that there have been limited comprehensive studies of wolverine behavior, or its physical and ecological requirements outside of the winter months in North America (*cf*. Banci 1987 (Yukon); Hornocker and Hash 1981 (Montana); Gardner 1985 (Alaska); Magoun 1985 (Alaska); Copeland 1996 (Idaho); Krebs *et al*. 2007 (Canada); Inman *et al*. 2013 (Greater Yellowstone Ecosystem)) due, in part, to the difficulty in tracking animals when snow cover is absent and their ability to move great distances across rugged terrain. In addition, den site locations for North America reported in the past have been biased to tundra regions where dens are more readily observed and located (Banci 1994, p. 110). In Scandinavia, snow cover has also been found to be a poor technique for tracking female wolverines during the time when they give birth and initiate denning (Aronsson and Persson 2016, p. 266).

Box 1. Snow Cover in an Ecological Context

Formozov (1961; 1963) prepared comprehensive reviews of the unique properties of snow in the context of its role in the ecology of animals and plants in Russia. In his 1963 review (translated from the 1946 original), he identified two important factors attributed to snow cover — *nastization* (the thickness of the crust on the surface of mature snow cover) and *firnization* (process of snow compaction) — relative to its ecological influence (Formozov 1963, p. 8). Snow cover provides not only a substrate that allows some animals to move across the landscape, it also provides a matrix within which other animals can create tunnels and build nests (Formozov 1963, p. 8). Additional fundamental concepts described in this study are provided below:

- Snow has very low thermal conductivity which promotes cooling at the surface while at the same time protects the deeper layers from chilling; but this property varies by region, by depth, by season, and by year (e.g., the more continuous the snow cover during winter, the greater the warming effect); as snow changes to ice (through compaction and melting), the thermal conductivity decreases (Formozov 1963, pp. 7, 8, 108)
- Snow therefore creates a thermo-insulating layer, which allows for a unique temperature regime on the surface and underneath; as an example, soil temperatures measured in January (near Saint Petersburg, Russia) averaged 15°C higher with snow cover than without snow cover, with up to a 32°C difference, depending on the day and depth measured (Formozov 1963, p. 109)
- Snow cover in mountains:
    - Depth of snow cover and its duration increases with elevation; even minor elevation differences are noticeable (Formozov 1963, p. 123)
    - This spotty distribution is also affected by unequal distribution of snow precipitation on slopes with different exposures, transport of snow by wind, melting of snow on sun-exposed slopes, avalanche or rolling down of snow from steeper areas, and vegetation (Formozov 1963, p. 123)
    - Snow cover areas near Arctic limits and at treeline in mountain regions is more strongly influenced by wind (which compacts and re-works snow cover) (Formozov 1963, p. 29)
- Snow cover in forests:
    - The maximum depth, density, duration and date of melting, thickness of snow surface crust are all much different in forested areas as compared to open treeless areas (Formozov 1963, p. 19)
    - Snow accumulates slowly under trees and is generally thicker the further away from the forest than within the forest; thus, the compaction and settling of snow under a forest canopy is less than tundra or open fields (with a less icy crust), so for some vertebrates, forested areas can provide a more preferable place to winter or migrate (Formozov 1963, pp. 24, 26)
    - Snow cover in forested areas also melts slower than open fields and clearings (Formozov 1963, p. 28)
- Snow cover also plays an important role in the overwintering conditions for insect eggs, caterpillars, pupae, and adult insects in litter and soil, and some plants (Formozov 1963, p. 121)

Although it has been assumed that wolverines have an obligate relationship with snow for natal denning, including persistent spring snow cover, the key elements or combination of elements that define this relationship have not been empirically analyzed. As noted above, adult wolverines have a wide range of thermoneutrality. However, newborns, who are born with lighter, less dense fur are likely to have a more limited ability to control their internal temperature, though huddling (a thermotactic behavior) of small mammals in dens can conserve heat (Barnett and Mount 1967, p. 439). Relatedly, basal metabolic production of heat is the source of heat that maintains bodily warmth, and is not easily modifiable unlike the flexibility of insulation (Irving 1972, p. 121). However, metabolic heat above an animal's basal rate for preservation of warmth is restricted by its limited capacity for metabolic production of heat, but also by food availability and the time and opportunity for nourishment (Irving 1972, p. 121). In general, metabolic production of heat is costly to animals, but variable insulation represents a conservative strategy (Irving 1972, p. 121).

Another key element related to den location is the protection that dens provide to a nursing female and her young. Because wolverines are known to den in a variety of structures, it is unclear if the apparent relationship to snow cover is based on selecting den locations in remote, high elevation areas to avoid predators. Bare rock and boulders at den sites can offer dry and secure cavities and enhance the ruggedness of the landscape (May *et al*. 2012, p. 198). "Ruggedness," a measure derived from elevational changes and irregularity of land surface (density of contour lines) traversing a given area (Beasom *et al*. 1983, p. 1,163) has been found to be an important variable (i.e., secure habitat from predation risk) for female wolverines in winter (British Columbia, Canada) (Krebs *et al*. 2007, p. 2,188) and for den site selection at site-specific, home range, and landscape scales (southcentral Norway) (May *et al*. 2012, pp. 200–201).

Wolverine denning habitat varies across its Holarctic range. For example, in southcentral Norway, wolverine dens were snow tunnels dug into deep snow at the tree line (elevation 1,100 m (3,609 ft)), but most of the tunnel systems extended down to boulder fields, talus slopes, or rock crevices such that young could crawl around within these structures (May *et al*. 2012, p. 201). Snow tunnels are also reported for wolverine natal dens in Alaska (Magoun 1985, pp. 84, 185, 190). However, reproductive dens are not always excavated in deep snow. In Canada, female wolverines are said to give birth in dens where snow cover persists at least until April, and can den under snow-covered rocks, logs, or within snow tunnels (COSEWIC 2014, p. v). As an example, in northwestern Ontario, den site habitat for a female in lower Boreal Forest habitat (elevation 250 to 500 m (820 to 1,640 ft), 51°N) included large boulders and downed trees, similar to dens described for wolverines in montane ecosystems (Dawson *et al*. 2010, p. 139). In Finland, Pulliainen (1968, p. 340) reported a den site (January) at the base of a tree and not covered in snow, and also described other structural features such as rocks, fallen trees, and deep ravines as denning habitat (likely both natal and maternal dens) (Pullianinen 1968, pp. 338–341). In Russia, where wolverine habitat has been described as located far from human-inhabited areas within boreal forests and, to some extent, tundra, and taiga (Novikov 1962, pp. 199, 200), den locations were described as "clefts in rocks, among stones, and under roots of upturned trees" (Novikov 1962, p. 200). A study from northwestern Ontario noted that, because lowland boreal forest habitat in this region does not support deep, wind-hardened snowdrifts, other structural

elements within snow layers such as trees and boulders can be important components of wolverine denning habitat (Dawson *et al*. 2010, p. 142).

Limited studies to date have evaluated the importance of denning habitat to reproductive success, or the key physiological and ecological characteristics, including avoidance and/or protection from predators, prey availability, availability of caching habitat, that define denning behavior and den site selection. Population density, trapping pressure, population genetics, and other measures of habitat quality may also influence wolverine fecundity (Anderson and Aune 2008, p. 28). In addition, studies of wolverine denning activity have not reported the condition of the natal or maternal den location following abandonment; that is, what is the persistence and/or depth of snow at the natal den at the end of the denning season and how does this affect survival of young?

A bioclimatic model was used by Copeland *et al*. (2010, p. 234) to test the following hypothesis: "…wolverine distribution **at the broadest spatial scale** is constrained within a climatic envelope defined by an obligate association with persistent spring snow cover and by an upper limit of thermoneutrality." However, this hypothesis was based on the premise "**If persistence of wolverine populations is linked to** the availability of suitable reproductive den sites ([citing] Banci 1994), snow cover that persists throughout the denning period **may be** a critical habitat component **that limits the wolverine's geographic distribution**" (Copeland *et al*. 2010, p. 234). The authors tested this hypothesis by "comparing and **correlating** the locations of wolverine reproductive dens from throughout their circumboreal range, and telemetry locations from 10 recent wolverine studies in western North America and Scandinavia, with spatial models representing the distribution of spring snow cover and average maximum August temperatures" (Copeland *et al*. 2010, p. 234) (emphasis added).

Bioclimatic models "use associations between aspects of climate and known occurrences of species across landscapes of interest to define sets of conditions under which species are likely to maintain viable populations" (Araújo and Peterson 2012, p. 1,527). They are correlational by nature and are often applied to study a variety of conservation issues, including forecasting potential climate change effects on species' distributions (Araújo and Peterson 2012, p. 1,527). However, these types of correlational models have received some criticisms and require careful framing to avoid misapplication (Sieck *et al*. 2011, p. 6; review by Araújo and Peterson 2012, entire). They generally represent a first step for evaluating current and future species distributions, and, when coupled with climate change scenarios, results are presented at a coarse scale that may not accurately project shifts in species distribution at a smaller scale (Sieck *et al*. 2011, p. 6). In particular, when used to estimate extinction risk, these types of models provide only an estimate of the empirical relationships between a species' current distribution and climate variables and then use inferred relationships to identify potential areas where the species is distributed under future climate scenarios (Araújo and Peterson 2012, p. 1,553). Extinction risk is not represented in the model's input data and therefore is not the targeted parameter of the model; thus, a bioclimatic model's usefulness may be limited in these types of applications given that it only offers partial explanatory evidence for reasons for potential extinction related to the shifts in climate suitability within the time frame being modeled (Araújo and Peterson 2012, p. 1,533 and citations therein). In addition, climate niche projections generally do not incorporate factors such as competition, dispersal, and evolutionary capacity, which also influence range

boundaries (Michalak *et al*. 2017, p. 370). Thus, these types of models are more applicable at broad scales in which the effects of fine-scaled topography and biological interactions play a more limited role (Michalak *et al*. 2017, p. 370); however, both of those factors are important for wolverine, particularly at the den-site scale.

Finally, Post (2013, p. 50) suggested that the niche conservatism approach may not be appropriate in predicting changes to species' distributions under future climate change scenarios. He concluded that, based on redistribution patterns of flora and fauna throughout the Pleistocene epoch, but particularly the Late Pleistocene period of rapid warming, species movement is not always predictable in directions or rates based simply on their association with the more predictably changing environmental/abiotic measures.

As noted above, Copeland *et al*. (2010, entire), used a bioclimatic model to evaluate an assumed association not at the den site scale, but at a broad scale. The results presented in Copeland *et al*. (2010, entire) were based not on the condition of snow cover at a particular den site at the time of denning, but rather their evaluation of snow persistence (April 24 to May 15) was based on satellite images summed over a 7-year period (2000 to 2006) for the den locations. The spatial resolution of the snow measurement used to detect daily snow cover was 500 m (1,640 ft), using Moderate-Resolution Imaging Spectroradiometer (MODIS). If persistent snow cover was observed in any one year, it was included in the bioclimatic model regardless of whether denning occurred during that particular year.

In addition, although the study found that 69 percent of dens for North American wolverines were located within satellite images (pixels) in areas that had snow cover for 6–7 years, just over one-third (31 percent) of the identified den locations were located in areas that were identified as having spring snow cover 5 years or less out of 7 years. Also, the den location attributes (e.g., den structure, how long it was used) were not recorded relative to the observed persistent snow cover and some of the 560 dens (e.g., Norway) were identified by snow tracking rather than direct observation. In essence, the results presented by Copeland *et al*. (2010, entire) provided a fairly accurate, though preliminary, assessment of where **wolverine populations** are expected to be observed, but did not evaluate (model) snow persistence at the den site scale based on location and denning period (emphasis added).

We also note here that results from group scoring exercises using modified (no consensus) Delphi techniques (i.e., group discussions followed by group scoring exercises with points allocated for beliefs on wolverine habitat needs and behavior, as well as uncertainty in allocation of points) of a panel of scientists convened by the Service in April 2014 (Wolverine Science Panel Workshop), indicated that most panelists allocated points to an obligate relationship of wolverines with deep snow at the den-site scale, but there was a wide range of scores from the panel as to whether contiguous snow was limiting at the home-range or species-range scales (Wolverine Science Panel Workshop Report 2014, pp. 9–11).

Since the 2013 (78 FR 7864; February 4, 2013) and 2014 (79 FR 47522; August 13, 2014) proposed rules for the wolverine, several publications have presented additional study results related to wolverine distribution and snow cover. In Alberta, Canada, Webb *et al*. (2016, entire) found that, based on wolverine harvest data, wolverine occurrence relative to spring snow cover (percent of area covered, with greater than 75 percent snow coverage, on April 1 and 15) varied

based on the different regions of Alberta. This study used meterological data from 2009 to 2015, in northern Alberta (north of 54°N) and differentiated between spring snow cover that persisted in ≥ 1 of 7 years and more frequently (≥4 of 7 yr) (Webb *et al*. 2016, pp. 1462–1464). Although the study found an overall positive trend of more frequent wolverine harvests in those areas expected to have spring snow cover, the study did not find consistent large differences between these areas, and did not typically detect significant relationships with frequent spring snow cover (4–7 years) in all regions (Webb *et al*. 2016, p. 6). The Rocky Mountains region was the only region in which wolverines were reported in areas with more frequent spring snow cover (4–7 years) (Webb *et al*. 2016, p. 5). This region, which is located along the western border of Alberta, contains montane, subalpine and alpine habitat, with elevations from 1,000 m (3,281 ft) to 3,700 m (12,139 ft) (Webb *et al*. 2016, p. 9). Conversely, the study found that in the Boreal Forest region of Alberta (i.e., wetland habitat interspersed with coniferous, mixed wood, and deciduous forests, with elevations between 1,500 m (4,921 ft) to 1,100 m (3,609 ft)), a female wolverine denned under large boulders and downed trees (Webb *et al*. 2016, p. 8). The authors noted that wolverine den locations within low elevation, forest habitats have not been well-described (Webb *et al*. 2016, p. 8). As noted above (Novikov 1962, p. 200), in boreal forested habitat, wolverines den in rock areas and in tree root structures. A similar finding was reported in Sweden, where a majority of dens (n=49) were in boulder areas located within mature, mixed coniferous forests (i.e., not alpine or tundra habitat) (Makkonen 2015, p. 14); all den sites provided cover for young *without snow* (Makkonen 2015, p. 17). A recently published study reported two wolverine natal dens in logged areas (cutblocks) in northern Alberta, Canada; specifically, within a slash pile and log deck (Scrafford *et al*. 2017, p. 35).

A study of wolverine populations and distribution in Sweden observed that wolverine populations were found outside areas with persistent spring snow cover (mean snow depth and proportion of years with snow cover on March 15; 1961–1990) and expanding into boreal forest habitat located to the east and south of alpine areas (Aronsson and Persson 2016, p. 266). This southern and eastern expansion (from 1996 to 2014) indicates recolonization of their historical distribution in Sweden, and is thought to be the result of an increase in population, with more dispersers colonizing forest habitat, and an increase in year-round scavenging opportunities due to an increase in Scandinavian wolf packs (Aronsson and Persson 2016, p. 266; Aronsson 2017, pp. 43–44). As of the spring of 2017, over 80 reproductive dens have been observed outside the boundary of the snow model presented in Copeland *et al*. (2010) (Persson 2017, pers. comm.). Similarly, in Finland, Koskela (2013, p. 38) found that 10 observed wolverine dens observed were determined to be "snow dens," but 8 of the 10 dens were located in areas outside the Copeland *et al*. (2010) modeled, satellite-based spring snow cover area.

Snow depth can be affected at a local level by terrain, ruggedness, slope and aspect; slope and aspect together will affect the exposure to snow accumulation (May *et al*. 2012, p. 198). In an effort to document and compare snow persistence at the wolverine den-site scale, Magoun *et al*. (2017, entire) evaluated the use of low-altitude aerial photography during late May 2016 in areas within the Rocky Mountains (Idaho and Montana) and northwestern Alaska. In Idaho and Montana, flight lines were established along transects through the long axis of previously documented home ranges of denning female wolverines and, in Alaska, known den sites (from 2016) were visited by helicopter and remaining snow was photographed (Magoun *et al*. 2017, p. 383). Transect segments in the Rocky Mountain study areas documented snow on May 31 in all but one segment, with 82 percent classified in low to heavy snow retention categories, and 58 percent considered as moderate to heavy (Magoun *et al*. 2017, p. 383). In the Alaska study area,

photographs documented widely scattered patches of snow on May 29, with remnant snowdrifts observed at all four wolverine den sites (Magoun *et al*. 2017, p. 383). The documentation of the existence of scattered patches of snow in the Rocky Mountains persisting into late May in areas previously detected to be bare of snow on May 29 (MODIS persistent spring snow cover, McKelvey *et al*. 2011, p. 2,889, Figure 4D; Magoun *et al*. 2017, p. 384, Figures 2b and 2d) suggests that persistent spring cover may not always be detectable at the den-site scale using remote sensing methods (Magoun *et al*. 2017, p. 384), and is affected by terrain, ruggedness, slope, and aspect.

To evaluate snow cover at previously recorded den site locations in the western United States, we reviewed natal, maternal, and known den sites relative to derived 'melt-out' dates using MODIS/Terra Snow Cover, 8-day series (Hall and Riggs 2016). Melt-out dates represent the first day of the 8-day composite series when the cell in which the den was located switches from "snow" to "no snow." The spatial resolution for these data is 500 m by 500 m (1,640 ft by 1,640 ft). Because MODIS data was only available from the years 2000 to present, we were only able to evaluate 21 of the 34 den sites documented in our records. As shown in Table 3, the earliest melt-out date was May 14 (2006) and the latest was July 12 (2002).

Table 3. Wolverine Den Site Melt-Out Dates, 2002–2008.

Den #	Den Type	Melt-out Date	Elevation, meters (feet)	Structure	State
1	Unknown	7/12/2002	1,814 m (5,951 ft)	None Listed	WA
2	**Natal**	5/25/2003	1,928 m (6,326 ft)	Log Complex	MT
3	Maternal	5/25/2003	1,995 m (6,545 ft)	Log Complex	MT
4	**Natal**	6/4/2004	1,807 m (5,923 ft)	Log Complex	MT
5	**Natal**	6/9/2004	2,399 m (7,871 ft)	None Listed	WY
6	**Natal**	6/17/2004	2,487 m (8,160 ft)	None Listed	MT
7	Maternal	6/29/2004	1,823 m (5,981 ft)	Downed Log	MT
8	Maternal	6/29/2004	1,893 m (6,211 ft)	Log/Boulder	MT
9	Maternal	6/11/2005	1,912 m (6,273 ft)	Spider Tree	MT
10	Maternal	6/11/2005	1,973 m (6,473 ft)	Spider Tree	MT
11	**Natal**	6/11/2005	1,977 m (6,486 ft)	Spider Tree	MT
12	**Natal**	7/12/2005	2,693 m (8,835 ft)	None Listed	MT
13	Unknown	5/14/2006	1,514 m (4,967 ft)	Log Complex	MT
14	Unknown	5/25/2006	2,093 m (6,867 ft)	None Listed	MT
15	Maternal	5/31/2006	1,851 m (6,073 ft)	Log Complex	MT
16	**Natal**	5/31/2006	1,843 m (6,047 ft)	Log Complex	MT
17	Unknown	6/7/2006	2,252 m (7,389 ft)	None Listed	MT
18	**Natal**	6/18/2006	2,695 m (8,842 ft)	None Listed	MT
19	**Natal**	5/25/2007	2,820 m (9,252 ft)	None Listed	MT
20	**Natal**	6/4/2007	1,922 m (6,306 ft)	Log/Boulder	MT
21	Unknown	7/3/2008	2,505 m (8,219 ft)	None Listed	ID

For *natal* den sites only, the range for melt-out dates was May 25 to July 12. All of these sites indicate a melt-out date that is past the May 15 date used for the persistent spring snow cover model presented in Copeland *et al*. (2010), which suggests that snow is persistent at these locations past the time when young begin moving out of natal dens (i.e., late April; see Use of Dens and Denning Behavior section). Additional studies are needed to further document wolverine den structure, snow conditions at dens, and how long dens are used, particularly for those locations outside of areas expected to have spring snow cover, to better understand the relationship of wolverines and snow cover (Webb *et al*. 2016, p. 8; Magoun *et al*. 2017, pp. 6–7).

Other physical or biotic variables are also likely to be important for wolverine den site locations. Elevation affects snow depth and persistence at the landscape scale (May *et al*. 2012, p. 198). Inman *et al*. (2012a, p. 782) found that wolverines (12 females and 6 males) monitored in the Greater Yellowstone Ecosystem selected, on an annual basis, areas above 2,600 m (8,530 ft) latitude-adjusted elevation. In central Idaho, natal dens were also found in secluded, high elevation (above 2,500 m (8,202 ft)) cirque basins (Copeland 1996, p. 94).

We evaluated 34 den sites in the lower United States using a linear regression model to evaluate whether the elevation of wolverine den sites is related to latitude. We note here that not all of these dens were characterized as to whether they were natal or maternal dens and a few records were not verified through tracking of females or direct observations. Given these caveats, our examination of these records indicated that, in general, wolverine dens at lower latitudes (36 to 38°N) occur at higher elevations (range: 2,688 to 3,562 m) (8,819 to 11,686 ft) while the converse is seen for those dens at higher latitudes, or approximately 44 to 49°N (range: 1,514 to 2,820 m) (4,967 to 9,252 ft). Given our assumptions (small sample size, test of normality (i.e., Shapiro test for elevation is just met)) we used linear regression (R Software; R Development Core Team, 2014) to test this association. We found a significant association with elevation and latitude [adjusted $R^2 = 0.76$, $F = 108.1$, df=32; $p\text{-value} = 8.24 \times 10^{-12}$], such that dens found at lower elevation were associated with higher latitudes. However, the results of this simple model indicate that 76 percent of the elevation for this sample is explained by latitude; thus, other potential explanatory variables or interactions between variables should be considered using multiple regression techniques.

The steep slopes found at higher elevations also provide conditions conducive to avalanches, which result in debris and talus/boulder piles that provide structure for dens (Inman 2013, pers. comm.). Steep slopes and the availability of rocks were found to be important to wolverine den site selection for wolverines studied in Norway (May *et al*. 2012, p. 200). These areas also offer either exclusive or higher frequencies of maternal food sources during the high energy demands for reproducing females, such as marmot emerging from hibernation and neonatal ungulates (Inman 2013, pers. comm.) (see *Diet and Feeding* discussion below).

In summary, wolverines select den sites for different characteristics depending on location. Dens located under snow cover may be related to wolverine distribution based on other life history traits, including morphological, demographic, and behavioral adaptations that allow them to successfully compete for food resources (Inman 2013, pers. comm.). Structure (e.g., uprooted trees, boulders and talus fields) appears to be essential for natal den sites with or without snow cover. Sensitivity to human disturbance and predator avoidance are also likely important factors

in selecting both natal and maternal den sites. However, reproductive success of wolverines has not been evaluated relative to the depth and persistence of snow cover, or in combination with these or other important characteristics, including prey availability and predator avoidance.

Demography

The lifespan of the wolverine is variable. Jackson (1961, p. 361) reported an upper range of 8–10 years in the wild and potentially up to 18 years in captivity. Based on trapper-submitted carcasses from the Yukon, an upper age of 11.9 years for a male wolverine and 12.9 years for (pregnant) female was reported (Jung and Kukka 2013, pp. 8, 12). Inman *et al*. (2012a, p. 781) classified wolverines less than 1 year old as juveniles (or cub), those 1 to 2 years old as subadults, and those at least 3 years old as adults. Generation time for wolverines has been estimated at 7.5 years (COSEWIC 2014, p. 23).

Survival of adult female wolverines is considered to be an important demographic parameter in the wolverine's life history (Sæther *et al*. 2005, entire). As noted by Aronsson (2017, p. 13), because most polygamous species display a dispersal pattern that is sex-based, their population distribution is generally limited by the dispersal behavior of the sex that is more philopatric (the tendency of a species to remain within or return to its birth area). Thus, the distribution of wolverine populations and colonization is generally limited by dispersal of female wolverines (Aronsson *et al*. 2017, p. 2).

Stochastic factors (both demographic and environmental) also strongly influence the population dynamics of the wolverine (Sæther *et al*. 2005, p. 1,011–1,012). Given the rapid maturity of young wolverines, survival of female wolverines with young is likely dependent on the availability and distribution of food sources during the "snow-free season" (late spring and summer) (Banci 1994, p. 114). For example, a study of wolverines in Norway found that survival of young was primarily influenced by the abundance of small rodents (Landa *et al*. 1997, p. 1,293).

Evaluating how variations in demographic rates are influenced by the interactions between costs of reproduction, individual quality (e.g., breeding status), and environmental factors can provide a better understanding of the dynamics and viability of animal populations (Robert *et al*. 2012; p. entire; Rauset *et al*. 2015, entire). The interactions between individual age, environmental resources, and reproductive costs of wolverines in Sweden were recently examined (Rauset *et al*. 2015, entire). The results of this study provide important details regarding the influences on wolverine reproduction productivity. The study found that age-related variation in reproductive output for female wolverines is driven by the interactions between age, reproductive costs, and availability of resources (Rauset *et al*. 2015, p. 3,160). As an example, female wolverines were found to be more likely to give birth and nurse young in home ranges with greater food resource abundance at the time of fetal development (Rauset *et al*. 2015, p. 3,158). The study also concluded that a favorable reproductive strategy for female wolverines is a conservative one, wherein older female wolverines do not "trade" current reproduction against their own survival (Rauset *et al*. 2015, p. 3,161).

Intraspecific predation of wolverines is another important influence on wolverine population dynamics (Persson *et al*. 2003, p. 26). The altricial life history stage (early May to end of July) is likely a period of high juvenile mortality in solitary carnivores, such as the wolverine, since females are balancing the energetic demands of lactation (Sadleir 1984, pp. 179–180) and providing protection to young (Persson *et al*. 2003, p. 22). Young (juveniles) wolverines are vulnerable to predation during the time period when left unattended in the natal den (generally March-April) and when they first exit the natal den and are left at rendezvous sites, or around May-June (Magoun 1985, pp. 49, 73, 77). An additional vulnerability occurs when juvenile wolverines are required to become nutritionally independent and begin exploratory movements away from their mother's protection, generally August-September (Vangen *et al*. 2001, p. 1,644).

Mortality

There are a few natural predators of wolverines, but interactions with wolves can lead to severe injury and death (Burkholder 1962, p. 264; Banci 1987, pp. 81, 91; White *et al*. 2002, p. 132). Mountain lions are suspected of killing wolverines (Copeland 1996, p. 46; Krebs *et al*. 2004, p. 497; Aubry *et al*. 2016, pp. 27, 32). Starvation has also been identified as a cause of mortality in wolverines (Hornocker and Hash 1981, p. 1,296; Banci 1987, pp. 91, 110; Krebs *et al*. 2004, p. 497). Intraspecific predation also contributes to wolverine deaths. Persson *et al*. (2003, p. 25) found that juvenile survival rate tended to be lower during the altricial period (May–July), and intraspecific predation was the most common cause of mortality, occurring either as infanticide or after independence. Avalanches have also been documented as a cause of wolverine deaths (Inman *et al*. 2007, p. 89).

In North America, anthropogenic causes of mortality for wolverine populations include hunting, trapping, and road kill. Discussion of the effects of hunting, trapping, and human development is provided below (see Biological Status–Current Condition section).

Diet and Feeding

Wolverines have been described as opportunistic foragers (Inman *et al*. 2012b, p. 639) and as a "seasonal scavenger on the fringe of the food web" (Larsen 1980, p. 399). They are both scavengers and predators, with a diet that varies between seasons and years, and switching between food sources depending on availability (Magoun 1987, p. 396; Cardinal 2004, pp. 19–22; Mattisson *et al*. 2016, p. 9). The term "polyphagous" was used by Landa *et al*. (1997, p. 1,292) to describe the switching of food sources depending on prey availability by wolverines. Regional variations in diet have also been observed for wolverine populations (Nunavut, Canada) (Awan and Szor 2012, p. 9). The availability of ungulate carrion is believed to be more important than a particular habitat type for wolverines (Cardinal 2004, p. 20).

Early studies from northwestern Montana using scat analysis found that carrion (deer or elk) was an important component of wolverine diet (Hornocker and Hash 1981, p. 1,297). However, during winter, hoary marmots (*Marmota caligata*) were also important food items consumed and, in the spring, Columbian ground squirrels (*Urocitellus columbianus*) were heavily preyed upon (Hornocker and Hash 1981, p. 1,298). As reported by Cardinal (2004, pp. 20–21), wolverines in Canada have a large and varying diet based on reports from aboriginal traditional

knowledge holders; in addition to large animals as prey or carrion, wolverine diet includes rabbits and ptarmigans (*Lagopus* sp.), porcupine (*Erethizon dorsatum*), mice, beaver (*Castor canadensis*), fish, ducks, seals, gulls and gull eggs, and lemmings, as well as antlers, bones, and skulls. Native mountain goats (*Oreamnos americanus*) and bighorn sheep (*Ovis canadensis*), that occupy high elevation winter ranges in portions of North America, have also been suggested as important components of wolverine winter diet, particularly during the reproductive denning period (Buell Environmental 2016, pers. comm.). Snowshoe hares may also be an important food item for wolverines in parts of Canada (Jung and Kukka 2013, p. 20).

In northwestern Alaska, analyses of wolverine winter diet using carcasses collected from hunters (1996–2002) within the migratory range of the Western Arctic Caribou Herd found that caribou represented the most common food item, likely through scavenging behavior, followed by moose (*Alces alces*), and to a lesser degree, microtine rodents, Arctic ground squirrels (*Spermophilus parryii*), porcupines, wolverines, red fox (*Vulpes vulpes*), sheep and ptarmigan (Dalerum *et al*. 2009, p. 249). One study year found stomach contents contained a large portion of muskoxen (*Ovibos moschatus*) and Dall's sheep (*Ovis dalli*) (Dalerum *et al*. 2009, p. 249). Wolverines were found to be the main predator of caribou calves (less than 14 days of age) in northern British Columbia, Canada (Gustine *et al*. (2006, pp. 13–14). Wolverine diets in winter (scat analysis) and summer (primarily direct observation) were evaluated by Magoun (1987, entire) in northwestern Alaska. Results from that study indicate a large number of Arctic ground squirrels were eaten in summer, while the winter diet consisted primarily of caribou and Arctic ground squirrels (Magoun 1987, p. 393). Scavenging was found to be an important feeding strategy in winter, including remnants of buried caribou carcasses or bone/hide in the tundra (Magoun 1987, p. 396).

Food habits of wolverines from 2002 to 2007 in Glacier National Park were evaluated by Yates and Copeland (*in prep*) by reviewing prey remains and scat samples, or direct observations of feeding behavior. Their scat analysis found that 72 percent of samples contained more than one prey species, and 89 percent contained plant material, primarily conifer needles (Yates and Copeland, *in prep*). The latter may be related to scent-marking behavior of territories, either by defecation after chewing on twigs/shrubs or terpenes released during urination, or the result of stomach contents found within their consumed herbivorous prey (Yates and Copeland, *in prep*). Overall, deer and elk represented the most frequent prey item (37 percent), but hibernating rodents were also common in scats (36 percent). Other prey items included mice, voles, lemmings, bovids (e.g., bighorn sheep, mountain goat), birds, and hares (Yates and Copeland, *in prep*). Temporal differences in the occurrence of prey were also observed.

Snow tracking in Montana found that wolverines hunted in brush piles, log jams, and heavy cover, and routinely entered "tree wells," areas immediately under dense, low growing conifers where snow does not accumulate, that provide easy access to small, ground-dwelling mammals (Hornocker and Hash 1981, p. 1298). Wolverines have been described as moving and lifting large stones in order to access human-cached meat (Freuchen 1935, p. 98).

Several foraging strategies have been described for wolverines. Predation behavior on reindeer (Sweden) was detailed by Haglund (1966, p. 275). A study of elk in Siberia, Russia, noted that, in most instances, wolverines will attack young, pregnant females, young of the year, and

wounded or sick animals (Knorre 1959, p. 27). Elk were chased, sometimes by two wolverines during periods of heavy snow (Knorre 1959, pp. 10, 27) and wolverines have been observed feeding in groups on large animal carcasses (Cardinal 2004, p.21). However, wolverines have been described as neither an effective predator of large game animals, nor a serious competitor with other predators (Cardinal 2004, p. 21).

Based on studies in Alaska, Dalerum *et al*. (2009, p. 251) suggested that wolverines occupying this region are large ungulate specialists, but use a generalist feeding strategy by switching between ungulate food sources (e.g., caribou and moose) depending on their availability. Thus, during periods of low caribou abundance, wolverines can switch from caribou (migratory) to moose (non-migratory) while still maintaining their ecological role as a scavenger on ungulate carcasses (Dalerum *et al*. 2009, p. 251).

A study of wolverine diet using scat samples in Finland found that breeding female wolverines opportunistically used carrion and hunted less on small prey as compared to males and non-breeding females (Koskela 2013, p. 35). In addition, in areas with low densities of mid-size ungulates, smaller prey and carcasses may be important in the wolverine diet (Koskela 2013, p. 35). These results supported an optimal foraging theory; that is, wolverines will opportunistically use foods that are the most energy-efficiently available (Koskela 2013, p. 41). In other words, hunting ungulates or smaller prey (rabbits, birds) may incur greater energetic costs than scavenging for food, but searching for wolf- or human-killed carcasses will take more time (Koskela 2013, p. 41).

