From: Andrea Ray - NOAA Federal
To: Steve Torbit; John Guinotte; Candida Dewes - NOAA Affiliate; Ben Livneh; Imtiaz Rangwala; Aaron Joseph Heldmyer; Joseph Barsugli
Subject: Re: Abstract for AGU -- heads up, will want you to look at it
Date: Wednesday, July 26, 2017 4:19:27 PM

Joe wasn't intentionally left off, now on...he did help think about the title!

On Wed, Jul 26, 2017 at 3:55 PM, Andrea Ray - NOAA Federal <andrea.ray@noaa.gov> wrote:

> Hi all, I'm planning to submit an abstract to AGU on the "co-production" aspects of the wolverine project to a session Jeremy Littell and others are conveningon "Global change science for resource management: dimensions of co-production in landscape conservation" : https://agu.confex.com/agu/fm17/preliminaryview.cgi/Session26036.html
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To:	Steve Torbit; John Guinotte; Candida Dewes - NOAA Affiliate; Ben Livneh; Imtiaz Rangwala; Aaron Joseph Heldmyer; Joseph Barsugli
Subject:	Re: Abstract for AGU -- heads up, will want you to look at it
Date:	Sunday, July 30, 2017 7:02:12 PM

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From:	Grizzle, Betty
To:	Shoemaker, Justin; Bush, Jodi; John Guinotte; Stephen Torbit; Bryon Holt; Caitlin Snyder; Gregg Kurz; Josh Hull; Madeline Drake; Kit Hershey
Cc:	Dana Jacobsen
Subject:	Agenda topics for Wolverine Core Team call tomorrow
Date:	Monday, July 31, 2017 2:53:14 PM
Attachments:	Wolverine Detailed Timeline_06142017.docx

Hi Everyone - Justin is unable to make the call tomorrow so I will be facilitating the core team meeting.
Here are my proposed agenda items. Let me know if you have other topics you'd like to discuss.

1. Revised Timeline – **see attached** schedule as FYI
2. Genetic studies (Steve)
3. NOAA/CU study update (John)
4. SSA Report update (Betty)
5. Other topics - update on multi-state occupancy surveys (winter 2016-2017); update on PVA analysis (Betty)

Thanks and talk to you tomorrow,
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

Wolverine Listing Determination Timeline
6/14/17 version

Task	Responsible Parties	Dates	Length of time
Species Status Assessment (SSA) Phase			
FR notice opening comment period on 2013 proposed listing rule	MTFO	Oct 18, 2016	done
DIP letters sent out to States and partners	MTFO	Oct 2016	done
Public comment period, input from States, partners, etc.		Oct 18-Nov 17, 2016	30 days, done
Conduct science analysis (SSA)	SSA core team	By Sept 15, 2017	in process
Draft SSA report	Betty Grizzle (FO Lead Bio)	By Oct 7, 2017	in process
SSA core team meeting in Denver	Core team, R6 management and decision support staff	Feb 15-16, 2017	2 days, done
SSA report check-in w/ RD	SSA core team, management	June 15, 2017	1 hr briefing
Peer review planning and contracting	Justin Shoemaker (ULT lead), Caitlin Snyder (ULT assist)	Aug – Oct 2017	2 months to get contracted peer reviewers in place
SSA report core team review	SSA core team	Oct 7-14, 2017	1 week
Edit SSA report based on core team review	Betty Grizzle	Oct 14-Oct 21, 2017	1 week
SSA report to peer reviewers and partners*	Justin Shoemaker, Jodi Bush (MTFO Project Leader)	Oct 21-Nov 21, 2017	1 month
Edit and finalize SSA report	Betty Grizzle	Nov 21-Dec 19, 2017	4 weeks
Listing Decision Analysis Phase			
SSA report to recommendation team	Justin Shoemaker, Jodi Bush	Dec 19, 2017	At least 2 weeks prior to recommendation team meeting
Decision meeting	RDs or delegates, ARDs, other management, SSA core team	First or second week of Jan **2018**	2 days
Draft decision summary for the record or certify decision meeting notes	R6 RD or delegate	early Jan 2018	3 days (after recommendation team meeting)
Process for final withdrawal of proposed listing (if decision is to not list) - or revised proposed listing rule (if decision is to list)			
Draft final withdrawal (not-warranted) FR notice or revised proposed listing rule (and if necessary, proposed 10(j), 4(d))	Justin Shoemaker and Betty Grizzle	Jan 15-Feb 12, 2018	4 weeks

*Includes States, Tribes, Federal Agencies

Core team reviews FR notice, make revisions	SSA core team, Justin Shoemaker	Feb 12-Feb 26, 2018	2 weeks
Regional Office Surnames and concurrence	Marjorie Nelson, Mike Thabault, Matt Hogan, Noreen Walsh, and concurring regional RDs/ARDs or delegates	Feb 26-March 12, 2018	2 weeks
SOL surname	DOI SOL	Feb 26-March 12, 2018	2 weeks
PPM	PPM	Feb 26-March 12, 2018	2 weeks
Revise based on RO/SOL/PPM comments	Justin Shoemaker and Betty Grizzle	March 12-March 21, 2018	10 days
HQ review	Sarah Quamme, Bridget Fahey	March 21, 2018	2 weeks (submit 6 weeks prior to FR submittal date)
Asst. Director for ES Surname	Asst. Director for ES	April 4, 218	5 business days
FWS Director Surname	Director of FWS	April 11, 2018	5 business days
Fish, Wildlife, and Parks Surname	FWP	April 18, 2018	10 business days
Executive Secretary Surname	Executive Secretary's Office	May 2, 2018	3 business days
Deliver to FR	HQ	May 7, 2018	
Publication of withdrawal or proposed rule	Federal Register	May 14, 2018	
Public comment period on revised proposed listing (only if decision is to list)		May 14-June 12, 2018	30 days (may need to be 60 days, if so will revise)
Process for final listing Federal Register document			
Comment and response strategy meeting – develop plan to review and address comments received	SSA core team, management	Mid May 2018	half day
Review and address public comments on proposed listing	SSA core team, support staffing as needed from R6 RO	June 12-July 16, 2018	1 month
Meeting with decision team to discuss public comment and any new info, revisit decision	Marjorie Nelson, Mike Thabault, Matt Hogan, Noreen Walsh, and concurring regional RDs/ARDs or delegates	Early July 2018	half day
Draft final listing FR doc (if necessary 10(j), 4(d))	Justin Shoemaker and Betty Grizzle	by July 16, 2018	2 months from proposed listing publication
SSA core team reviews FR notice, make revisions	SSA core team	July 16-July 23, 2018	1 week
Regional Office Surnames and	Marjorie Nelson,	July 23-Aug 6, 2018	2 weeks

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concurrence	Mike Thabault, Matt Hogan, Noreen Walsh, and concurring regional RDs/ARDs or delegates		
SOL surname	DOI SOL	July 23-Aug 6, 2018	2 weeks
PPM	PPM	July 23-Aug 6, 2018	2 weeks
Revise based on RO/SOL/PPM comments	Justin Shoemaker and Betty Grizzle	Aug 6-Aug 13, 2018	1 week
HQ review	Sarah Quamme, Bridget Fahey	Aug 7, 2018	6 weeks prior to FR date (may need to start this review concurrent w/ RO,SOL, PPM revisions)
AES Surname	Assistant Director Ecological Services	Aug 21, 2018	5 business days
FWS Director Signature	Director of FWS	Aug 28, 2018	5 business days
Fish, Wildlife, and Parks Surname	FWP	Sep 5, 2018	10 business days
Executive Secretary Surname	Executive Secretary's Office	Sep 19, 2018	3 business days
Deliver to FR	HQ	Sep 24, 2018	
Publication of final rule	Federal Register	Sep 28, 2018	Note: We've committed to final rule in FY 18 in the work plan

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From: Guinotte, John
To: Stephen Torbit
Subject: Fwd: Abstract for AGU -- heads up, will want you to look at it
Date: Monday, July 31, 2017 7:25:57 AM

Hi Steve, I haven't read this carefully, but I thought we agreed to word refugia was misleading. Best, John

John Guinotte
Spatial Ecologist
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: **Andrea Ray - NOAA Federal** <andrea.ray@noaa.gov>
Date: Sun, Jul 30, 2017 at 7:01 PM
Subject: Re: Abstract for AGU -- heads up, will want you to look at it
To: Steve Torbit <Stephen_Torbit@fws.gov>, John Guinotte <john_guinotte@fws.gov>, Candida Dewes - NOAA Affiliate <candida.dewes@noaa.gov>, Ben Livneh <ben.livneh@colorado.edu>, Imtiaz Rangwala <imtiaz.rangwala@noaa.gov>, Aaron Joseph Heldmyer <Aaron.Heldmyer@colorado.edu>, Joseph Barsugli <joseph.barsugli@noaa.gov>

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To:	Andrea Ray - NOAA Federal
Cc:	Steve Torbit; Candida Dewes - NOAA Affiliate; Ben Livneh; Imtiaz Rangwala; Aaron Joseph Heldmyer; Joseph Barsugli
Subject:	Re: Abstract for AGU -- heads up, will want you to look at it
Date:	Monday, July 31, 2017 9:06:59 AM

Hi Andrea, I added a couple of comments to this. I'm happy to be a co-author if Steve doesn't have any objections to this.
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John Guinotte
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To: Guinotte, John; andrea.ray@noaa.gov
Cc: Candida Dewes - NOAA Affiliate; Ben Livneh; Imtiaz Rangwala; Aaron Joseph Heldmyer; Joseph Barsugli
Subject: Re: Abstract for AGU -- heads up, will want you to look at it
Date: Tuesday, August 1, 2017 5:47:20 AM

Andrea, I am in Kansas at a meeting and reviewed this quickly before I left. I can't see John's edits, but am sure they are appropriate. The only quick comment from me is not to use the word "Refugia". We have been calling this a snow persistence assessment.

I defer to John on other edits. I am fine with being a coauthor. I should be able to get into the google drive by later on Weds.

Thanks
Steve

Sent from my iPad

On Jul 31, 2017, at 9:07 AM, Guinotte, John <john_guinotte@fws.gov> wrote:

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From: Grizzle, Betty
To: 222wsheridan@gmail.com
Subject: Wolverine and effects of fire
Date: Thursday, August 3, 2017 9:17:04 AM

Hi Audrey - Hope you are enjoying your summer.
In our agency's last status review, we didn't provide an extensive discussion of fire and potential effects to wolverine - either direct or indirect (prey, predators, habitat). Other than a USFS account prepared by P. Luensmann from 2008 that contains some discussion of potential effects, I haven't found much in my search on this topic.