Finally, diet and feeding strategies of wolverines were evaluated in Scandinavia (Mattisson *et al*. 2016, entire). Wolverine feeding strategies were found to be flexible and temporarily shifted from scavenging to predation and heavily influenced by seasonal dependent responses to availability of prey and the supply of carrion (Mattisson *et al*. 2016, p. 9). Predictable anthropogenic food sources (i.e., remains from hunted ungulates) also influenced wolverine feeding strategies in their study area by increasing scavenging behavior relative to predation (Mattisson *et al*. 2016, p. 10).

Aboriginal traditional knowledge holders in Canada have reported wolverines as being largely dependent on wolves or another large predator to obtain large mammal carrion such as caribou, but also scavenge off polar bear (*Ursus maritimus*) and grizzly bear (summer) kills (Cardinal 2004, p. 20). Wolverines were observed following the tracks of Eurasian lynx (*Lynx lynx*) and then scavenging on prey left behind from lynx kills (Haglund 1966, pp. 272–273). Myhre and Myrberget (1975, p. 756) noted that the hunting abilities of wolverine and Eurasian lynx are not the same and that the two animals use the meat of their prey differently, which, together, may allow the two carnivores to coexist in the same environment.

In Sweden, Mattisson *et al*.'s (2011b, p. 1,326) study of Global Positioning System (GPS)-collared wolverines found that they spent three times longer scavenging ungulate carrion as compared to feeding on wolverine-killed prey, and more than half of the reindeer carcasses scavenged by wolverines were killed by Eurasian lynx. That study concluded that lynx can increase the availability of food for wolverines and other scavengers and that lynx behavior around kill sites minimizes potential encounter conflicts (Mattisson *et al*. 2011b, p. 1,328). In

their study area, Eurasian lynx do not appear to pose a significant threat to wolverines, neither by exclusion in space or time (Mattisson *et al*. 2011a, p. 79) nor from mortality (Persson *et al*. 2009, p. 327). We are not aware of similar evaluations for North American populations of wolverines and Canada lynx. This lack of study on interspecific processes in the more predator-diverse North American landscape is an important gap in our understanding of wolverine distribution (Fisher *et al*. 2013, p. 712).

Large carnivores can act as "sympatric ungulate predators" (Dalerum *et al*. 2009, p. 251), generating carrion at kill sites, particularly during winter months, but also as competitors and potential sources of mortality (White *et al*. 2002, p. 132; Krebs *et al*. 2004, p. 497; Koskela *et al*. 2013b, p. 221). Wolverines apparently balance their exposure to the risk of predation with foraging opportunities (Scrafford *et al.* (2017, p. 32). Thus, even though wolverines may not be dependent on lynx or other sympatric predators for their survival or reproduction, an increase in the availability of carrion likely has a positive influence on the reproductive rate (e.g., number of offspring) in wolverine populations (Mattisson *et al*. 2011b, p. 1,328).

Caching of food is an important behavior of wolverines and is a key component of wolverine population dynamics (Hornocker and Hash 1981, p. 1,297; Inman *et al*. 2012b, p. 640). Food is cached in both summer and winter, by both sexes, and allows for food to be available past the peak periods of mortality and predation (Inman *et al*. 2012b, p. 639). Wolverines will typically move between carcasses and cache sites and are able to remove large parts of a carcass in a short time (Mattisson *et al*. 2011b, p. 1,327). Caching behavior in Sweden was reported most commonly in snow, as well as crevices in rock piles, and found that wolverines carried food to cache sites over long distances (8 and 10 km (5 and 6 mi)) (Haglund 1966, p. 274). As an example, Bjärvall (1982, p. 319) reported a female wolverine carried a reindeer head (with antlers) about 22 km (13.67 mi) back to a den site in Sweden. In northwestern Alaska, wolverines fed on cached ground squirrels during winter (Magoun 1987, p. 395).

A study of wolverine caching behavior in boreal forest habitat in Canada reported that cache sites varied from simple caches, a single feeding site or excavation, to cache complexes, which included feeding stations, latrines, resting sites, and climbing trees dispersed over varying spatial landscapes (Wright and Ernst 2004b, pp. 61–62). All cache sites included bones and hides of moose, which were likely scavenged from wolf kills (Wright and Ernst 2004b, p. 62). Cache sites were often excavated in snow, but also in the ground under boughs of large spruce (*Picea* spp.) trees (Wright and Ernst, 2004b, p. 62). Wolverines also appeared to select cache sites and resting areas that offered good visibility of approaching competitors or predators (Wright and Ernst 2004b, pp. 63–64).

Wolverine energetic demands and food requirements are related to their foraging strategies. Caching provides important energy for female wolverines during the lactation period and helps ensure survival of newborns (Inman *et al*. 2012b, p. 640). Wolverines were found to have high energetic needs compared to other mammalian carnivores (Young *et al*. (2012, p. 2,252), similar to results previously presented by Iversen (1972a, p. 343), who concluded the basal metabolism of mustelids weighing over 1 kg (2.2 lbs) is approximately 20 percent higher than for other mammals. A study by Andrén *et al*. (2011, p. 36) estimated a 1.2 kg/day (2.65 lbs/day) (range: 1.0–1.4 kg/day (2.2–3 lbs/day)) food requirement for wolverines, while Young *et al*. (2012, p.

223) estimated a male wolverine would require an average of 0.85 kg (1.87 lb) of prey/day in winter and 0.95 kg/day (2.1 lbs/day) in "snow-free" periods." Based on energy equivalent value of various prey sources, Young *et al*. (2012, pp. 223, 225) estimated that a winter diet for a male wolverine would include the equivalent of 1.8 ungulates, 70.7 sciurids (squirrels), 20.6 lagomorphs (rabbits), and 832.7 small mammals, while in snow free season this would include the equivalent of 0.9 ungulates, 122.9 sciurids, and 3362.1 small mammals.

The study by Young *et al*. (2012, p. 225) concluded that wolverines consume 0.1 kg (0.22 lb) of prey per day more outside winter season, but that prey expected to be consumed in winter had a higher caloric content than other seasons; thus, the mass requirement is lower. As an example, they cite the higher proportion of ungulates consumed in winter, which provide about 1.3 times more energy (kilojoules per kilogram) than squirrels (Young *et al*. 2012, p. 225). Other researchers have also noted that food during the summer is just as important as the availability of cached ungulate food in the winter (e.g., during the energy demanding lactation period) (Inman *et al*. 2012b, pp. 640–642). The post-weaning growth period (May–August) was identified as a high energetic demand for food by a wolverine family group (Inman *et al*. 2012b, p. 640). Taken together with the lactation period, the calories available to wolverines therefore likely reaches a maximum from March to April (Inman *et al*. 2012b, p. 640).

Population Structure

As discussed above, wolverines recolonized much of North America after periods of glaciation and then experienced heavy human persecution in much of their range. As shown in our current range map (Figure 3) and described below in our *Population Abundance and Distribution* section, wolverines occur across a broad expanse of North America, where the contiguous United States represents the southern extent of the species' range. A number of biological factors can affect wolverine populations, including the species' low intrinsic rate of population increase, naturally low densities, and need for large, intra-sexual home ranges (Banci and Proulx 1999, p. 180). Their extensive dispersal abilities make possible the recolonization of individuals into vacant habitats (Vangen *et al*. 2001, p; 1,647; Aronsson 2017, p. 43). As noted above (*Diet and Feeding*), interactions with sympatric predators and the availability of prey and carrion can also directly and indirectly affect wolverine populations.

Wolverines in the contiguous United States are considered to represent a metapopulation (set of local or subpopulations within a larger area and where migration is possible between patches (Hanski and Simberloff 1997, p. 11)) (Inman *et al*. 2013, p. 277) and occupy habitat in high alpine patches at low densities, dispersing into suitable areas (Inman *et al*. 2012a, pp. 782–784). Wolverines in Canada are considered to occur as a single large group as they are easily able to move between areas of good habitat and because wolverine habitat is relatively contiguous (Harrower 2017, pers. comm.).Wolverine populations in Alaska are considered to be continuous with populations in the Yukon and British Columbia provinces of Canada based on genetic studies (COSEWIC 2014, p. 37).

Studies of wolverines in the North Cascades region have documented movement of wolverines from Washington into British Columbia (Aubry *et al*. 2016, pp. 16, 20). The 2014 COSEWIC Report indicated that rescue (immigration from another population) of Canadian wolverine

populations along the Canada-Alaska international boundary was likely (based on nuclear DNA evidence), but was negligible *from* the contiguous United States (COSEWIC 2014, p. 37). Based on mitochondrial DNA studies, Tomasik and Cook (2005, p. 390) concluded the gene flow in wolverines in northwestern North America is likely male-mediated, and is primarily due to long distance dispersal between low-density populations. Genetic studies of North American wolverines conducted by Kyle and Strobeck (2002, entire) found high levels of gene flow across northern populations (Canada and Alaska).

Genetics

Evaluation of genetic material can provide an understanding of population dynamics (Cegelski *et al*. 2006, p. 209). The geographical genetic structure of wolverines is believed to be largely structured around the strong female philopatry characteristic of this species (Rico *et al*. 2015, p. 2), and, given the species polygamous behavior, wolverine population distributions (at least in Scandinavia) are considered to be primarily limited by dispersal of the more philopatric sex (females) (Aronsson 2017, p. 13). However, the extensive and often asymmetrical movement of male wolverines from core populations to the periphery of their range can result in the addition of nuclear genetic material to these edges (Zigouris *et al*. 2012, p. 1,553). Thus, the dispersal pattern for male wolverines may help explain why allelic richness (i.e., nuclear DNA) can be similar across regions, but haplotype richness (mitochondria DNA) is lower at the periphery of the species' range (Zigouris *et al*. 2012, p. 1,553). Additionally, the extensive dispersal movements of both male and female wolverines can produce gene flow among diverged populations, making it difficult to distinguish, without additional sampling and analysis, between long-distance dispersal and fragmentation based on the patchy distribution of some haplotypes (Zigouris *et al*. 2013, p.10).

Studies evaluating the genetic structure of wolverines, primarily within its core range in North America, were presented in Chappell *et al*. (2004) and Kyle and Strobeck (2001, 2002). Using microsatellite markers, Kyle and Strobeck (2002) and Zigouris *et al*. (2012) found a greater genetic structure of wolverines toward their eastern and southern peripheries of their North American distribution, likely due to a west-to-east recolonization during the Holocene (Zigouris *et al*. 2013, p. 9). Similarly, based on mitochondria DNA, McKelvey *et al*. (2014, p. 330) concluded that modern wolverine populations in the contiguous United States are the result of recolonization (following persecution from hunting and trapping) from the north.

Genetic diversity and population genetic structure of a larger sample size of wolverines were examined by Cegelski *et al*. (2006, entire) for the southern extent of their North American range using both microsatellite markers and mitochondrial DNA. They concluded that the wolverine populations in the contiguous United States were not sources for dispersing individuals into Canada (Cegelski *et al*. 2006, p. 208). They found that there was significant differentiation between most of the populations in Canada and the United States (Cegelski *et al*. 2006, p. 208). However, they cautioned that their statistical analysis may not have been able to detect "effective migrants" and that sample size can affect the detection of dispersers (Cegelski *et al*. 2006, p. 208). They concluded that some migration of wolverines was occurring between the Rocky Mountain Front region (northwestern Montana) and Canada as well as among wolverine populations in the United States, with the exception of Idaho (Cegelski *et al*. 2006, p. 208). In

addition, results from testing of allelic differences among the populations were interpreted by the authors as likely inadequate to counter the effects of genetic drift due to low numbers of migrants (Cegelski *et al*. 2006, p. 208). They estimated that, based on genetic diversity observed at that time, two effective migrants from either Canada or Wyoming into the Rocky Mountain Front population would be needed to maintain the levels of genetic diversity in that population, and one effective migrant was needed to maintain levels of diversity in the Gallatin, Crazybelt, or Idaho populations (Cegelski *et al*. 2006, p. 209). The authors concluded that migration is essential for maintaining diversity in wolverine populations in the contiguous United States since effective population size may never be reached due to the naturally low population densities of wolverines (Cegelski *et al*. 2006, p. 209).

Effective population size (N_e) (see **Box 2**) is defined as "the size of an idealized population that would experience the same amount of genetic drift and inbreeding as the population of interest. In popular terms, N_e is the number of individuals in a population that contribute offspring to the next generation" (Hoffman *et al*. 2017, p. 507). It represents a metric for quantifying rates of inbreeding and genetic drift and is often used in conservation management to set genetic viability targets (Olsson *et al*. 2017, p. 1). It is not the same as the more commonly used metric, census population size (N), but is often assumed to represent the *genetically* effective population size.

An effective population size analysis for wolverines in the contiguous United States was presented in Schwartz *et al*. (2009, p. 3,225) using wolverine samples from the main part of the Rocky Mountains populations (e.g., central and eastern Idaho, Montana, northwestern Wyoming). Excluded in this analysis, were subpopulations from Crazy and Belt Mountains in Montana (based on suggestion by Cegelski *et al*. (2003) that they represented separate groups) (Schwartz *et al*. 2009, p. 3,225). Samples were divided into three time frames and the computer program ONeSAMP was used to estimate effective population size in each time frame [sample size appears to be between 142 and 210]. The summed effective population size was estimated at 35, with credible limits from 28–52, and the summed values for the three time frames was reported as follows: $N_{e\ 1989–1994} = 33$, credible limits 27–43; $N_{e\ 1995–2000} = 35$, credible limits 28–57; $N_{e\ 2001–2006} = 38$, credible limits 33–59 (Schwartz *et al*. 2009, p. 3,226).

However, Cegelski *et al*.'s (2006, p. 203) evaluation of nuclear DNA population structure in wolverines in Canada (sample size of 101) and the contiguous United States (sample size of 116), as depicted by a principle component analysis plot and dendrogram, found that all of the Canadian wolverine populations clustered together. In the contiguous United States, the Rocky Mountain Front subpopulation clustered with the Wyoming subpopulation, the Crazybelt Mountains' area subpopulation clustered with the Gallatin (Montana) population, and the Idaho population was highly differentiated (Cegelski *et al*. 2006, p. 203). That study concluded that some exchange of migrants is occurring between the Gallatin and Crazybelt wolverine populations (Cegelski *et al*. 2006, p. 207), but noted that this grouping is more genetically differentiated and isolated from the other populations they sampled *when compared to* the Rocky Mountain Front population (Cegelski *et al*. 2003).

In addition, the map presented in Schwartz *et al*. (2009, p. 3,223) depicting the locations of the wolverine samples used in preparing their effective population size estimate shows significant gaps within the wolverine's range in Idaho and parts of Montana (e.g., interior of the Bob

Marshall Wilderness area). Thus, other wolverine subpopulations and/or individuals were likely missed for this analysis. Studies within the Southwestern Crown of the Continent (SWCC) in northwestern Montana have detected cross-valley movements of wolverines, which researchers believe is an indication of good connectivity in this region (SWCC Wildlife Working Group 2016, pers. comm.). Current efforts to collect additional wolverine hair samples for genetic analyses are underway through a multi-state occupancy survey project (see *Population Abundance and Distribution* section below).

Another evaluation of mitochondria DNA was conducted by Francis (2008), who found an overall lack of regional (geographic) genetic structure for North American wolverines, but noted that a few populations (Crazybelts (Montana), Southeast Alaska, Nunavut (Canada), and Kenai Peninsula) appeared to be isolated from the others (Francis 2008, p. 12). However, statistical testing did not identify any genetically defined sampling localities (Francis 2008, p. 13). Minimal differences were found between core and peripheral wolverine populations, as grouped in that analysis (Francis 2008, p. 21; Table 4). Conversely, the study by Zigouris *et al*. (2012, p. 1,554; Table 5) did find support for genetic clusters for wolverine populations in Canada, and Zigouris *et al*. (2013, p. 5; Table 3) identified several worldwide regional genetic groups. In addition, an analysis of estimated population growth found signals of population expansion in several wolverine populations (Francis 2008, p. 13; Table 5) including Rocky Mountain Front, Wyoming, Central, South, and Northwestern Alaska, British Columbia, Northwest Territories, and Nunavut.

Box 2. Effective Population Size and Genetic Variation

The concept of effective population size (N_e) (see review by Wang *et al*. 2016) and, relatedly, minimum viable population, has been a topic of debate, particularly the 50/500 rule, which was developed over 30 years ago. As noted by Laikre *et al*. (2016, p. 280), the concept and guidelines for *genetically* effective population size were developed for single, isolated populations, but it's unclear which of the various N_e metrics was referenced in the original concept proposed by Franklin (1980) (i.e., inbreeding effective size, realized effective size, total inbreeding effective size of a metapopulation, or eigenvalue effective size (Laikre *et al*. 2016, p. 288)).

There are differing interpretations of the values proposed for effective population size. For example, should the minimum viable effective population size be derived genetically to set a threshold for a minimum viable population? Here, the rule is interpreted as 50 being the short-term number (for inbreeding depression) and 500 as the long-term number (for retention of genetic variation). Or should the N_e value of 500 be interpreted as a long-term goal for maintaining a healthy, genetically robust population, and not a threshold trigger that predicts extinction risk? In addition, some view the 500 value to be a global reference value rather than a local value, and that it may not be necessary to maintain a local N_e of 500 as long as there is some gene flow into a population (Jamieson and Allendorf 2012, p. 580).

Finally, others have recommended changes to the 50/500 rule. Laikre *et al*. (2016, entire) presented an analysis of the metapopulation effective size for the Fennoscandian wolf population and recommended that long-term conservation genetic target for metapopulations (N_{eMeta}) ≥ 500, but also a realized effective size of *each subpopulation* (N_{eRx}) ≥ 500. Frankham *et al*. (2014, p. 59) have recommended modifying the 50/500 rule to 100/1000.

It can be difficult to make inferences about the relationship between population size and point estimates of genetic diversity without continued genetic monitoring and an understanding of the demographic history of a species' population (Hoffman *et al*. 2017, p. 507), including factors that have influenced movement patterns and connectivity. It's also important to note that genetic diversity can be a reflection of favorable adaptations (natural selection) and is necessary for species to locally adapt to environmental stressors or to facilitate range shifts (Zigouris *et al*. 2012, p. 1,544). Genetic distinctiveness in peripheral populations may play a role in both maintaining and generating biological diversity for a species (Zigouris *et al*. 2012, p. 1,544; citing results presented in Channell and Lomolino 2000, p. 84). Genetic variation that is adaptive is a better predictor of the long-term success of populations as compared to overall genetic variation (Hoffman *et al*. 2017, p. 510). The challenge is to be able to determine whether genetic variation is adaptive and is a reflection of remnants of high genetic diversity from ancestral populations, or whether that variation is a reflection of accumulated deleterious, nonadaptive genes due to genetic drift in small populations (Hoffman *et al*. 2017, p. 509).

In summary, the currently known spatial distribution of genetic variability in wolverines in North America appears to be a reflection of a complex history where population abundance has fluctuated since the time of the last glaciation, and insufficient time has passed since human persecution for a full recovery of wolverine densities (Cardinal 2004, pp. 23–24; Zigouris *et al*. 2012, p. 1,554). Zigouris *et al*. (2012, p.1,545) noted that the genetic diversity reported in Cegelski *et al*. (2006) and Kyle and Strobeck (2001, 2002) for the southwestern edge of the North American range represented only part of the diversity in the northern populations of wolverines. Zigouris *et al*. (2012, p. 1,545) posit that the irregular distribution of wolverines in the southwestern periphery and the genetic diversity observed in those analyses is a result of population bottlenecks that were caused by range contractions from a panmictic (random mating) northern core population approximately 150 years ago coinciding with human persecution. Demographic studies as well as additional genetic analyses from contemporaneous wolverines currently occupying the contiguous United States are needed to evaluate the current status of wolverine populations in North America. In addition, ecological, phenotypical, and environmental information should be used to complement genomic data when interpreting the strength of conclusions or inferences of spatial patterns of adaptation or for adaptively divergent populations (Jamieson and Allendorf 2012, p. 492).

Summary

In this SSA report, we have incorporated information from several new studies related to the wolverine published since our 2013 proposed rule and previous studies that were not considered (e.g., Magoun *et al*. 2017). We have also reviewed new publications and publications in preparation from wolverine researchers in Scandinavia (e.g., Aronsson 2017; Bischof *et al*. 2016; Makkonen 2015; Mattisson *et al*. 2016; Myhr 2015; Persson *et al*. 2017, *in prep*). This information informs our assessment of the most current information regarding the description of the wolverine and its life history and ecology across its North American range. We have included in this SSA Report detailed discussions of wolverine physiology, and spatial and temporal patterns and trends related to reproduction and diet/feeding. We also prepared a revised current range map (see Figure 3) based on information we received from Federal, State, and others, including Canada.

A species' current and future conditions and overall viability (in terms of resiliency, redundancy, and representation), are largely impacted by the availability of what the species needs at the individual, population, and species level. The needs described below are necessary for wolverines to have resources for the basic requirements of life (breeding, feeding, and sheltering) at all levels. Overall, the best available information indicates that within the contiguous United States the wolverine's physical and ecological needs include:

(1) large territories in remote landscapes; at high elevation (1,800 to 3,500 meters (5,906 to 11,483 feet))
(2) access to a variety of food resources, that varies with seasons; and
(3) physical/structural features (e.g., talus slopes, rugged terrain) linked to reproductive behavioral patterns.

Biological Status – Current Condition

This section provides an overview of the wolverine's current condition, including those stressors that may be impacting the species or its habitat. In this SSA Report, we have identified stressors based on impacts that may negatively affect the physical and ecological needs of the species, including temporary or permanent impacts to habitat features that the species relies on for survival and reproduction.

Population Abundance and Distribution

Since our 2013 proposed rule, we have received additional reports of wolverine observations including Utah, Colorado, and Oregon, and an updated Canadian status review for the wolverine has been prepared (COSEWIC 2014, entire). Additional studies have also been published related to wolverine populations in British Columbia and Alberta (e.g., Regehr and Lacroix 2016; Stewart *et al*. 2016; Webb *et al*. 2016). As noted above, we developed a Current Range map for the North American wolverine (see Figure 3). For the conterminous United States, this map was based on several resources, including the primary habitat model developed by Inman *et al*. (2013), EPA Ecoregion mapping (2010), Forest Service NRIS data, and information received from State agencies. We used the 2014 COSEWIC Assessment and Status Report's current range map for Canada and Alaska. For Canada, the range of occurrence includes the Yukon, Northwest Territories, Nunavut, British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Québec, Newfoundland, and Labrador (COSEWIC 2014, p. vii).

Contiguous United States

Areas in the western contiguous United States were identified by Inman *et al*. (2013, entire) as suitable for wolverine survival (long-term survival; used by resident adults), or **primary habitat** (Inman *et al*. 2013, p. 279), reproduction (used by reproductive females), and dispersal (female and male) of wolverines (see methodology in Inman *et al*. 2013, pp. 279–280; Figure 2). From these results, the researchers estimated potential and current distribution and abundance of wolverines in the western contiguous United States (Inman *et al*. 2013, p. 282). They estimated current population size of wolverines to be 318 (range 249–626) located within the Northern Continental Divide (Montana) and areas within the following ecoregions: Salmon-Selway

(Idaho, portion of eastern Oregon), Central Linkage (primarily Idaho, Montana), Greater Yellowstone (Montana, Idaho, Wyoming), and Northern Cascades (Washington) (Inman *et al*. 2013, p. 282). Potential wolverine population capacity based on their RSF habitat modeling was estimated to be 644 (range: 506–1881) (Inman *et al*. 2013, p. 282). However, these estimates did not consider spatial characteristics related to behavior, such as territoriality, of wolverine populations. The discussion below provides a summary of recent studies of wolverine detections and observations in the western United States; however, no comprehensive surveys have been conducted across the species' entire range.

In the northern Cascades region of Washington and Canada, researchers tracked activity areas for 14 wolverines via satellite telemetry from 2007 through 2015 (Aubry *et al*. 2016, entire). This study demonstrated that the region supports a resident population, with 9 of 11 study animals documented primarily within Washington (Aubry *et al*. 2016, p. 40).

The Oregon Department of Fish and Wildlife (ODFW) reports that wolverines have been found in the Oregon Cascades on Three-fingered Jack (glaciated volcano) in Linn County, on the Steens Mountain in Harney County, and Broken Top Mountain in Deschutes County, in the Eagle Cap Wilderness Area in the Wallowa Mountains of northeastern Oregon, and, more recently (2012), in Wallowa County, northeast Oregon (ODFW 2017, no page number).

In California, camera trap data indicate the continued presence of a single male wolverine in the Truckee area, as of March 2017 (Shufelberger 2017, pers. comm .). The California Department of Fish and Wildlife (CDFW) has received reports of wolverine detections from the public over past several years, particularly the region near Carson Pass, as well as near Meeks Bay, Lake Tahoe (Stermer 2017, pers. comm.). CDFW researchers are conducting multi-species predator surveys, targeting the potential occurrence of Sierra Nevada red fox and wolverine using camera trapping with hair snares in an effort to determine occupancy, detection probability, distribution, and habitat associations (Stermer 2017, pers. comm.).

A pilot study to evaluate wolverine occupancy was conducted in Wyoming from February through June in 2015 (Inman *et al*. 2015, entire). Results from that survey (hair snares and camera traps in 18 stations across 5 mountain ranges) indicated at least three individual wolverines (at five stations) with at least one individual in the Gros Ventre and Wind River mountain ranges, and at least two individuals in the Southern Absaroka mountain range (Inman *et al*. 2015, p. 9). Occupancy modeling estimated a probability of occupancy for sampled sites of 62.9 percent (Inman *et al*. 2015, p. 8).

In an effort to assess wolverine occupancy in the western United States, the Western Association of Fish and Wildlife Agencies (WAFWA), in coordination with Tribal partners, have formed a multi-state, multi-agency working group (Western States Wolverine Working Group) to design and implement the Western States Wolverine Conservation Project (WSWCP)–Coordinated Occupancy Survey (see Bjornlie *et al*. 2017 for details of protocol). The primary objectives of the WSWCP include: 1) implement a monitoring program to define a baseline wolverine distribution and genetic characteristics of the metapopulation across Montana, Idaho, Wyoming, and Washington, 2) model and maintain the connectivity of the wolverine metapopulation in western United States, and 3) develop policies to address socio-political needs to assist wolverine

population expansion as a conservation tool, including translocation of wolverines (IDFG 2016, pers. comm.; Montana Fish, Wildlife, & Parks (FWP) 2016, pers. comm.; WGFD 2016, pers. comm.).
The WGFD began implementation of the survey in Wyoming in the Greater Yellowstone Ecosystem region and the Bighorn Mountains (25 grid cells) in the winter of 2015–2016 (WGFD 2016, pers. comm.). That initial survey detected, based on unique fur markings, at least two unique wolverines in the Wind River and southern Absaroka Mountain Ranges (WGFD 2016, pers. comm.). The WGFD reported 26 independent wolverine visits, and detections at least once within their study area during each of the four sampling periods (December 2015 through March 2016) (Bjornlie *et al*. 2017, pp. 4–5). Genetic analyses of collected hair samples, including sex and individual identification, are underway.

The monitoring effort was expanded in the winter of 2016–2017 to 187 cells (cell area of 225 km^2 (87 mi^2)) across four states (Washington, Idaho, Montana, and Wyoming). Preliminary results for the 2016–2017 winter detected wolverines in 85 survey cells (WAFWA 2017). Photographic detections of wolverine include 18 from Idaho, 48 in Montana (including detection of wolverines in all 10 cells surveyed in the SWCC region (Davis 2017, pers. comm.)), 10 in Washington, including detections south of Interstate 90 (Davis 2017, pers. comm.), and 9 in Wyoming; genetic analyses, to date, have reported a total of 157 wolverine samples (WAFWA 2017). It has not yet been determined from the camera-trap images and hair samples how many of these detections are the same individual. **Appendix B** contains a map illustrating these preliminary detections (as of July 2017).

Based on a 6-year study of monitoring resident wolverines (live trapping and camera stations) in central Idaho (Centennial, Smoky, and Salmon Mountains) and the western Yellowstone region (Teton Mountains), Heinemeyer (2016, pers. comm.) suggested that subpopulations of the species at this southern periphery of their North American range are still unstable with low rates of recruitment. We therefore requested additional information from State and Federal agencies regarding the most recent wolverine detections in the Winter Recreation Project study areas of Idaho and Wyoming. In the Teton Mountains region, two wolverines were detected in March 2017, in two different areas (Dewey 2017, pers. comm.). In addition, at least one wolverine was detected on the east side of the Teton Mountains during the winter of 2016-2017, as part of the Western States Wolverine Conservation Project–Coordinated Occupancy Survey monitoring and occupancy study, and a member of the public reported wolverine tracks within Grand Teton National Park in March 2017, while skiing (Walker 2017, pers. comm.). In Idaho, IDFG reported 5 wolverine detections in the Salmon Mountains in Central Idaho in the winter of 2016 (Mack 2017a and 2017b, pers. comm.). These recent detections are displayed in **Appendix C** relative to the study areas of the Winter Recreation Project study areas for the McCall, Idaho, and Teton Mountains. A wolverine was also detected in the winter of 2016-2017 in the Gravelly Range in southwestern Montana about 25 km (15.5 mi) north of the Centennial Mountains area surveyed during the winter recreation project (Inman 2017b, pers. comm.).

Alaska

The ADF&G Trapper Questionnaire Annual Reports include estimates of relative abundance and trends of wolverines and other furbearers as reported by trappers (Parr 2016, p. 38). Table 4 below provides a summary of abundance and trends from 2010–2016 of those reports by region.

Table 4. Relative Abundance and Trend of Wolverine Populations, Alaska (as reported by trappers), 2010-2016.* For Trend, + indicates increase, − indicates declining/decrease, and n/c indicates no change. Sources: ADF&G 2012, 2013a, 2013b; Parr 2016.

Region	Relative Abundance				Trend			
	2010-2011	2011-2012	2012-2013	2015-2016	2010-2011	2011-2012	2012-2013	2015-2016
Region I – Southeast Alaska	scarce	scarce	scarce	scarce	n/c	n/c	n/c	–
Region II – Southcentral Alaska	scarce	scarce	scarce	scarce	n/c	n/c	n/c	–
Region III – Interior Alaska	scarce	scarce	scarce	scarce	n/c	n/c	n/c	–
Region IV – Central and Southwest Alaska	N/A	N/A	N/A	scarce	N/A	N/A	N/A	–
Region V - Northwest	N/A	N/A	N/A	scarce	N/A	N/A	N/A	–
Southwest	common	scarce	scarce	N/A	n/c	–	n/c	N/A
Arctic and Western	common	common	scarce	N/A	n/c	n/c	n/c	N/A

*No reports written for years 2009-2010, 2013-2015.

However, relying exclusively on trapping reports is likely to present an incomplete assessment of wolverine populations. The accuracy of information provided in the most recent report is dependent on how many trappers reply to the annual survey; for 2016 the response rate was only 11.7 percent (Parr 2016, p. 3). Trapping effort was reported to have increased by some trappers (45 percent of those reporting) during the 2015–2016 season, and 80 percent of those who increased their efforts reported an increase in their overall catch (Parr 2016, p. 15). However, this assessment does not consider how this increased trapper effort relates to harvest levels for wolverine, nor does it account for an unknown and unreported number of wolverines taken for subsistence purposes (Gardner *et al*. 2010, p. 1,894). Estimates of density, described below, provide a better depiction of wolverine population status in Alaska.

Canada

Similar to Alaska, determining wolverine population abundance and trends in Canada is difficult as numbers are developed from harvest activity (COSEWIC 2014, p. 25). Wolverine harvest trends are also difficult to estimate given the temporal and spatial variability in trapping effort and reporting of harvest, and not all regions use mandatory pelt sealing, compulsory reporting, or fur export permits/fur dealer records (COSEWIC 2014, p. 26).

According to the most recent COSEWIC Assessment and Status Report on the Wolverine, *Gulo gulo* in Canada (COSEWIC 2014, entire), Canada's western subpopulation has been estimated at 15,688 to 23,830 adults, though this value is based on several assumptions (consistent trapping effort and uniform densities across the species' range); the eastern population is estimated at less than 100 individuals or may be extirpated (COSEWIC 2014, p. 36). Population trends across all

of Canada are not known, but wolverine populations have been stable over areas within the country's northern range for the last three generations (22.5 years) (COSEWIC 2014, p. v).

In northern Manitoba and Ontario, wolverines may be increasing in number as aerial surveys in northern Ontario have indicated an eastward reoccupation of its former range (towards James Bay and Québec) (COSEWIC 2014, p. v). However, although observations of wolverines continue to be reported within Québec and Labrador (the eastern sub-population), there have been no verifiable observations since 1978, and wolverines are likely extirpated from much of southeastern Canada (COSEWIC 2014, p. v). In addition, declines in the southern regions (within parts of British Columbia and Alberta) may be occurring (COSEWIC 2014, p. 36). Table 5 presents a more detailed summary of wolverine populations in Canada.

Table 5. Wolverine Population Estimates for Canadian Territories. Source: COSEWIC, 2014.

Territory	Number of wolverines
Yukon Territory	3,500–4,500
Northwest Territories	3,430–7,325 (with an additional 220–470 juveniles)
Nunavut	Estimated at 2,000–2,500
British Columbia	2,700–4,760
Alberta	Estimated at 1,500–2,000
Saskatchewan	Less than 1,000
Manitoba	1,100–1,600
Ontario	458–645
Québec	Very rare, at non-detectable level, or extirpated
Labrador (including mainland Newfoundland)	Very rare or extirpated

In addition to the 2014 COSEWIC summary, Cardinal 2004 (entire) prepared a complimentary summary report of wolverine trends in Canada based on Aboriginal traditional knowledge. Trends reported indicate: (1) high, relatively stable levels of wolverines in the Yukon; (2) high levels of wolverines in the North Slave region of the Northwest Territories, though population levels are estimated to be stable to decreasing; (3) high levels of wolverine along forested areas in the northern portions of the mainland within the Inuvialuit Settlement Region (ISR) (located in the northwest corner of the Northwest Territories) and Kitikmeot region of Nunavut; (4) an increase in wolverines in the Kivalliq region of Nunavut, but at lower levels than populations in the Boreal and North Mountain ecological areas; and (5) least abundant in the northeastern corner of Nunavut and the Arctic Islands (Cardinal 2004, pp. 22–29). In sum, the majority of traditional knowledge holders in Nunavut, Northwest Territory, and Yukon Territory describe wolverine populations as either stable or increasing in northern Canada and is now found in areas where they occurred in the past; however, they are still considered naturally uncommon; only in Yellowknife did people report that wolverines might be decreasing (Cardinal 2004, pp. iii– iv, 10, 23).

Other inventory and occupancy studies include an inventory of wolverines conducted by Regehr and Lacroix (2016, entire) in the winter of 2012 on the east side of the Coast Mountains in British Columbia using a multi-method approach. They identified six individuals using genetic analysis, and one additional individual by photography, which was higher than expected as compared to model predictions of density and habitat quality (Regehr and Lacroix 2016, pp.

248–249). Estimates of wolverine occupancy were also evaluated for the Canadian Crown of the Continent ecosystem (central and southern Canadian Rockies) (Clevenger *et al*. 2016, entire). Occupancy estimates were found to vary from year-to-year and exhibited a north-south gradient, likely due to the differences in habitat quality among areas that were sampled by year (Clevenger *et al*. 2016, p. 4). For 2016, estimated wolverine occupancy probability was 0.40 for their British Columbia Rockies study area, with a declining pattern from north to south (Clevenger *et al*. 2016, p. 4). In general, their research has found that wolverines are more abundant in rugged, remote areas that have minimal human activity and landscape disturbance (Clevenger *et al*. 2016, p. 5). This study projected an expected number of wolverines in their study area of about 28 (Clevenger *et al*. (2017, p. 6). To the south, in the Southwestern Crown of the Continent (SWCC) region (northwestern Montana, approximately 1.5 million acres), wolverine surveys (snow tracking, bait stations/hair snares) have been conducted since 2012 (SWCC Wildlife Working Group 2016, pers. comm.). These survey efforts have detected 22 unique wolverines (11 males, 11 females) across three U.S. Forest Service districts, and they reported an increase in the frequency of detections from 2012 to 2015 (SWCC Wildlife Working Group 2016, pers. comm.).

The 2014 COSEWIC report indicates that trends in wolverine populations in the northern range, while uncertain, appear to be stable or increasing, but also notes that there is some concern for populations in the southern areas of British Columbia and parts of the northern United States (COSEWIC 2014, p. 22, and references cited therein). In British Columbia, researchers are currently conducting a multi-phase project using landscape genetic analyses to identify and delineate functional populations of wolverines and provide an estimate of size and sustainable harvest within each functional population (Weir 2017, pers. comm.).

Estimates of Density

Wolverine densities vary across North America, and have been described as "naturally low" (van Zyll de Jong 1975, p. 434) and "naturally uncommon" (Cardinal 2004, p. iii) given the species' large home range, wide-ranging movements, and solitary characteristics. The most recent estimates (at that time) of density (number of wolverines per 1,000 km^2 (386 mi^2)) for North America were prepared by Inman *et al*. (2012a, p. 789; Table 5). In the contiguous United States, density estimates ranged from 3.5 for the Greater Yellowstone region (2001–2008) (areas above 2,150 m (7,054 ft) (latitude-adjusted elevation), 4.5 for central Idaho (1992–1995), to 15.4 for northwestern Montana (1972–1977).

In Alaska and Yukon, density estimates presented by Inman *et al*. (2012a, p. 789) range from 3 to about 14 wolverines per 1000 km^2 (386 mi^2), using a number of methods. For example, Royle *et al*. (2011, p. 609) estimated wolverine densities for southeastern Alaska (Tongass National Forest; 2008) from 8.2 to 9.7 per 1000 km^2 (386 mi^2) (using mark-recapture), where the higher estimate incorporates a positive, trap-specific behavioral response. Density of wolverines were recently reported as an estimated 5–10 wolverines per 1000 km^2 (386 mi^2) (based on snow tracking) for southcentral Alaska, and approximately 10 per 1000 km^2 (386 mi^2) (based on DNA mark-recapture methods) for southeast Alaska (Golden 2017, pers. comm.). A wolverine occupancy study in 2015 within an area of central Alaska reported a density estimate of 9.48 wolverines per 1,000 km^2 (386 mi^2) (ADF&G 2015a, p. 7).

Wolverine density estimates for Canada varies across regions, from 5 to 10 per 1000 km^2 (386 mi^2) in northern mountain and boreal regions to 1 to 4 per 1000 km^2 (386 mi^2) in southern boreal areas (COSEWIC 2014, p. 27). More recently, Clevenger *et al*. (2017, entire) presented a density estimate (using spatial capture/recapture models) for the Kootenay region of British Columbia of 0.78 wolverines per 1000 km^2 (386 mi^2), for 3 study years (2014–2016), which they reported as lower than expected (Clevenger *et al*. 2017, p. 6).

Stressors – Causes and Effects

We reviewed the best available information to identify current conditions and potential stressors that may be affecting wolverine populations or its habitat. These include roads and other infrastructure, recreational activity and other human disturbances, wildland fire, disease or predation, and overutilization for commercial, recreational, scientific, or educational purposes. Because wolverines in North America move between both borders of Canada (i.e., contiguous United States, Alaska), we included in our evaluation stressors identified for wolverines in Canada and Alaska that are also relevant for wolverine populations in the contiguous United States.

As an initial step, we reviewed the land ownership of the area defined as primary habitat by Inman *et al*. (2013, entire) in the contiguous United States, and determined that 96 percent of that modeled habitat is located on Federal land (see **Appendix D**). Lands managed by the Forest Service represent the largest portion of Federal lands (89 percent) within this modeled primary habitat.

Effects from Roads

Roads and rail lines can be a cause of mortality to wolverines and habitat models have identified road density as an important association (avoidance) for selection of habitat (e.g., Rowland *et al*. 2003; Bowman *et al*. 2010; Inman *et al*. 2013). Road density has been listed as a threat to wolverines occupying the boreal/western mountain regions of Canada (Canadian Boreal Forest Agreement 2014, p. 2). In the wolverine's southern Canadian range, roads may be facilitating direct mortality by improving motorized access of hunters, trappers, and recreational users into remote areas (COSEWIC 2014, p. 21).

In their review of 12 radio-telemetry studies (1972 to 2001) of wolverines in North America, Krebs *et al*. (2004, p. 497) reported 3 mortalities of wolverines from road-rail kills. More recently, road mortalities have been recorded in Idaho (1 confirmed in 2014) (IDFG 2017a) and 2 in Montana (2004) (Kociolek *et al*. 2016, p. 68); one in Utah (2016) (Hersey 2017, pers. comm.); and two other wolverine road-rail fatalities in Montana were reported in 2015 (Inman 2017a, pers. comm.). In Canada, anthropogenic causes of mortality for wolverine populations also include road kill (COSEWSIC 2014, p. v). One road mortality of a male wolverine was reported in a lowland boreal forest region of Ontario, Canada (Dawson *et al*. (2010, p. 142). More recently, Scrafford *et al*. (2017, p. 34) described a report in which 9 wolverines were struck and killed by vehicles in the Hay-Zama region of northwestern Alberta, Canada (2013–2015), and 1 road mortality occurred within the town of Rainbow Lake in Alberta.

Roads may also affect den site selection (May *et al*. 2012, p. 202), particularly areas within their range where they cannot select for high elevation habitat (e.g., central lowland forests of Canada) (Dawson *et al*. 2010, p. 143). In Norway, May *et al*. (2012, p 202) found that wolverine dens were generally located far from infrastructure (public roads and private roads and/or recreational cabins). The authors reported a minimum threshold in den site selection relative to infrastructure of 1.4 km (0.87 mi) from private roads and 7.5 km (4.7 mi) from public roads (May *et al*. 2012, p. 202). However, they found that wolverines in their study area had a wide tolerance range at the home-range scale (1.0–2.75 km (0.62–1.7 mi) for private roads and 6.0–11.0 (3.7–6.8 mi) for public roads) (May *et al*. 2012, p. 201; Figure 4), supporting conclusions from other studies that have found that, once a general area is used, it appears to be re-used in subsequent years including by successive individuals colonizing the sites (May *et al*. 2012, p. 202).

Wolverine road crossings were evaluated in the western Greater Yellowstone region through telemetered animals and visual observations of snow tracks, direct observations of crossings, and road-kill mortality (Packila *et al*. 2007, entire). That study documented 43 crossings of U.S. and State highways by 12 wolverines (Packila *et al*. 2007, p. 105). Within the Big Sky, Montana, area, they documented 67 crossings of MT64/Jack Creek Road by 4 wolverines (Packila *et al*. 2007, p. 105). Most (76%) road crossings were made by subadult wolverines, dispersing or otherwise exploring new areas (Packila *et al*. 2007, p. 105). One road-caused mortality was observed and the authors report two others from additional sources during their study period (Inman *et al*. 2007, p. 89). The study results indicate that roads do not act as absolute barriers to movement by wolverines, but they can directly affect individuals (road kill) and may have secondary effects at the population level (Packila *et al*. 2007, p. 105).

In an effort to evaluate the potential impact of major roads to wolverine (individuals and populations), we conducted a spatial analysis of roads[2] found within Inman *et al*.'s (2013, p. 281) primary wolverine habitat and female wolverine dispersal habitat in the western United States, as measured by number of kilometers (miles). In our analysis, we identified four road classes: Interstate Highway, U.S. Highway, State Highway, and secondary roads. Secondary roads encompassed all roads not included in any of the first three categories and include paved and unpaved roads, including Forest Service roads, and are generally likely to have less traffic volume than major highways in the regions evaluated. Our analysis found that secondary roads represented 97 percent (29,892 km (18,574 mi)) of all roads (30,805 km (19,141 mi)) within modeled primary habitat, and 97.5 percent (144,279 km (89,650 mi)) of all roads (148,029 km (91,980 mi)) within modeled female dispersal habitat.

We then evaluated the type of roads at high elevation within our estimated Current Range (shown in Figure 3). Using the 2,300 m (7,546 ft) elevation as a benchmark (based on its use as a predictor variable for wolverine occurrence in Inman *et al*. 2013, and results from predictive models presented in Copeland *et al*. 2007, p. 2,205), we evaluated the length of roads above and below this elevation, and also the type of roads at or above 2,300 m (7,546 ft). The results are illustrated in **Appendix E**. Overall, we found that approximately 85 percent of *all* roads were

[2] Using U.S. Geological Survey National Transportation Dataset Downloadable Data Collection based on TIGER/Line data provided through U.S. Census Bureau and supplemented with 'HERE' road data to create tile cache base maps.

below 2,300 m (7,546 ft). Of the roads located at or above 2,300 m (7,546 ft), 95 percent are *secondary* roads (see charts in **Appendix E**).

Using the same dataset, we evaluated road density (km/km^2) based on regional blocks of primary wolverine habitat in the western United States delineated by Inman *et al*. (2013; Figure 3). Those results are shown in Table 6. With the exception of the Southern Rockies (at 0.47 km/km^2), the mean road densities at elevations equal to or greater than 2,300 m (7,546 ft) are very low.

Table 6. Mean Road Density in Wolverine Primary Habitat.

Geographic Region[‡]	Mean density (km/km^2), all roads	Mean density (km/km^2), all roads ≥ 2,300 m (7,546 ft)
Northern Cascade	0.54	0.00
North Continental Divide	0.54	0.00
Salmon-Selway	0.70	0.03
Central Linkage	0.84	0.06
Greater Yellowstone	0.24	0.06
Southern Rockies	0.55	0.47
Sierra Nevada	0.09	0.03
Uinta	0.15	0.12
Bighorn	0.00	0.00
Great Basin	0.06	0.03
Oregon Cascade	0.72	0.00

[‡]Regions defined in Inman *et al*. (2013; Figure 3).

We also reviewed den site locations (natal, maternal, or unknown dens) within our database relative to roads (see map in **Appendix E**). Our results indicate that wolverine dens are located in areas with minimal roads, including secondary roads; however, we caution that this analysis is based on a limited den site dataset and should be viewed in the context of other abiotic and biotic variables including landscape features at the den site scale and availability of food. Additionally, most den locations in much of the wolverine's range in the contiguous United States are at high elevations and roads in these areas would likely be impassable or closed entirely to vehicles during the time of denning (January–March).

In summary, wolverines are associated with habitat found in high elevation areas, but are known to disperse across great distances. Major highways can present mortality risks to dispersing individuals and affect immigration to open territories, but roads do not represent absolute barriers to wolverine movements. Wolverines den during winter months in remote locations that are often inaccessible or restricted to motorized vehicles, though, secondary roads and trails are used for winter recreational activity. Although we recognize there are likely additional events that have not been reported, we estimated the total number of wolverine mortalities due to roads from 1972 to 2016 (44 years) in North America was 20, at least 11 of which are from Canada (see citations above). As discussed above, we calculated a low proportion of major highways in both modeled primary habitat and female dispersal habitat, and a low mean density of roads at high elevations where wolverines have been observed, with the exception of the southern Rocky Mountains. Roads present a low stressor to wolverines at the individual and population level in most of its current contiguous United States range.

Disturbance due to Winter Recreational Activity

Wolverine behavior patterns, such as denning, rearing of young, movement and dispersal, and foraging/scavenging, may be affected by recreational activities (COSEWIC 2014, p. 42). As noted above, in Norway, May *et al*. (2012, p. 201) found, at the home range scale, a minimal threshold distance of approximately 1.5 km (0.93 mi) for wolverine den sites from private roads and/or recreational cabins. Krebs *et al*. (2007, entire) evaluated habitat use associations for wolverines in two multiple use areas in British Columbia, Canada. Using logistic regression models, the authors found that in an area of active recreation (Columbia Mountains), female wolverines were negatively associated with helicopter and backcountry skiing in their winter models (Krebs *et al*. 2007, pp. 2,187–2,188). However, in summer months, Copeland *et al*. (2007, p. 2,210) reported that wolverines in their study area of central Idaho were not uncommonly found near maintained trails and active campgrounds.

The Wolverine–Winter Recreation Study represents an on-going project to evaluate the potential effects of backcountry winter recreation (e.g., backcountry skiers, heli-skiers, cat-skiers, snowmobilers) on wolverines (Heinemeyer 2016, pers. comm.). The multiyear study areas include central Idaho and areas in the western Yellowstone region ('Island Park' and Teton Mountains) (Heinemeyer and Squires 2015, p. 3). The study has been monitoring wolverines using GPS collars using movement rates and percent of time active (vs. resting) as indicators of potential responses of wolverines to winter recreation activities (Heinemeyer 2013, pers. comm.). Backcountry winter recreation activities are monitored through GPS units voluntarily carried by recreationists (Heinemeyer 2016, pers. comm.). Early analysis of the data suggest that wolverines demonstrate a behavioral response to recreation activities, such as increased movement rates and a reduction in resting periods in areas of high recreation activity, especially high recreation days (Saturday and Sunday) (Heinemeyer and Squires 2013, pp. 5, 7–8).

However, this research has also found that wolverines maintained their home ranges within areas with relatively high winter recreation activity over several years of monitoring, including some areas found to contain the highest recreational activities (Heimemeyer 2016, pers. comm.). The study has not been able to determine whether these resident wolverines are reproductively successful due to the limited monitoring information available for reproductive females (Heinemeyer 2016, pers. comm.).

Conservation measures currently being implemented that address the effects of roads in the Teton Mountains include winter closures in certain areas (generally from November 1 through May 1), including road closures in the Bridger-Teton and Caribou-Targhee National Forests and in Grand Teton National Park as shown in **Appendix F** (additional details for Grand Teton National Park are described in Superintendent's Compendium (National Park Service (NPS) 2017; pp. 8–9); see also maps at https://jhalliance.org/campaigns/dont-poach-the-powder/ Jackson Hole Conservation Alliance 2017). These closures are being implemented to help minimize disturbance to wildlife (e.g., migration pathways).

State Wildlife Action Plans prepared for individual western States identify recreation management strategies within wolverine habitats. For example, in the State of Oregon, the

ODFW Conservation Strategy identifies management of winter recreation use in order to avoid impacts to wolverines (ODFW 2016). In Montana's State Wildlife Action Plan, conservation actions are identified for addressing potential impacts from recreation, such as consideration of seasonal closures during breeding season (Montana FWP 2015, p. 63). The IDFG *Management Plan for the Conservation of Wolverines in Idaho* also includes conservation strategies related to winter recreation (e.g., characterizing wolverine response to recreational activities (IDFG 2014, p. 35)), and the State continues to support the Wolverine-Winter Recreation Study. **Appendix F** provides additional details on individual State conservation strategies.

In summary, wolverine behavior (movement) can be affected by winter recreational activity. Results from one long-term study in parts of the wolverine's range in the contiguous United States have found that wolverines can maintain residency in high winter recreational use areas. Wolverines have recently been detected in areas that experience winter recreational activity. Conservation strategies and actions have been identified in several western States' Wildlife Action Plan to address potential impacts of this stressor to wolverines. Based on the best available scientific and commercial information, the effect of winter recreational activity represents a low stressor to wolverines in the contiguous United States at the individual and population level.

Other Human Disturbance

Infrastructure, such as pipelines, active logging or clearcuts, seismic lines, and activities associated with mining (e.g., producing mines, mines under development, mineral exploration areas), may also affect individual wolverine behavior (e.g., avoidance) or loss or modification of wolverine habitat. As discussed above (see Habitat Use section), Johnson *et al*. (2005, entire) evaluated habitat relationships for the wolverine and other arctic wildlife, including the cumulative effects of human activities and associated infrastructure on the distribution of wolverines in the Canadian central Arctic using RSF modeling. However, because human disturbance factors (i.e., major developments, mineral explorations, seasonal outfitter camps) were mostly absent from the range of monitored wolverines, the researchers were not able to reliably model their effects (Johnson *et al*. 2005, p. 23).

The 2014 COSEWIC status review identified several potential stressors to wolverines and their habitat in Canadian territories. They indicated potential permanent, temporary, and functional losses to wolverine habitat from forestry; oil, gas and mineral exploration and development; and large hydroelectric reservoirs (COSEWIC 2014, p. 21). As discussed above, Scrafford *et al*. (2017, entire) evaluated habitat selection of wolverines in response to human disturbance in the western Canadian boreal forest in both winter and summer months. Their analysis found that wolverines were attracted to some industrial infrastructure (older seismic lines exhibiting latter stages of regeneration) and disturbance (areas of active logging), likely related to foraging opportunities (e.g., small prey), but avoided interior areas of intermediate-aged cutblocks (areas authorized for logging) (Scrafford *et al*. 2017, pp. 32–34). Their results found evidence of road avoidance, but wolverines were attracted to all-season road sections with borrow pits, which they suggest was related to foraging opportunities at these pits (e.g., presence of beavers in water-filled pits) and less predation risk, since wolves avoid these roads (Scrafford *et al*. 2017, p. 34). In sum, these authors concluded that wolverine selection patterns relative to industrial activity

and infrastructure in their study area represent a balance between exposure to predators and foraging opportunities (Scrafford *et al*. 2017, p. 32).

Additional studies of wolverine behaviors related to the effects of disturbance due to infrastructure and other human activities are needed. Based on the best available scientific and commercial information, these effects are small or narrow in scope and scale and appear to represent a trade-off between foraging opportunities in areas that provide minimal risk of predation and avoidance of open areas and/or higher predation risk (Scrafford *et al*. 2017, pp. 33–34).

Effects from Wildland Fire

Wildland fire can produce both direct and indirect effects to wildlife. Direct effects include injury and mortality as well as escape or emigration movement away from fires (Lyon *et al*. 2000, pp. 17–21). Small mammals will generally find refuge underground or within sheltered places within the burning area, while larger mammals will move to safe areas in unburned patches or outside the burn (Lyon *et al*. 2000, p. 18). For animals that emigrate during fire events, the length of time before they return is dependent on the degree to which fire has altered habitat structure and food supply (Lyon *et al*. 2000, p. 20).

We are unaware of any studies evaluating direct effects of wildland fire to wolverines. Wildland fire is likely to temporarily displace wolverines, which could affect home range dynamics. Given that wolverines can travel long distances in a short period of time, individuals would be expected to move away from fire and smoke (Luensmann 2008, p. 14). In addition, because young are born during winter months, fire risk at that critical life stage is very low (Luensmann 2008, p. 14).

Indirect effects of wildland fire can include habitat-related effects or effects to prey and competitors/predators; however, we are unaware of empirical studies evaluating these potential effects as they relate to wolverines. In a study area within the Yukon (Canada), wolverines were reported occupying regenerating forested habitat that contained remnants of mature timber which had burned 30 years prior (Slough and Mowat 1996, p. 948). Additionally, fire suppression in conjunction with logging activities in boreal forests (northwestern Ontario) can increase the prevalence of deciduous tree habitats, at least at a regional level, which is negatively associated with wolverine occurrence (Bowman *et al*. 2010, p. 464).

A study in northern Idaho of the effects of multiple wildland fires over several years, including very large fires, to forest habitat occupied by another mustelid, the American marten (*Martes americana*) found that fire events had created a mosaic of vegetation that supported a diverse assemblage of cover and food resources that was favorable to this species (Koehler and Hornocker 1977, p. 503). Similar to wolverines, the summer and fall diet of the American marten is represented by diverse prey, and wildland fire events can create and maintain forest openings for ground squirrels and voles (Koehler and Hornocker 1977, p. 504). The development of these types of mosaic forest communities following certain wildland fire events also provides discontinuous fuel loads, which in turn should result in smaller and cooler wildland fires, with less replacement of marten habitat (Koehler and Hornocker 1977, p. 504). However, large,

uniform burns would be expected to result in more severe impacts to American marten habitat (Lyon *et al*. 2000, p. 21).

Studies of the effects of wildland fire to a key prey species for the wolverine in parts of its North American range, the caribou, was reviewed by Klein (1982, entire). This review highlighted the importance of separating short-term effects of wildland fire in boreal forests to caribou ecology from long-term effects (Klein 1982, p. 393). Given that long-term benefits to the species' ecology can be disproportionate to the short-term detrimental effects on populations and herds, (including the species' lack of reproductive plasticity), caribou may be more appropriately considered as fire-influenced, rather than fire-adapted (Klein 1982, p. 393). Other ungulate prey species respond more positively to fire. An increase in spring and summer grasses following fall burns can provide forage for elk and deer, and sprouting of deciduous trees, such as aspen, birch and willow, following burns provides forage for moose (Luensmann 2008, p. 18).

Management measures to address this potential stressor are identified in USDA Forest Service National Forest Land Management Plans. Examples of these goals and objectives are described in **Appendix G**. In addition, the Idaho State Wildlife Action Plan includes measures to address fire threats to the wolverine and its habitat, including removal of perceived barriers to allow more prescribed natural fire on State and private forest lands and promoting/facilitating the use of prescribed fire as a habitat restoration tool, on both public and private lands where appropriate, and leaving fire-killed trees standing as wildlife habitat if they pose no safety hazard, all in an effort to restore a more natural fire interval that allows for return to historical forest conditions (IDFG 2017b, pp. 91, 134, 180).

Given the diversity of habitats occupied by wolverines, their occupancy of high elevations, and extensive mobility, wildland fire represents a limited stressor, in scope and scale, to wolverine habitat and its prey in the contiguous United States range.

Disease or Predation

Disease

We are unaware of comprehensive surveys evaluating the prevalence of diseases in wolverines in the contiguous United States. Early accounts of endoparasites species and their prevalence in wolverines include a review by Erickson (1946, p. 503), and a report by Rausch (1959, entire), who documented 7 species of helminth parasites in 86 percent of wolverines examined from trapper-supplied carcasses in Alaska. In 1994, Copeland (1996, p. 26) collected a single specimen of the parasite *Toxascaris* sp. from wolverine scat in Idaho. In Alaska, carcasses sampled (during necropsy or predator control activities) in 2012–2014 to determine the prevalence of *Trichinella* and its genotypes reported one wolverine with *Trichinella* T6 genotype in that single sample (ADF&G 2015b, p. 8). Results from Alaska trapper questionnaires for the prevalence of ectoparasites on wolverines were either scarce or not present across all reporting regions in 2015–2016 (Parr 2016, p. 21).

Rabies is endemic to Alaska in Arctic and red fox along north and west coasts of Alaska (ADF&G 2013c). Under the ADF&G enhanced rabies surveillance program, the agency

confirmed rabies in one wolverine (out of 49 sampled) in 2012, a female found dead in the North Slope region (Woodford and Beckman 2012). This was the first confirmed case of rabies in wolverines in North America (Woodford and Beckham 2012).

The 2014 COSEWIC Assessment and Status Report for the wolverine presented a summary of reported parasitic species observed in wolverines in Canada (COSEWIC 2014, p. 25). These observations included: parasitic nematode roundworms (*Trichinella* spp.) in 88 percent of wolverine samples tested from Nunavut and 26 percent from the lower MacKenzie region; helminth parasites (trematodes, cestodes and nematodes) in wolverine digestive tracts from the lower Mackenzie River valley; and, from the Nunavut region, protozoan parasites infections including *Sacrosystis* spp. (80 percent) and *Toxoplasma gondii* (41 percent) (citations omitted). Banci (1987, pp. 81, 110) reported parasitic pneumonia as a cause of mortality in southwest Yukon Territory, a female thought be nutritionally-stressed following the raising of young.

An evaluation of trapper-submitted wolverine carcasses harvested was conducted for the Yukon Territory in the fur trapping seasons 2005–2006 through 2011–2012 (Jung and Kukka 2013, entire). No samples tested positive for rabies (Jung and Kukka 2013, p. 17). Another study of intestinal parasites of wolverine carcasses from both the Yukon and Northwest Territories reported *Trichinella* spp. in 74 percent of carcasses and several intestinal parasites, including cestodes (parasitic flatworms) such as *Taenia* spp. (Luck *et al*. 2016, no page number).

In summary, other than a parasitic pneumonia mortality event and the single rabies case, we are not aware of any other studies documenting impacts of disease to wolverines in North America. At this time, based on the best available scientific and commercial information, we do not find that disease is a population or species level stressor to the wolverine in the contiguous United States.

Predation

As discussed above (*Diet and Feeding* section), a number of potential natural predators have been identified for wolverines across its North American range, including intraspecific predation. However, we have no information that suggests this predation represents a significant stressor to the wolverine at either an individual or population level.

In summary, the best scientific and commercial information available indicates that disease or predation is not a stressor the wolverine. We are unaware of any management or conservation measures currently in place to reduce potential impacts associated with disease or predation.

Overutilization for Commercial, Recreational, Scientific, or Educational Purposes

There is currently no allowable trapping or harvesting of wolverines in the contiguous United States, though incidental trapping mortalities have been documented as we reported in our proposed rule (78 FR 7881; February 4, 2013). Two mortality events from shootings of wolverines were documented in Idaho (2001, 2007) (Idaho Department of Fish and Game (IDFG) 2014, p. 26).

In Montana, wolverines were a legally harvested furbearer in Montana up until 2012; however, the trapping season is currently suspended with a zero statewide quota (Montana Natural Heritage Program and Montana FWP 2017). Unlike populations in Eurasia, wolverines rarely prey on livestock in North America (*cf*. domestic sheep predation in Wyoming reported (Mead 2013, pers. comm.)) and therefore they are not directly targeted for predator control (COSEWIC 2014, p. 41). However, incidental trapping can result in the capture of non-target species such as wolverine. In Idaho, the IDFG has a mandatory furtaker harvest report that requests all live incidental catches be reported by species and any wolverine catch that results in mortality is required to be reported (IDFG 2013, pers. comm.). Since 1965, over a period of just over 50 years, 16 incidentally-trapped wolverines were reported during the State's furbearing seasons, with 6 animals known to be released alive and 6 mortalities (IDFG 2013, pers. comm.; IDFG 2016, pers. comm.). This total includes four wolverines caught during the 2013-2014 furbearer season, with three released alive and one mortality (IDFG 2014, p. 26). Within the State of Wyoming, there are two confirmed reports of incidental take, one in 1996 (Mead 2013, pers. comm.) one in 2006. The 2006 animal was released unharmed (Inman 2012, pers. comm.). In Montana, since the closing of the trapping season for wolverine in 2013 (2013 through 2016), four wolverines have been incidentally trapped, one in 2013 and three in 2014 (Inman 2017c, pers. comm.). The 2013 capture was released unharmed and the three caught in 2014 were all mortalities (Inman 2017c, pers. comm.).

Predator control programs targeting wolves, including poison and incidental trapping, can result in incidental losses of wolverines (COSEWIC 2014, p. 41). Specific to wolf control for livestock protection in Idaho, three wolverines have been trapped incidental to authorized wolf control activities since 1995, with two released alive and one animal euthanized (IDFG 2014, p. 26). Preventive measures have been adopted to reduce these incidental captures, including implementation of educational programs to minimize incidental capture of wolverines during trapping seasons (IDFG 2014, p. 27). Licensed wolf trappers are required to complete a Wolf Trapper Education course with specific instruction for reducing incidental trapping of wolverine, Canada lynx, and other non-target species (IDFG 2014, p. 27). In addition, the U.S. Department of Agriculture Wildlife Services (Wildlife Services) agency has also temporarily stopped (as of April 2017) using cyanide predator control devices in the State of Idaho (Moeller 2017).

In Alaska, wolverine trapping and hunting is controlled by seasons and bag limits, with about 550 animals harvested each year (Alaska Department of Fish and Game (ADF&G) 2017a). For the 2015–2016 reporting period, wolverine harvest, based on furbearer sealing records,[3] totaled 527 animals (Parr 2016, p. 42). This level of harvest has been fairly consistent since 2010, as shown in Table 7 below.

[3] Wolverines taken in Alaska are required to be sealed by an authorized department representative before pelts are shipped to an out-of-state buyer or auction house (Parr 2016, p. 44). For those species that require sealing, the number of animals sealed represents the best information regarding the statewide harvest (Parr 2016, p. 41).

Table 7. Number of wolverines harvested in Alaska, as reported from regulatory year sealing records, 2010–2015. Adapted from Parr (2016, p. 42; Table 10).

Alaska Region	2010	2011	2012	2013	2014	2015
I	25	20	25	31	14	15
II	25	29	50	31	16	37
III	233	235	261	358	268	214
IV	180	160	170	158	99	150
V	140	110	135	133	109	111
Total	603	554	641	711	506	527

Trapping and harvesting of wolverines occurs over much of the range in Canada, as summarized in the 2014 COSEWIC wolverine status review (COSEWIC 2014, pp. 10, 29–35). Specifically, wolverines are harvested in the northern and western territories–Manitoba, Saskatchewan, Alberta, British Columbia, Yukon, Northwest Territories, and Nunavut (COSEWIC 2014, p. 43). Non-aboriginal harvest of wolverines has not been permitted since 2001–2002 in Québec and Labrador (COSEWIC 2014, p. 43). Trapping is closed in Ontario (except through treaty rights), though incidental trapping results in 1 to 4 mortalities per year (Bowman *et al*. 2010, p. 465). Harvest levels in western provinces have remained relatively stable since 1992 (COSEWIC 2014, p. 38; Table 1).

The management of wolverine harvest in Canada incorporates spatial and temporal elements such as season length, quotas, limited entry, and trapline management by trappers (reviewed by Slough *et al*. 1987). Wolverine harvest levels in Canada are monitored using mandatory pelt sealing, annual harvest reporting, or through monitoring of fur exports (COSEWIC 2014, p. 43). In some northern communities, wolverine pelts are used locally and harvests are monitored through carcass collection programs (COSEWIC 2014, p. 43).

The COSEWIC Assessment and Status Report for the wolverine also noted that range contraction and habitat trends of wolverines in Canada are not solely the result of habitat or trapping pressure (COSEWIC 2014, p. 20). Reductions in ungulate (e.g., caribou) populations, which provide an important winter food resource, were also likely an important factor in range contractions of wolverines in its northern range (COSEWIC 2014, p. 20), and likely continue to influence populations today. Snowmobiles have allowed for better access for hunters and trappers and may be increasing the number of wolverine harvested in its northern North America range; however, the areas of exploitation are still relatively small concentrated areas, and large areas of refugia continue to be found (Cardinal 2004, p. 31).