Do you know of any other publications/studies?
--

Betty J. Grizzle, D.Env.
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2177 Salk Ave, Suite 250
Carlsbad, CA 92008
760-431-9440, ext. 215
760-431-5901 fax

From: Grizzle, Betty
To: A J
Subject: Re: Wolverine and effects of fire
Date: Monday, August 7, 2017 9:33:42 AM

Thanks for sending this article, which is not in our administrative record.
I will reach out to Andrea.

On Fri, Aug 4, 2017 at 5:54 PM, A J <222wsheridan@gmail.com> wrote:

> Hi Betty
> I'm afraid I won't be of much help on this question. The only study that I know of that actually is directly looking at wolverine and wildlire is Andrea Shortsleeve's (USFS) work in the Bitterroot National Forest but I haven't seen any reports yet. You might try contacting her if you haven't already. Here is a short piece about it a couple of years ago. I imagine that a number of the camera monitoring projects in the west will also have information on the use of burns in that region but so far I haven't seen a report on the subject or even mention of it other than Andrea's work. I believe Andrea (or someone) is continuing her work.
> ashortsleeve@fs.fed.us
>
> http://wildfiretoday.com/2013/12/28/researchers-study-carnivores-in-burned-areas/
>
> Other than that, the only paper published that included burn areas in the habitat analysis that I know of is Bowman et al. 2010, which you have probably seen. The takeaway on that one is that wolverines were neither positively or negatively associated with burns in our study area in Ontario. My sense from doing that work was that wolverines did not spend much time in very recent burns, either because of the openness or because caribou avoided burns and moose had not yet had time to respond to them, but that changes with time.
>
> I believe there is potentially a lot of data lying around from GPS-collared wolverine studies that could be used to retroactively look at movements and time in burn areas but has yet drawn the attention of researchers. I assume you contacted Bob Inman and also Kim Heinemeyer and Copeland.
>
> There is so little work on wolverine and prey/predators and habitat at the various scales. Lots of work on the effects of wildfire on the various prey species but not in relation to the wolverine. There are a number of EIS reports out there that talk about the potential effects of wildfire on wolverines, but it is all conjecture at this point in my opinion.
> Sorry I don't have more for you.
> Audrey
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> On Thu, Aug 3, 2017 at 7:17 AM, Grizzle, Betty <betty_grizzle@fws.gov> wrote:
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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: Joe Barsugli
To: Guinotte, John; Stephen Torbit
Subject: Fwd: Re: DHSVM vegetation issue (model runs)
Date: Monday, August 7, 2017 10:45:22 AM

John (steve). Aaron finished the runs late Friday night. As per the e-mail, I should do a verification that everything looks ok. Joe

Joe

-------- Forwarded Message --------
Subject: Re: DHSVM vegetation issue
Date: Fri, 4 Aug 2017 22:46:24 -0600
From: Aaron Joseph Heldmyer <Aaron.Heldmyer@colorado.edu>
Reply-To: Aaron.Heldmyer@colorado.edu
To: Joe Barsugli <joseph.barsugli@noaa.gov>
CC: Ben Livneh <Ben.Livneh@colorado.edu>, Andrea Ray - NOAA Federal <andrea.ray@noaa.gov>

Hello,

The runs are now complete and on the Drive! Let me know if anything is out of place or missing; it's a pretty complicated file structure, and I may have put something in the wrong place.

On Wed, Aug 2, 2017 at 5:51 PM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:

> Thanks for your attention to this! Once the runs are done we need to talk about reproducing the relevant figures (probably not ALL the figures from before). Joe.
>
> On 8/2/2017 5:09 PM, Aaron Joseph Heldmyer wrote:
>
> > Hi everyone,
> >
> > Another update - as of today everything has been uploaded *except* the ROMO historical run with the updated vegetation, and the ROMO bareground run. I'm still working on the errors that are arising there. These are all on the Drive. To summarize what these are:
> >
> > 1) ASCII vegetation files I was using for GLAC and ROMO
> > 2) GCM scenario runs for GLAC and ROMO, including config files used and the raw SWE files I received before converting them to individual rasters
> > 3) Historical runs, both new and old, for both regions (except new ROMO), again with config and raw SWE files
> > 4) Bareground run for GLAC with config and raw SWE file
> >
> > I hope to have the rest of ROMO done soon. Thanks for your patience!
> >
> > On Mon, Jul 31, 2017 at 1:12 PM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:

It does look like a lot more than 25% difference, though. Curioius if my perception is correct and if so, why? Joe

On 7/31/17 11:56 AM, Ben Livneh wrote:

> Thanks Aaron,
> So the increase in SWE is as expected. If you can share a similar plot for the old run (evergreen) it would be useful to compare side-by-side.
> Best
> Ben
>
> Sent from my phone. Please forgive the brevity, the typos, and the lack of nuance
>
> On Jul 31, 2017 9:25 AM, "Aaron Joseph Heldmyer" <Aaron.Heldmyer@colorado.edu> wrote:
>> Hi Joe, Ben, Andrea,
>>
>> I processed the GLAC bareground data, and there seems to be a lot more SWE present on the ground. Here's a comparison between the new vegetated historical run (left) and the bareground run (right) for Mar. 01, 2000:
>>
>> Inline image 1
>>
>> I'm adding the bareground results to the Drive. The GCM runs for GLAC are also running now, and if there are no issues should be on the Drive today as well. Also, I put the vegetation file for GLAC on the Drive. These materials will all be in the same folder (Data and Maps > UpdatedInputs7-22-17).
>>
>> On Tue, Jul 25, 2017 at 3:38 PM, Ben Livneh <Ben.Livneh@colorado.edu> wrote:
>>> Aaron et al.,
>>> I think next week (middle) is a good target for the completed runs, albeit I think interim updates on progress and intermediate results will be helpful.
>>> Ben
>>>
>>> Sent from my phone. Please forgive the brevity, the typos, and the lack of nuance

On Jul 25, 2017 2:43 PM, "Aaron Joseph Heldmyer" <Aaron.Heldmyer@colorado.edu> wrote:

> Pending Ben's input - I'm wrapping up the summer institute at the moment with a few more presentations at the ongoing conference, packing and cleaning, then the flight home on Friday
>
> On Jul 25, 2017 3:40 PM, "Aaron Joseph Heldmyer" <Aaron.Heldmyer@colorado.edu> wrote:
>
> > If things go well, I can have materials ready next week.
> >
> > On Jul 25, 2017 3:29 PM, "Joe Barsugli" <joseph.barsugli@noaa.gov> wrote:
> >
> > > What sort of timetable can you manage? Andrea and I are going to alert Steve and John to this later this week, and it would be good to communicate what a reasonable timetable is...
> > >
> > > Joe
> > >
> > > On 7/25/17 12:57 PM, Ben Livneh wrote:
> > >
> > > > Hi everyone,
> > > > I agree with Joe's priorities. I think redoing several parametric tests will also be helpful.
> > > > Ben
> > > >
> > > > On Tue, Jul 25, 2017 at 1:29 PM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:
> > > >
> > > > > Thanks again for all the hard work so far. This is a fairly serious discrepancy, but it does not affect the areas in the trees much (but it does a bit in places, so I guess there are openings in the forest in the new runs as well...
> > > > >
> > > > > I think we will have to re-do the rest of the runs. Here is a suggested priority list...
> > > > >
> > > > > 1. Put the Forcing files in a format that is more friendly (or tell me how to read them). Was the Veg map the only difference? It would be nice to have a Veg file for each study area so that we can look at the SWE in forested areas separately from above treeline/open areas....
> > > > >
> > > > > 2. Re-do the GLAC runs first -- as these were the ones that were more closely related to the Wolverine dens. When I get to the point where I can reproduce the SWE vs Elevation graphs with the dens on them (which takes only a few minutes once we have all the rasters), then we will have a better idea whether the interpretation of the results is affected.
> > > > >
> > > > > 3. Then Re-Do the ROMO runs. I have

checked the area of April 15 > 1 meter (roughtly .33 m of SWE) and it is now in the 100's of km^2.

The bigger questions comes in the "validation" step... For GLAC we just did it by eye -- comparing some MODIS maps to model output. For ROMO we computed the metrics.... I suppose we could compute the metrics and see what they did. But do we attempt a re-run of the parameter tests? I might suggest testing a small subset of the parameter sets that made a difference in the past set... maybe 3 or 4 runs that look at the parameters to which model output was most sensitive.

Joe

On 7/24/2017 9:54 AM, Ben Livneh wrote:

> Joe,
> I'm sharing a preliminary result from Aaron, which shows the increased snow at high-elevations in the new runs, where the correct vegetation removes forest from the highest elevations. I suspect the comparisons with MODIS will be improved as well...
>
>
>
> On Mon, Jul 24, 2017 at 1:05 AM, Aaron Joseph Heldmyer <Aaron.Heldmyer@colorado.edu> wrote:
>
> > Hi Joe and Ben,
> >
> > I've uploaded a folder called UpdatedInputs7-22-17 into Data and Maps that contains rasters for both old (where all vegetation was incorrectly set to evergreen, same as the runs used in the report) and new (with actual vegetation). Working through the weekend, I was able to

have both ROMO and GLAC more or less complete, with the exception of ROMO-new, which crashed in 2009 for as-of-yet unknown reasons. I still included the rasters up to 2009 in the folder anyway.

I haven't had the chance to compare the results myself to much extent, but it does appear that there is more SWE present in the new runs. Currently, I'm giving the bareground runs another shot - they've been experiencing the same crash in 2009 as the ROMO-new run did above.

Anyway, thanks for your patience as these things get sorted out - DHSVM fought every step of the way!

Let me know if something doesn't look right and I'll take a look myself as soon as I can.

On Sat, Jul 22, 2017 at 12:57 PM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:

> What bad timing! I was planning on a short day on Monday, starting in the afternoon. As long as I can have GLAC to look at first, which looks like it is already happening, then Tuesday is fine for ROMO. Best of luck to Aaron on his presentation !
>
> Joe
>
> On 7/22/17 8:24 AM, Ben Livneh wrote:
>
> > Hi all,
> >
> > We had a back and forth with Leanne this week (who is traveling, unfortunately) about regenerating more

than just the vegetation files for ROMO, namely the solar shading file, so that we can be sure that everything is correct when we rerun the model. Everything is set in GLAC for a rerun, and I believe Aaron rerunning that now. We hope to get ROMO rerun soon, ideally on Monday or shortly thereafter-- once we get all the files verified from Leanne.
Logistically, Aaron is going to be presenting his final project on Monday and I am going to be attending, in Alabama.

On Fri, Jul 21, 2017 at 7:55 PM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:

> Ben and Aaron (cc Andrea)
>
> We are under time pressure to figure this out -- at least to know whether or not this is a significant effect. How soon can you get the historic runs re-done with the newer veg file and put the output SWE on the drive? I'm hoping by Monday if possible. That way we can compare the area coverage and elevation dependence and see whether we expect a large difference in

the quantities that we have given to Steve and John -- I can do those latter calculations if that makes things go faster. Andrea is going on a trip starting this coming Thursday and we will have replied to the last round of comments on the draft by then and hope to have this at least under control by then.