Population growth rate scenarios for North American wolverines were modeled by Krebs *et al*. (2004, p. 499), including trapped and untrapped populations. Of note, at the time of this study, wolverines were considered furbearer or game animals and trapped or hunted in 8 of their 12 study areas in North America, including Montana (Krebs *et al*. 2004, p. 495; Table 1). Estimated (logistic) rates of population growth (λ) were found to be lower for trapped populations (λ = 0.878) as compared to untrapped populations (λ = 1.064) (Krebs *et al*. 2004, p. 499). Based on their analysis, harvesting was considered to be an "additive mortality" in the populations studied and is likely sustained by dispersal from untrapped areas that provide refugia (Krebs *et al*. 2004,

pp. 499–500). However, as described in the 2014 COSEWIC report, trends in wolverine populations in the northern range, while uncertain, appear to be stable or increasing, with some concern for populations in the southern areas of British Columbia and parts of the northern United States (COSEWIC 2014, p. 22, and references cited therein). Similarly, in Alaska, over the past 6 years, on average, 590 wolverines are taken each year (see Table 7). The consistent harvest levels in these regions suggest relatively stable wolverine populations.

We evaluated trapping of wolverines in British Columbia and Alberta regions of Canada in an effort to document potential impacts to dispersing wolverines along the U.S.–Canada border. As described above (*Population Abundance and Distribution*), the population of wolverines in British Columbia is estimated to be 2,700–4,760 and 1,500–2,000 animals in Alberta (COSEWIC 2014, p 36). We obtained 9 years (2007-2015) of harvest data for southern BC wildlife management units from the British Columbia Ministry of Environment, Ecosystems Branch for our analysis. Twenty seven years (1989–2015) of harvest data was obtained for Alberta in addition to locations of wolverines from a 2012–2015 study and other sources (Webb *et al*. 2016, p. 1,465; Webb 2017, pers. comm.).

Figure 5 presents the results from our spatial analysis and indicates a total of 77 wolverines were trapped in British Columbia wildlife management units within 110 km (68.35 mi) of the U.S.–Canada border from 2007–2015 (average of 8.5 animals per year). We used this distance since it's similar to both the average maximum distance per dispersal movement of 102 km (63 mi) for male wolverines reported by Inman *et al*. (2012a, p. 784) for the Greater Yellowstone region of Montana, and a reported 100 km (62 mi) dispersal distance for a juvenile male for Ontario, Canada (COSEWIC 2014, p. 24, citing unpublished data from Dawson *et al*. 2013). As shown below, one management area contains nearly one-third (23 individuals) of this total number. The other management units along the international border indicate very few animals harvested over this 8-year period (i.e., areas on map identified as zero). There is no open trapping season or hunting season on wolverines in the management units in the Okanagan (Region 8) (north of Washington State) or South Coast (Region 2) (southwest corner of British Columbia) with a trapping season for wolverines only in the Kootenay (Region 4, the eastern half of the southern part of the province) (Weir 2017b, pers. comm.). In addition, there has not been an open trapping season in Region 2 since at least 1985 and since 1993 in the Okanagan region (Weir 2017c, pers. comm.). For Alberta, we identified a total of 15 wolverines harvested by trappers and data presented in other studies within 110 km (68.35 mi) of the U.S.–Canada border from 1989–2014 (average of less than 1.0 animal per year). Researchers in Canada are currently conducting a landscape level analysis to estimate the size and sustainable harvest for wolverine populations within British Columbia (Weir 2017a, pers. comm.).

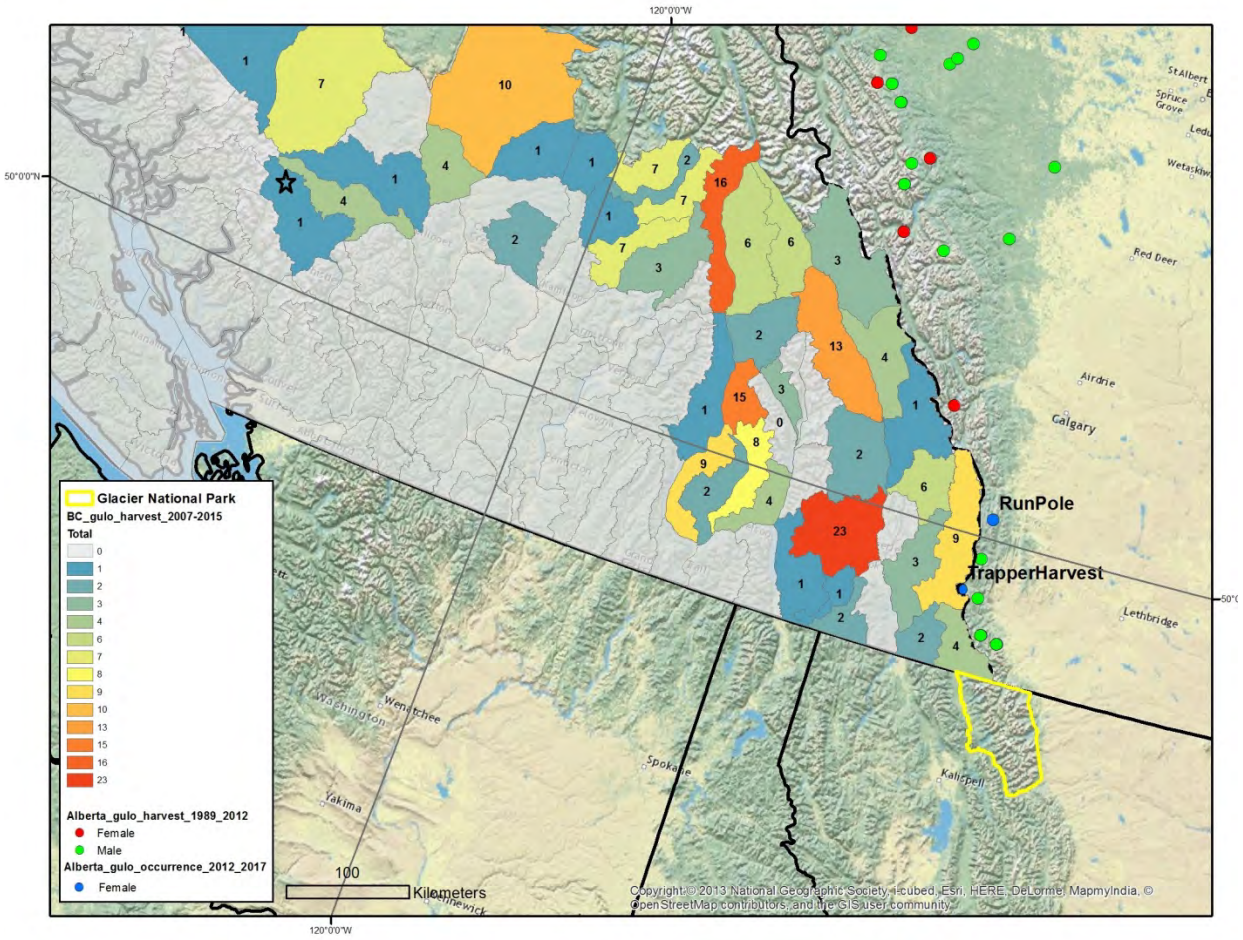

Figure 5. Numbers of wolverines harvested in British Columbia and Alberta, Canada. Sources: British Columbia Ministry of Environment; Webb *et al.* 2016; Webb 2017, pers. comm.

Based on this analysis, trapping effort along the U.S.–Canada border does not represent a significant barrier to wolverine movement and dispersal along the international border. As noted above, Regehr and Lacroix's (2016, entire) multi-method inventory of wolverines within an area located in the eastern side of the Coast Mountains of British Columbia (see **black** star in Figure 5 above) found unexpectedly high numbers of wolverines, which may have been the result of the rugged landscape features in this mountainous area and abundant food resources (both winter and summer) (Regehr and Lacroix 2016, pp. 249–250).

Legal Status/Protection

In the western United States, the wolverine status is as follows: a state-threatened species in Oregon (ODFW 2016) and California (CDFW 2017a); state-endangered species in Colorado (Colorado Parks and Wildlife 2015a) ; a candidate species in Washington (Washington Department of Fish and Wildlife (WDFW) 2013); a protected nongame species and species of greatest conservation need in Idaho (IDFG 2014); a protected animal and species of greatest conservation need in Wyoming (WGFD 2017); a species of greatest conservation need in Utah (Utah Wildlife Action Plan Joint Team 2015); a furbearer and species of concern in Montana (Montana Natural Heritage Program and Montana FWP 2017); and, in Nevada, the Nevada

Administrative Code lists wolverines as a protected mammal (NAC 503.030), which provides full legal protection. There is no protected status for wolverines in the State of Alaska. The State of New Mexico Department of Game and Fish does not recognize the wolverine as a native mammal. Additional discussion regarding State regulatory mechanisms that provide protections for wolverines is provided in **Appendix G**.

The Idaho Department of Fish and Game issues permits allowing live capture, handling, and release of wolverines for scientific studies, which usually involved log box-traps that do not cause physical injury to the captured animals (IDFG 2014, p. 27). The agency also issues scientific collection permits to various agencies and organizations and to IDFG biologists that can include the capture, chemical immobilization, and placement of radio-collars/radio-markers on wolverines (IDFG 2014, p. 27). These permittees (and IDFG staff) are required to comply with animal trapping and handling protocols approved by IDFG's Wildlife Health/Forensic Laboratory and other animal welfare and research institutions. Over the past 20 years, there have been two documented wolverine deaths due to live capture activities in Idaho (IDFG 2014, p. 27).

In Wyoming, the Wyoming Game and Fish Commission (Commission) Regulation Chapter 52, Nongame Wildlife, authorizes take of wolverine only for scientific or educational purposes as regulated by Commission Regulation Chapter 33 (Regulation Governing Issuance of Scientific, Research, Educational, or Special Purpose Permits). We received information from the State of Wyoming indicating that a search of electronic records of Chapter 33 permits (issued since 1997) found (as of May 2013) three permits have been issued for scientific purposes to further understanding of wolverine ecology in Wyoming (Mead 2013, pers. comm.).

In California, research permits for State-listed, State-candidate, and fully protected species in California are issued as a Memorandum of Understanding (MOU). Currently, there are no active MOUs for research on wolverine in California (Burkett 2017, pers. comm.).

In Canada, provincial designations for the wolverine include Endangered in Labrador, and Threatened in Ontario and Québec ('Threatened' is equivalent to Endangered in Québec), with the remaining provincial designations ranging from no ranking to Sensitive or Special Concern and the Vancouver Island population designated as Imperilled (COSEWIC 2014, p. 44). Recovery planning for the wolverine is focused on the eastern population (Canadian Boreal Forest Agreement Secretariat 2015, p. 3).

In summary, overutilization does not represent a stressor to the wolverine the contiguous United States at the individual, population, or species level. Wolverine populations in the contiguous United States are currently protected under several State laws and regulations. Hunting and trapping activities for wolverines are currently suspended or closed entirely for animals within the contiguous United States, though occasional incidental trapping can occur. Trapping in Alaska and Canada has been and appears to be sustainable given large areas of available refugia in these regions. Trapping or harvesting of wolverines along the contiguous U.S.–Canada border does not represent a stressor to wolverines migrating into the contiguous United States at the individual or population level. In addition, wolverine populations along the Alaska–Canada

border are continuous with the Yukon region of Canada, which suggests a rescue effect for Canadian populations along this international boundary (COSEWIC 2014, p. 37).

Summary of Current Conditions

Wolverine populations in much of North America are still recovering from large losses of individuals from intensive hunting and persecution pressures in the late 1880s into the mid-20th century. Although there is limited rangewide survey information, based on the best available information, wolverines continue to be detected across suitable habitat within the contiguous United States. Studies are currently underway to estimate the species' current distribution and genetic characteristics of the metapopulation across Montana, Idaho, Wyoming, and Washington. In Canada, the total wolverine population is estimated at over 10,000 adults (COSEWIC 2014, p. 47). In Alaska, estimates of populations are not available and are best evaluated based on density (Parr 2017, pers.comm.), which are naturally low for this species. Recent density estimates range from 5 to 10 wolverines per 1000 km^2 (386 mi^2) for Alaska (Parr 2017, pers. comm).

Based on our collection of observations and detections of wolverines in the contiguous United States and the 2014 status review for Canada, we prepared a Current Range map to illustrate the species' North American range (Figure 3). We estimated that the proportion of the current North American range of the wolverine encompassed within the contiguous United States is approximately 6 percent.

We determined that 96 percent of the previously modeled primary habitat (Inman *et al*. 2013) in the lower United States is considered to be lands owned or managed by the Federal government (see **Appendix D**). We also estimated that 41 percent of this modeled primary habitat is located in designated wilderness areas. **Appendix G**, *Regulatory Mechanisms and Conservation Measures*, provides a more detailed summary of management actions.

We evaluated several potential stressors that may be affecting wolverine populations or its habitat, including effects from roads, disturbance due to winter recreation and other activities, effects from wildland fire, disease and predation, and overutilization for (primarily) commercial purposes. We determined that the effects of roads (evaluated by number of miles, density, and location) and disturbance represent low level stressors to the wolverine in the contiguous United States. Wildland fire was determined to be a short-term stressor to wolverine habitat and its prey. Disease and predation are not considered stressors to the wolverine.

Legal trapping or hunting of wolverines is currently prohibited in the contiguous United States. Incidental trapping of wolverines is infrequent in the contiguous United States, and, in Idaho, education programs are being implemented to reduce this stressor. In Alaska, the level of harvest of wolverines has been fairly consistent since 2010, and, as noted above, density estimates indicate no declining trend in wolverine populations.

Wolverines are harvested in several Canadian provinces with management and monitoring oversight based on spatial and temporal elements. We reviewed trapping information from Canada (within 110 km (68.35 mi) of the contiguous U.S.–Canada border) to assess potential impacts to dispersing wolverines into the United States. We found that, in Alberta, 15 wolverines

were harvest over a 25 year period (average of less than 1.0 animal per year), and, for British Columbia, we found an average of 8.5 animals per year, though one management area contained nearly one-third (23 individuals) of this total. Researchers in Canada are currently conducting a landscape level analysis to estimate the size and sustainable harvest for wolverine populations within British Columbia (Weir 2017, pers. comm.). Based on the best available commercial and scientific information, overutilization does not represent a stressor to the wolverine in the contiguous United States.

Status – Future Conditions

The future timeframe evaluated in our analysis is approximately 40 to 50 years, which captures the range of time periods for proposed projects within the species' range, as well as our best professional judgment of the projected future conditions related to trapping/harvesting, climate change, or other potential cumulative impacts.

After considering the current conditions for the wolverine and its habitat, we describe here the most likely future scenario to potentially have an effect on wolverine at the population level in the contiguous United States:

- Climate change effects (i.e., significantly elevated temperatures resulting in decline in snowpack) may modify suitable habitat, which could also change the scope of the wildland fire stressor.

Based on our review of the best available information, we determined that there were no other plausible scenarios that were likely to have population level impacts to wolverine in the contiguous United States. We expect that the effects of trapping and roads, human disturbance, effects of wildland fire to continue to be at low levels in the future. We have no information that indicates that mortality from roads or disease would increase within the range of wolverine in the contiguous United States in the future.

Climate Change Effects

In this section, we consider climate changes that may affect environmental conditions that the wolverine relies on. As defined by the Intergovernmental Panel on Climate Change (IPCC), the term "climate" refers to the mean and variability of different types of weather conditions over time, with 30 years being a typical period for such measurements, although shorter or longer periods also may be used (IPCC 2013a, p. 1450). The term "climate change" thus refers to a change in the mean or the variability of relevant properties, which persists for an extended period, typically decades or longer, due to natural conditions (e.g., solar cycles) or human-caused changes in the composition of atmosphere or in land use (IPCC 2013a, p. 1,450).

Scientific measurements spanning several decades demonstrate that changes in climate are occurring. In particular, warming of the climate system is unequivocal and many of the observed changes in the last 60 years are unprecedented over decades to millennia (IPCC 2013b, p. 4). The change in temperature reported in the Northern Hemisphere in recent history (past 150 years) at +0.6°C (1.08°F) is twice the change reported for the Southern Hemisphere (+0.3°C (0.54°F)) and there is much year-to-year variation (Post 2013, p. 4). With regard to precipitation over land,

there has been a decline in global total annual precipitation, but the variability between years in total precipitation has increased since about the 1970s (Post 2013, p. 9). The Palmer Drought Severity Index (PDSI) compares the actual amount of precipitation received in an area during a certain time period with the normal or average amount expected during that same period (National Weather Service (NWS) 2015) and is generally used as a measure of water stress. Time series analysis of the PDSI indicates worsening persistent drought-like or drought-potential conditions across the globe since 1980, a reflection of the influence of temperature on atmospheric dynamics (Post 2013, pp. 10–11).

Comprehensive assessments of other observed and projected changes in climate and associated effects and risks, and the basis for them, are provided for global and regional scales in recent reports issued by the IPCC (2013c, 2014), and similar types of information for the United States and regions within it can be found in the National Climate Assessment (Melillo *et al*. 2014, entire). Results of scientific analyses presented by the IPCC show that most of the observed increase in global average temperature since the mid-20th century cannot be explained by natural variability in climate and is "extremely likely" (defined by the IPCC as 95 to 100 percent likelihood) due to the observed increase in greenhouse gas (GHG) concentrations in the atmosphere as a result of human activities, particularly carbon dioxide emissions from fossil fuel use (IPCC 2013b, p. 17 and related citations).

Scientists use a variety of climate models, which include consideration of natural processes and variability, as well as various scenarios of potential levels and timing of GHG emissions, to evaluate the causes of changes already observed and to project future changes in temperature and other climate conditions. Model results yield very similar projections of average global warming until about 2030, and thereafter the magnitude and rate of warming vary through the end of the century depending on the assumptions about human population levels, emissions of GHGs, and other factors that influence climate change. Thus, absent extremely rapid stabilization of GHGs at a global level, there is strong scientific support for projections that warming will continue through the 21st century, and that the magnitude and rate of change will be influenced substantially by human actions regarding GHG emissions (IPCC 2013b, 2014; entire).

Global climate projections are informative, and, in some cases, the only or the best scientific information available. However, projected changes in climate and related impacts can vary substantially across and, as noted above, within different regions and hemispheres (e.g., IPCC 2013c, 2014; entire) and within the United States (Melillo *et al*. 2014, entire). Therefore, we use "downscaled" projections when they are available and have been developed through appropriate scientific procedures, because such projections provide higher resolution information that is more relevant to spatial scales used for analyses of a given species (see Glick *et al*. 2011, pp. 58–61, for a discussion of downscaling). We note here that multiple lines of evidence, not just projections derived from quantitative models, should be examined when conducting climate vulnerability assessments (Michalak *et al*. 2017, entire). Thus, we provide below projected effects from climate change in the western United States relative to both abiotic (e.g., temperature, precipitation, snow cover) and biotic (e.g., phenology, behavior) factors.

Abiotic Factors

California

Regional temperature and precipitation observations for assessing climate change are often used as an indicator of how climate is changing. For evaluating climate trends in California, the Western Regional Climate Center (WRCC) has defined 11 climate regions (Abatzoglou *et al*. 2009, p. 1,535). The relevant region for our assessment is the north/north-central Sierra Nevada region (Tahoe National Forest), currently occupied by a male wolverine, or the northeast region as defined in Abatzoglou *et al*. (2009, p. 1,535) .

Two indicators of temperature, the increase in mean temperature and the increase in maximum temperature, are important for evaluating trends in climate change in California. For the climate region that encompasses the Tahoe National Forest region, the 100-year linear trends provided by the WRCC indicate an increase in mean temperatures (Jan–Dec) of approximately 0.92°C/100 yr (± 0.29°C/100 yr) (1.66°F ± 0.53°F/100 yr) since 1895 from present day; 1.55°C/100 yr (± 0.67°C/100 yr) (2.79°F ± 1.21°F/100 yr) since 1949 to present day; and 2.41°C/100 yr (±1.54°C/100 yr) (4.33°F ± 2.78°F/100 yr) since 1975 to present day (WRCC 2017). Thus, the increase in mean temperature has not been constant—the rate of increase over the past 42 years in this region has been 2.6 times higher than the past 122 years. We assume the rate of temperature increase for this region is higher for the second and third time periods (since 1949 and 1975, respectively) than for the first time period (since 1895) due to the increased use of fossil fuels in the later part of the 20th and early 21st century.

Although these observed trends provide information as to how climate has changed in the past, climate models can be used to simulate and develop future climate projections. Both state-wide and regional probabilistic estimates of temperature and precipitation changes for California (by the 2060s) using downscaled data from 16 global circulation models and 3 nested regional climate models were presented by Pierce *et al*. (2013, entire). The study looked at a historical (1985–1994) and a future (2060–2069) time period using the IPCC Special Report on Emission Scenarios A2 (Pierce *et al*. 2013, p. 841), which is an IPCC-defined scenario used for the IPCCs Third and Fourth Assessment reports, and is based on a global population growth scenario and economic conditions that result in a relatively high level of atmospheric GHGs by 2100 (IPCC 2000, pp. 4–5; see Stocker *et al*. 2013, pp. 60–68, and Walsh *et al*. 2014, pp. 25–28, for discussions and comparisons of the prior and current IPCC approaches and outcomes). Importantly, the projections by Pierce *et al*. (2013, pp. 852–853) include daily distributions and natural internal climate variability.

Simulations using these downscaling methods project an increase in *yearly* temperature for the area that encompasses the Tahoe National Forest (Sierra Nevada) ranging from 2.1°C (3.78°F) to 3.2°C (5.76°F) by the 2060s time period (Pierce *et al*. 2013, p. 844), compared to 1985–1994. The simulations indicated a yearly *upper* temperature increase of 2.5°C (4.5°F) from 1985–1994 to 2060–2069 (averaged across models) for this area, and an increase of 1.9°C (3.42°F) for the December–February period (Pierce *et al*. 2013, p. 842).

Beginning in 2012 and continuing into 2016, California experienced a severe drought throughout most of the state (Griffin and Anchukaitis 2014, p. 9,020). Although three-year droughts in California are not unusual when evaluated over the past 1000 years, the severity of these drought conditions during this period was demonstrated in the 2014 summer PDSI, which was estimated to be the lowest on record (1901–2014) (Williams *et al*. 2015, p. 6,823). An evaluation of how unusual this drought event was in the context of the last millennium using blue oak (*Quercus douglasii*) tree ring data from four sampling sites (with additional tree sampling following the 2014 growth season) was conducted by Griffin and Anchukaitis (2014, entire). Their paleoclimate drought and precipitation reconstructions for Central and Southern California show that, although the precipitation during this drought has not been anomalously low, it was not outside the range of variability (Griffin and Anchukaitis 2014, p. 9,017). However, the 2014 drought was the worst single drought year of at least the last 1,200 years in California and the 2012–2014 drought was the most severe of three consecutive drought years, based on three events found in the record for the last 1,200 years (Griffin and Anchukaitis 2014, pp. 9,020–9,021). The study concluded that low precipitation combined with high temperatures was responsible for creating this worst short-term drought episode (Griffin and Anchukaitis 2014, pp. 9,021–9,022).

A study by Williams *et al.* (2015, entire) estimated the anthropogenic contribution to California's drought during 2012–2014. They found that the intensifying effect of high potential evapotranspiration on this drought event (measured by summer PDSI) was almost entirely the result of high temperatures (18–27 percent in 2012–2014; 20–26 percent in 2014) (Williams *et al*. 2015, p. 6,825). Another study evaluating the influence of temperature on the drought in water year 2014 in California found that, although the low level of precipitation was the primary driver for the drought conditions, temperature was an important factor in exacerbating the drought, noting that the water year 2014 was the third year of the multiyear drought event and therefore conditions were drier than normal at the beginning of the water year (Shukla *et al*. 2015, p. 4,392).

In sum, these projections indicate that increased temperatures are likely to occur in the Tahoe National Forest region by the 2060s due to the effects of climate change.

Precipitation patterns can also be used as an indicator of potential climate change. We obtained yearly snowfall data for the Tahoe City station located in the northern Sierra Nevada region from the WRCC (https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca8758) since that dataset was the most complete for the area. We then conducted a nonparametric correlation test, the Mann-Kendall statistical test (Hipel and McLeod 1994, pp. 63–64, 856–858), which is commonly used for analyzing climatic time series (e.g., Ahmad *et al*. 2015, entire), to evaluate trends in snowfall over time. This analysis was conducted using the R and R Studio software programs (Version 3.1.2; R Development Core Team, 2014) with the "Kendall" package (Version 2.2) (McLeod 2011). We found that annual snowfall amounts showed no statistically significant trend (increasing or decreasing) from 1909–2017 (tau = –0.0289, two-sided *p*-value of 0.6705) for the Tahoe City station.

State-wide and regional probabilistic estimates of precipitation changes for California were also evaluated by Pierce *et al*. (2013, entire). When averaged across all models and downscaling

methods, small annual mean decreases in precipitation were found for the Sierra Nevada region of California, but that study also found an increase in precipitation for the December through February period (wetter winters) (Pierce *et al*. 2013, pp. 849, 855). There was significant disagreement across the models, with percent changes ranging from a12 percent decrease to a 9 percent increase (Pierce *et al*. 2013, p. 851), and the projected changes in seasonal-mean precipitation were generally small when compared to natural internal climate variability (Pierce *et al*. 2013, p. 850; Figure 9).

Columbia River Basin Region

This region covers a large area within Washington, Oregon, and Idaho, and parts of British Columbia, Canada, and includes portions of the current range of the wolverine. Rupp *et al*. (2017, entire) used simulations from 35 Global Climate Models (GCMs) to provide projections of climate in the Columbia River Basin into the 2080s under two emissions scenarios, Representative Concentration Pathways (RCP) (RCP 4.5, which represents moderate reduction in GHG emissions ("intermediate emissions"), and RCP 8.5, which represents a continued increase in GHG emission "high emission"). The results of their multi-model ensemble for the RCP 4.5 scenario indicate mean annual temperature increases (above Bonneville Dam), above the 1970–1999 baseline average, of 1.3°C (2.34°F) for the 2010–2039 period, 2.3°C (4.14°F) for the 2040–2069 period, and 2.8°C (5.04°F), for the 2070–2099 future period (Rupp *et al*. 2017, p. 1,788). By season, the winter period (December–February) mean change result indicates an increase of 1.1°C (2.52°F) for 2010–2039, 2.2°C (3.96°F) for 2040-2069, and 2.7°C (4.86°F) for 2070–2099, as compared to the 1970–1999 baseline average (Rupp et al. 2017, p. 1,788).

For the RCP 8.5 scenario, the multi-model ensemble projections indicate mean annual temperature increases, above the 1970–1999 baseline average, of 1.4°C (2.34°F) for the 2010–2039 period, 3.1°C (5.58°F) for the 2040–2069 period, and 5.0°C (9.0°F), for the 2070–2099 period (Rupp *et al*. 2017, p. 1,788). For the winter season (December–February) mean change increase of 1.4°C (2.34 °F) for 2010–2039, 2.9°C (5.22°F) for 2040-2069, and 4.7°C (8.46°F) for 2070–2099, as compared to the 1970–1999 baseline average (Rupp *et al*. 2017, p. 1,788). The anthropogenic-forced (human caused or influenced) change for these projections is higher than the annual variability; thus, by the year 2050, it is very unlikely that the temperature for this year or any year following during this century would be as low as the historical average (Rupp *et al*. 2017, p. 1,788).

Precipitation projections were much less robust; the multi-model ensemble mean precipitation projections indicate an increase above baseline of up to 8 percent by 2099 for RCP 8.5 and slightly less for RCP 4.5 (Rupp *et al*. 2017, p. 1,788). When viewed seasonally, for the winter season, the ensemble projections indicate increases in precipitation for all three future time periods for both the RCP 4.5 and RCP 8.5 scenarios (ranging from 3 to 14 percent) as compared to the baseline period (1970–1999) (Rupp *et al*. 2017, p. 1,788). The projections of anthropogenic-forced increases in precipitation are lower than the interannual variability; however, despite these increases, the authors indicate that years of anomalously low precipitation relative to baseline would be expected with high frequency throughout the 21st century (Rupp *et al*. 2017, p. 1,788).

Within three subregions of the Pacific Northwest within the current range of the wolverine, Sheehan *et al*. (2015, p. 20; Table 4) also found that, when compared to a historical baseline (1971–2000), all future climate projections (RCP scenarios 4.5 and 8.5; 2036–2066, 2071–2100) indicate a rise in both minimum and maximum monthly temperatures, and a generally positive change in mean annual precipitation, though the latter results varied across projections.

Upper Snake River Basin

The Upper Snake River Tribe Foundation and its Tribal members prepared a climate change vulnerability assessment for the Upper Snake River Watershed (Petersen *et al*. 2017, entire). The assessment covers large areas of southern Idaho and eastern Oregon, and small areas of northern Nevada, northern Utah, and western Wyoming (Petersen *et al*. 2017, p. 15). Within three geographic/model domains of this larger region, downscaled climate projections were created from 20 GCMs run with two emissions scenarios (RCPs 4.5 and 8.5) and these outputs were then used to calculate potential future changes in temperature and precipitation (Petersen *et al*. 2017, pp. 15–16). The projections were analyzed in reference to a baseline period (1950-2005) for three future time periods—the 2030s (2020–2049), the 2050s (2040–2069), and the 2080s (2070–2099) (Petersen *et al*. 2017, p. 16).

For temperature, their projections indicated an increase in average annual temperatures in both future emission scenarios and across all time periods. Under RCP 8.5 (high emissions scenario), the ensemble mean temperature increase was about 6.11°C (11ºF), and 2.78°C (5ºF) under the RCP 4.5 intermediate emissions scenario across all three geographic/model domains (Petersen *et al*. 2017, Appendix A, p. 2). For the North and East domains (areas with greater topographical variability), there was some indication of a small increase in total annual precipitation by the end of the century, though there was less agreement among the models (Petersen *et al*. 2017, Appendix A, p. 2).

For all geographic/model domains, the average temperature is projected to increase under both emissions scenarios for all seasons (Petersen *et al*. 2017, Appendix A, p. 2). For the winter months (December, January, February), for RCP 4.5, the average seasonal temperature is projected to increase by 3.89 to 5°C (7 to 9ºF) by the end of the century, and an increase of approximately 2.22 to 3.33°C (4 to 6ºF) for the other seasons (Petersen *et al*. 2017, Appendix A, pp. 2, 6). The winter season projections for RCP 8.5 add an additional 1.67 to 2.22°C (3 to 4ºF) by the end of the century (Petersen *et al*. 2017, Appendix A, pp. 2, 6).

Rocky Mountain Region (Colorado)

A report by Lukas *et al*. (2014, entire) presented an assessment of observed and future projections of climate change effects for Colorado. They reported that, statewide, annual average temperatures have increased by 1.1°C (2.0°F) over the past 30 years, and 1.4°C (2.5°F) over the past 50 years (Lukas *et al*. 2014, p. 11). These warming trends have been observed in much of the State (Lukas *et al*. 2014, p. 11). They report no significant long-term trends in annual precipitation (30-, 50-, and 100-year trends) through 2012, but they indicate an observed trend towards more severe soil-moisture drought conditions in Colorado, based on the PDSI, over the past 30 years (Lukas *et al*. 2014, pp. 12, 21).

This report also presents results from climate change modeling using an ensemble of CMIP5 model projections, run with RCP 4.5 and 8.5 scenarios (Lukas *et al*. 2014; Section 5). The results indicate future warming in Colorado for all of the climate model projections (Lukas *et al*. 2014, p. 59). By 2050, for the RCP 4.5 (intermediate) emissions scenario, the statewide average annual temperatures are projected to increase by 1.4 to 2.8°C (2.5 to 5°F) (relative to a 1971–2000 baseline), and increase by 1.9 to 3.6°C (3.5 to 6.5°F) under the RCP 8.5 (high) emissions scenario (Lukas *et al*. 2014, p. 59). For precipitation, they report that climate model projections show less agreement regarding future precipitation change for Colorado, but most projections indicate increasing winter precipitation by 2050 (Lukas *et al*. 2014, p. 59).

Summary

Observed trends and future climate model projections indicate warming temperatures for much of the western United States, including areas within the current range of the wolverine. The degree of future warming varies by region and is dependent upon the future emission scenario used during the modeling process. Future precipitation trends are less certain for many regions, in part, due to naturally high, inter-annual variability; some regions are projected to experience greater winter precipitation. Wolverines have been found to have a wide range in critical temperature depending on season, and undergo seasonal changes in fur insulation to adapt to warmer temperatures in summer. Wolverines also exhibit changes in behavior, such as moving to water bodies or higher elevations in summer months. These physiological and behavioral adaptations allow wolverines to adapt to warming temperatures.

Biotic Factors

In addition to evaluating changes in these abiotic factors, biotic interactions should be considered in evaluating species' response to climate change (reviewed by Post 2013). Although abiotic changes drive ecological processes, the alterations in biotic interactions (e.g., competition among conspecifics, interactions with competitors, resources, and predators) represent the ecological responses that result from those changes (Post 2013, p 1). Changes in certain abiotic factors, such as snow and ice cover, should also be considered in an ecological context since they represent habitat for many species (Post 2013, p. 11).

Ecological studies evaluating the effects of climate change often evaluate phenology, the timing of life history events and how they vary in space and time, generally at the population or site-specific level, though phenological variation at the individual level may also be important (Post 2013, p. 54). Previous meta-analyses of the rate of phenological advancement have suggested advances of between 2–5 days per decade, across taxa, and between low-mid to mid-high latitudes (Post 2013, p. 59). A more recent meta-analysis from Cohen *et al*. (2017, p. 4) found, on average, significant advancement in the phenology of animals since 1950, advancing by about 2.88 days per decade and 3.08 days per degree Celsius.

Within the Pacific Northwest region, Ford *et al*. 2016 (entire) modeled the timing of growth initiation in coast Douglas-fir trees (*Pseudotsuga menziezii* var. *menziezii*) within the species' range in Washington and Oregon to evaluate its ability to track changes in climate with changes

in phenology. This study found that, for high latitudes and elevations, growth initiation was predicted to occur earlier in the year, which allows trees to track the beginning of favorable growing conditions, without exposure to frost risk (i.e., adaptive phenological response) (Ford *et al*. 2016, pp. 3718, 3,721). Conversely, their model predicted that at lower latitudes and elevations, growth initiation will lag behind climate change shifts due to reduced chilling with lower productivity, which suggested that coast Douglas-fir has an obligate chilling requirement for height (but not diameter growth initiation) (Ford *et al*. 2016, pp. 3,717–3,719).

Another study reported on the effects of encroachment of woody plants (willows (*Salix* sp.)) in alpine environments to alpine wildflowers and their pollinators due to temporal overlap in flowering phenology, which may result in establishment of plant species with broader environmental tolerance in high alpine ecosystems (Kettenbach *et al*. 2017, p. 6,969). Similarly, in Sweden, Wilson and Nilsson (2009, entire) reported on encroachment of woody vegetation in arctic-mountain habitat, though primarily at lower elevations in response to observed temperature increase of 2.0°C (3.6°F) over 20 years, though this increase in cover was observed primarily at lower elevations (Wilson and Nilsson 2009, p. 1,682).

A high-latitude, North American study evaluated the effect of weather and broad-scale climate variables and vegetation productivity on the timing of spring and fall migrations of migratory caribou herds in northern Québec and Labrador, Canada (Le Corre *et al*. 2017, entire). That study found that, since 2000, except for the spring arrival, migrations occurred earlier, and were affected by resource availability, likely through intraspecific competition factors (Le Corre *et al*. 2017, p. 266).

In addition to phenological changes related to habitat variables or reproduction patterns, the effects of climate change may affect food resources important to wolverine, either directly (e.g., survival) or indirectly (e.g., effects to their habitat). An early study by Wang *et al*. (2002, p. 217) projected a potential increase in ungulate populations in Rocky Mountain National Park (Colorado) under future climate scenarios due to enhanced survival and recruitment of juvenile animals in response to less severe winters. The authors note that their results should be interpreted qualitatively given the uncertainties in applying climate change scenarios based on global models to ecological systems at the local scale (Wang *et al*. 2002, p. 217). In addition, they report that vegetation response (e.g., succession) to climate change effects may result in changes to ungulate habitat (Wang *et al*. 2002, p. 219). Overall, the study concluded that their results were consistent with those reported in other studies that have evaluated the relationships between the effect of weather and density dependence and ungulate population dynamics (Wang *et al*. 2002, p. 219).

Summary

The results presented above indicate biotic effects resulting from climate change, varying from phenological changes to shifts in vegetation and vegetation succession. We are unaware of studies that have directly evaluated these types of effects to the North American wolverine or its habitat. Given the extensive range and varied habitats occupied by wolverines in the contiguous United States, the shifts in vegetation are likely to be relatively narrow in scope and scale. Furthermore, we have no information to suggest that wolverines selectively use any specific

vegetation type and some changes in vegetation may actually be advantageous for wolverine prey.

Climate Change and Potential for Cumulative Effects

Threats can work in concert with one another to cumulatively create conditions that may impact the wolverine or its habitat beyond the scope of each individual threat. Given an expected increase in temperature in the western United States, the best available information indicates that, if there are any cumulative impacts in the future, the most likely to have population level effects on wolverine in the contiguous United States could be: 1) changes in snowpack from the combination of increased temperature and changes in precipitation patterns, or 2) changes in snowpack and increase in wildland fire potential.

Snowpack/Snow Cover

Upper Snake River Watershed (Pacific Northwest region)

The Upper Snake River Tribal Foundation assessment (discussed above) included projected changes in snowpack for three locations in the Upper Snake River watershed, including areas located within our estimated Current Range of the wolverine (from Climate Impacts Group Pacific Northwest (PNW) Hydroclimate Scenarios Project (2860); http://warm.atmos.washington.edu/2860/products/sites/). Model results, based on snow water equivalent (SWE) (the water content of snowpack, expressed as depth), indicate a projected loss in April 1st snowpack of 36 percent for the 2030–2059 period and 64 percent for the 2070–2099 period for the *Salmon River at White Bird* location (average of percent change across all models relative to the long-term average for 1916–2006 ("historical period")). For the *Snake River at Brownlee Dam* location, the projected loss is 37 percent for the 2030–2059 period and 64 percent for the 2070–2099 period (summary presented in Petersen *et al*. 2017, p. 20). These projected changes were found to be consistent with overall changes projected for the Columbia River Basin snowpack in an earlier study. Hamlet *et al*. (2013, p. 404; Figure 7) found that, relative to the long-term average for 1916 to 2006, the April 1st snowpack in the Columbia River Basin is projected to decline by 29% for the 30-year period spanning 2030-2059 and decline by 52% for the period spanning 2070-2099 for the A1B emissions scenario. [Note: the A1B emission scenario represents a more balanced energy portfolio than RCP 8.5, with GHG emissions leveling off by the middle of the 21st century].

Sierra Nevada

Walton *et al*. (2017, entire) developed snow cover projections for the Sierra Nevada region in California, incorporating snow albedo feedback using a hybrid downscaling approach to develop future climate projections. This feedback loop is known to be important for regional climate change (Thackeray and Fletcher 2016, p. 395) and occurs when warming causes snow pack to shrink at margins and the exposed ground absorbs more sunlight than snow, which enhances the warming, resulting in more melting of snow (Walton *et al*. 2017, p. 1,417). This study (using 3 km (1.86 mi) resolution) found that, by the end of the 21st century (2081–2100), warming and loss of snow cover is expected to occur, though the degree varies depending on the GHG

scenario (Walton *et al*. 2017, p. 1,430). Under the RCP 8.5 (high emissions) scenario, the study found that the total area covered by snow during the typical month of April decreases by 48 percent, as compared to historical average (1981–2000) (using ensemble mean) (Walton *et al*. 2017, p. 1,432). Under the RCP 4.5 (moderate emissions) scenario, snow cover losses were projected at about half of those for RCP 8.5 (Walton *et al*. 2017, p. 1,434; Figure 13). The effects of warming were more pronounced at lower elevations and were most severe in May and June (Walton *et al*. 2017, p. 1,431; Figure 12). For the months of March and April, the highest elevations were found to have nearly complete snow cover (measured as snow covered fraction) for all GCM simulations (Walton *et al*. 2017, p. 1,431; Figure 12).

Northern and Southern Rocky Mountains–Glacier and Rocky Mountain National Parks

The effects of climate change on snow persistence has been suggested as an important negative impact on wolverine habitat and populations by the mid-21st century (McKelvey *et al*., 2011, entire). The Service therefore pursued a refined methodology to provide insights into the potential impacts of climate change on snow persistence.

The Service engaged the National Oceanic and Atmospheric Administration (NOAA) laboratories and University of Colorado in Boulder, Colorado (CU) to evaluate and model fine scale persistence of snow in occupied and potential wolverine habitat in the contiguous United States. Those discussions revealed significant progress in fine scale modeling approaches since the early 2000s. The Service provided funding for an assessment of snow extent and depth to assess the effects of climate change on snow persistence in two areas of the western United States, Rocky Mountain and Glacier National Parks (Ray *et al*. 2017, entire). The primary objective of this study was to refine the spatial and temporal scale of snow modeling efforts and improve the scientific understanding of the extent of spring snow retention currently and into the future under a changing climate (Ray *et al*. 2017, p. 9). The objectives of the study included (Ray *et al*. 2017, p. 10):

- Use of fine-scale models to analyze the topographic effects of snow, including slope and aspect (compass direction that slope faces)
- Use of a range of plausible future climate change scenarios to assess snow persistence
- Analysis of extremes and year-to-year variability by selecting representative wet, dry, and near normal years (using observed conditions) and then modeling changes for those base years under several future climate scenarios
- Assessment of changes in snow persistence by elevation

The study was designed to parallel as much as possible and thereby refine the previous assessment of snow cover persistence in the western United States presented in McKelvey *et al*. (2011). However, an exact replication of the McKelvey *et al* (2011) study was not possible given the time, funding, and computational constraints needed to develop a fine-scale assessment. The current study was limited to two study areas (approximately 1,500 to 3,000 km^2 (579 to 1,158 mi^2) each) in the northern and southern Rocky Mountains (see **Appendix H** for maps). The two study areas were selected because they encompass the latitude and elevational range of wolverines within the contiguous United States. Glacier National Park (GLAC) is representative of a high latitude and relatively low elevation area currently occupied by wolverines. The Rocky

Mountain National Park region (ROMO) is a lower latitude and higher elevation area within the wolverine's historical range, which was recently occupied by a wolverine from 2009 to at least 2012.

Methods: We provide here a brief summary of the methods used in this study. Additional details are contained in the full report authored by Ray *et al*. (2017). The initial step of the analysis was a review of the observed climate and variability to provide context for trends and year-to-year variability. Next, historical snow cover extent and variability were analyzed using satellite remote sensing (MODIS) data from 2000 to 2016 to calculate a snow disappearance date for each year at each pixel. Summary statistics include total snow covered area (total area covered by snow), representation of snow pack by aspect (percent of land areas covered by snow for each of the 17 years in the historical record by topographic aspect based on compass direction that the slope faces), and elevation dependence for wet, near-normal, and dry years (with median of all years used as reference). Future snow pack projections were then generated using the Distributed Hydrology Soil Vegetation Model (DHSVM), for the historic period 1998-2013, and then validated against SNOTEL observing stations and MODIS satellite data.

Both Ray *et al*. (2017) and McKelvey *et al*. (2011) used the delta method to estimate future snow persistence. The NOAA-DHSVM delta method uses historical observed weather (1998–2013) as the baseline and applies future changes in temperature and precipitation from the chosen GCMs (approximately Year 2055) to estimate future snow persistence on the landscape. Five future scenarios (GCMs) were selected from CMIP5 global climate model projections to capture variability in temperature and precipitation, using the RCP 4.5 (moderate) and RCP 8.5 (high) emissions scenarios. Representative wet, near normal, and dry years were analyzed for the historical simulations and evaluated for the five future scenarios. The number of years (out of 16) with snow depth greater than 0.5 m (20 in) was also analyzed as was the change in Snowcovered Area (SCA) (area with depth greater than 0.5 m (20 in)). This snow depth was selected based on an analysis of the depth of snow at documented wolverine den sites in Glacier National Park (Ray *et al*. 2017; Table 5-2). Results were reported for "light snow cover" (snow depth greater than 1.25 cm (0.5 in)) and "significant" snow (snow depth > 0.5 m (20 in)) for April 15, May 1, and May 15 for previously defined representative years. These dates were selected based on studies indicating den site abandonment generally occurs before May 1 (see Use of Dens and Denning Behavior discussion above in *Reproduction and Growth* section). The term "light snow cover" was incorporated as the most directly comparable parameter to McKelvey *et al*.'s "light" snow cover. The average change in SCA and SWE was analyzed as a function for both study areas of elevation and was overlaid with the elevations of documented wolverine den sites (2003–2007) in GLAC.

Comparison with McKelvey *et al*. (2011): Although the methods used in this study have similarities with those presented in McKelvey *et al*. (2011), there are several key differences. Ray *et al*. (2017) used a finer spatial resolution model (DHSVM) than McKelvey *et al*. (2011) (0.0625 km^2 vs. 35 km^2) that incorporated slope and aspect. The grid cells represented in McKelvey *et al*. (2011) were assumed to be flat (i.e., north-facing slopes treated as identical to south-facing slopes). McKelvey *et al*. (2011) focused on May 1st snow depth as a proxy for May 15th snow disappearance, while Ray *et al*. (2017) focused directly on May 15th snow disappearance and produced results for the presence or absence of deeper snow (nominally

greater than or equal to 0.5 m (20 in) depth) on May 1st *and* April 15th.[4] Because of the increased resolution of this study, Ray *et al*. (2017) were able to consider whether any areas of snow with depth greater than 0.5 m (20 in) will persist in these areas. Additional comparisons are outlined below in Table 8 and in Ray *et al*. (2017, p. 6).

Table 8. Comparison of Methods, Ray *et al*. (2017) vs. Copeland *et al*. (2010) and McKelvey *et al*. (2011)

Feature	Ray *et al*. (2017)	Copeland *et al*. (2010) and McKelvey *et al*. (2011)
Spatial Resolution	250 m x 250 m = 62,500 m^2 or 0.0625 km^2 (0.24 mi^2)	0.125 degrees (~5 km x 7 km; 37 km^2 (14.29 mi^2))
Geographic Area	Glacier and Rocky Mountain National Parks, 300 m below treeline and above	Western United States, except California and Great Basin
Topography	Slope, aspect, and shading were used	Slope and aspect were not used
Validation	SNOTEL (in-situ observations) and MODIS (satellite remote sensing)	None specific to the snow dataset used
Future Scenario Method	Delta Method, used to project 2000-2013 conditions out to Year 2055 (average of 2041–2070)	Delta Method (Years: 2045 (2030–2059), 2085 (2070-2099)
Future Scenarios (GCMs)	*miroc*, *giss*, *fio, cnrm* (both study areas); *canesm* (Glacier National Park only) *hadgem2* (Rocky Mountain National Park only)	Ensemble mean of 10 GCMs, *pcm1*, and *miroc 3.2*
Time-related Results	Long-term means and year-to-year variability (i.e., wet, near normal, and dry years)	Changes in long-term mean snowpack only
Snow Detection and Measurements	Snow presence: 1.25 cm (0.5 in) snow depth threshold on May 15. "Significant snow": snow depth (0.5 meter (20 in) threshold. Snow depth determined by conversion from Snow Water Equivalent using bulk snow density.	Snow presence (13 cm (5.12 in) snow depth threshold on May 1). Snow depth determined by VIC model.
Number of Years of MODIS Data	17 (2000-2016)	7 (2000-2006)
Snow Model	DHSVM (University of Washington)	VIC (University of Washington)
Snow Cover Dates Analyzed	April 15, May 1, and May 15	May 15 (derived from May 1), May 29 (derived from May 1)

Results: While there are challenges in comparing the results from McKelvey *et al*. (2011) directly to the Ray *et al*. (2017) study due to differences in methodology and focus, the qualitative picture can be summarized as follows: projected warming has a larger effect at lower elevations whereas projected precipitation changes may dominate the springtime snowpack in the high country. We present below a summary of the main results from Ray *et al*. (2017).

[4] Ray *et al*. (2017) originally focused on May 15th to compare to the McKelvey *et al*. (2011) study, and June 1st to bracket the snowmelt season. However, April 15 and April 30 dates were added to the evaluation of snowcovered areas to align with temporal reproductive patterns of the wolverine (see Use of Dens and Denning Behavior discussion in *Reproduction and Growth* section above).

MODIS Observed Historic Snowpack Variability Analysis:

- In GLAC, SCA varies considerably by year, including wet years such as 2011 with very persistent snow, years with strong melt in early May, such as 2012, or in late May (2009, 2001), and dry years (2004, 2005) (Ray *et al*. 2017, Section 4.3).
- Even in dry years, northeast-facing slopes in GLAC tend to hold more snow and melt later in the season.
- More than 80 percent of the GLAC study area above approximately 2,000 m (6,562 ft) elevation on May 1 has snow cover during dry years, and more than 95 percent has snow cover above approximately 1,200 m (3,937 ft) during wet years.
- In ROMO, the SCA also varies considerably by year.
- The northwest-facing slopes in ROMO tend to hold more snow even during dry years. In very dry years, snow cover peaks at intermediate elevations, suggesting that the high-altitude snowpack may be particularly vulnerable in this region under warm/dry conditions.

Future Snowpack Projections: The area-wide SCA results include snow cover changes in both forested and above-treeline (alpine) terrain, which may have different implications for wolverine biology.

Glacier National Park (GLAC):

- Projections for April 15th, May 1st, and May 15th SCA and area with snow depth greater than 0.5 m (20 in) show declines on average in all scenarios, compared to the 2000–2013 historic average, except for small increases in the Warm/Wet scenario and for almost all years.
    - For April 15th, light SCA area is reduced by 3–23 percent and significant snow cover (greater than 0.5 m (20 in)) declines by 7–44 percent.
    - For May 15th, light SCA is reduced by 10–36 percent, and the area with significant snow cover declines by 13–50 percent.
- All projections show declines in the number of years with significant snow (equal to or greater than 0.5 m (20 in)), which varies by scenario (e.g., Figure 5-14 in Ray *et al*. 2017). Areas with frequent availability (at least 14 out of 16 years) of significant snow become concentrated in smaller high elevation areas. Lower elevation areas had the largest decreases in the number of years with significant snow cover.
- Most of the known den sites are located between 1,800 m (5,906 ft) and 2,000 m (6,562 ft) in GLAC. Below that elevation band, large snow losses are predicted (40 to 70 percent decrease for two of the scenarios, 16–20 percent for the other three). Above that elevation band, there is little change in SCA for four of the five scenarios (2–8 percent) except in maximum warming scenario (decline of 40 percent (Ray *et al*. 2017; Figure 5-22). In the 1,800–2,000 m (5,906–6,562 ft) band, the snowpack change is sensitive to elevation and to the future climate scenario used.
- For representative wet years, for May 15th, the higher elevations of the study areas experience only 2–7 percent loss of snowpack under the scenarios with “least” change and the “moderate” change, although for the dry years, losses range from 18–57 percent.

- The implication is that the wet, cold climate of the GLAC study area could act as a "buffer" to change in areas with of 0.5 m (20 in) of deep snow on May 1st, at least for elevations above 1,800 m (5,906 ft).

Rocky Mountain National Park (ROMO):

- Projections of May 15th SCA in ROMO decline on average in all scenarios, except for small increases in the Warm/Wet scenario, and for almost all years.
  - For April 15th, light SCA (depth ≥ 5 mm (0.2 in)) declines by 3–18 percent and significant SCA (depth > 0.5 m (20 in)) changes from −1– +16 percent for the five scenarios considered (compared to the 2000-2013 historical average).
  - For May 15th, the area with light snow cover declines 8–35 percent and the area with significant snow cover declines 6–38 percent.
- All projections show declines in the number of years with significant snow (equal to or greater than 0.5 (20 in), which varies by scenario (e.g., Figure 5-21in Ray *et al*. 2017). The areas with frequent availability (at least 14 out of 16 years) of significant snow become concentrated in smaller high elevation areas. In contrast, lower elevation areas had the largest decreases in the number of years with significant snow cover.
- Although no dens have been documented in ROMO, the elevation band for denning, modeled by regression analysis, is estimated at 2,700 to 3,600 m (8,858 to 11,811 ft). On May 1st, modest declines in SWE of about 15 percent and less for areas at 3,400 m (11,155 ft) or above result in losses of only about 10 percent snow cover.
  - The implication is that the wet, cold climate of the higher parts of the ROMO study area could also act as a "buffer" to change in the area of 0.5 m (20 in) deep snow on May 1st.

Elevation Dependence of Change: In general, and supported by the literature, the snowpack in the higher elevations of both areas is more responsive to precipitation change, while lower elevations are more responsive to temperature change. For GLAC, most of the observed den sites are located within the zone where temperature dominates the future effects of change. For the elevation of den sites in GLAC (i.e., above 1800 m (5,906 ft)), loss of SCA on May 1st spans the range of 5–40 percent, with a 70 percent decrease for the Hot/Wet (*miroc* GCM) scenario. Above 2,200 m (7,218 ft), the losses are less than 5 percent for all but the Hot/Wet scenario.

Current results may be a reasonable estimate for the high mountain ranges within the Rockies that lie between GLAC and ROMO. However, without further study, we cannot reasonably extend these results to say whether or not snow refugia will persist in the Central Rockies below our study elevations (approximately 1,000 m (3,281 ft)). These lower elevations are where McKelvey *et al*. (2011) predicted the greatest losses in snowpack. The NOAA/CU results also cannot be extrapolated to mountain ranges outside of the Rockies (i.e. the Cascade Range) that have different climates (temperature and precipitation). We note here that we have no documented wolverine den sites in the contiguous United States below 1,500 m (4,921 ft) elevation; that is, no documented den locations in the areas where McKelvey *et al*. (2011) predicted the greatest loss in snowpack.

Interpretation and additional analysis relative to wolverine den site scale: The Service was interested in exploring the question, "If snow cover is required for wolverine denning, will there be a sufficient amount of significant snow cover in the future in areas wolverines have historically used for denning in the contiguous United States?" The Service integrated future DHSVM projections (2000–2013 averages) of snow covered area (greater than 0.5 m (20 in) depth) on May 1st for GLAC and ROMO with new information obtained from a spatial analysis of documented den sites in the contiguous United States. This spatial analysis indicated 31 of 34 documented den sites in the contiguous United States were located in areas with slope less than 25 degrees. Avalanche risk increases significantly in areas with slope greater than 25 degrees (Scott 2017, pers. comm.) and wolverines may avoid these areas for denning due to this risk.

Using the projections prepared by Ray *et al*. (2017), we present in Figures 6–13 the spatial distribution of significant snow covered area with slopes less than 25 degrees and within the elevation bands indicated above for three future scenarios in each study area. The three scenarios for GLAC (*miroc*, *cnrm*, and *giss*) and for ROMO (*hadgem2*, *fio*, and *giss*) were chosen to span the range of GCM uncertainty regarding temperature and precipitation, and by extension significant SCA (see Figure 6 and Figure 7). We found that large portions of the study areas meet all three criteria—greater than 0.5 m (20 in) snow depth on May 1st, at elevation 1,514–2,252 m (4,967–7,389 ft) for GLAC or 2,700 to 3,600 m (8,858 to 11,811 ft) for ROMO, and with a slope less than 25 degrees—across both study sites in the future.

The GLAC *miroc* simulation shows the greatest decrease in future snow covered area in the elevation band historically used for denning (orange line in Figure 6). Figure 8 shows the spatial distribution of significant SCA with slope less than 25 degrees and elevation of 1,514–2,252 m (4,967–7,389 ft) for the *miroc* simulation on May 1st (approximately Year 2055). Approximately 494 km^2 (191 mi^2) of area meet the three criteria with an additional 803 km^2 (310 mi^2) of area retaining significant snow covered area, primarily at higher elevations. Moreover, we determined that large tracts of significant SCA are projected in close proximity to documented historical den sites across all three scenarios (Figures 8–10). As shown in Table 9, wolverines would not have to travel far, or at all, relative to either distance or elevation to reach areas with significant snow covered area in the future.

A similar analysis was performed for the ROMO study area and the results indicate that large portions of the study area meet all three criteria identified above. The *hadgem2* (Figure 11) and *cnrm* scenarios were found to have the greatest decrease in significant snow covered area of the five scenarios analyzed. Figure 11 (*hadgem2* simulation) shows the spatial distribution of significant SCA (greater than 0.5 m (20 in) depth), elevation of 2,700–3,600 m (8,858–11,811 ft), and slopes less than 25 degrees where denning would be expected to occur. Total area meeting these three criteria was 339 km^2 (131 mi^2) (dark blue in Figure 11), with an additional 446 km^2 (172 mi^2) with snow depth greater than 0.5 m (20 in) (light blue in Figure 11), mostly at higher elevations. Figures 12 (*fio* scenario) and Figure 13 (*giss* scenario) show a similar distribution, albeit larger areas of significant snow retention in the future (see map legends in Figures 12 and 13 for area estimates).

Table 9. Distance of historical GLAC dens (Years 2003–2007) from projected significant snow covered area in the future (approximately Year 2055) (using 2000–2013 average).

A 0 (zero) value indicates the den site location meets all three criteria in the future (greater than 0.5 m (20 in) snow depth on May 1st, at elevation 1,514–2,252 m (4,967–7,389 ft), and with a slope less than 25 degrees).

Den Site	Elevation, m (ft)	Distance from den site to nearest model cell, m (ft)		
		GCM scenario		
		miroc	*cnrm*	*giss*
1	2,252 (7,389 ft)	0	0	0
2	2,093 (6,867 ft)	0	0	0
3	1,995 (6,545 ft)	0	0	0
4	1,977 (6,486 ft)	210 (689 ft)	0	0
5	1,973 (6,473 ft)	208 (682 ft)	0	0
6	1,928 (6,326 ft)	0	0	0
7	1,922 (6,306 ft)	9 (29.5 ft)	8 (26 ft)	8 (26 ft)
8	1,912 (6,273 ft)	170 (558 ft)	0	0
9	1,893 (6,211 ft)	110 (361 ft)	0	0
10	1,851 (6,073 ft)	87 (285 ft)	0	0
11	1,843 (6,047 ft)	74 (243 ft)	0	0
12	1,823 (5,981 ft)	56 (184 ft)	0	0
13	1,807 (5,929 ft)	0	0	0
14	1,514 (4,967 ft)	574 (1,883 ft)	571(1,873 ft)	296 (971 ft)

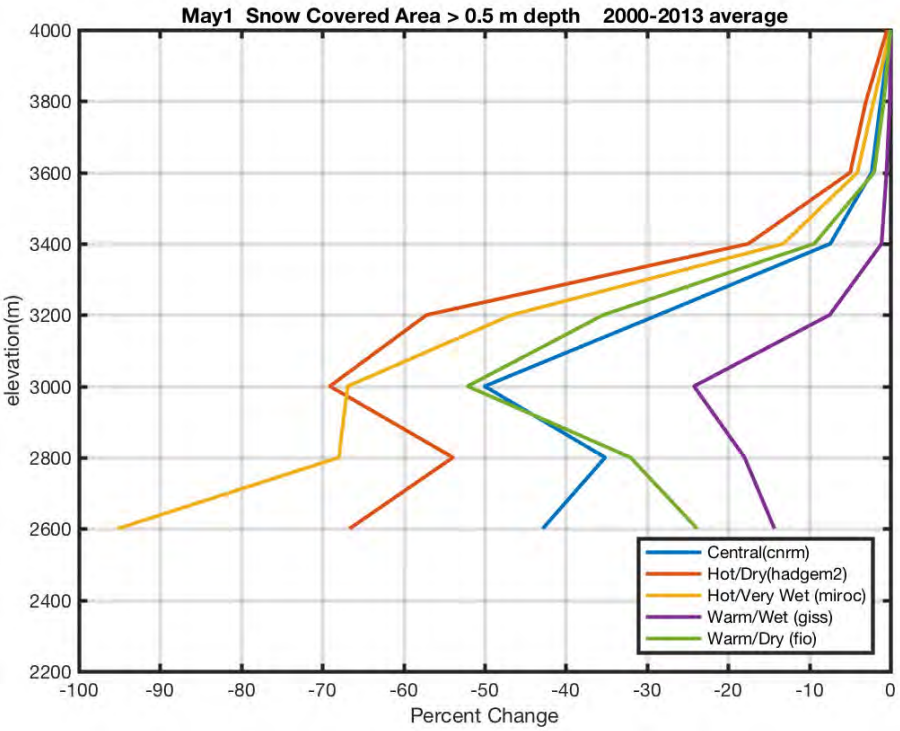

Figure 6. Average Snow Covered Area (depth ≥ 0.5 m (20 in)) percent change at elevation bands for GLAC for five future scenarios on May 1.

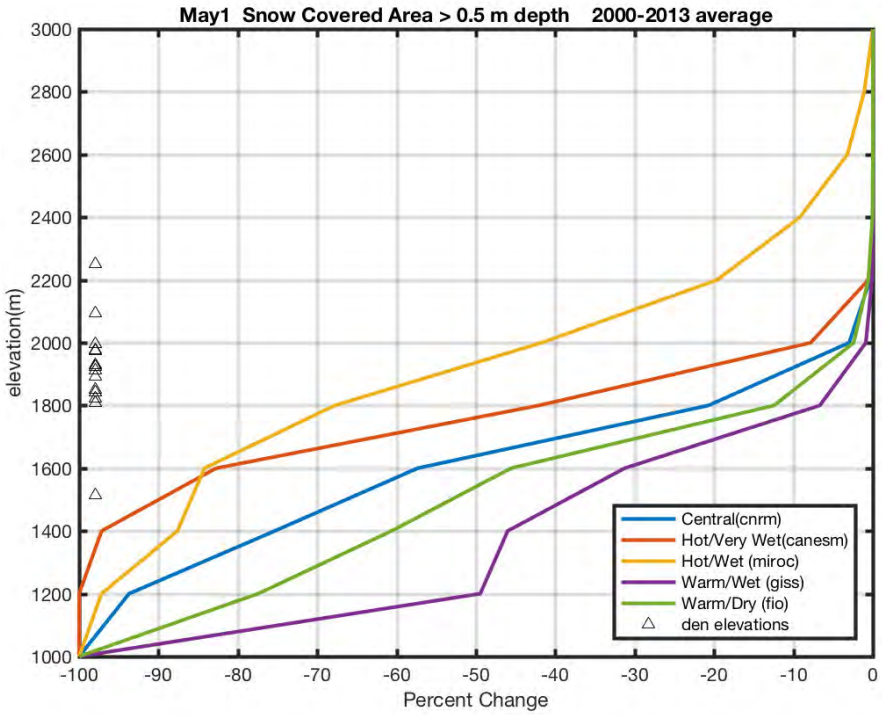

Figure 7. Average Snow Covered Area (depth ≥ 0.5 m (20 in)) percent change at elevation bands for ROMO for five future scenarios on May 1.

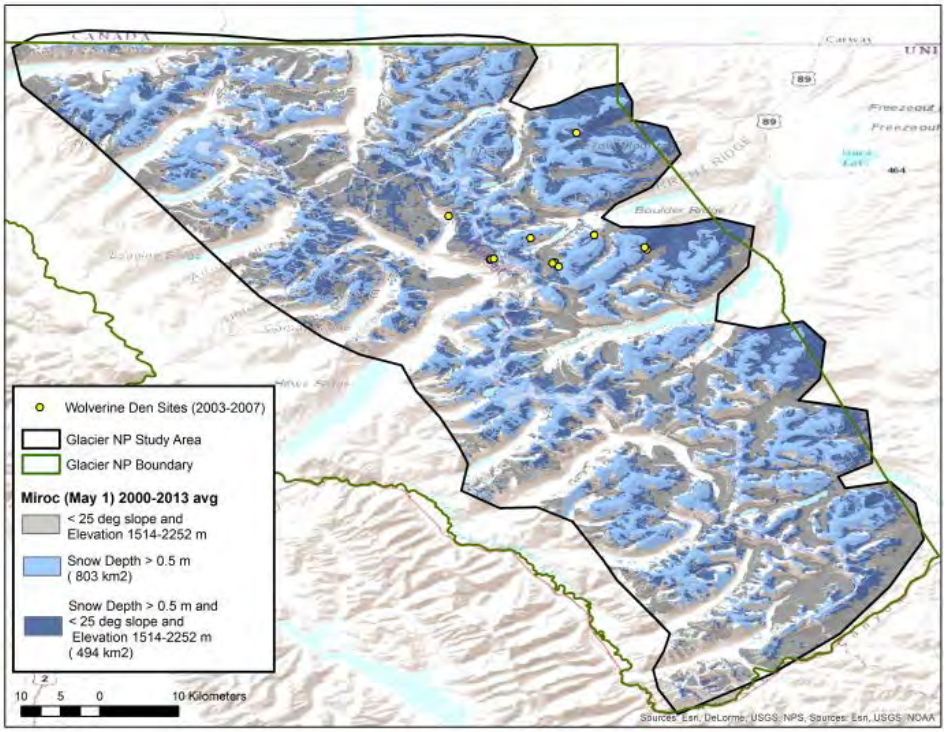

Figure 8. Spatial distribution of averaged (2000-2013) projected snow covered area (depth ≥ 0.5 m (20 in)) for May 1 under the *miroc* (Hot/Wet) scenario in Glacier National Park study area. Map legend shows where slopes are less than 25 degrees and elevations of 1,514–2,252 m (4,968–7,389 ft) (where dens have been documented).

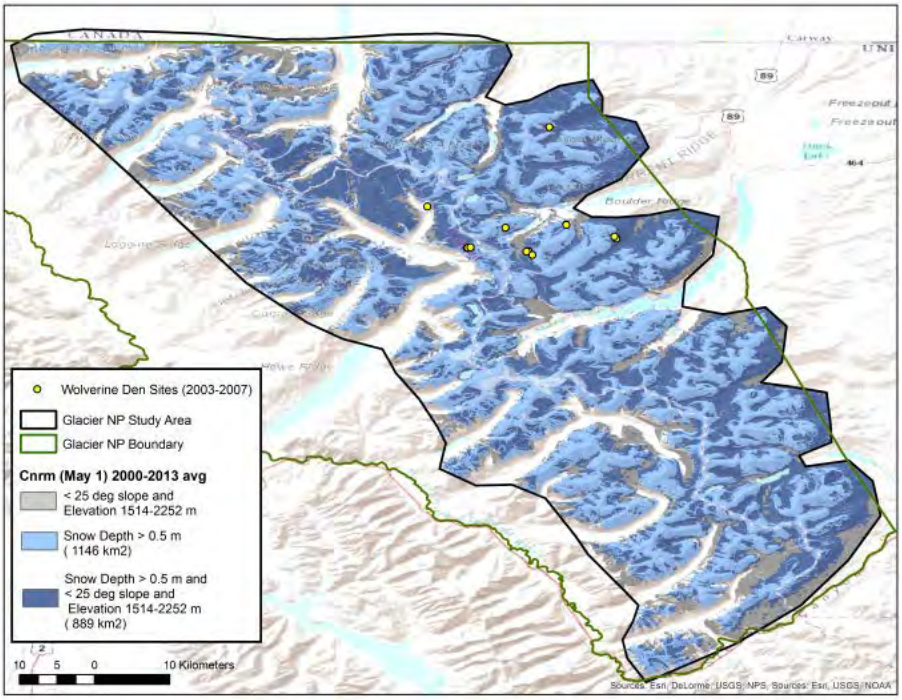

Figure 9. Spatial distribution of averaged (2000-2013) projected snow covered area (depth ≥ 0.5 m (20 in)) for May 1 under the *cnrm* (Central) scenario in Glacier National Park study area. Map legend shows where slopes are less than 25 degrees and elevations 1514–2252 m (4,968–7,389 ft) (where dens have been documented).