Joe

--
Joseph Barsugli, Research Scientist III
CIRES, UCB216
University of Colorado Boulder
Boulder CO 80309
303-497-6042
PSD Science Board and
Attribution and Predictability Assessments Team Member

--
Ben Livneh, Ph.D
Assistant Professor,
Department of Civil, Environmental, and Architectural Engineering
&
Fellow, Cooperative Institute for Research in Environmental Sciences (CIRES)
Campus Box 216 UCB, Ekeley S250C, University of Colorado, Boulder 80309, USA
Phone: 303-735-0288 | http://www.colorado.edu/lab/

livneh/

--
Joseph Barsugli
Research Scientist III
CIRES, UCB 216
University of Colorado at
Boulder
cell:720-244-5922

--
Aaron Heldmyer

Ph.D. Student, Civil Environmental, and
Architectural Engineering (CEAE)
University of Colorado - Boulder
SEEC S263, 4001 Discovery Dr, Boulder,
CO 80303
Phone: 970-361-8406 | E-mail:
aaron.heldmyer@colorado.edu

--
Ben Livneh, Ph.D
Assistant Professor, Department of Civil,
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Campus Box 216 UCB, Ekeley S250C,
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CIRES, UCB 216
University of Colorado at Boulder
cell:720-244-5922

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Ph.D. Student, Civil Environmental, and Architectural Engineering (CEAE)
University of Colorado - Boulder
SEEC S263, 4001 Discovery Dr, Boulder, CO 80303
Phone: 970-361-8406 | E-mail: aaron.heldmyer@colorado.edu

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Joseph Barsugli
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CIRES, UCB 216
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Joseph Barsugli
Research Scientist III
CIRES, UCB 216
University of Colorado at Boulder
cell:720-244-5922

From: Guinotte, John
To: Joseph Barsugli - NOAA Affiliate; Stephen Torbit
Subject: Re:
Date: Wednesday, August 9, 2017 7:18:26 AM

Thanks Joe. I'll sit tight until I hear back from you on the above. I'm pretty tied up today with other projects. Thanks for looking into this.
Best, John

John Guinotte
Spatial Ecologist
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 Tue, Aug 8, 2017 at 7:05 PM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:

> John -- I was in meetings most of the day. I'm glad you found the files.
>
> Just to be sure -- they are in FWS-wolverine/Data and Maps/UpdatedInputs7-22-17/ romo/romo_hist/SWE_rasters and analogous folders for glac and the climate change scenarios.
>
> It looks like a lot of them are there, but I haven't had the time to check for all the files. I have not had time to verify that the files are correct either. I should have time tomorrow to dig into this more.
>
> My plan is to do a bunch of plots maps first, but then reproduce the SWE and snow covered area vs. elevation plots, as that will be a pretty stringent test of whether there are duplicates of files that don't pass a reality check.
>
> Joe
>
> On 8/8/2017 2:08 PM, Guinotte, John wrote:
>
> > Hi Joe, Did you have a chance to look over the files Aaron sent? I found a few of them on the drive, but I'm hesitant to move forward on validation.
> > Thanks John
> >
> > John Guinotte
> > Spatial Ecologist
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Joseph Barsugli, Research Scientist III
CIRES, UCB216
University of Colorado Boulder
Boulder CO 80309
303-497-6042
PSD Science Board and
Attribution and Predictability Assessments Team Member

From: Guinotte, John
To: Stephen Torbit
Subject: Fwd:
Date: Friday, August 11, 2017 8:42:26 AM

FYI Steve. I sent this to Joe this am. Still waiting.

---------- Forwarded message ----------
From: **Guinotte, John** <john_guinotte@fws.gov>
Date: Fri, Aug 11, 2017 at 8:27 AM
Subject: Re:
To: Joseph Barsugli - NOAA Affiliate <joseph.barsugli@noaa.gov>

Hi Joe, Can you send me the plots when you have finished them and tell me one way or the other if the files are correct? I have a bunch of work I need to do, but I'm not going to start doing it until I know.
Thanks John

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Joseph Barsugli, Research Scientist III
CIRES, UCB216
University of Colorado Boulder
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From: Guinotte, John
To: Stephen Torbit
Subject: Fwd:
Date: Monday, August 14, 2017 11:12:25 AM

Hi Steve, Just in from Joe. Maybe wait to see if he sends me something today.
Best, John

John Guinotte
Spatial Ecologist
Ecological Services
U.S. Fish and Wildlife Service
Mountain Prairie Region 6
134 Union Blvd., Lakewood, CO 80228
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---------- Forwarded message ----------
From: **Joe Barsugli** <joseph.barsugli@noaa.gov>
Date: Mon, Aug 14, 2017 at 11:05 AM
Subject: Re:
To: "Guinotte, John" <john_guinotte@fws.gov>

John, I had to leave work early on Thursday due to illness. I will be back today and plan to finish the vetting of the Wolverine runs. Joe

On 8/11/17 8:27 AM, Guinotte, John wrote:

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Joseph Barsugli, Research Scientist III
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PSD Science Board and
Attribution and Predictability Assessments Team Member

--
Joseph Barsugli
Research Scientist III
CIRES, UCB 216
University of Colorado at Boulder
cell:720-244-5922

From: Ben Livneh
To: Joseph Barsugli - NOAA Affiliate
Cc: Guinotte, John; Aaron Joseph Heldmyer; Andrea Ray; Stephen Torbit
Subject: Re: choice of threshold for comparing DHSVM SWE to MODIS snow/no snow.
Date: Tuesday, August 15, 2017 7:36:05 PM

Hi Joe,

Yes--I agree with your reasoning for the 5mm threshold, as it limits the risk of 'false positives' from trace snowpack, i.e. 1 mm. I also agree that 13 is not a very meaningful threshold in light of our convergence on a much lower snow density than we originally assumed.

Thanks for the detailed discussion on this.

Ben

On Tue, Aug 15, 2017 at 7:04 PM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:

> A note on the threshold to use for "light snow cover". Since we are re-doing everything now is the time to get rid of references to "13 mm of SWE" as our "light snow threshold". That was based on the early idea that a 10-to-1 ratio was appropriate, which we no longer think is right. In your (John Steve Kevin) comments you note that you want this choice to be as consistent with McKelvey as possible.
>
> For the purpose of comparing DHSVM with MODIS, we should note the following....
>
> McKelvey used 13cm depth on May1 ... as a proxy for .... MODIS snow disappearance by May 15th. (because they didn't have model results on the 15th). This proxy was a compromise that was developed for their whole Western US domain.
>
> This study; 13 cm depth on May 1 is approx. 5cm (50mm) SWE using 2.5:1 ratio. .... but we have direct modeling of SWE on May 15th to compare with MODIS so we don't need a proxy.
>
> For direct (same date) comparison with MODIS, we should use a much lower threshold. Ben cautioned against using as strict "0 mm" threshold as the model sometimes carries very low snow amounts. Previously we had considered using 1mm SWE or 5 mm SWE. One advantage of using 5 mm SWE is that it is less affected by dustings of snow that might happen after the "MODIS snow disappearance date" (which is derived by finding the first day that there is bare ground during the time window we use for MODIS). Our algorithm for detecting snow used a cutoff of the NDSI at 0.1 (following NASA) , which still indicates the possibility of a small fractional snow cover in the MODIS pixel. Because of that it is appropriate to use a non-zero threshold for the DHSVM modeled values. Not sure even if 10mm would be OK, and would sound less random than 13 mm?
>
> My choice is 5mm of SWE as the cutoff, but I am awaiting Ben's approval on this....
>
> Joe

On 8/14/2017 11:13 AM, Guinotte, John wrote:

> Thanks Joe, Hope you are feeling better.
> John
>
> John Guinotte
> Spatial Ecologist
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Joseph Barsugli, Research Scientist III
CIRES, UCB216
University of Colorado Boulder
Boulder CO 80309
303-497-6042
PSD Science Board and
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--
Joseph Barsugli
Research Scientist III
CIRES, UCB 216
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--

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--

Ben Livneh, Ph.D
Assistant Professor, Department of Civil, Environmental, and Architectural Engineering
&
Fellow, Cooperative Institute for Research in Environmental Sciences (CIRES)
Campus Box 216 UCB, Ekeley S250C, University of Colorado, Boulder 80309, USA
Phone: 303-735-0288 | http://www.colorado.edu/lab/livneh/

From: Guinotte, John
To: Stephen Torbit
Subject: Fwd: New Rasters --
Date: Wednesday, August 16, 2017 7:23:40 AM

John Guinotte
Spatial Ecologist
Ecological Services
U.S. Fish and Wildlife Service
Mountain Prairie Region 6
134 Union Blvd., Lakewood, CO 80228
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---------- Forwarded message ----------
From: **Joe Barsugli** <joseph.barsugli@noaa.gov>
Date: Tue, Aug 15, 2017 at 5:49 PM
Subject: New Rasters --
To: "Guinotte, John" <john_guinotte@fws.gov>
Cc: Andrea Ray <Andrea.Ray@noaa.gov>, Ben Livneh <ben.livneh@colorado.edu>, Aaron Joseph Heldmyer <Aaron.Heldmyer@colorado.edu>

John,

I have checked out the new rasters and they appear to be correct and in the right locations.

I have created 2000-2013 averages for each of the runs and for each of the target dates (April 15, May 1, etc). and am uploading those files.

I have created mulit-panel figures that plot SWE for all years on one page for each run -- just for a santity check. I will upload these as well.

I will be creating the SWE vs elevation plots next, and will be sharing those via e-mail when I get them done.

I'm sending a separate e-mail about choice of thresholds for comparing DHSVM with MODIS.

Joe

On 8/14/2017 11:13 AM, Guinotte, John wrote:

Thanks Joe, Hope you are feeling better.
John

John Guinotte
Spatial Ecologist
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, Aug 14, 2017 at 11:05 AM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:

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From: Andrea Ray - NOAA Federal
To: Guinotte, John
Cc: Joseph Barsugli - NOAA Affiliate
Subject: Re: New Rasters --
Date: Wednesday, August 16, 2017 8:01:10 AM

Joe's going to have to answer this one...

On Wed, Aug 16, 2017 at 7:44 AM, Guinotte, John <john_guinotte@fws.gov> wrote:

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325 Broadway, Boulder, CO 80305-3328
(tel) 303-497-6434
(fax) 303-497-6449
andrea.ray@noaa.gov
www.researchgate.net/profile/Andrea_Ray2

From: Joe Barsugli
To: Guinotte, John; Andrea Ray
Subject: Re: New Rasters --
Date: Wednesday, August 16, 2017 12:35:44 PM

Yes. But he only used the "new"/"old" folders folder for the " hist" runs. The future runs only have the new data in them.

One other quirk of Aaron's system -- the files in the GLAC directory are labeled glac_hist_new(...) while the ROMO files are only labeled romo_hist(...) .

Note that the files labeled "bare" are the bare ground runs that were done to diagnose the other end-case of having all bare ground, and should be ignored for this report.

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From: Guinotte, John
To: Joe Barsugli
Cc: Andrea Ray - NOAA Federal; Stephen Torbit
Subject: Re: New Rasters --
Date: Wednesday, August 16, 2017 12:54:21 PM
Attachments: fig2-4.jpg
fig5-5.jpg

Hi All,
I updated figs 2-4 and 5-5 from the report with the new model run data. See attached. I have pixel counts for each of these classes if you want to include area of each class.
best, John

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On Wed, Aug 16, 2017 at 12:36 PM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:

> I agree. I'll do that this afternoon and send out a notice of how it is re-structured. Joe
>
> On 8/16/17 8:03 AM, Andrea Ray - NOAA Federal wrote:
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> > Good idea, we don't want to inadvertently grab the wrong images -- but I'm going to let Joe work with Aaron on this, b/c I haven't been involved with that.
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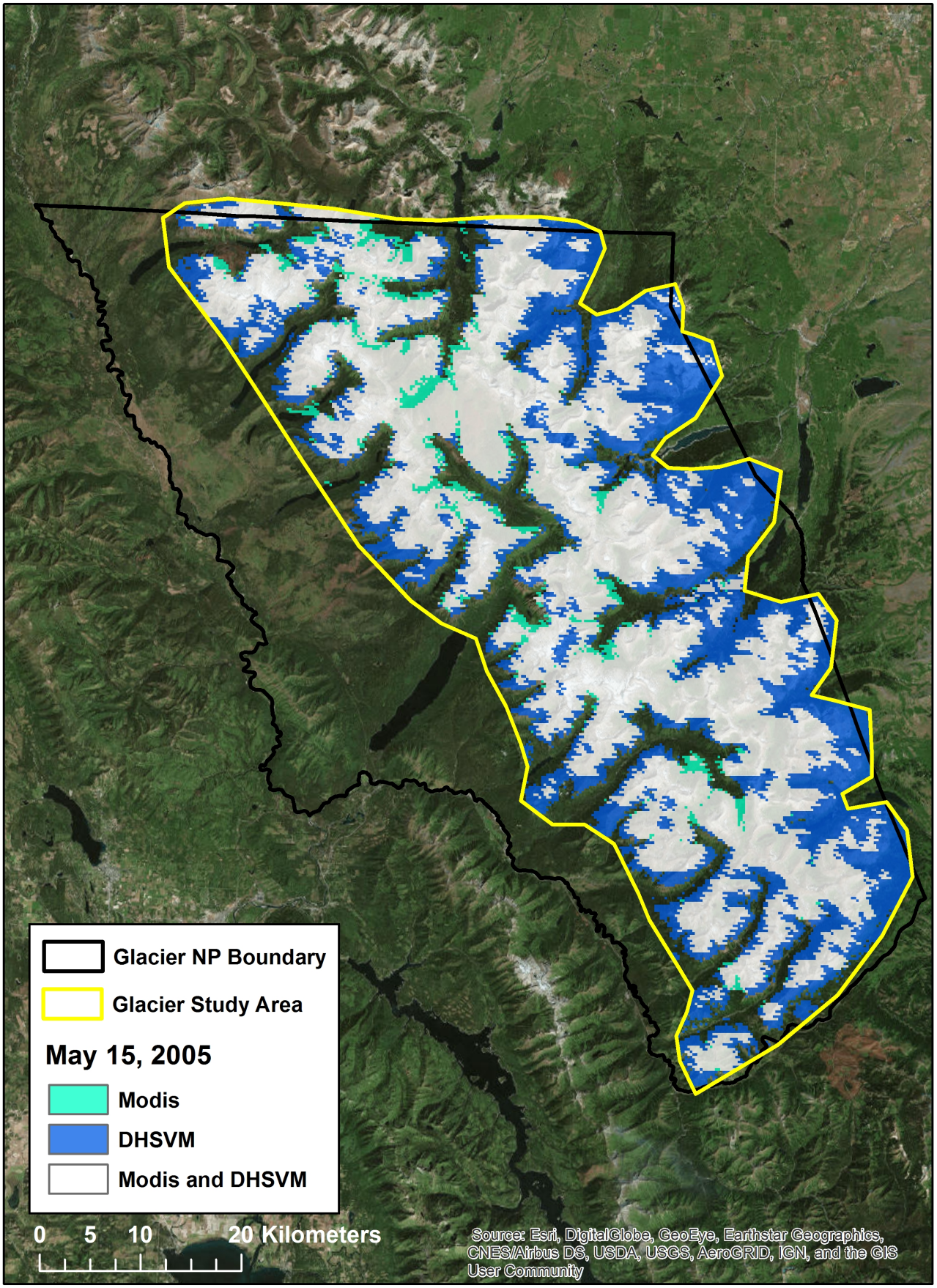
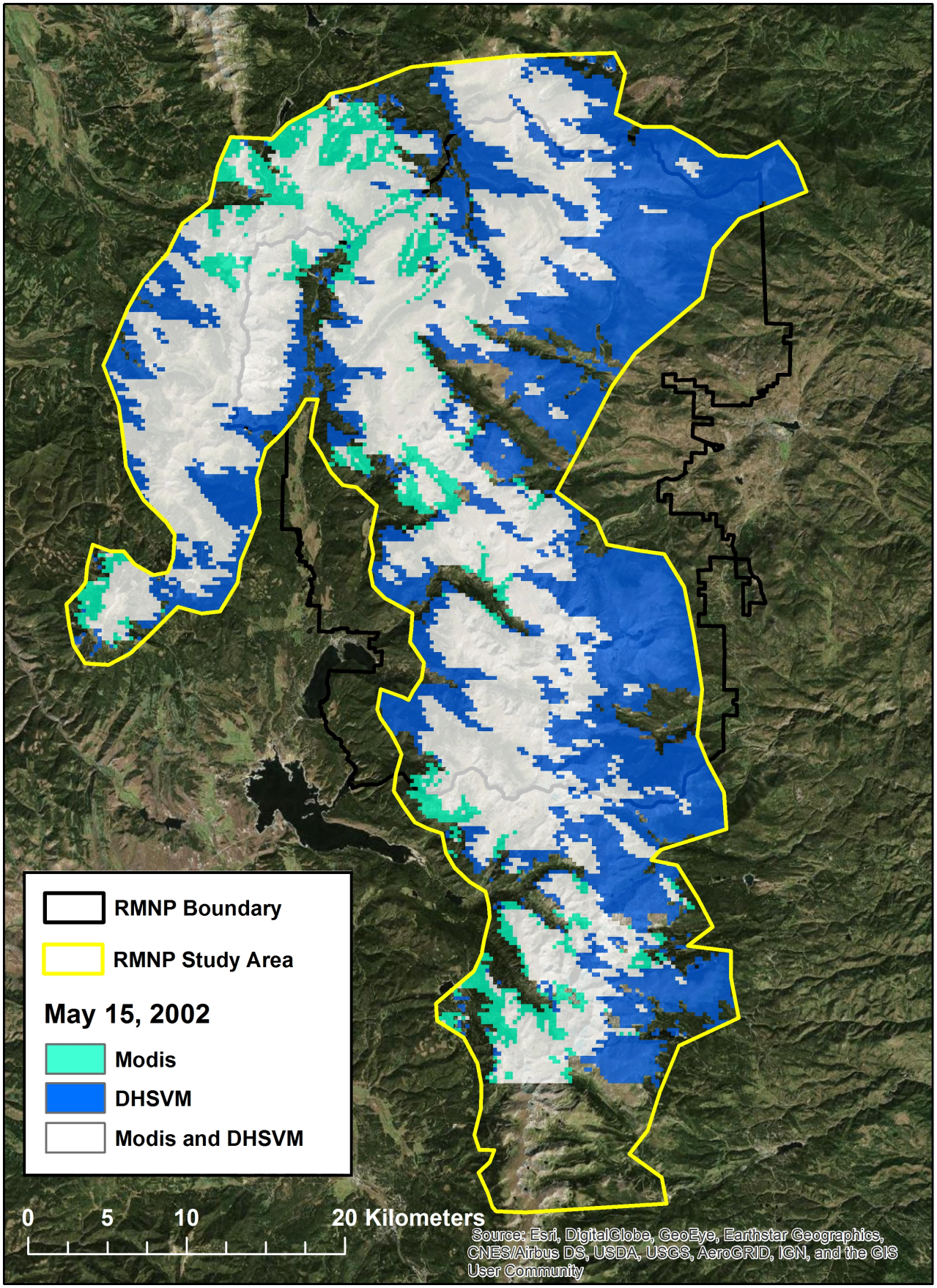

Glacier NP Boundary
Glacier Study Area
May 15, 2005
Modis
DHSVM
Modis and DHSVM
0 5 10 20 Kilometers
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community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To: Joseph Barsugli - NOAA Affiliate
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Subject: Re: New Rasters --
Date: Wednesday, August 16, 2017 3:25:54 PM

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On Wed, Aug 16, 2017 at 3:23 PM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:

> All,
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> following John's excellent suggestion, I have re-organized the Data and Maps folder to reduce confusion,
>
> - Historical Observed Data (MODIS;SNOTEL;SNODAS,etc) contains folders for the analysis of historical observations
> - DHSVM Supporting Files (DEMs, shapefiles, etc) contain the DEMs, boundary shapefiles and some other files that were not affected by the recent updates.
> - Updated DHSVM Runs (corrected inputs) has the updated Rasters and the graphics that I have produced so far. We should all put newly generated graphics into this Folder. Make your own sub-folders within this Folder.
> - Original DHSVM Runs (corrupted vegetation inputs) This contains all the folders of rasters and graphics that were dependent on the old model runs. Consider this as an archive for comparison purposes only.
> - A few other miscellaneous folders that I couldn't find a place for.
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303-497-6042
PSD Science Board and
Attribution and Predictability Assessments Team Member

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Andrea J. Ray, Ph.D.
NOAA Earth System Research Lab, Mailcode R/PSD1
325 Broadway, Boulder, CO 80305-3328
(tel) 303-497-6434
(fax) 303-497-6449
andrea.ray@noaa.gov
www.researchgate.net/profile/Andrea_Ray2

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Joseph Barsugli, Research Scientist III
CIRES, UCB216
University of Colorado Boulder
Boulder CO 80309
303-497-6042
PSD Science Board and
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From: Joe Barsugli
To: Guinotte, John
Subject: Re: New Rasters --
Date: Wednesday, August 16, 2017 4:45:40 PM

I'll upload them asap. The rasters should be there.