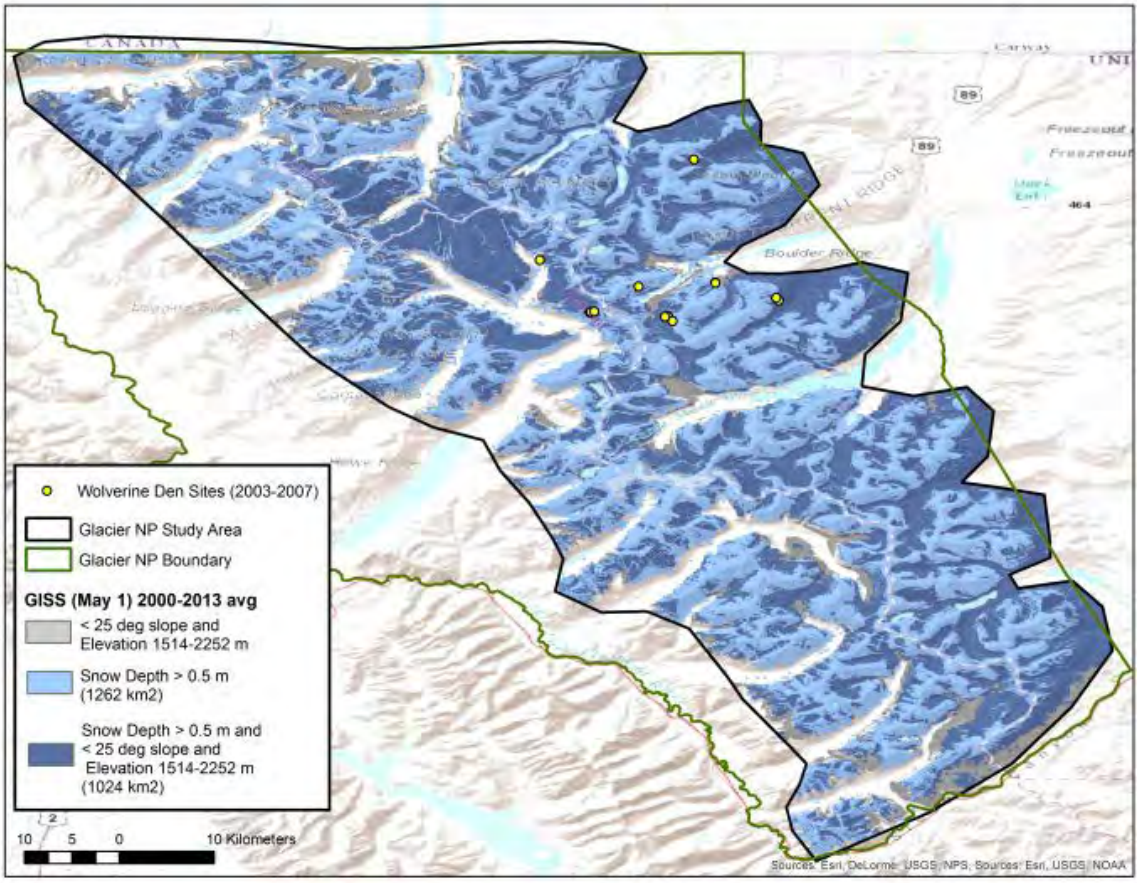

Figure 10. Spatial distribution of averaged (2000-2013) projected snow covered area (depth ≥ 0.5 m (20 in)) for May 1 under the *giss* (Warm/Wet) scenario in Glacier National Park study area. Map legend shows where slopes are less than 25 degrees and elevations 1,514–2,252 m (4,968–7,389 ft) (where dens have been documented).

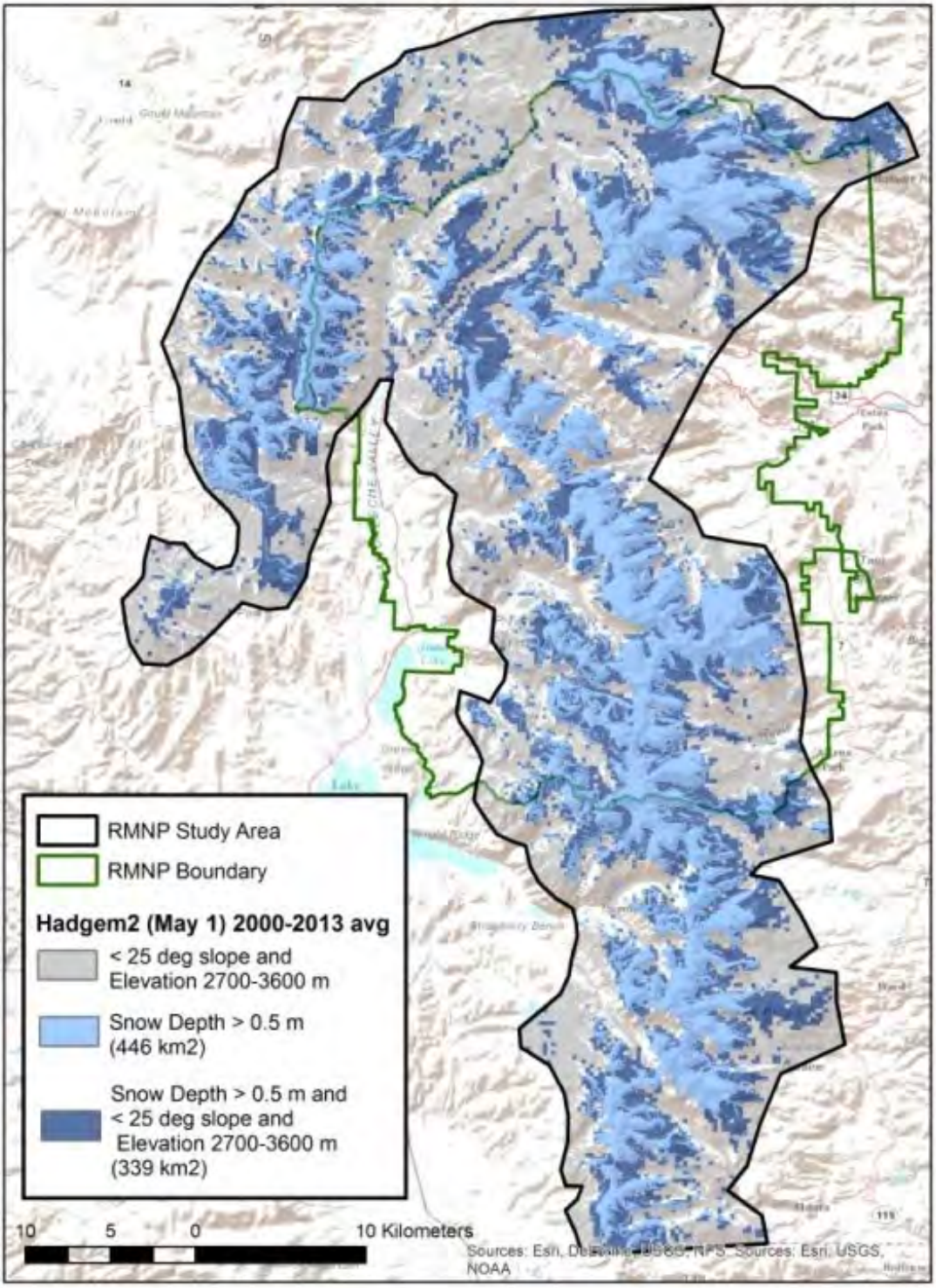

Figure 11. Spatial distribution of averaged (2000-2013) projected snow covered area (depth ≥ 0.5 m (20 in)) for May 1 under the *hadgem2* (Hot/Dry) scenario in Rocky Mountain National Park study area. Map legend shows where slopes are less than 25 degrees and elevations 2,700–3,600 m (8,858–11,811 ft) (inferred elevations where dens would be expected if occupied).

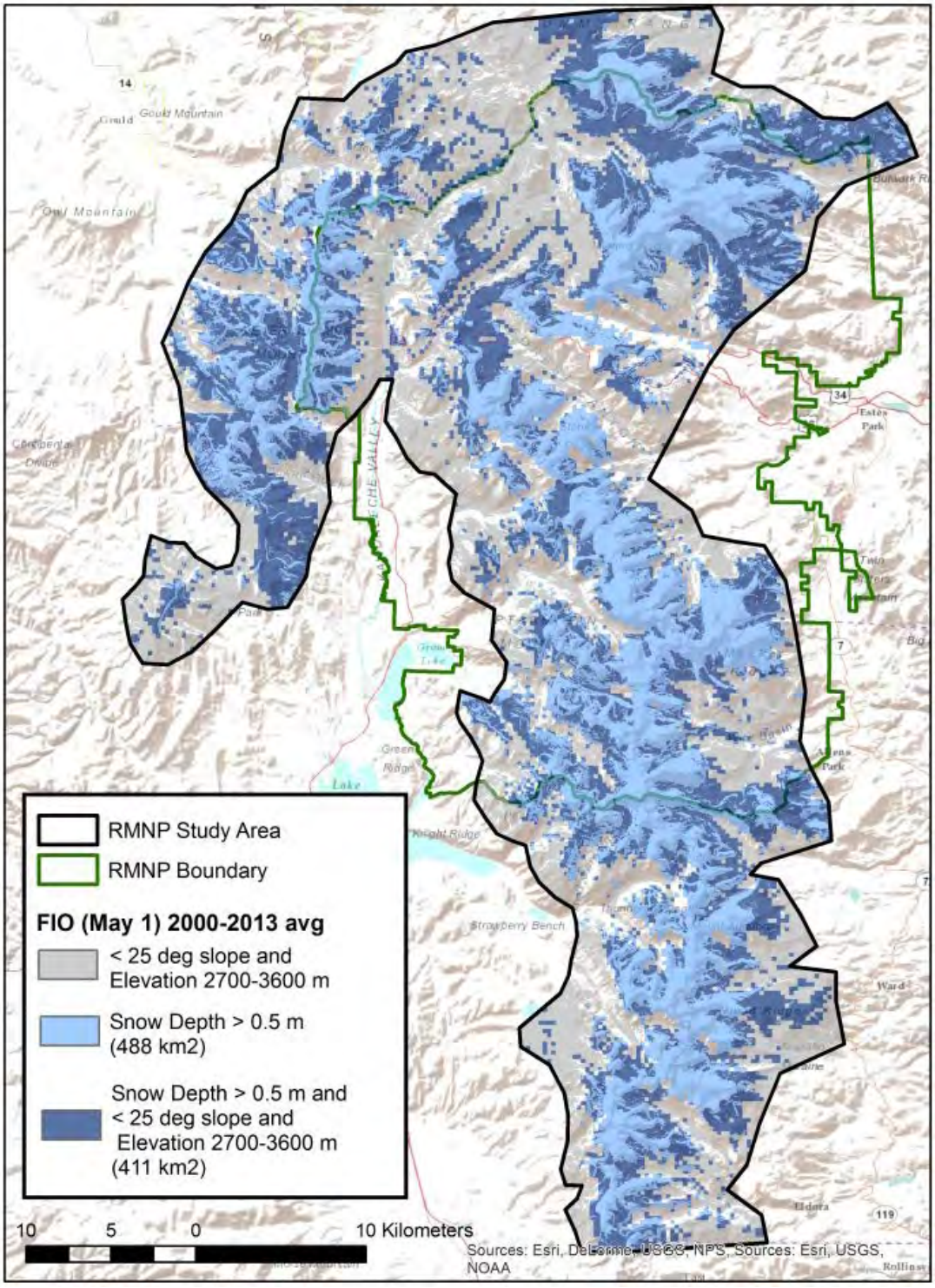

Figure 12. Spatial distribution of averaged (2000-2013) projected snow covered area (depth ≥ 0.5 m (20 in)) for May 1 under the *fio* (Warm/Dry) scenario in Rocky Mountain National Park study area. Map legend shows where slopes are less than 25 degrees and elevations 2,700-3,600 m (8,858–11,811 ft) (inferred elevations where dens would be expected if occupied).

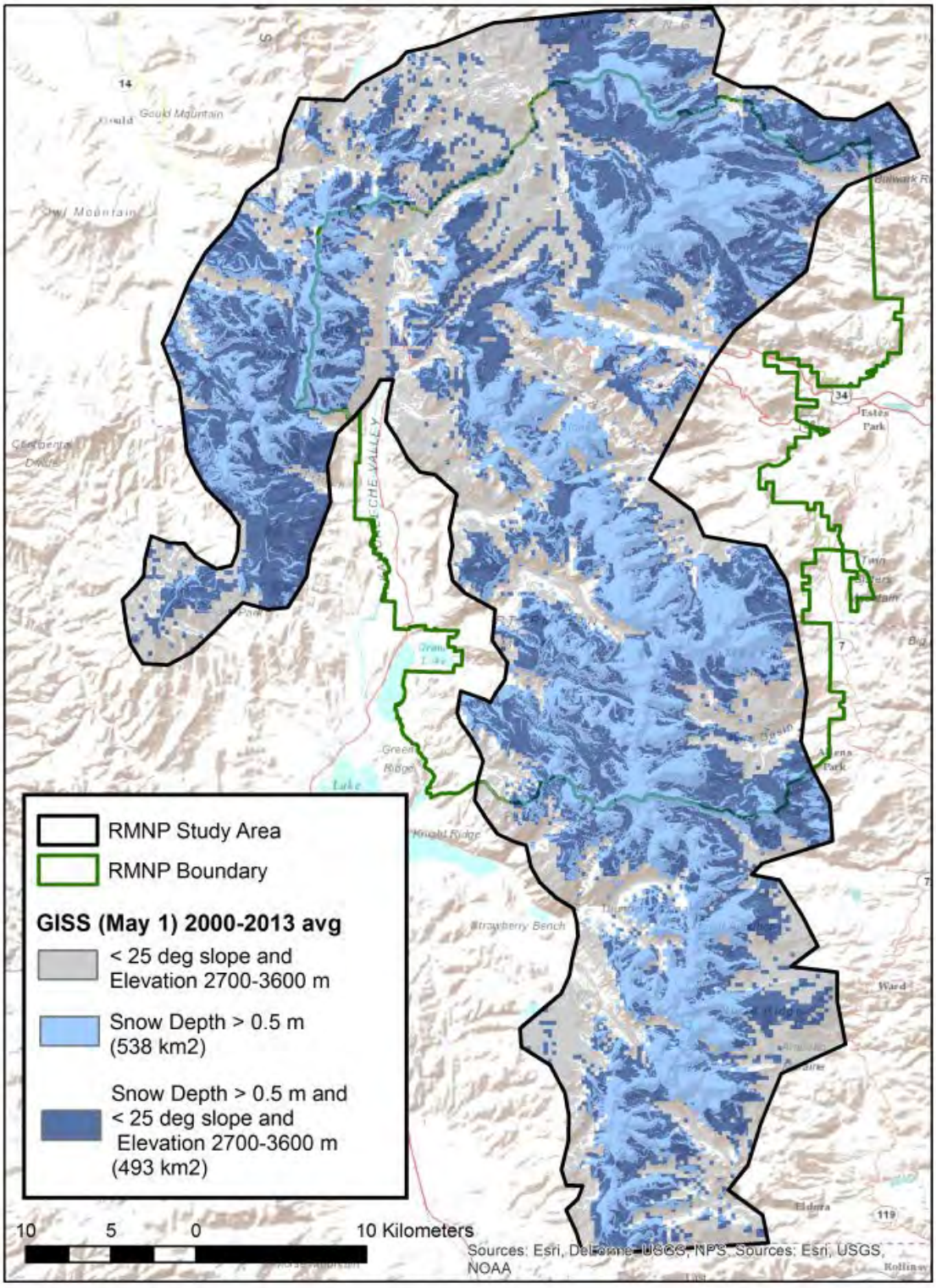

Figure 13. Spatial distribution of averaged (2000-2013) projected snow covered area (depth ≥ 0.5 m (20 in)) for May 1 under the *giss* (Warm/Wet) scenario in Rocky Mountain National Park study area. Map legend shows where slopes are less than 25 degrees and elevations 2,700-3,600 m (8,858–11,811 ft) (inferred elevations where dens would be expected if occupied).

Montana Climate Assessment

Another recent assessment of snowpack was conducted for the State of Montana (Whitlock *et al*. 2017, no page number). The report analyzed recent climate trends in Montana and assessed how climate is projected to change in the future (2040–2069). The study found that snowpack that accumulates at high elevations tends to be more stable and persists longer than at low elevations, due largely to the colder temperatures at high elevations. The largest projected changes in snowpack appear to be in areas located west of the Continental Divide, given their exposure to relatively warm Pacific air masses. Overall, the assessment found that declines in snowpack volume are likely in the future in the basins studied.

Wildland Fire

California

Keeley and Syphard (2016, entire) analyzed fire-climate relationships relative to predicting future fire regimes in California. Their review concluded that: (1) Climate is not a major determinant of fire activity across all landscapes; (2) hotter and drier conditions for areas at lower elevations and lower latitude were found to have little or no increase in fire activity as vegetation types in these regions are ignition limited; (3) increasing annual temperatures by themselves are not good predictors of increased fire activity; seasonality, especially spring and summer temperatures, are more important; and (4) fire-climate models need to be scaled to vegetation types; broad-scale models may produce over-predictions of the total increase in future fire regimes (Keeley and Syphard 2016, pp. 1, 10). Additionally, drought is a key factor in defining fire regimes and annual precipitation is the primary driver of drought variability (Williams *et al*. 2015, p. 6,819), but, at the present time, it is difficult to separate current droughts in California from natural cycles of drought (Keeley and Syphard 2016, p. 6).

Pacific Northwest

Sheehan *et al*. (2015, entire) used downscaled CMIP5 projections to model vegetation and fire changes, with and without fire suppression, within three subregions of the Pacific Northwest. Emission scenarios RCP 4.5 and 8.5 were used for future climate projections (2011–2100). The resulting trends varied by geographic region. In the Western Northwest subregion (from the crest of the Cascade Mountains west), the mean fire interval (MFI) averaged over all climate projections decreased by up to 48 percent, an increase in annual percent area burned (PAB), and the predominant conifer forest is replaced by mixed forest under future climate under both RCP scenarios, with and without fire suppression; thus, climate, rather than fire was found to be the primary influence in this subregion (Sheehan *et al*. 2015, pp. 22–26). In the Eastern Northwest Mountains (ENWM) subregion (mountainous areas east of the Cascade Mountains), the MFI (averaged across all climate projections) decreased by up to 81 percent, there was a projected increase in mean annual PAB, and, while subalpine communities are projected to be lost, conifer forests were projected to continue to dominate this subregion (Sheehan *et al*. 2015, pp. 22–24). When modeled using a without fire suppression regime, the future projections for ENWM indicated a lower MFI and higher mean annual PAB as compared to the with fire suppression regime (Sheehan *et al*. 2015, p. 22; Table 5). However, the eastern portion of the ENWM

subregion was found to show a differing response based on elevation; that is, higher elevations were found to have a *higher* MFI and a *lower* mean annual PAB during the 20th century as compared to lower elevations (Sheehan *et al*. 2015, p. 23).

Gergel *et al*. (2017, entire) evaluated the effects of climate change on snowpack, and soil moisture and fuel moisture (fire potential) in the western United States. This study used a statistical downscaling approach, using an ensemble of 10 GCMs across several mountainous regions known to be occupied by wolverines, with a 6.25 km (3.88 mi) spatial resolution hydrologic model. Simulations were run for three future periods: 2020s (2010–2039), 2050s (2040–2069), and 2080s (2070–2099) (Gergel *et al*. 2017, p. 291). The authors report significant declines in snowpack (measured as SWE) in all mountain ranges for all future scenarios (using RCPs 4.5 and 8.5) and GCMs (Gergel *et al*. 2017, p. 295). This study found that spring snowpack in mountains along the Pacific Coast is quite sensitive to warmer temperatures, but in the continental mountain ranges (Northern and Southern Rocky Mountains) spring snowpack is more sensitive to changes in precipitation (Gergel *et al*. 2017, p. 295). Differences were observed based on elevation (Gergel *et al*. 2017, p. 292). The study reported on future projected declines of summer soil moisture in forested areas (e.g., Northern Rockies) and the likelihood of increased risk of drought and therefore an increase in wildland fire risk for forested areas (e.g., Northern Rocky Mountains), though they recognize there is significant uncertainty in these future projections in high-elevation areas (Gergel *et al*. 2017, pp. 295–296).

In summary, based on these projections, wildland fire risk is likely to increase across the western United States, but future patterns and trends of wildland fire are dependent on several factors (e.g., degree of warming and drought conditions, fuel and soil moisture, wildland fire management practices, elevation) and geographic region.

Other Cumulative Effects

Finally, we note here that the effects of climate change on snowpack are projected to negatively affect the season lengths for winter recreational activities, such as skiing and snowmobiling (Wobus *et al*. 2017, entire), thus, potentially reducing this stressor to the wolverine in the future. Wobus *et al*. (2017) modeled potential changes in snowpack at locations across the contiguous United States using output from five GCMs, two representative pathways (RCPs) that represent a future scenario with continued high emissions growth with limited efforts to reduce GHGs (RCP 8.5) and a future scenario with global GHG mitigation (RCP 4.5), and two future time periods (2050 and 2090) (Wobus *et al*. 2017, pp. 2, 5). Although there was some inter-annual variability in 2050 for some model projections, in general, the Rocky Mountains and Sierra Nevada regions had smaller reductions in season length than other locations due to higher elevation, though for the RCP 8.5 scenario coupled with the 2090 future time period, the smallest projected reduction in season length was 15 percent (Wobus *et al*. 2017, p. 9).

Summary of Future Conditions

Models represent tools to describe basic physical and biological behaviors using the best available science, and, by presenting a range of plausible future outcomes, they can help generate hypotheses while also identifying knowledge gaps where greater accuracy is needed (Batchelet *et*

al. 2016, p. 23). Detecting a species' response to climate change in a single population, and sometimes multiple populations, may not always indicate the response throughout its range given the variation in annual mean surface temperatures over the past century (Post 2013, p. 5). In addition, inter-annual variability in temperature can be as important to a species' ecological needs as the actual temperature itself (Post 2013, p. 7).

Climate change model projections for the range of the wolverine within the contiguous United States indicate increases in temperature by the mid-21st century as compared to early to mid-20th century values. Precipitation patterns into the future are less clear as the climate models show significant disagreement in their many regional projections. Although drought conditions in the western United States are not unusual, drought duration and intensity have the potential to be exacerbated by projected temperature increases. Projected temperature and precipitation changes will affect future snow cover and the persistence of snow on the landscape.

Snow cover is projected to decline in response to warming temperatures and changing precipitation patterns, but this varies by elevation, topography, and by geographic region. Simulations of natural snow accumulation at winter recreation locations have found that, overall, higher elevation areas (e.g., Rocky Mountains, Sierra Nevada Mountains) are more resilient to projected changes in temperature and precipitation as compared to lower elevations (Wobus *et al*. 2017, p. 12). In general, models indicate higher elevations will retain more snow cover than lower elevations, particularly in early spring (April 30/May1).We present results (above) from several recent climate models projecting snowpack declines in the western United States. More specifically, we reviewed a new analysis from NOAA/CU that modeled future snow persistence for Glacier and Rocky Mountain National Parks (areas that encompass the latitudinal and elevational range of the wolverine in the contiguous United States) at high spatial resolution (Ray *et al*. 2017, entire). Their results indicate significant areas (several hundred square kilometers (miles) for each site) of future snow (greater than 0.5 m (20 in) in depth) will persist on May 1st at elevations currently used by wolverines for denning. This is true, on average, across the range of climate models used out to approximately Year 2055.

Although it has been assumed that wolverines have an obligate relationship with snow for natal denning, the key variables or combination of variables, that defined this relationship have not been empirically analyzed. As discussed above (**Box 1**), depth of snow cover and its duration increases with elevation; even minor elevation differences are noticeable (Formozov 1963, p. 123). The spotty distribution of snow cover is also affected by unequal distribution of snow precipitation on slopes with different exposures, transport of snow by wind, melting of snow on sun-exposed slopes, avalanche or rolling down of snow from steeper areas, and vegetation (Formozov 1963, p. 123). As discussed above (Denning Habitat), wolverines select den sites for differing characteristics depending on location, and wolverine (natal) dens have been observed outside of the boundary of the snow model presented in Copeland *et al*. (2010). In addition, very few studies to date have evaluated the importance of denning habitat to reproductive success, or the key physiological and ecological characteristics, including avoidance and/or protection from predators, prey availability, availability of food caching habitat, that define denning behavior and den site selection.

We also considered temperature and precipitation projections from climate change models in conjunction with wildland fire risk. This risk is likely to increase across the western United States, but patterns and trends are dependent on several factors (e.g., degree of warming and drought conditions, fuel and soil moisture) and geographic region.

As described above (see *Life History and Ecology* section), across their North American range, wolverines are found in a number of habitats, and exhibit wide-ranging movements. In conjunction with behavioral responses (e.g., dispersal over great distances, prey switching), physiological adaptations, including observed seasonal changes in the insulative capacity of fur, allow wolverines to occupy a variety of habitats throughout the year. Physiological adaptations at the cellular and biochemical level are also important in adapting to projected increases in temperature due to climate changes, though we are unaware of studies evaluating these types of responses in wolverines.

Overall Assessment

The wolverine's current range extends across the west-northwestern United States, large areas of Canada, and Alaska. In the contiguous United States, potentially suitable habitat (i.e., primary habitat), as determined by the physical and ecological features and the ecological needs of the wolverine, has been estimated at 164,125 km^2 (63,369 mi^2) (Inman *et al*. 2013, p. 281). The species is found in a variety of habitats, but generally occurs in remote locations.

In the contiguous United States, the structure of the wolverine population is represented as a metapopulation, although its genetic structure relative to its entire North American range has not been comprehensively evaluated. Wolverine populations in Alaska are considered to be continuous with populations in the Yukon and British Columbia provinces of Canada based on genetic studies (COSEWIC 2014, p. 37). Similarly, studies of wolverines in the North Cascades region have documented movement of wolverines from Washington into British Columbia (Aubry *et al*. 2016, pp. 16, 20).

Based on the best available information, wolverines select den sites for different characteristics depending on location. Dens located under snow cover may be related to wolverine distribution based on other life history traits, including morphological, demographic, and behavioral adaptations that allow them to successfully compete for food resources (Inman 2013, pers. comm.). Structure (e.g., uprooted trees, boulders and talus fields) appears to be essential for natal den sites. However, reproductive success of wolverines has not been evaluated relative to the depth and persistence of snow cover, or in combination with these or other important characteristics, including prey availability and predator avoidance. Recent studies of wolverine populations and distribution in Sweden have observed wolverine populations and reproductive den sites outside areas with persistent spring snow cover (Aronsson and Persson 2016; Persson 2017, pers. comm.).

We identified several potential stressors that may be affecting the species' and its habitat currently or in the future, including impacts associated with climate change effects. We recognize there is limited information available for the wolverine, including population estimates and abundance trends. Based on the best available information, demographic risks to the species

from either known or most likely potential stressors (i.e., effects from roads, disturbance due to winter recreational activities, effects of wildland fire, and overutilization) are low based on our evaluation of the best available information as it applies to current and potential future conditions for the wolverine and in the context of the attributes that affect the needs of the species.

Climate change model projections for the range of the wolverine within the contiguous United States indicate increases in temperature by the mid-21st century as compared to early to mid-20th century values. Our evaluation of climate change indicates that snow cover is projected to decline in response to warming temperatures and changing precipitation patterns, but this varies by elevation, topography, and by geographic region. In general, models indicate higher elevations will retain more snow cover than lower elevations, particularly in early spring (April 30/May1). Although the persistence of spring snow has not yet been evaluated as critical to wolverine survival in North America, our review of projected snow persistence (to approximately Year 2055) within the Northern and Southern Rocky Mountains, indicates that several hundred kilometers (miles) of deep snow will persist on May 1st at elevations used by the wolverine for denning.

Legal protections include State listing in California and Oregon (as threatened), endangered in Colorado, as a candidate species in Washington, and protection as a non-game species in Idaho and Wyoming. In Canada, provincial designations range from endangered to threatened in eastern provinces, and sensitive/special concern to no ranking in other provinces. Legal trapping or hunting of wolverines is currently prohibited in the contiguous United States. Trapping effort along the U.S.–Canada border does not represent a significant barrier to wolverine movement and dispersal along the international border.

Approximately 96 percent of modeled wolverine primary habitat in the contiguous United States is located on Federal lands, with 41 percent located in designated wilderness areas. Management actions for conservation of the wolverine and its habitat are included within State Wildlife Action Plans, the Idaho Wolverine Conservation Plan, and USDA Forest Service Land and Resource Management Plans (see **Appendix G**). Various provisions of these plans include, but are not limited to, winter road closures, fire management, and land acquisition or conservation easements. These management measures, currently and in the future, will alleviate effects associated with potential impacts related to stressors discussed in this report.

Based on our review of available relevant literature for similar species, we identified the physical and ecological needs of the species as follows: large territories in remote landscapes; at high elevation (1,800 to 3,500 meters (5,906 to 11,483 feet)) within the contiguous United States; access to a variety of food resources, that varies with seasons; and reproductive behavior linked to both temporal and physical features. These needs are currently met for wolverines in the contiguous United States and are expected to be met in the future.

Risk Assessment

In order to characterize a species' viability and demographic risks, we consider the concepts of resilience, representation, and redundancy. We also consider known and potential stressors that may negatively impact the physical and biological features that the species needs for survival and

reproduction. Stressors are expressed as risks to its demographic features such as abundance, population and spatial structure, and genetic or ecological diversity. We consider the level of impact a stressor may have on a species along with the consideration of demographic factors (e.g., whether a species has stable, increasing, or decreasing trends in abundance, population growth rates, diversity of populations, and loss or degradation of habitat).

Wolverine populations in much of North America are still recovering from large losses of individuals from intensively hunting and persecution pressures in the late 1880s into the mid-20th century. Surveys conducted in the winter of 2015, and 2016–2017 continue to document its presence across its range in the contiguous United States. These surveys have recorded 85 observations, including in locations where they have not been recently detected (e.g., south of Interstate 90 in Washington, Teton Mountain Range/Grand Teton National Park). Thus, based on the best available information, wolverines continue to be detected across suitable habitat within the contiguous United States. Redundancy, the ability to withstand catastrophic events, can be characterized by the distribution and connectivity of populations. In considering wolverine in the contiguous United States, individuals are spread across a wide range of locations and connected habitats, affording protection to withstand catastrophic events. Additionally, wolverines in the contiguous United States appear to be connected to wolverine populations in Canada, also contributing to current and future redundancy.

Resiliency, the ability to withstand stochastic events, can be characterized by numbers of individuals and abundance trends. As indicated above, population size, growth rate, and current population trends are unknown for the wolverine due to the lack of abundance information. The range of the wolverine occurs within a large area of northern North America (see Figure 3). The most recent estimate for Canada indicates over 10,000 adult wolverines, as well as expansion of wolverines into historically occupied areas in both Canada and the contiguous United States with movement across both international borders. The 2014 COSEWIC report concluded that a climate-driven decline in wolverine populations in North America is not evident at this time in much of its range (COSEWIC 2014, p. 22). Wolverine populations in Canada are considered stable. Density estimates indicate no declining trend in wolverine populations in Alaska. We recognize that there is limited information on population sizes for the wolverine in the contiguous United States, and no comprehensive studies to indicate what a viable (or minimal) wolverine population size should be across its North American range. However, the best available information does not indicate either increasing or declining numbers of the wolverine in North America, including the contiguous United States. Further, at this time, the best available information does not indicate that the species' abundance is significantly impacted by human-caused stressors and this is unlikely to change in the future, supporting current and future resiliency.

As discussed above (Status–Future Conditions), both direct and cumulative effects of climate change (e.g., higher temperatures, loss of snow cover, wildland fire) may affect the resilience of the wolverine by creating an environment that is less favorable to its physiological and ecological needs. We are unaware of studies of the wolverine that have formally evaluated the species' responses (e.g., reproductive success) to warming temperatures or other climate change effects. However, a recent evaluation of behavioral plasticity, as an adaptive response to climate change effects, was presented for another mammal considered to be sensitive to climate change

effects—the American pika (*Ochotona princeps*; pika) (Beever et al. 2017, entire). As with the wolverine, this species is known to use several behavioral responses to variability in climate including changes in foraging strategies, use of habitat, and thermoregulation (Beever *et al*. 2017, p. 302). The pika was recently detected in heavily shaded rainforest habitat adjacent to talus patches at lower elevation (Columbia River Gorge) not typical of the talus-type habitats commonly used in many alpine areas of the western United States (Beever *et al*. 2017, p. 302). The authors suggest that, in the Columbia River Gorge region, this species is selecting microclimates in nearby shaded forests that provide insulation from warm summer temperatures (Beever *et al*. 2017, p. 302).This study also included results from a review of available literature related to behavior as a response to changing environmental conditions for several taxonomic groups. They found that behavioral responses to climate change effects were most commonly observed in longer-lived species, and the most common response, across all taxa, was a change in reproductive behavior, followed by dispersal or migration (Beever *et al*. 2017, p. 300). Most of the studies they evaluated identified temperature as the climate metric that was responsible for, or correlated with, changes in behavior; however, about 14 percent of the examined literature included responses to indirect (biotic) factors, such as changes in food resources (Beever *et al*. 2017, p. 300).

The authors also note that there are tradeoffs (e.g., reduction in time for foraging due to sheltering) that may impact long-term persistence and population viability (Beever *et al*. 2017, pp. 301–302), and the pika's flexibility in habitat selection has not been observed in populations in the Great Basin (Beever *et al*. 2017, p. 302), where some populations have been extirpated (Beever *et al*. 2016, p. 1,498; Table 1). A recent study concluded that the pika has been extirpated from an interior portion of its geographic distribution in the Sierra Nevada region (California) due to climate effects (i.e., increase in temperature, decline in snowpack), and although sites surrounding this core area still harbor the species, the net effect has been fragmentation of habitat and species distribution (Stewart *et al*., 2017, entire).

However, the pika continues to be found at sites that are outside of areas contained within bioclimatic envelop models (Jeffress *et al*. p. 253). The study found previously undocumented extant populations of the American pika in a region of the Great Basin (northwestern Nevada) that has been described as extirpated (Jeffress *et al*. 2017, entire). Relative to wolverine, the authors note that these results highlight the need for monitoring programs, particularly at remote and isolated locations, and the importance of evaluating occupancy at multiple scales (Jeffress *et al*. 2017, p. 266). In addition, the study noted the inconsistency of modeled climate factors in explaining occupied/unoccupied sites, and the likely importance of the pika's talus (micro) habitat as well as the scale in which environmental variables are examined (Jeffress *et al*. 2017, p, 264). Resilience of pika populations is therefore likely related to these types of landforms, which act to decouple surface temperatures, with the talus rock habitat providing cool refugia (Jeffress *et al*. 2017, pp. 253, 264–265), but additional microsite data is needed as well as analyses of physiological variables to develop predictions of persistence (Jeffress *et al*. 2017, pp. 265–266). In sum, these studies indicate that small mammals exhibit adaptive responses to changing climate provided that refugia are available to support life history requirements. These studies also highlight the importance of continued monitoring and surveillance for difficult to study animals such as the wolverine, who are found in remote areas in naturally low densities, as

well as the potential for geographical variation and habitat structure in adaptation to climate change effects.

As described in this SSA Report, the best available information indicates confirmed observations of wolverines denning in areas with patchy snow cover in Alaska, Canada, and Scandinavia. Given their high rate of movement, large dispersal, and other observed life history traits (e.g., behavioral plasticity) observed in wolverines, we do not predict a significant loss of individual and population resiliency to the species in the future within its North America range, including the contiguous United States.

Currently, we are unaware of any documented specific risks for the wolverine related to a substantial change or loss of diversity in life history traits, population demographics, morphology, behavior, or genetic characteristics which can be used to characterize species representation (the ability to adapt to change). Rates of dispersal or gene flow are not known to have changed. Additionally, there is no currently available information to indicate that the current abundance of the wolverine across its current range is at a level that is causing inbreeding depression or loss of genetic variation that would affect representation. Nor is there any information to indicate that this species is unable to adapt or adjust to changing conditions (e.g., potential reduction in snow cover). We do not expect a reduction in representation of the wolverines in the contiguous United States in the future.

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[**Add reviewer names, agency, Tribal Nations**]

USDA Forest Service (Regional Offices)
California State Agency
Washington State Agency
Oregon State Agency
Idaho State Agency
Montana State Agency
Wyoming State Agency
Tribal Nations

[**Add peer reviewer names**]

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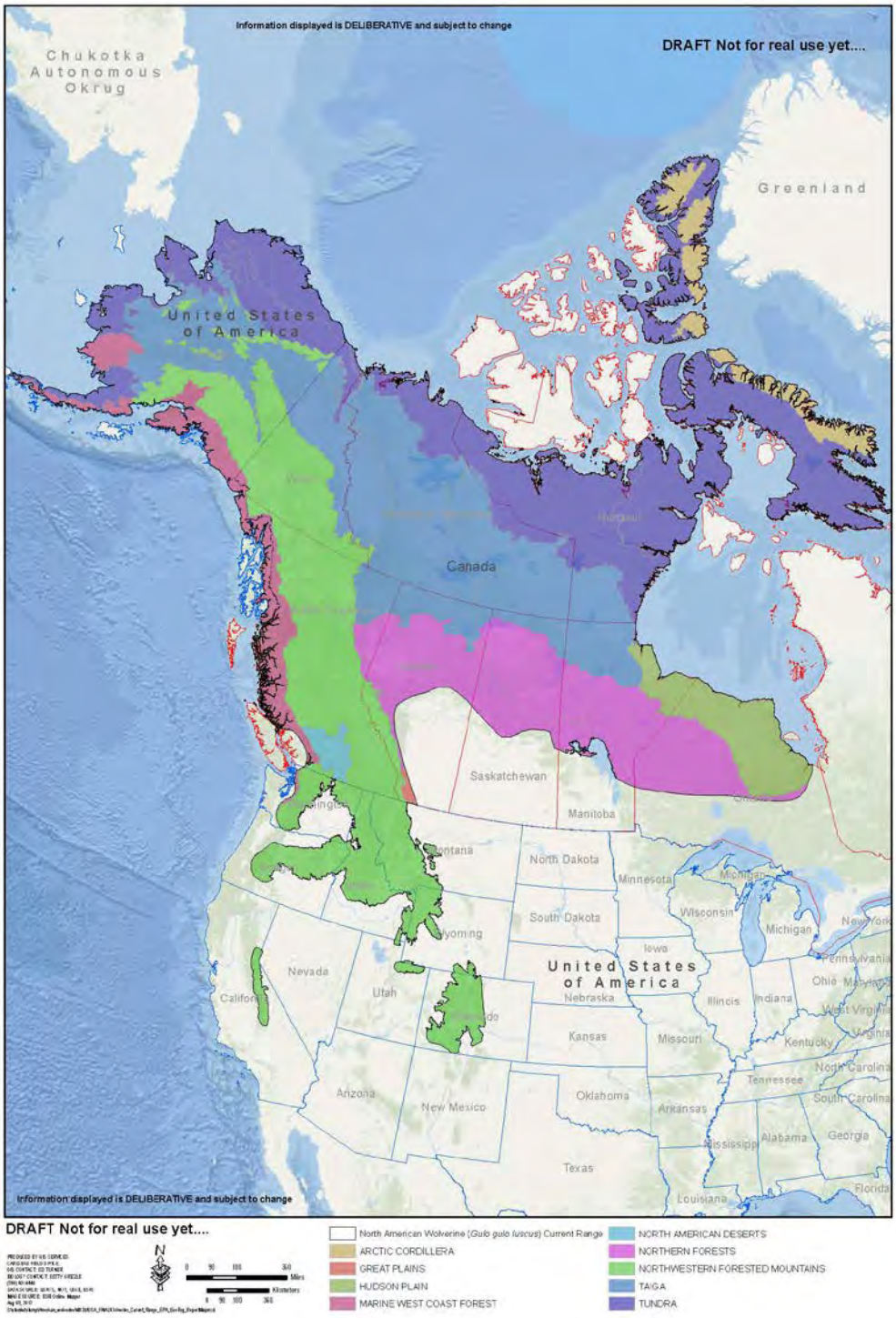
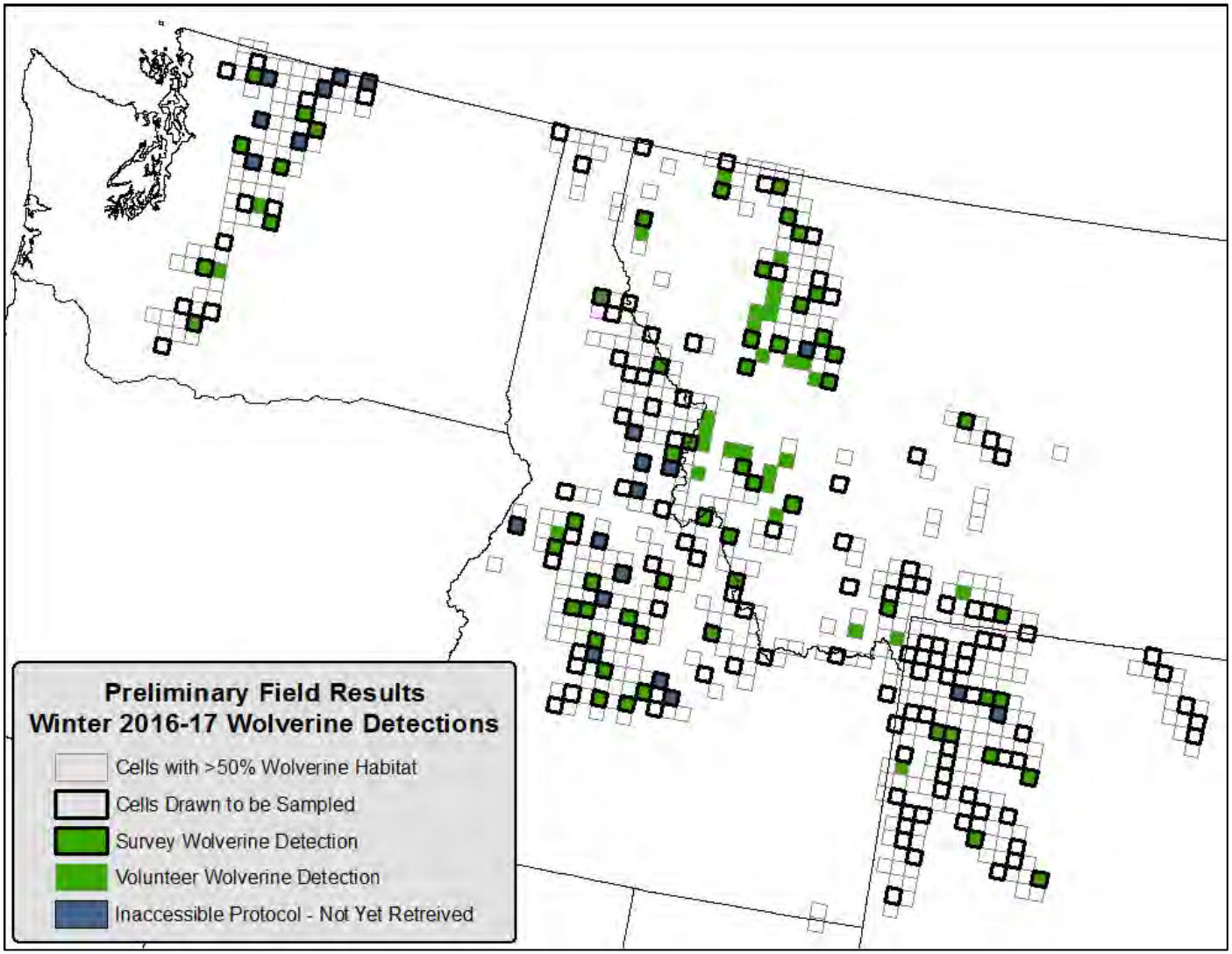
Appendices

Appendix A – Ecoregions of North American within Estimated Current Range of North American Wolverine
(Adapted from EPA 2010)

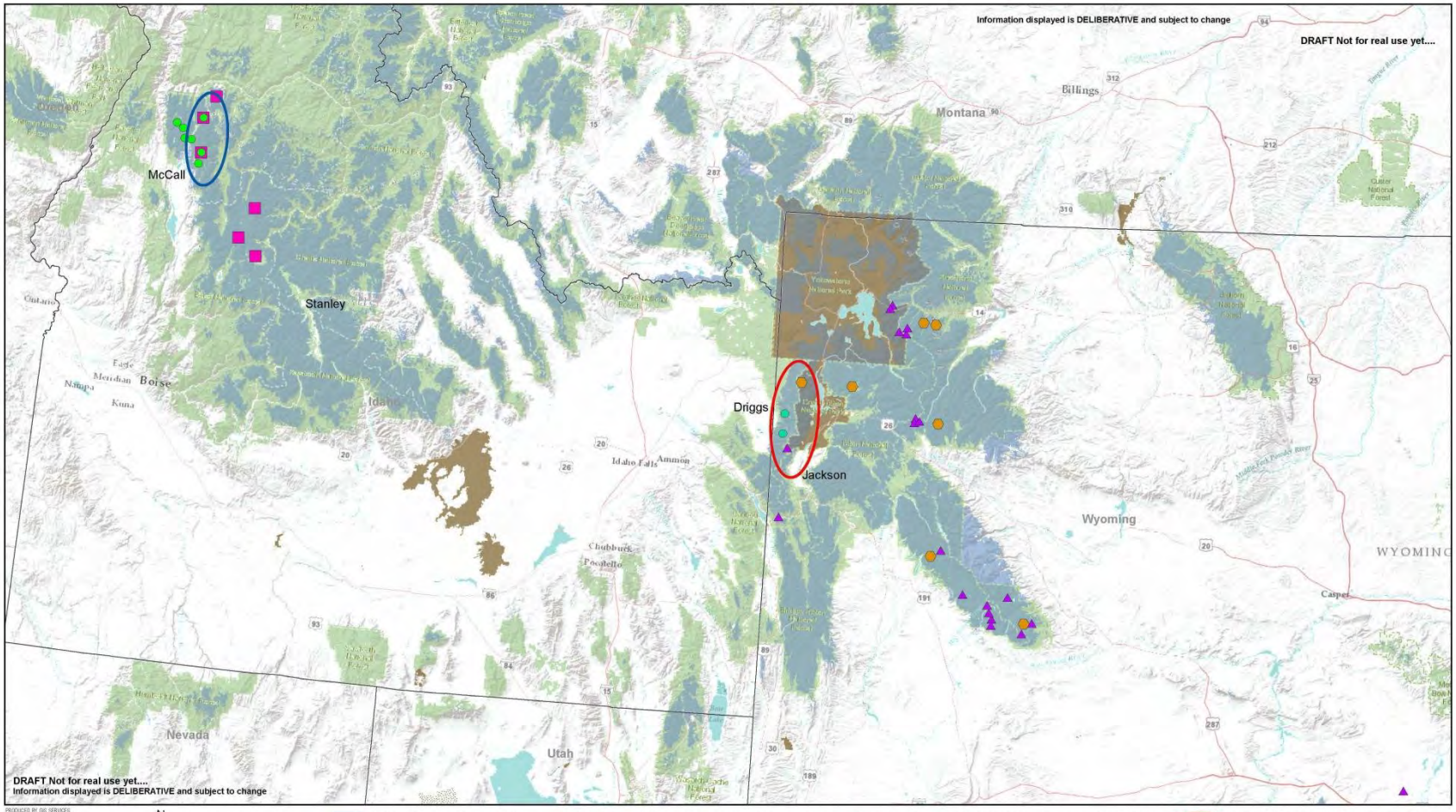


Appendix B – Wolverine Detections, Winter 2016–2017 (as of July 2017)
Source: Inman 2017b, pers. comm.



Appendix C – Recent Wolverine Detections, Idaho and Wyoming

Sources: Dewey 2017, pers. comm.; Evans Mack 2017a and 2017b, pers. comm.; Walker 2017, pers. comm.

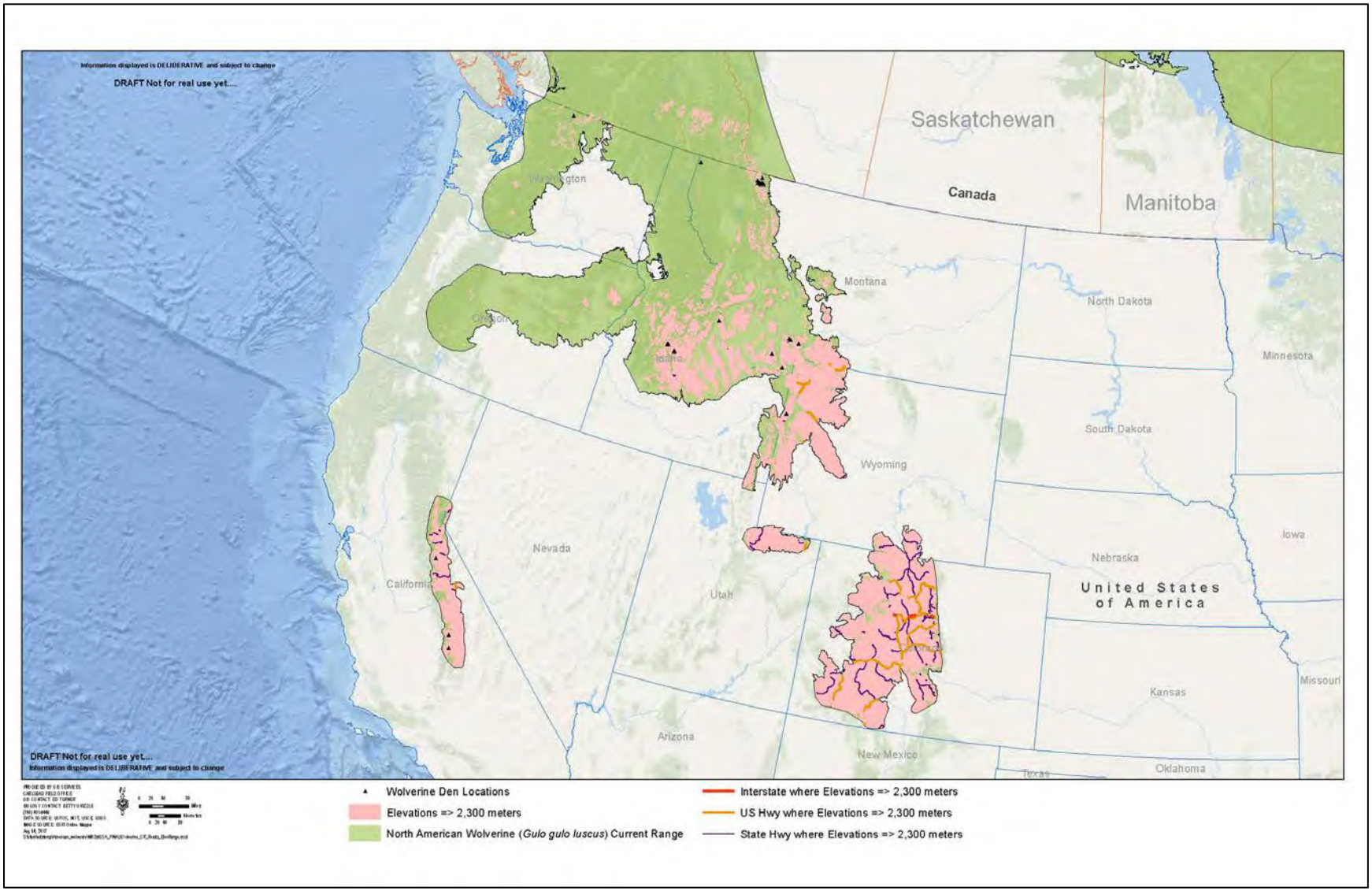


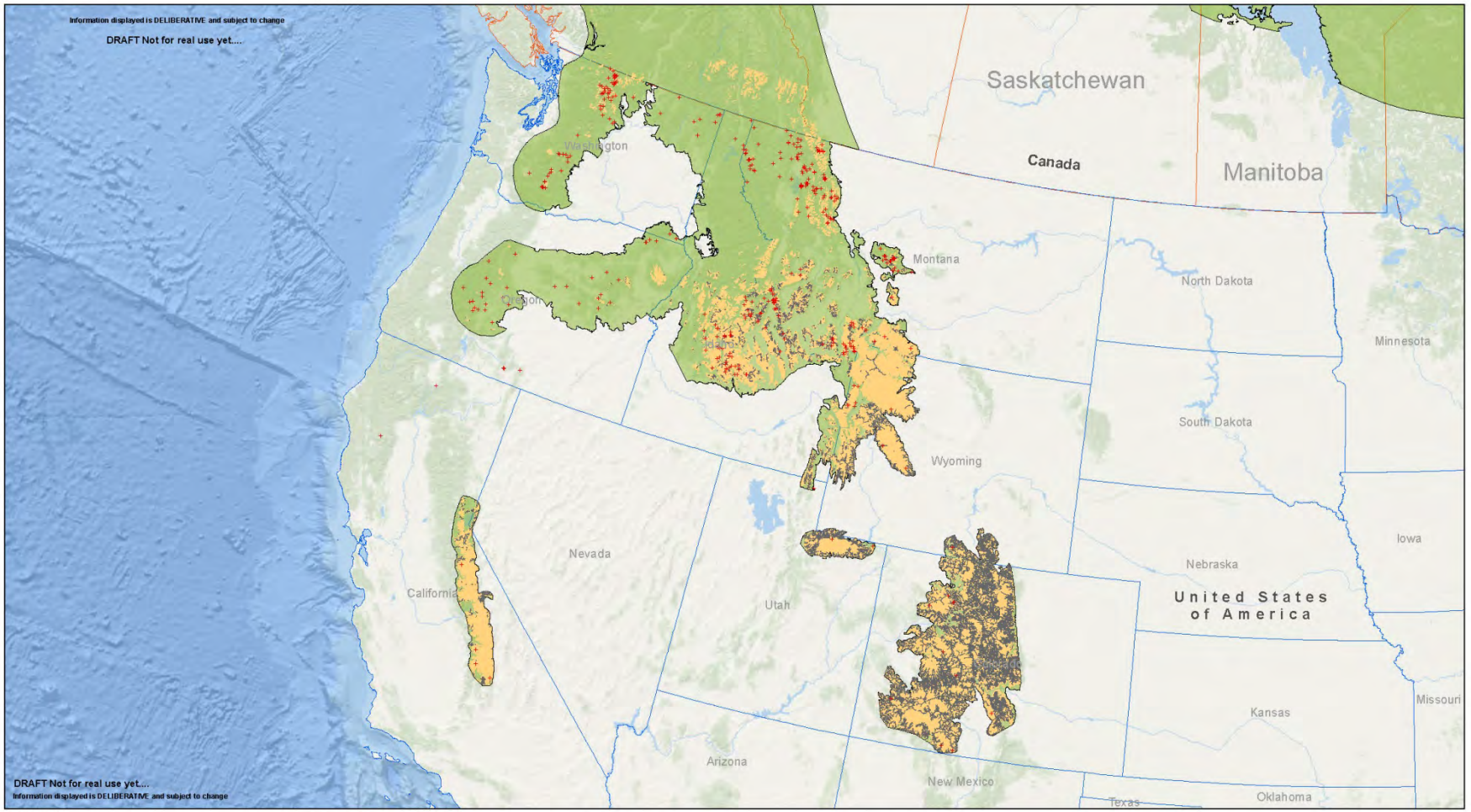
Appendix D – Land Ownership of Modeled Wolverine Primary Habitat in Contiguous United States
(based on model from Inman *et al*. 2013)

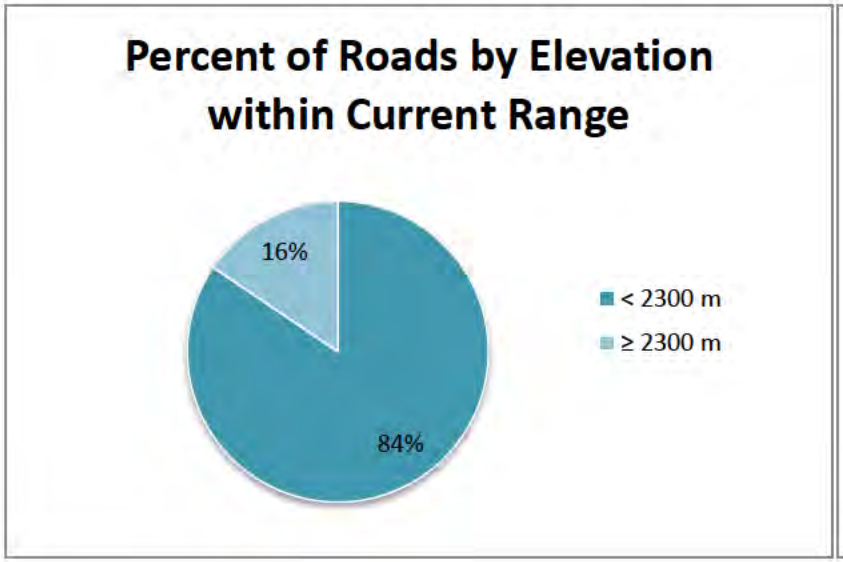
Ownership (% of total)	**Agency or other Entity**	**Total (acres)**	**Total (hectares)**
Federal Lands	Bureau of Indian Affairs	453,866	183,673
	Bureau of Land Management	498,977	201,929
	Bureau of Reclamation	1,868	756
	Forest Service	34,331,515	13,893,471
	U.S. Fish and Wildlife Service	5,528	2,237
	National Park Service	3,791,491	1,534,362
	Other U.S. Department of Agriculture	13,312	5,387
	Other Federal	0.05	0.02
Total Federal (96.4%)		**39,096,557**	**15,821,815**
State Lands (0.68%)	Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming	**277,181**	**112,171**
Local Government (0.12%)		**49,464**	**20,017**
Private Lands (2.63%)		**1,064,858**	**430,933**
No Code ("99") (0.15%)		**60,380**	**24,435**
Undetermined (0.02%)		**7,598**	**3,075**
Total (100%)		**40,556,038**	**16,412,446**

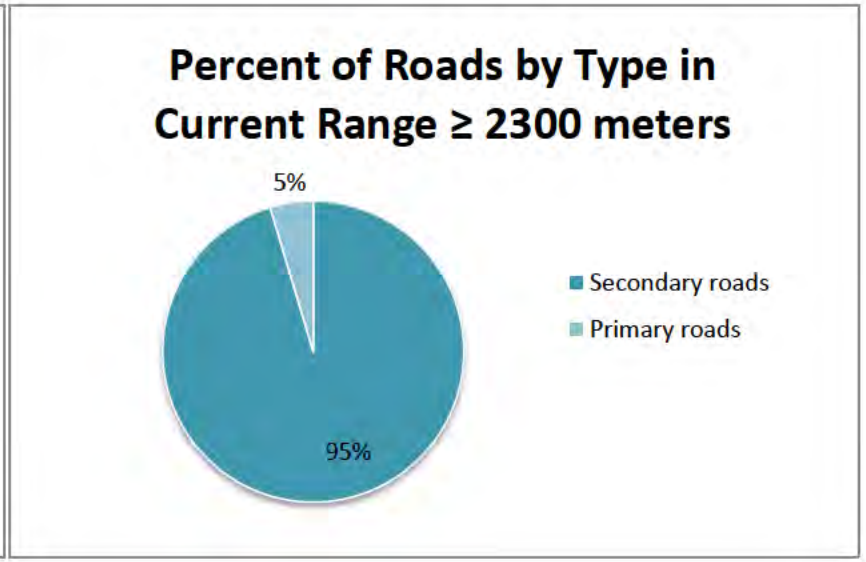
Note: Numbers may not total to 100 percent due to rounding.

Appendix E – Results from Spatial Analysis of Roads within Current Range of Wolverine

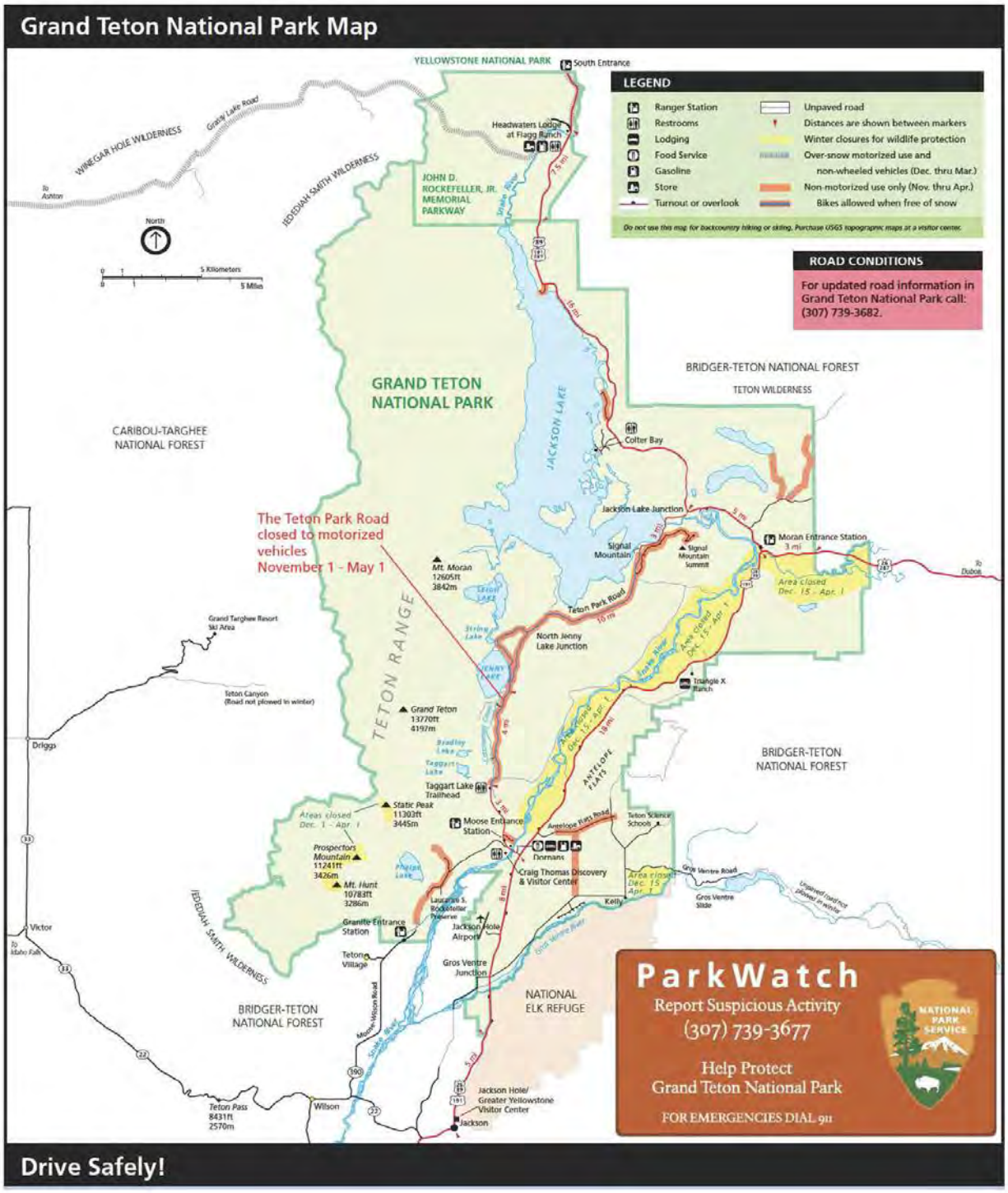



Information displayed is DELIBERATIVE and subject to change
DRAFT Not for real use yet....
Saskatchewan
Canada
Manitoba
Montana
North Dakota
Minnesota
South Dakota
Wyoming
Nevada
California
Utah
Nebraska
Iowa
United States of America
Kansas
Missouri
Arizona
New Mexico
Texas
Oklahoma
DRAFT Not for real use yet...
Information displayed is DELIBERATIVE and subject to change
Current Range Wolverine Locations
Secondary Roads where Elevations => 2,300 meters
Elevations => 2,300 meters
North American Wolverine (Gulo gulo luscus) Current Range


Percent of Roads by Elevation within Current Range
16%
84%
< 2300 m
≥ 2300 m


Percent of Roads by Type in Current Range ≥ 2300 meters
5%
95%
Secondary roads
Primary roads

Appendix F – Road Closure Map, Grand Teton National Park
Retrieved from: https://2v9usu38jb9t3l8big1ialsn-wpengine.netdna-ssl.com/wp-content/uploads/2015/11/GTNP-closure-map.pdf



Appendix G – Existing Regulatory Mechanisms and Voluntary Conservation Measures

Federal Mechanisms

Organic Administration Act of 1897 and the Multiple–Use, Sustained–Yield Act of 1960

The USFS Organic Act of 1897 (16 U.S.C. § 475–482) established general guidelines for administration of timber on USFS lands, which was followed by the Multiple–Use, Sustained–Yield Act (MUSY) of 1960 (16 U.S.C. § 528–531), which broadened the management of USFS lands to include outdoor recreation, range, watershed, and wildlife and fish purposes.

National Forest Management Act

The National Forest Management Act (NFMA) (16 U.S.C. § 1600 *et seq*.) requires the Forest Service to develop a planning rule under the principles of the MUSY of 1960 (16 U.S.C. § 528–531). The NFMA outlines the process for the development and revision of the land management plans and their guidelines and standards (16 U.S.C. § 1604(g)).