On 8/16/17 3:35 PM, Guinotte, John wrote:

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> Thanks John
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> John Guinotte
> Spatial Ecologist
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> 303-236-4264
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To: Guinotte, John
Subject: Re: New Rasters --
Date: Wednesday, August 16, 2017 4:49:21 PM

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From: Guinotte, John
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Subject: Re: New Rasters --
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From: Andrea Ray - NOAA Federal
To: Guinotte, John; Joseph Barsugli
Subject: Re: latest figures
Date: Thursday, August 17, 2017 2:23:03 PM

John -- did you or Kevin make any comments in this file? Wolverine Report Figures FINAL DRAFT 5May2017.docx

I have your comments in the text file, i.e. the main report, but want to make sure I'm not missing anything.

thanks! andrea

On Wed, Aug 16, 2017 at 7:59 AM, Andrea Ray - NOAA Federal <andrea.ray@noaa.gov> wrote:

> Hi John, its still the "Wolverine Report Figures FINAL DRAFT 5May2017.docx" May 2 version word doc here: https://drive.google.com/drive/folders/0ByT4y_bFYaBGem5kWENvSFc4eXM
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> On Wed, Aug 16, 2017 at 7:51 AM, Guinotte, John <john_guinotte@fws.gov> wrote:
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> John,
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> I've sent this on to Ben and Aaron. Culd you also include them on any future results or questions relevant to the model? That way we can eliminate the middleman.
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> Joe
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> On 8/16/2017 12:54 PM, Guinotte, John wrote:
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> > Hi All,
> > I updated figs 2-4 and 5-5 from the report with the new model run data. See attached. I have pixel counts for each of these classes if you want to include area of each class.
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> On Tue, Aug 15, 2017 at 5:49 PM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:
>
> > John,
> >
> > I have checked out the new rasters and they appear to be correct and in the right locations.
> >
> > I have created 2000-2013 averages for each of the runs and for each of the target dates (April 15, May 1, etc). and am uploading those files.
> >
> > I have created mulit-panel figures that plot SWE for all years on one page for each run -- just for a santity check. I will upload these as well.
> >
> > I will be creating the SWE vs elevation plots next, and will be sharing those via e-mail when I get them done.
> >
> > I'm sending a separate e-mail about choice of thresholds for comparing DHSVM with MODIS.
> >
> > Joe

On 8/14/2017 11:13 AM, Guinotte, John wrote:

> Thanks Joe, Hope you are feeling better.
> John
>
> John Guinotte
> Spatial Ecologist
> 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, Aug 14, 2017 at 11:05 AM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:
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> > John, I had to leave work early on Thursday due to illness. I will be back today and plan to finish the vetting of the Wolverine runs. Joe
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> > > john_guinotte@fws.gov
> > >
> > > On Tue, Aug 8, 2017 at 7:05 PM, Joe Barsugli <joseph.barsugli@noaa.gov>

wrote:

> John -- I was in meetings most of the day. I'm glad you found the files.
>
> Just to be sure -- they are in FWS-wolverine/Data and Maps/UpdatedInputs7-22-17/romo /romo_hist/SWE_rasters and analogous folders for glac and the climate change scenarios.
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>
> Joe
>
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>
> > Hi Joe, Did you have a chance to look over the files Aaron sent? I found a few of them on the drive, but I'm hesitant to move forward on validation. Thanks John
> >
> > John Guinotte

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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

--
Joseph Barsugli, Research Scientist III
CIRES, UCB216
University of Colorado Boulder
Boulder CO 80309
303-497-6042
PSD Science Board and Attribution and Predictability Assessments Team Member

--
Joseph Barsugli
Research Scientist III
CIRES, UCB 216
University of Colorado at Boulder
cell:720-244-5922

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Joseph Barsugli, Research Scientist III
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University of Colorado Boulder
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Andrea J. Ray, Ph.D.
NOAA Earth System Research Lab, Mailcode R/PSD1
325 Broadway, Boulder, CO 80305-3328
(tel) 303-497-6434
(fax) 303-497-6449

andrea.ray@noaa.gov
www.researchgate.net/profile/Andrea_Ray2

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PSD Science Board and
Attribution and Predictability Assessments Team Member

From: Guinotte, John
To: Andrea Ray - NOAA Federal
Cc: Joseph Barsugli
Subject: Re: latest figures
Date: Thursday, August 17, 2017 2:39:19 PM

Hi Andrea, No, we didn't make comments in the figures file.
Best, John

John Guinotte
Spatial Ecologist
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 Thu, Aug 17, 2017 at 2:22 PM, Andrea Ray - NOAA Federal <andrea.ray@noaa.gov> wrote:

> John -- did you or Kevin make any comments in this file? Wolverine Report Figures FINAL DRAFT 5May2017.docx
>
> I have your comments in the text file, i.e. the main report, but want to make sure I'm not missing anything.
>
> thanks! andrea
>
> On Wed, Aug 16, 2017 at 7:59 AM, Andrea Ray - NOAA Federal <andrea.ray@noaa.gov> wrote:
>
> > Hi John, its still the "Wolverine Report Figures FINAL DRAFT 5May2017.docx" May 2 version word doc here: https://drive.google.com/drive/folders/0ByT4y_bFYaBGem5kWENvSFc4eXM
> >
> > On Wed, Aug 16, 2017 at 7:51 AM, Guinotte, John <john_guinotte@fws.gov> wrote:
> >
> > > Hi Andrea, Can you send me the link to the lastest version on your report figures? I need to redo a few of the ones I did for you.
> > > Thanks, John
> > >
> > > John Guinotte
> > > Spatial Ecologist
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> > > U.S. Fish and Wildlife Service
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> > --
> > --
> > Andrea J. Ray, Ph.D.

NOAA Earth System Research Lab, Mailcode R/PSD1
325 Broadway, Boulder, CO 80305-3328
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(fax) 303-497-6449
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www.researchgate.net/profile/Andrea_Ray2

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325 Broadway, Boulder, CO 80305-3328
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(fax) 303-497-6449
andrea.ray@noaa.gov
www.researchgate.net/profile/Andrea_Ray2

From: Guinotte, John
To: Joseph Barsugli - NOAA Affiliate
Subject: Re: choice of threshold for comparing DHSVM SWE to MODIS snow/no snow.
Date: Wednesday, August 23, 2017 10:02:24 AM

Hi Joe,
I just want to double check that the swe:snow depth conversion for both glac and romo for may 01 is 2.5:1.
Thanks John

John Guinotte
Spatial Ecologist
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 Tue, Aug 15, 2017 at 7:04 PM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:

> A note on the threshold to use for "light snow cover". Since we are re-doing everything now is the time to get rid of references to "13 mm of SWE" as our "light snow threshold". That was based on the early idea that a 10-to-1 ratio was appropriate, which we no longer think is right. In your (John Steve Kevin) comments you note that you want this choice to be as consistent with McKelvey as possible.
>
> For the purpose of comparing DHSVM with MODIS, we should note the following....
>
> McKelvey used 13cm depth on May1 ... as a proxy for .... MODIS snow disappearance by May 15th. (because they didn't have model results on the 15th). This proxy was a compromise that was developed for their whole Western US domain.
>
> This study; 13 cm depth on May 1 is approx. 5cm (50mm) SWE using 2.5:1 ratio. .... but we have direct modeling of SWE on May 15th to compare with MODIS so we don't need a proxy.
>
> For direct (same date) comparison with MODIS, we should use a much lower threshold. Ben cautioned against using as strict "0 mm" threshold as the model sometimes carries very low snow amounts. Previously we had considered using 1mm SWE or 5 mm SWE. One advantage of using 5 mm SWE is that it is less affected by dustings of snow that might happen after the "MODIS snow disappearance date" (which is derived by finding the first day that there is bare ground during the time window we use for MODIS). Our algorithm for detecting snow used a cutoff of the NDSI at 0.1 (following NASA) , which still indicates the possibility of a small fractional snow cover in the MODIS pixel. Because of that it is appropriate to use a non-zero threshold for the DHSVM modeled values. Not sure even if 10mm would be OK, and would sound less random than 13 mm?
>
> My choice is 5mm of SWE as the cutoff, but I am awaiting Ben's approval on this....
>
> Joe

On 8/14/2017 11:13 AM, Guinotte, John wrote:

> Thanks Joe, Hope you are feeling better.
> John
>
> John Guinotte
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Joseph Barsugli, Research Scientist III
CIRES, UCB216
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Joseph Barsugli
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Boulder CO 80309
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From: Joseph Barsugli - NOAA... (via Google Drive)
To: john_guinotte@fws.gov
Cc: andrea.ray@noaa.gov
Subject: Wolverine Report Figures REVISED 31Aug2017.docx
Date: Thursday, August 31, 2017 4:11:37 PM

Joseph Barsugli - NOAA Affiliate has shared the following document:

Wolverine Report Figures REVISED 31Aug2017.docx

Revised Figure Document for Wolverine Report. We need to double check some of the captions, but all the relevant figures have been replaced with the new simulations

Open

Google Drive: Have all your files within reach from any device.
Google Inc. 1600 Amphitheatre Parkway, Mountain View, CA 94043, USA

From: Andrea Ray - NOAA Federal
To: John Guinotte
Subject: Re: Tables for theWolverine TEXT document
Date: Thursday, August 31, 2017 4:55:59 PM

On Wed, Aug 30, 2017 at 1:45 AM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:

> Andrea,
>
> The Tables of changes in snow covered area need to be updated for the text of the wolverine report, These files are attached and can be replaced in the word doc. I decided to add April 15th to these and remove June 1 as per the request of John and Kevin. The captions will have to be modified to reflect this change.
>
> Also. I have made a table comparing the old and new(corrected) runs in terms of snow covered area (just the average of all years...) You can see that the newer runs have a similar pattern of percent changes, but the delcines in snow cover are a little less in the newer runs. I anticipate the messaging on this will remain very similar to the old version because of these similarities.
>
> Joe
>
> --
> Joseph Barsugli, Research Scientist III
> CIRES, UCB216
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> PSD Science Board and
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(fax) 303-497-6449
andrea.ray@noaa.gov
www.researchgate.net/profile/Andrea_Ray2

From: Guinotte, John
To: Stephen Torbit
Subject: Fwd: Tables for theWolverine TEXT document
Date: Thursday, August 31, 2017 5:40:57 PM
Attachments: ROMO_0.5m_depth_table.pdf
ROMO_5mmSWE_table.pdf
GLAC_0.5m_depth_table.pdf
GLAC_5mmSWE_table.pdf
SCA_Average_percent_change_comparison_old_corrected_runs.pdf

John Guinotte
Spatial Ecologist
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: **Andrea Ray - NOAA Federal** <andrea.ray@noaa.gov>
Date: Thu, Aug 31, 2017 at 5:00 PM
Subject: Fwd: Tables for theWolverine TEXT document
To: John Guinotte <john_guinotte@fws.gov>