A new National Forest System (NFS) land management planning rule (Planning Rule) was adopted by the U.S. Department of Agriculture Forest Service (Forest Service) in 2012 (77 FR 21162; April 9, 2012). The new Planning Rule guides the development, amendment, and revision of land management plans for all units of the NFS to maintain and restore NFS land and water ecosystems while providing for ecosystem services and multiple uses. Land management plans (also called Forest Plans) are designed to: (1) Provide for the sustainability of ecosystems and resources; (2) meet the need for forest restoration and conservation, watershed protection, and species diversity and conservation; and (3) assist the Forest Service in providing a sustainable flow of benefits, services, and uses of NFS lands that provide jobs and contribute to the economic and social sustainability of communities (77 FR 21261, April 9, 2012). A land management plan does not authorize projects or activities, but projects and activities must be consistent with the plan (77 FR 21261; April 9, 2012). The plan must provide for the diversity of plant and animal communities including species-specific plan components in which a determination is made as to whether the plan provides the "ecological conditions necessary to…contribute to the recovery of federally listed threatened and endangered species…" (77 FR 21265; April 9, 2012).

The Record of Decision for the final Planning Rule was based on the analyses presented in the *Final Programmatic Environmental Impact Statement, National Forest System Land Management Planning* (77 FR 21162–21276; April 9, 2012), which was prepared in accordance with the requirements of the National Environmental Policy Act (NEPA) (discussed below). In addition, the NFMA requires land management plans to be developed in accordance with the procedural requirements of NEPA, with a similar effect as zoning requirements or regulations as these plans control activities on the national forests and are judicially enforceable until properly revised (Coggins *et al.* 2001, p. 720).

A Species of Conservation Concern (SCC) is defined in the 2012 Planning Rule and in regulation (36 CFR 219.9(c)), as "a species, other than federally recognized threatened,

endangered, proposed, or candidate species, that is known to occur in the plan area and for which the regional forester has determined that the best available scientific information indicates substantial concern about the species' capability to persist over the long-term in the plan area." The 2012 Planning Rule requires Regional Foresters to identify SCC for plan revision, and, when identified for a National Forest, monitoring plans are changed as needed (77 FR 21250, 21267; April 9, 2012). Wolverine is considered a SCC in the Rocky Mountain Region (Region 2). It is considered a Sensitive Species in the Intermountain Region (Region 4) and Northern Region (Region 1).

Within our estimated Current Range of the wolverine (see Figure 3), we identified 49 National Forests or Scenic Recreation Areas in the contiguous United States, and 2 within the State of Alaska. These areas are contained within 6 Forest Service Regions across the western United States and Alaska.

National Forest Land Management Plans (Forest Plans)

We reviewed several Forest Plans or related planning documents in an effort to describe how these plans provide conservation management for the wolverine and its habitat, including wildland fire management practices. The sections below are, in most cases, taken directly from relevant documents. However, this discussion is not intended to be inclusive of all NFS management strategies and activities across the entire Current Range of the wolverine in the contiguous United States.

Sierra Nevada Forest Plan Implementation

The 2004 Sierra Nevada Forest Plan Amendment (referred to as the Sierra Nevada Framework) amended the Land and Resource Management Plans (LRMP) for the eleven National Forests in the Sierra Nevada range to improve protection of old forests, wildlife habitats, watersheds and communities in the Sierra Nevada Mountains and Modoc Plateau. This amendment applies to the Tahoe National Forest, which has been occupied by a single male wolverine since at least 2008 (Moriarty *et al*. 2009, p. 150). The emphasis of the 2004 Sierra Nevada Framework is to adopt an integrated strategy for vegetation management that is aggressive enough to reduce the risk of wildfire to communities in the wildland urban interface, while modifying fire behavior over the broader landscape. Direction is provided as management goals and strategies, desired conditions, management intents and objectives, and management standards and guidelines. The 2004 Framework addressed five problem areas: old forest ecosystems and associated species; aquatic, riparian and meadow ecosystems and associated species; fire and fuels management; noxious weeds; and lower west side hardwood ecosystems (Forest Service 2013, p. 2–3).

Kootenai National Forest

The Kootenai National Forest is located in the northwest corner of Montana along the Canadian border and includes about 2.2 million acres of public land (Forest Service 2015, p. 7). The Forest Service published a Revised Land Management Plan for the Kootenai National Forest in 2015 that identifies forestwide direction, including goals, desired conditions, objectives, standards, and guidelines for physical and biological elements including wildlife such as management activities

that promote connectivity and avoiding or minimizing disturbance at known active denning sites for sensitive, proposed, threatened, or endangered species not covered under other forestwide guidelines. It also outlines objectives and guidelines related to the use of fire to maintain or improve habitat and maintaining unlogged conditions in some portions of areas burned by wildfires for 5 years post-fire (Forest Service 2015, pp. 28–32).

The Kootenai National Forest Land Management Plan also identifies *proposed or possible* actions for wildlife management that includes establishing and maintaining the vegetation diversity necessary to provide food, cover, and security for wildlife species native to the Kootenai National Forest in cooperation with federal, state, and other organizations. For wolverine, those management activities might include maintaining, managing, and protecting lands known or suspected to contribute to landscape linkages for wolverine (and other carnivores) in order to promote genetic dispersal and healthy populations (Forest Service 2015, p. 128).

Beaverhead-Deerlodge National Forest

The Beaverhead-Deerlodge National Forest covers 3.38 million acres in southwest Montana (Forest Service 2009, p. 2). The Beaverhead-Deerlodge National Forest Land and Resource Management Plan identifies goals, objectives, and standards for wildlife management (Forest Service 2009, pp. 45–49). Of relevance to the wolverine, wildlife security management goals include securing areas and connectivity for ungulates and large carnivores and managing the density of open motorized roads and trails by landscape region (Forest Service 2009, p. 45). Objectives include management of habitat conditions for elk security and winter habitat integrity for wolverine and mountain goat relative to changes in abundance of these Management Indicator Species (Forest Service 2009, p. 47). Monitoring elements are defined in the Land and Resource Management Plan that link goals and objectives to elements of the National Monitoring and Evaluation Framework (Forest Service 2009, pp. 273–280). For wildlife security, three performance measures relative to determining whether management activities are effectively protecting high elevation winter habitats for wolverines and mountain goats are defined: (1) presence or absence of wolverines in high elevation habitats, (2) populations of mountain goats (from Montana Fish Wildlife & Parks), and (3) number of snowmobile entries into non-motorized high elevation units protected for wolverines and mountain goats (Forest Service 2009, p. 277). In addition, in order to evaluate objectives related to road and trail densities, a performance measure related to changes in open motorized road and trail density for both seasons by landscape is included (Forest Service 2009, p. 277).

The Forest Service is monitoring the Mount Jefferson Recommended Wilderness boundary for illegal snowmobile intrusions into the wolverine habitat closure; that is, illegal use will be monitored and recorded (number and distance of intrusions) during the period open to snowmobiles December 2 to May 15 and any other time of the year snow conditions make snowmobiling possible (Forest Service 2009, p. 277). A reassessment of the decision to allow snowmobile use will be triggered if: (1) illegal intrusions are documented throughout the closure period; (2) illegal intrusions into the closed area, or (3) illegal intrusions that extend as far as the Bureau of Land Management (BLM) Wilderness Study Area (Forest Service 2009, p. 277).

Flathead National Forest

The Flathead National Forest is located in the northern Rocky Mountains in western Montana and includes approximately 2.4 million acres of public land (Forest Service 2016a, p. 3). This National Forest is surrounded by the Kootenai, Lewis and Clark, and Lolo National Forests, Glacier National Park, and Canada and includes large areas of designated wilderness (e.g., Bob Marshall Wilderness Complex, Mission Mountains Wilderness), Crown of the Continent Ecosystem, and wild and scenic river systems (Forest Service 2016a, pp. 3–4).

A Draft Revised Forest Plan was prepared for the Flathead National Forest in 2016 (Forest Service 2016b, entire). The Draft Revised Forest Plan identifies components to guide future projects and activities and the plan monitoring program, though these components are not commitments or final decisions approving projects or activities (Forest Service 2016b, p. 3). These components include desired conditions, objectives, standards, guidelines, suitability, and monitoring questions and monitoring indicators (Forest Service 2016b, p. 3). [A *desired condition* is a description of specific social, economic, and/or ecological characteristics of the plan area, or a portion of the plan area, toward which management of the land and resources should be directed, while an *objective* a concise, measurable, and time-specific statement of a desired rate of progress toward a desired condition or conditions (Forest Service 2016b, p. 4). A *standard* is a mandatory constraint on project and activity decision making, established to help achieve or maintain the desired condition or conditions, and a *guideline* is a constraint on project and activity decision-making that allows for departure from its terms, and are established to help achieve or maintain a desired condition or conditions, to avoid or mitigate undesirable effects, or to meet applicable legal requirements (Forest Service 2016b, pp. 4–5).]

Relative to wolverine, plan components for the revised forest plan include two guidelines that are protective of wolverine habitat; one that would protect modeled wolverine maternal denning habitat with respect to new projects or activity authorizations involving helicopter use and one that stipulates no net increase in the percentage of modeled wolverine maternal denning habitat where motorized over-snow vehicle use would be suitable on National Forest System lands. Additionally, as described in the Final EIS, management area allocations for Alternatives A, B modified and C include recommended wilderness areas that would add to existing wilderness. Desired conditions related to maintaining connectivity for wolverine and other wildlife are also identified within several geographic areas (Kuennen 2017, pers. comm.).

Federal Land Policy and Management Act (FLPMA) of 1976

FLMPA (43 U.S.C. 1711-1712) represents the BLM's "organic act" for public lands management under the principles of multiple use and sustained yield. Its implementing regulations give BLM regulatory authority over activities for protection of the environment, including mining claims. Under FLPMA and BLM policy, public lands must be managed so as to protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archaeological values (BLM 2005, p. 1).

Land Use and Resource Management Plans

BLM land use planning requirements are established by Sections 201 and 202 of FLMPA and regulations at 43 CFR 1600 (BLM 2005, p. 1). A *Land Use Planning Handbook* (BLM 2005, entire) provides guidance for implementing land use planning requirements established under FLMPA and implementing regulations. Land use plans prepared by BLM include resource management plans (RMPs) and management framework plans (BLM 2005, p. 1). The RMPs establish the basis for actions and approved uses on the public lands and are prepared for areas of public lands, called planning areas (BLM 2005, pp. 1, 14). These plans are periodically evaluated and revised in response to changed conditions and resource demands (BLM 2005, pp. 33–34).

National Environmental Policy Act (NEPA)

All Federal agencies are required to adhere to the NEPA of 1970 (42 U.S.C. 4321 et seq.) for projects they fund, authorize, or carry out. Prior to implementation of such projects with a Federal nexus, NEPA requires the agency to analyze the project for potential impacts to the human environment, including natural resources. The Council on Environmental Quality's regulations for implementing NEPA state that agencies shall include a discussion on the environmental impacts of the various project alternatives (including the proposed action), any adverse environmental effects that cannot be avoided, and any irreversible or irretrievable commitments of resources involved (40 CFR part 1502). The public notice provisions of NEPA provide an opportunity for the Service and other interested parties to review proposed actions and provide recommendations to the implementing agency. NEPA does not impose substantive environmental obligations on Federal agencies—it merely prohibits an uninformed agency action. However, if an Environmental Impact Statement is prepared for an agency action, the agency must take a "hard look" at the consequences of this action and must consider all potentially significant environmental impacts. Federal agencies may include mitigation measures in the final Environmental Impact Statement as a result of the NEPA process that may help to conserve the wolverine and its habitat.

Although NEPA requires full evaluation and disclosure of information regarding the effects of contemplated Federal actions on sensitive species and their habitats, it does not by itself regulate activities that might affect the wolverine; that is, effects to the subspecies and its habitat would receive the same scrutiny as other plant and wildlife resources during the NEPA process and associated analyses of a project's potential impacts to the human environment. The Service receives notification letters for Draft and Final Environmental Impact Statements prepared by the Forest Service, BLM and other Federal agencies pursuant to NEPA for specific proposed projects including those within National Forests or National Parks, and preparation of Forest Service Land and Resource Management Plans, as discussed above.

Wilderness Act

The Wilderness Act of 1964 (16 U.S.C. 1131–1136) provides protection of habitat from most forms of development, though no single agency is responsible for administration of lands provided this designation, which are designated (or modified) by Congress. The Wilderness Act prohibits commercial enterprises and permanent roads within wilderness area and restricts temporary roads, motorized and mechanical transport, and structures, but does not prohibit all commercial uses (e.g., grazing). Within the portion of our estimated Current Range of the

wolverine in the contiguous United States and Alaska, approximately 15 percent is designated as wilderness areas under the Wilderness Act. We also evaluated wilderness contained within modeled wolverine primary habitat from Inman *et al*. (2013). We found 41 percent of this suitable habitat was designated as wilderness areas.

State Mechanisms

California

As noted above, the wolverine is a threatened species under the California Endangered Species Act or CESA, which prohibits the take of any species of wildlife designated by the California Fish and Game Commission as endangered, threatened, or candidate species (CDFW 2017b). CDFW may authorize the take of any such species if certain conditions are met through the issuance of permits (e.g., Incidental Take Permits) (CDFW 2017b). The wolverine is also a Species of Greatest Conservation Need (SGCN) in the State's Wildlife Action Plan[5] and is a focal species of conservation strategies for conservation targets in the Southern Cascades and Sierra Nevada Ecoregions, and in the Mono Ecoregion of the Deserts Province section (Big Sagebrush Scrub (CDFW 2015, pp. 5.2-16, 5.4-23, 5.6-19).

In 2011, the CDFW (formerly California Department of Fish and Game) prepared an assessment/briefing document, *California Wolverine Population Augmentation Considerations*, in response to a *Feasibility Assessment and Implementation Plan for Population Augmentation of Wolverines in California* (November 2010) submitted to the Department by the Institute for Wildlife Studies (California Department of Fish and Game (CDFG) 2011). As of August 2017, no action has been taken by CDFW toward implementation of augmentation of wolverines in California.

Oregon

The wolverine has been listed as threatened species in Oregon since 1975, under the Oregon Endangered Species Act, and is fully protected under management authority of the ODFW (Anglin 2013, pers. comm.).

A Conservation Strategy for conserving the State's fish and wildlife has been prepared by the ODFW. The Conservation Strategy identifies 294 Strategy Species, which are Oregon's SGCN, (including wolverine) and are defined as those species having small or declining populations, are at-risk, and/or are of management concern (ODFW 2016). For each of the Strategy Species, the Conservation Strategy identifies information on the special needs, limiting factors, data gaps, and conservation actions. For wolverine, conservation actions include management of recreational use to avoid impacts to the species (ODFW 2016). Other Strategy Species identified in the

[5] The U.S. Congress created the State Wildlife Grant (SWG) funding program in 2000 (Title IX, Public Law 106-553 and Title 1, Public Law 107-63). SWG funds are to be used "…for the planning and implementation of [States and territories] wildlife conservation and restoration program and wildlife conservation strategy, including wildlife conservation, wildlife conservation education, and wildlife-associated recreation projects." Congress stipulated that each State or territory applying for this funding program must develop a wildlife conservation strategy (**State Wildlife Action Plan** (SWAP)) by October 1, 2005. All 56 states and territories submitted SWAPs by 2005 and made commitments to review and/or revise their SWAP at least every 10 years.

State's Conservation Strategy are prey species important to wolverine, including the Rocky Mountain bighorn sheep and Columbian white-tailed deer (ODFW 2016).

Washington

The wolverine is a candidate species for listing in the State of Washington and, since 2006, the Washington Department of Fish and Wildlife (WDFW) has been collaborating with wolverine researchers in the Cascades of northern Washington and southern British Columbia to better understand the status, distribution, and general ecology of wolverines in this region (WDFW 2013). It is also considered a SGCN, and is identified as a species whose population is in critical condition (WDFW 2013, pp. 3-7).

Washington's State Wildlife Action Plan (updated in 2015) identifies several major conservation strategies to address the conservation of fish and wildlife habitat and biodiversity in Washington, on both public and private lands (WDFW 2015, pp. 2-12–2-28). The wolverine is included in several identified ecological systems of concern such as alpine scrub, forb meadow, and grassland vegetation, cliff, scree and rock vegetation, and temperate forests (WDFW 2015, pp. 4-19, 4-27, 4-98). The State's *Wildlife Action Plan* identifies major stressors and key actions needed to maintain habitat quality for each of these ecological systems.

Of relevance to wolverine, the WDFW and its partners have been targeting land acquisition and conservation easements with high habitat or biodiversity values such as mixed-conifer forests as well as areas that support winter range and connectivity for wolverine and other carnivores (e.g., Methow River and Okanogan River Watersheds projects) (WDFW 2015, pp. 2-15–2-17). Other landscape conservation efforts highlighted in the State's Wildlife Action Plan include a Federal-State partnership with Washington's Department of Transportation to implement the Interstate-90 Snoqualmie Pass East Project to enhance wildlife connectivity that includes wildlife underpasses under the highway along creeks and rivers and two 150-foot wide wildlife bridges over the highway (WDFW 2015, p. 2-26).

Idaho

In Idaho, the wolverine is a protected nongame species and SGCN in Idaho (IDFG 2014). The *Idaho State Wildlife Action Plan, 2015* is a statewide plan for conserving and managing Idaho's fish and wildlife and their habitats, and provides a framework for conserving Idaho's 205 SGCN and their habitats, which includes the wolverine (IDFG 2017b, pp. xv–xviii). The wolverine is identified as a Tier 1 SGCN, which indicates it represents a species of most critical conservation need (IDFG 2017b, p. xvi). The statewide plan presents a species assessment for each SGCN and ecological section plans. Each of the ecological section plans presents a conservation target (e.g., habitat, species assemblage) that summarizes its viability as well as prioritized threats and strategies (IDFG 2017b, p. xv). A section outlining species designation, planning, and monitoring is also provided. The wolverine is included in three of the defined conservation targets—forested lowlands, subalpine-high montane conifer forest, and low density forest carnivores (IDFG 2017b, p. 76). Along with objectives and strategies, these summaries identify actions for the SGCNs included in the defined conservation targets. Examples include: develop and implement a long-term multi-taxa monitoring program; determine high risk areas for wildlife

crossings; construct highway over- and underpasses; promote and/or facilitate the use of prescribed fire as a habitat restoration tool, on both public and private lands where appropriate; determine best management practices to maintain cool microsites and benefit cool air associated species; and implement strategies to minimize disturbance from winter recreation activities as outlined in the *Management Plan for the Conservation of Wolverines in Idaho, 2014–2019* (IDFG 2017b, pp. 79, 80, 91, 94, 110).

The *Management Plan for the Conservation of Wolverines in Idaho, 2014–2019* (Management Plan) (IDFG 2014, entire) represents a framework for proactive efforts to ensure the long-term persistence and viability of wolverine populations in Idaho (IDFG 2016, pers. comm.). The Management Plan is described as a voluntary guidance document to lead conservation efforts at the State and local level, as well as to facilitate communication and collaboration efforts among wildlife and land managers (IDFG 2014, p. v).

Conservation issues and management actions are described in the Management Plan and the appropriate section plans of the *Idaho State Wildlife Action Plan*. The recommended strategies include development of finer-scale climate projections, research regarding wolverine-snow relationships, characterizing wolverine response to recreational activities, developing predictions of the potential overlap of wolverine and high levels of snow-sports recreation, and educating trappers to minimize incidental trapping of nontarget species, including the wolverine (IDFG 2014, pp. 32–39; IDFG 2017b, p. 1058). Seven conservation and management objectives are outlined in the Management Plan (IDFG 2014, pp. 32–39) and, as outlined in a November 2016 response letter, there has been progress on all of these objectives (IDFG 2016, pers. comm.). As an example, the agency (under the Multi-species Baseline Initiative) has developed and implemented a baseline micro-climate monitoring protocol for collecting environmental parameters in an effort to identify areas that serve as cool-air refugia (IDFG 2016, pers. comm.). As described above (*Overutilization for Commercial, Recreational, Scientific, or Educational Purposes*), the IDFG has prepared educational materials to promote best management practices for minimizing non-target wolverine captures and continues to educate trappers under a legislative mandate passed in 2016 (State of Idaho House Bill 378) (IDFG 2016, pers. comm.).

In addition, management of prey species important to the wolverine diet is outlined in the Idaho Elk Management Plan 2014-2024 (IDFG 2014a), the Mule Deer Management Plan 2008-2017 (2008) and the Bighorn Sheep Management Plan (2010).

Montana

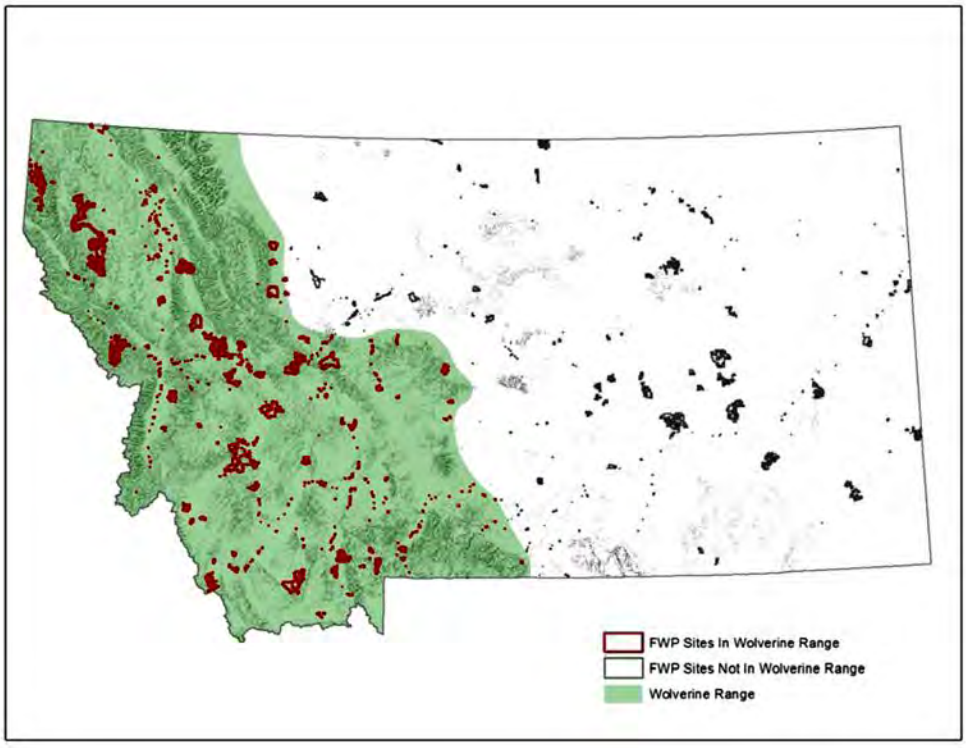
In the State of Montana, the wolverine is classified as a furbearer and species of concern. Since 2013, there has been a zero quota for trapping or harvest of wolverine and trappers that capture a wolverine must notify a designated Montana FWP employee within the relevant trapping district within 24 hours for collection if the animal cannot be released uninjured (Montana FWP 2016, pers. comm.).

There are two broad-scale wildlife conservation efforts that provide conservation benefits to the wolverine. *Montana's State Wildlife Action Plan* (updated and revised in 2015) identifies the wolverine as one of 128 SGCN (Montana FWP 2015, Appendix N). The State's Wildlife Action

Plan identifies priority community types, focal Areas, and species to help informing Montana FWP's priorities and decisions and to assist other agencies and organizations in making decisions as to where to focus their conservation efforts (Montana FWP 2015, p. 2). Community types and focal areas are designed to identify and direct attention to specific geographical areas in the State that have the greatest conservation need (Montana FWP 2015, p. 5). For the wolverine, *Montana's State Wildlife Action Plan* identifies wolverine habitats in seven community types, all designate Tier I (or those with greatest conservation need), and in all focal areas (also Tier I) within those community types (Montana FWP 2016, pers. comm.). For each community type, impacts, threats, and corresponding conservation actions are identified, as well as specific impacts and threats such as habitat fragmentation (e.g., prioritize land acquisition, provide wildlife under- and overpasses), land management (e.g., management to address altered fire regimes), recreation (e.g., consider seasonal closures during breeding season), and climate change (e.g., collection of baseline data to document shifting range limits of SGCN and Community Types of Greatest Conservation Need) (Montana FWP 2015, pp. 59–63).

The second conservation effort in the State of Montana is a Crucial Area Assessment to identify crucial areas and fish and wildlife corridors, and development of a Crucial Areas Planning System (URL: http://fwp.mt.gov/fishAndWildlife/conservationInAction/crucialAreas.html). This is a Montana FWP mapping application and planning tool designed to assist in future planning of development and conservation (Montana FWP 2016, pers. comm.).

The State of Montana is also conserving wildlife habitat through land acquisition and conservation easements (Montana FWP 2016, pers. comm.). In western Montana, including areas known to be occupied by the wolverine, 425 properties for a total 310,523 ha (767,320 ac) have been either acquired (e.g., State Parks, Wildlife Management Areas) or protected by conservation easements, as of November 2016, as shown in figure below (Montana FWP 2016, pers. comm.).



Wyoming

The wolverine is a protected animal and SGCN in Wyoming (WGFD 2017). The *Wyoming Game and Fish Department State Wildlife Action Plan* directs the activities of the WGFD and serves to guide in conserving Wyoming's SGCN through the combined efforts of government agencies, conservation organizations, academia, tribes, and others (WGFD 2017, p. I–1-1). As noted above, the wolverine is identified as a SGCN, a designation intended to identify species whose conservation status warrants increased management attention and funding, and consideration in conservation, land use, and development planning in the State (WGFD 2017, p. IV– i-1). The *State Wildlife Action Plan* incorporates the wolverine as a SGCN in several terrestrial habitat types or ecological systems, including cliffs, canyons, and rock outcrops, montane and subalpine forests, and mountain grasslands and alpine tundra (WGFD 2017, pp. III–2-5, III–5-7, III–6-5).

In 2015, Wyoming funded a pilot project (through The Wolverine Initiative) to evaluate wolverine detection and monitoring of the species in the State and is a contributing collaborator in the Multistate Wolverine Working Group implementing a monitoring strategy (the WSWCP) in the winter of 2016–2017 across four western states (WGFD 2017, p. IV–5-357). Results of those studies (e.g., Inman *et al*. 2015) are summarized above (*Population Abundance and Distribution*). The WSWCP is also updating and refining connectivity models for the wolverine in an effort to focus and prioritize habitat conservation and management (WGFD 2016, pers. comm.).

Colorado

The wolverine is a state-endangered species in Colorado (Colorado Parks and Wildlife 2015a); however, there is no known current resident or reproducing wolverine population.

The *Colorado State Action Plan* (Colorado Parks and Wildlife 2015b) provides a blueprint for a collaborative effort to conserve Colorado's at-risk wildlife and their habitats, with a primary goal for securing wildlife populations in order to avoid protections implemented so that they do not require protection via federal or state listing regulations (Colorado Parks and Wildlife 2015b, p. 1). The wolverine is designated as a Tier 1 (highest conservation priority; up from Tier 2) SGCN (Colorado Parks and Wildlife 2015b, p. 19). The primary conservation action for wolverine described in the 2015 State Action Plan is to continue discussions among wildlife managers, conservation partners and stakeholders of the social and political aspects regarding reintroduction of wolverine populations into the southern Rocky Mountains (Colorado Parks and Wildlife 2015b, p. 186). The State has not yet prepared a potential restoration program for the species (Broscheid 2016, pers. comm.).

Other Conservation Mechanisms

Tribes

Nez Perce Tribe

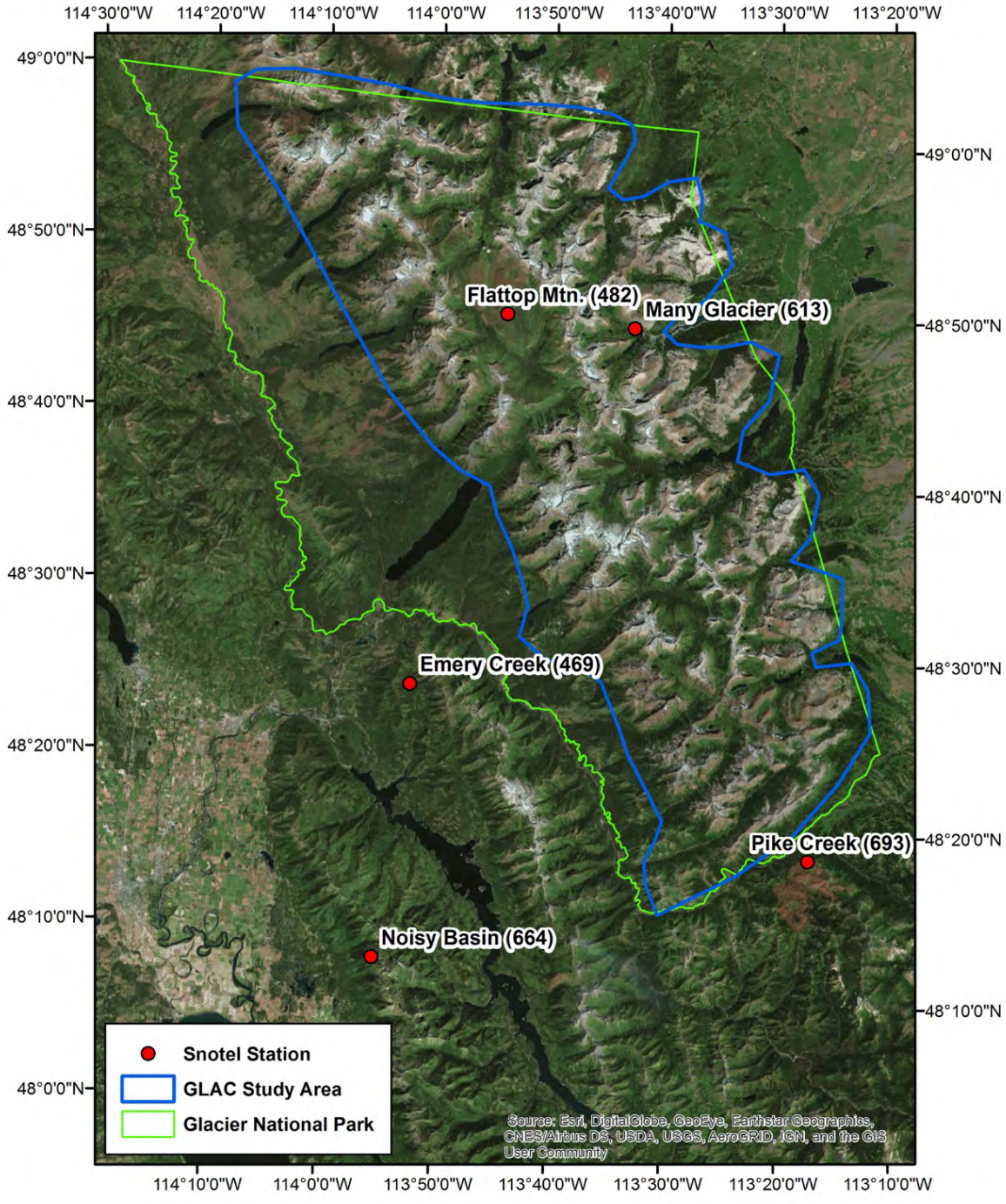
Wolverines are found within the aboriginal territory of the Nez Perce Tribe in north-central Idaho, and conservation and restoration of the species within the Nez Perce homeland is important to the Nez Perce Tribe (Miles 2017, pers. comm.). The Nez Perce Tribe is currently preparing an Integrated Resource Management Plan (IRMP), a Plant and Wildlife Conservation Strategy, and a Forest Management plan with the wolverine defined as a species of conservation concern in all three draft plans (Miles 2017, pers. comm.). The planning area for the IRMP, which is being prepared in partnership with the Bureau of Indian Affairs, incorporates the approximately 311,608 ha (770,000 ac) Nez Perce Reservation, located within portions of Nez Perce, Lewis, Clearwater, Latah, and Idaho Counties in north-central Idaho (http://www.nezperce.org/irmp/; accessed August 24, 2017). The preparation of the IRMP is currently at the scoping stage in the NEPA process for development of a Programmatic Environmental Impact Statement (http://www.nezperce.org/irmp/; accessed August 24, 2017).

The Shoshone-Bannock Tribes

The Shoshone-Bannock Tribes are currently conducting climate change modeling for the Northern Rocky Mountains as part of its preparation of a Climate Change Adaptation Plan (Edmo 2016, pers. comm.). The Upper Snake River Tribes Foundation (USRT), which is comprised of four member tribes—the Burns Paiute Tribe, Fort McDermitt Paiute-Shoshone Tribe, Shoshone-Bannock Tribes of the Fort Hall Reservation, and Shoshone-Paiute Tribes of the Duck Valley Reservation—within the Upper Snake River Watershed region, prepared a *Climate Change Vulnerability Assessment* in February 2017 (Petersen *et al*. 2017, entire). The assessment is the first of three steps the USRT and its member tribes plan activities over the next several years as part of a comprehensive climate change effort, and will include an Adaptation Plan (expected to be completed in 2017–2018), and, depending on future funding, a process for development of Implementing Adaptation Actions and Monitoring (Petersen *et al*. 2017, p. 7).

Appendix H–NOAA/CU Study Areas Used to Evaluate Future Snow Persistence (from Ray et al., 2017)

Glacier National Park Study Area



Rocky Mountain National Park Study Area