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To: Andrea Ray <Andrea.Ray@noaa.gov>

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ROMO **Snow Covered Area sq-km (0.5 m depth threshold)**

	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	1000	803	1176	1021	776	1571	924	1008	1178	1336	1536	1111	768	1529	710	935	**1086**	**1014**
	Central (cnrm)	914	727	1170	929	765	1475	757	1039	1023	999	1533	1035	747	1478	583	967	**1009**	**983**
	Hot/Dry (hadgem2)	796	660	963	922	699	1372	692	891	1042	1076	1482	994	737	1417	485	887	**945**	**906**
	Hot/Very Wet (miroc)	781	588	948	897	724	1271	629	990	1071	811	1500	845	761	1361	426	1043	**915**	**871**
	Warm/Wet (giss)	1006	789	1184	1098	781	1553	862	1019	1217	1313	1559	1157	806	1531	677	1051	**1100**	**1074**
	Warm/Dry (fio)	823	690	1062	821	728	1499	742	817	960	1123	1442	987	700	1462	565	826	**953**	**825**
1-May	historical	871	852	1029	819	719	1556	841	987	983	1147	1365	1148	837	1519	594	1119	**1024**	**985**
	Central (cnrm)	835	747	944	713	661	1423	710	888	811	847	1286	980	769	1454	472	1052	**912**	**841**
	Hot/Dry (hadgem2)	742	636	742	672	561	1254	636	725	797	840	1136	817	703	1354	356	845	**801**	**742**
	Hot/Very Wet (miroc)	736	596	772	694	595	1182	583	819	845	706	1251	825	759	1326	315	1105	**819**	**766**
	Warm/Wet (giss)	890	822	960	799	691	1521	782	915	981	1110	1406	1093	837	1510	541	1141	**1000**	**938**
	Warm/Dry (fio)	773	720	927	723	665	1464	716	792	800	965	1191	1004	762	1441	490	962	**900**	**796**
15-May	historical	852	864	705	712	681	1549	532	1017	943	995	1357	1005	981	1454	577	1041	**954**	**962**
	Central (cnrm)	738	699	569	556	569	1377	406	834	728	709	1151	744	854	1328	429	853	**784**	**733**
	Hot/Dry (hadgem2)	584	546	296	398	406	1104	238	611	640	610	925	505	691	1080	262	635	**596**	**597**
	Hot/Very Wet (miroc)	636	558	451	534	497	1136	298	753	724	610	1110	627	818	1175	271	907	**694**	**631**
	Warm/Wet (giss)	809	797	629	670	632	1502	487	911	895	936	1320	902	957	1421	513	988	**898**	**898**
	Warm/Dry (fio)	753	721	608	617	610	1455	402	826	778	832	1190	866	859	1343	484	897	**828**	**802**

ROMO **Snow Covered Area % change (0.5 m depth threshold)**

	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central (cnrm)	-9	-9	-1	-9	-1	-6	-18	3	-13	-25	0	-7	-3	-3	-18	3	**-7**	**-3**
	Hot/Dry (hadgem2)	-20	-18	-18	-10	-10	-13	-25	-12	-12	-19	-4	-11	-4	-7	-32	-5	**-13**	**-11**
	Hot/Very Wet (miroc)	-22	-27	-19	-12	-7	-19	-32	-2	-9	-39	-2	-24	-1	-11	-40	12	**-16**	**-14**
	Warm/Wet (giss)	1	-2	1	8	1	-1	-7	1	3	-2	1	4	5	0	-5	12	**1**	**6**
	Warm/Dry (fio)	-18	-14	-10	-20	-6	-5	-20	-19	-19	-16	-6	-11	-9	-4	-20	-12	**-12**	**-19**
1-May	Central (cnrm)	-4	-12	-8	-13	-8	-9	-16	-10	-17	-26	-6	-15	-8	-4	-21	-6	**-11**	**-15**
	Hot/Dry (hadgem2)	-15	-25	-28	-18	-22	-19	-24	-27	-19	-27	-17	-29	-16	-11	-40	-24	**-22**	**-25**
	Hot/Very Wet (miroc)	-15	-30	-25	-15	-17	-24	-31	-17	-14	-38	-8	-28	-9	-13	-47	-1	**-20**	**-22**
	Warm/Wet (giss)	2	-3	-7	-3	-4	-2	-7	-7	0	-3	3	-5	0	-1	-9	2	**-2**	**-5**
	Warm/Dry (fio)	-11	-15	-10	-12	-7	-6	-15	-20	-19	-16	-13	-13	-9	-5	-18	-14	**-12**	**-19**
15-May	Central (cnrm)	-13	-19	-19	-22	-17	-11	-24	-18	-23	-29	-15	-26	-13	-9	-26	-18	**-18**	**-24**
	Hot/Dry (hadgem2)	-31	-37	-58	-44	-40	-29	-55	-40	-32	-39	-32	-50	-30	-26	-55	-39	**-38**	**-38**
	Hot/Very Wet (miroc)	-25	-35	-36	-25	-27	-27	-44	-26	-23	-39	-18	-38	-17	-19	-53	-13	**-27**	**-34**
	Warm/Wet (giss)	-5	-8	-11	-6	-7	-3	-9	-10	-5	-6	-3	-10	-2	-2	-11	-5	**-6**	**-7**
	Warm/Dry (fio)	-12	-17	-14	-13	-10	-6	-25	-19	-17	-16	-12	-14	-12	-8	-16	-14	**-13**	**-17**

ROMO **Snow Covered Area sq-km (5 mm SWE threshold)**

	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	1575	1522	1575	1593	1564	1596	1433	1593	1590	1587	1597	1583	1586	1594	1393	1595	**1561**	**1587**
	Central (cnrm)	1442	1348	1486	1519	1428	1590	1026	1550	1536	1447	1596	1495	1526	1582	1105	1590	**1454**	**1507**
	Hot/Dry (hadgem2)	1317	1199	1405	1491	1246	1575	917	1496	1530	1475	1595	1463	1485	1569	806	1578	**1384**	**1480**
	Hot/Very Wet (miroc)	1123	944	1248	1360	1208	1528	835	1418	1439	1094	1586	1275	1351	1505	1010	1589	**1282**	**1313**
	Warm/Wet (giss)	1539	1486	1555	1585	1507	1595	1253	1584	1586	1576	1597	1573	1582	1593	1251	1594	**1528**	**1579**
	Warm/Dry (fio)	1509	1438	1552	1572	1508	1593	1122	1579	1580	1552	1597	1557	1557	1591	1206	1594	**1507**	**1557**
1-May	historical	1557	1519	1537	1546	1417	1592	1368	1596	1564	1568	1596	1573	1542	1594	1058	1593	**1514**	**1560**
	Central (cnrm)	1367	1274	1380	1256	1125	1559	957	1569	1394	1296	1590	1441	1387	1576	735	1538	**1340**	**1384**
	Hot/Dry (hadgem2)	1180	1073	1135	1096	900	1486	829	1306	1250	1265	1577	1341	1172	1547	570	1491	**1201**	**1215**
	Hot/Very Wet (miroc)	1058	873	1075	1030	928	1449	726	1555	1238	979	1563	1172	1217	1494	475	1457	**1143**	**1124**
	Warm/Wet (giss)	1496	1442	1459	1460	1233	1583	1154	1584	1515	1520	1595	1549	1496	1591	897	1587	**1447**	**1505**
	Warm/Dry (fio)	1460	1429	1486	1448	1262	1577	1055	1591	1516	1494	1594	1536	1452	1590	830	1582	**1431**	**1490**
15-May	historical	1463	1452	1173	1281	1245	1587	1041	1536	1507	1481	1590	1512	1516	1591	915	1574	**1404**	**1494**
	Central (cnrm)	1122	1148	895	906	926	1527	667	1316	1153	1047	1553	1185	1302	1535	612	1424	**1145**	**1151**
	Hot/Dry (hadgem2)	840	912	565	679	661	1376	479	982	945	922	1410	891	1039	1431	427	1144	**919**	**917**
	Hot/Very Wet (miroc)	885	751	700	779	754	1371	484	1117	1032	816	1485	943	1163	1424	403	1304	**963**	**914**
	Warm/Wet (giss)	1306	1335	993	1109	1040	1570	841	1420	1380	1355	1579	1401	1441	1580	762	1542	**1291**	**1367**
	Warm/Dry (fio)	1290	1316	1023	1084	1063	1562	817	1433	1385	1317	1582	1410	1444	1578	723	1534	**1285**	**1351**

ROMO **Snow Covered Area % change (5 mm SWE threshold)**

	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central (cnrm)	-8	-11	-6	-5	-9	0	-28	-3	-3	-9	0	-6	-4	-1	-21	0	**-7**	**-5**
	Hot/Dry (hadgem2)	-16	-21	-11	-6	-20	-1	-36	-6	-4	-7	0	-8	-6	-2	-42	-1	**-11**	**-7**
	Hot/Very Wet (miroc)	-29	-38	-21	-15	-23	-4	-42	-11	-10	-31	-1	-19	-15	-6	-27	0	**-18**	**-17**
	Warm/Wet (giss)	-2	-2	-1	0	-4	0	-13	-1	0	-1	0	-1	0	0	-10	0	**-2**	**0**
	Warm/Dry (fio)	-4	-5	-1	-1	-4	0	-22	-1	-1	-2	0	-2	-2	0	-13	0	**-3**	**-2**
1-May	Central (cnrm)	-12	-16	-10	-19	-21	-2	-30	-2	-11	-17	0	-8	-10	-1	-31	-3	**-11**	**-11**
	Hot/Dry (hadgem2)	-24	-29	-26	-29	-36	-7	-39	-18	-20	-19	-1	-15	-24	-3	-46	-6	**-21**	**-22**
	Hot/Very Wet (miroc)	-32	-43	-30	-33	-34	-9	-47	-3	-21	-38	-2	-26	-21	-6	-55	-9	**-24**	**-28**
	Warm/Wet (giss)	-4	-5	-5	-6	-13	-1	-16	-1	-3	-3	0	-2	-3	0	-15	0	**-4**	**-4**
	Warm/Dry (fio)	-6	-6	-3	-6	-11	-1	-23	0	-3	-5	0	-2	-6	0	-22	-1	**-5**	**-5**
15-May	Central (cnrm)	-23	-21	-24	-29	-26	-4	-36	-14	-23	-29	-2	-22	-14	-4	-33	-10	**-18**	**-23**
	Hot/Dry (hadgem2)	-43	-37	-52	-47	-47	-13	-54	-36	-37	-38	-11	-41	-31	-10	-53	-27	**-35**	**-39**
	Hot/Very Wet (miroc)	-40	-48	-40	-39	-39	-14	-53	-27	-32	-45	-7	-38	-23	-10	-56	-17	**-31**	**-39**
	Warm/Wet (giss)	-11	-8	-15	-13	-17	-1	-19	-8	-8	-9	-1	-7	-5	-1	-17	-2	**-8**	**-9**
	Warm/Dry (fio)	-12	-9	-13	-15	-15	-2	-22	-7	-8	-11	-1	-7	-5	-1	-21	-3	**-8**	**-10**

GLAC **Snow Covered Area sq-km (0.5 m depth threshold)**

	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	2628	2801	2708	2826	2876	2733	2532	2338	2650	2484	2830	2866	2380	2901	2833	2797	**2699**	**2765**
	Central (cnrm)	2047	2444	2202	2577	2753	2387	1889	1502	2077	1933	2574	2705	1858	2871	2454	2414	**2293**	**2400**
	Hot/Very Wet (canesm)	1730	2121	1904	2081	2515	1922	1403	1203	1674	1339	2365	2437	1298	2774	1932	2047	**1922**	**1927**
	Hot/Wet (miroc)	1406	1171	1539	1530	1265	1989	1078	1265	1354	1439	2349	1619	1176	2290	1280	1569	**1520**	**1422**
	Warm/Wet (giss)	2402	2647	2525	2683	2829	2530	2251	2004	2405	2197	2732	2785	2152	2899	2660	2633	**2521**	**2581**
	Warm/Dry (fio)	2269	2445	2279	2647	2730	2584	2084	1720	2278	2072	2588	2745	1874	2890	2662	2499	**2398**	**2472**
1-May	historical	1970	2638	2380	2468	2855	2537	2235	2062	2324	1906	2704	2777	2011	2901	2544	2680	**2437**	**2503**
	Central (cnrm)	1296	2045	1744	2058	2588	1976	1481	1265	1569	1332	2371	2523	1393	2856	1791	2118	**1900**	**1884**
	Hot/Very Wet (canesm)	1139	1783	1470	1535	2313	1494	1056	970	1325	852	2152	2191	995	2725	1418	1811	**1577**	**1482**
	Hot/Wet (miroc)	1159	1142	1175	1089	1015	1767	922	1181	1037	1077	1826	1581	1056	2229	888	1582	**1295**	**1150**
	Warm/Wet (giss)	1621	2399	2060	2187	2726	2168	1845	1709	1941	1510	2537	2626	1707	2893	2167	2449	**2159**	**2167**
	Warm/Dry (fio)	1491	2153	1880	2105	2645	2249	1698	1435	1790	1446	2402	2560	1455	2880	2103	2237	**2033**	**2104**
15-May	historical	1043	2593	2152	1708	2778	2360	1922	1670	2035	1224	2479	2625	1956	2886	2274	2227	**2121**	**2189**
	Central (cnrm)	496	1927	1457	1231	2377	1690	1160	927	1236	648	1882	2101	1312	2710	1459	1401	**1501**	**1429**
	Hot/Very Wet (canesm)	521	1724	1283	963	2151	1321	870	724	1116	450	1838	1922	975	2556	1179	1339	**1308**	**1231**
	Hot/Wet (miroc)	899	1046	761	706	908	1655	634	1035	818	770	1572	1208	1161	1975	748	1215	**1069**	**972**
	Warm/Wet (giss)	833	2346	1819	1455	2619	1990	1577	1374	1646	932	2270	2418	1683	2838	1861	1950	**1851**	**1840**
	Warm/Dry (fio)	623	2077	1611	1284	2506	2002	1382	1096	1437	778	2003	2261	1398	2785	1752	1528	**1658**	**1570**

GLAC **Snow Covered Area % change (0.5 m depth threshold)**

	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central (cnrm)	-22	-13	-19	-9	-4	-13	-25	-36	-22	-22	-9	-6	-22	-1	-13	-14	**-15**	**-13**
	Hot/Very Wet (canesm)	-34	-24	-30	-26	-13	-30	-45	-49	-37	-46	-16	-15	-45	-4	-32	-27	**-29**	**-30**
	Hot/Wet (miroc)	-47	-58	-43	-46	-56	-27	-57	-46	-49	-42	-17	-44	-51	-21	-55	-44	**-44**	**-49**
	Warm/Wet (giss)	-9	-6	-7	-5	-2	-7	-11	-14	-9	-12	-3	-3	-10	0	-6	-6	**-7**	**-7**
	Warm/Dry (fio)	-14	-13	-16	-6	-5	-5	-18	-26	-14	-17	-9	-4	-21	0	-6	-11	**-11**	**-11**
1-May	Central (cnrm)	-34	-22	-27	-17	-9	-22	-34	-39	-32	-30	-12	-9	-31	-2	-30	-21	**-22**	**-25**
	Hot/Very Wet (canesm)	-42	-32	-38	-38	-19	-41	-53	-53	-43	-55	-20	-21	-51	-6	-44	-32	**-35**	**-41**
	Hot/Wet (miroc)	-41	-57	-51	-56	-64	-30	-59	-43	-55	-43	-32	-43	-47	-23	-65	-41	**-47**	**-54**
	Warm/Wet (giss)	-18	-9	-13	-11	-5	-15	-17	-17	-16	-21	-6	-5	-15	0	-15	-9	**-11**	**-13**
	Warm/Dry (fio)	-24	-18	-21	-15	-7	-11	-24	-30	-23	-24	-11	-8	-28	-1	-17	-17	**-17**	**-16**
15-May	Central (cnrm)	-52	-26	-32	-28	-14	-28	-40	-44	-39	-47	-24	-20	-33	-6	-36	-37	**-29**	**-35**
	Hot/Very Wet (canesm)	-50	-34	-40	-44	-23	-44	-55	-57	-45	-63	-26	-27	-50	-11	-48	-40	**-38**	**-44**
	Hot/Wet (miroc)	-14	-60	-65	-59	-67	-30	-67	-38	-60	-37	-37	-54	-41	-32	-67	-45	**-50**	**-56**
	Warm/Wet (giss)	-20	-10	-15	-15	-6	-16	-18	-18	-19	-24	-8	-8	-14	-2	-18	-12	**-13**	**-16**
	Warm/Dry (fio)	-40	-20	-25	-25	-10	-15	-28	-34	-29	-36	-19	-14	-29	-4	-23	-31	**-22**	**-28**

GLAC **Snow Covered Area sq-km (5 mm SWE threshold)**

	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	2838	2876	2901	2886	2901	2869	2772	2615	2836	2784	2899	2900	2853	2901	2892	2890	**2851**	**2881**
	Central (cnrm)	2501	2732	2901	2804	2879	2708	2278	2067	2500	2297	2849	2870	2604	2897	2748	2743	**2649**	**2737**
	Hot/Very Wet (canesm)	2080	2342	2900	2589	2748	2288	1784	1630	1972	1714	2610	2695	2177	2839	2215	2405	**2312**	**2315**
	Hot/Wet (miroc)	2043	2069	2210	2326	2161	2419	1489	1993	2087	2020	2753	2245	2200	2591	1766	2700	**2192**	**2181**
	Warm/Wet (giss)	2697	2819	2901	2840	2887	2769	2578	2361	2677	2572	2881	2885	2706	2901	2827	2828	**2758**	**2823**
	Warm/Dry (fio)	2604	2735	2901	2839	2887	2808	2469	2176	2634	2490	2867	2883	2712	2900	2848	2785	**2721**	**2797**
1-May	historical	2625	2814	2707	2818	2892	2788	2608	2494	2694	2563	2888	2901	2598	2901	2775	2861	**2745**	**2782**
	Central (cnrm)	1949	2433	2160	2505	2820	2405	1948	1657	2072	1917	2773	2882	2008	2887	2202	2619	**2327**	**2303**
	Hot/Very Wet (canesm)	1578	2059	1815	1985	2580	1899	1400	1287	1633	1271	2499	2792	1419	2813	1730	2249	**1938**	**1857**
	Hot/Wet (miroc)	1828	1865	1806	1843	1731	2214	1324	2354	1721	1727	2655	2129	1845	2542	1374	2319	**1955**	**1844**
	Warm/Wet (giss)	2327	2653	2482	2647	2861	2556	2293	2142	2416	2204	2854	2896	2276	2901	2529	2739	**2548**	**2543**
	Warm/Dry (fio)	2256	2522	2301	2634	2832	2628	2214	1906	2337	2172	2824	2892	2257	2900	2531	2697	**2494**	**2526**
15-May	historical	1658	2756	2516	2413	2875	2695	2383	2211	2460	1865	2825	2838	2488	2900	2595	2597	**2505**	**2555**
	Central (cnrm)	918	2232	1832	1814	2664	2156	1572	1296	1652	1105	2457	2534	1813	2818	1816	1844	**1908**	**1824**
	Hot/Very Wet (canesm)	859	1948	1568	1409	2434	1703	1197	1002	1381	749	2241	2261	1259	2684	1468	1664	**1614**	**1518**
	Hot/Wet (miroc)	1414	1611	1223	1305	1476	2070	1053	1597	1396	1266	2391	1781	1731	2373	1119	1960	**1610**	**1537**
	Warm/Wet (giss)	1342	2562	2220	2109	2810	2413	2068	1829	2099	1455	2693	2714	2152	2883	2250	2342	**2246**	**2235**
	Warm/Dry (fio)	1166	2378	2045	1994	2729	2456	1870	1564	1953	1338	2588	2659	2073	2866	2171	2053	**2119**	**2063**

GLAC **Snow Covered Area % change (5 mm SWE threshold)**

	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central (cnrm)	-12	-5	0	-3	-1	-6	-18	-21	-12	-17	-2	-1	-9	0	-5	-5	**-7**	**-5**
	Hot/Very Wet (canesm)	-27	-19	0	-10	-5	-20	-36	-38	-30	-38	-10	-7	-24	-2	-23	-17	**-19**	**-20**
	Hot/Wet (miroc)	-28	-28	-24	-19	-25	-16	-46	-24	-26	-27	-5	-23	-23	-11	-39	-7	**-23**	**-24**
	Warm/Wet (giss)	-5	-2	0	-2	0	-3	-7	-10	-6	-8	-1	-1	-5	0	-2	-2	**-3**	**-2**
	Warm/Dry (fio)	-8	-5	0	-2	0	-2	-11	-17	-7	-11	-1	-1	-5	0	-2	-4	**-5**	**-3**
1-May	Central (cnrm)	-26	-14	-20	-11	-2	-14	-25	-34	-23	-25	-4	-1	-23	0	-21	-8	**-15**	**-17**
	Hot/Very Wet (canesm)	-40	-27	-33	-30	-11	-32	-46	-48	-39	-50	-13	-4	-45	-3	-38	-21	**-29**	**-33**
	Hot/Wet (miroc)	-30	-34	-33	-35	-40	-21	-49	-6	-36	-33	-8	-27	-29	-12	-50	-19	**-29**	**-34**
	Warm/Wet (giss)	-11	-6	-8	-6	-1	-8	-12	-14	-10	-14	-1	0	-12	0	-9	-4	**-7**	**-9**
	Warm/Dry (fio)	-14	-10	-15	-7	-2	-6	-15	-24	-13	-15	-2	0	-13	0	-9	-6	**-9**	**-9**
15-May	Central (cnrm)	-45	-19	-27	-25	-7	-20	-34	-41	-33	-41	-13	-11	-27	-3	-30	-29	**-24**	**-29**
	Hot/Very Wet (canesm)	-48	-29	-38	-42	-15	-37	-50	-55	-44	-60	-21	-20	-49	-7	-43	-36	**-36**	**-41**
	Hot/Wet (miroc)	-15	-42	-51	-46	-49	-23	-56	-28	-43	-32	-15	-37	-30	-18	-57	-25	**-36**	**-40**
	Warm/Wet (giss)	-19	-7	-12	-13	-2	-10	-13	-17	-15	-22	-5	-4	-13	-1	-13	-10	**-10**	**-13**
	Warm/Dry (fio)	-30	-14	-19	-17	-5	-9	-22	-29	-21	-28	-8	-6	-17	-1	-16	-21	**-15**	**-19**

ROMO Snow Covered Area % change (average of all years)

		"light snow cover"		0.5 m depth	
	Scenario	old run (13mm)	corrected (5mm)	old run	corrected
1-May	Central (cnrm)	-16	-11	-16	-11
	Hot/Dry (hadgem2)	-30	-21	-42	-22
	Hot/Very Wet (miroc)	-36	-24	-23	-20
	Warm/Wet (giss)	-6	-4	2	-2
	Warm/Dry (fio)	-8	-5	-32	-12
15-May	Central (cnrm)	-27	-18	-30	-18
	Hot/Dry (hadgem2)	-53	-35	-64	-38
	Hot/Very Wet (miroc)	-45	-31	-37	-27
	Warm/Wet (giss)	-12	-8	-7	-6
	Warm/Dry (fio)	-13	-8	-31	-13

GLAC Snow Covered Area % change (average of all years)

		"light snow cover"		0.5 m depth	
	Scenario	old run (13mm)	corrected (5mm)	old run	corrected
1-May	Central (cnrm)	-17	-15	-27	-22
	Hot/Very Wet (canesm)	-31	-29	-39	-35
	Hot/Wet (miroc)	-34	-29	-66	-47
	Warm/Wet (giss)	-8	-7	-15	-11
	Warm/Dry (fio)	-11	-9	-23	-17
15-May	Central (cnrm)	-26	-24	-34	-29
	Hot/Very Wet (canesm)	-37	-36	-40	-38
	Hot/Wet (miroc)	-42	-36	-68	-50
	Warm/Wet (giss)	-12	-10	-15	-13
	Warm/Dry (fio)	-18	-15	-29	-22

From: Stephen Torbit
To: Guinotte, John
Subject: Re: Tables for theWolverine TEXT document
Date: Thursday, August 31, 2017 5:43:39 PM

Thanks for this and the VM tonight. Hopefully we will get the report soon.

Sent from my iPhone

On Aug 31, 2017, at 5:41 PM, Guinotte, John <john_guinotte@fws.gov> wrote:

> John Guinotte
> Spatial Ecologist
> 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: **Andrea Ray - NOAA Federal** <andrea.ray@noaa.gov>
> Date: Thu, Aug 31, 2017 at 5:00 PM
> Subject: Fwd: Tables for theWolverine TEXT document
> To: John Guinotte <john_guinotte@fws.gov>
>
> ---------- Forwarded message ----------
> From: **Joe Barsugli** <joseph.barsugli@noaa.gov>
> Date: Wed, Aug 30, 2017 at 1:45 AM
> Subject: Tables for theWolverine TEXT document
> To: Andrea Ray <Andrea.Ray@noaa.gov>
>
> Andrea,
>
> The Tables of changes in snow covered area need to be updated for the text of the wolverine report, These files are attached and can be replaced in the word doc. I decided to add April 15th to these and remove June 1 as per the request of John and Kevin. The captions will have to be modified to reflect this change.
>
> Also. I have made a table comparing the old and new(corrected) runs in terms of snow covered area (just the average of all years...) You can see that the newer runs have a similar pattern of percent changes, but the delcines in snow cover are a little less in the newer runs. I anticipate the messaging on this will remain very similar to the old version because of these similarities.

Joe

--
Joseph Barsugli, Research Scientist III
CIRES, UCB216
University of Colorado Boulder
Boulder CO 80309
303-497-6042
PSD Science Board and
Attribution and Predictability Assessments Team Member

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Andrea J. Ray, Ph.D.
NOAA Earth System Research Lab, Mailcode R/PSD1
325 Broadway, Boulder, CO 80305-3328
(tel) 303-497-6434
(fax) 303-497-6449
andrea.ray@noaa.gov
www.researchgate.net/profile/Andrea_Ray2

<ROMO_0.5m_depth_table.pdf>

<ROMO_5mmSWE_table.pdf>

<GLAC_0.5m_depth_table.pdf>

<GLAC_5mmSWE_table.pdf>

<SCA_Average_percent_change_comparison_old_corrected_runs.pdf>

From: Guinotte, John
To: Andrea Ray
Subject: Fwd: wolverine study areas
Date: Friday, September 1, 2017 8:22:48 AM
Attachments: glacier.jpg
rocky_mountain.jpg

Hi Andrea, Have a look at these maps re where we originally started for determining the study areas. approx 300m below treeline and above. elevations are in the map legends. Note though how much we expanded the Romo study area to the east

John Guinotte
Spatial Ecologist
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: **Guinotte, John** <john_guinotte@fws.gov>
Date: Wed, Jul 6, 2016 at 1:03 PM
Subject: wolverine study areas
To: Stephen Torbit <Stephen_Torbit@fws.gov>, Jodi Bush <jodi_bush@fws.gov>, Marjorie Nelson <marjorie_nelson@fws.gov>, Justin Shoemaker <justin_shoemaker@fws.gov>

Dear All,

Quick update and potential maps of study areas attached. I spoke to Ben Livneh, one of the CU Co-PIs, about details on the 1000km2 study areas. Do these areas have to be by watershed, block, or can they be separate polygons dictated by elevation limits? He wasn't able to answer my question, but thought it was a good one and asked me to send him the polygons Steve and I drafted this am. Ben was going to run this by some of his people to see if running the model on elevation derived polygons was possible. If it is, it will maximize the amount of modeled area in potential wolverine habitat. If it isn't, we'll likely have to fall back on running the model on HUC 8 size watershed polygons. Ben's contact person is out until Monday so I don't think we'll hear anything back before then. See attached draft maps.

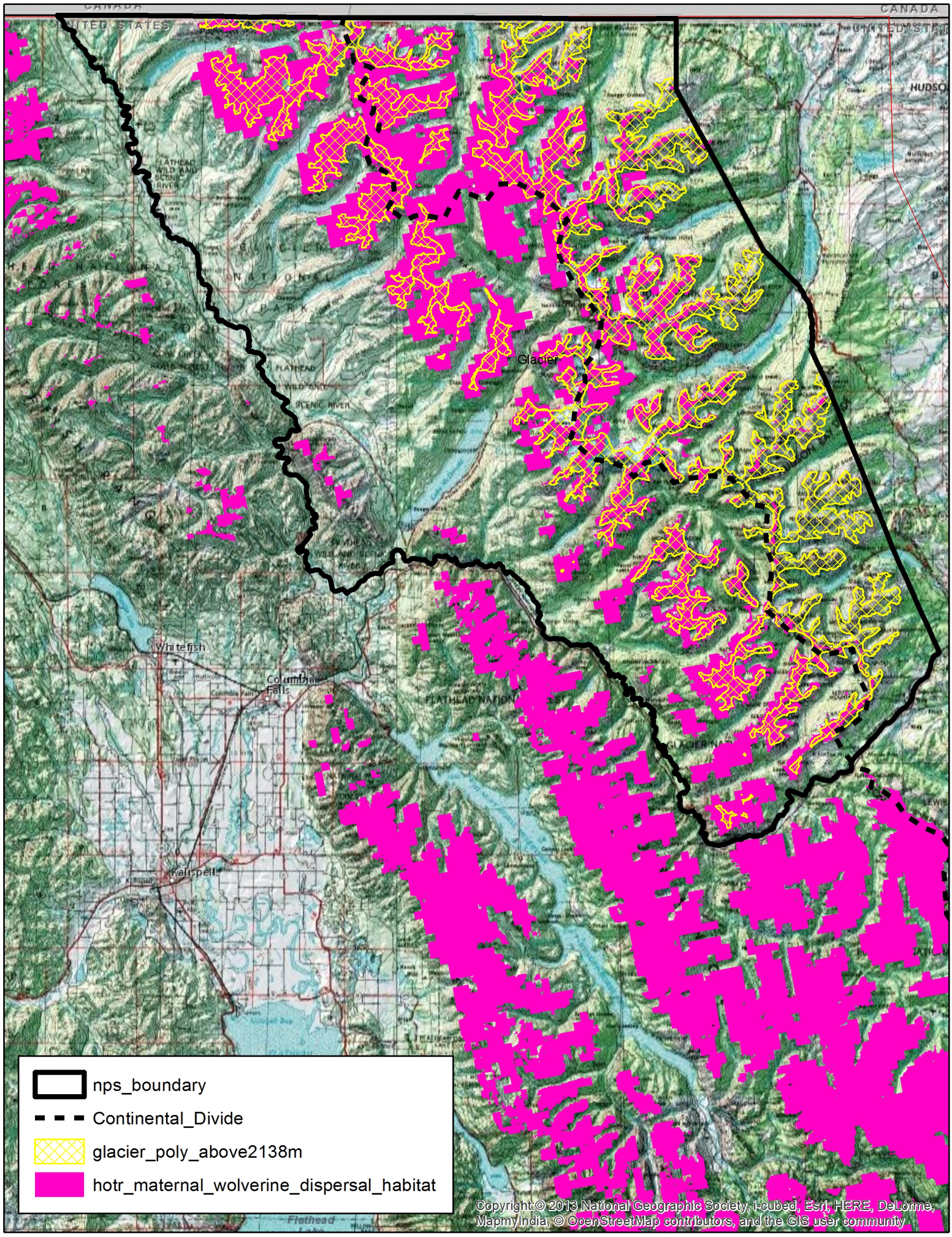
Rocky_mountain.jpg
The yellow polygon is approximately 1000km2.

Glacier.jpg
The yellow polygons total approx 1600km2. These would have to be reduced to 1000km2. The pink areas are from the Inman et al 2013 paper. Figure 3.

Elevations for both maps were 300m below treeline and above.

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


CANADA
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Whitefish
Columbia Falls
Kalispell
FLATHEAD NATION
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Continental_Divide
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hotr_maternal_wolverine_dispersal_habitat
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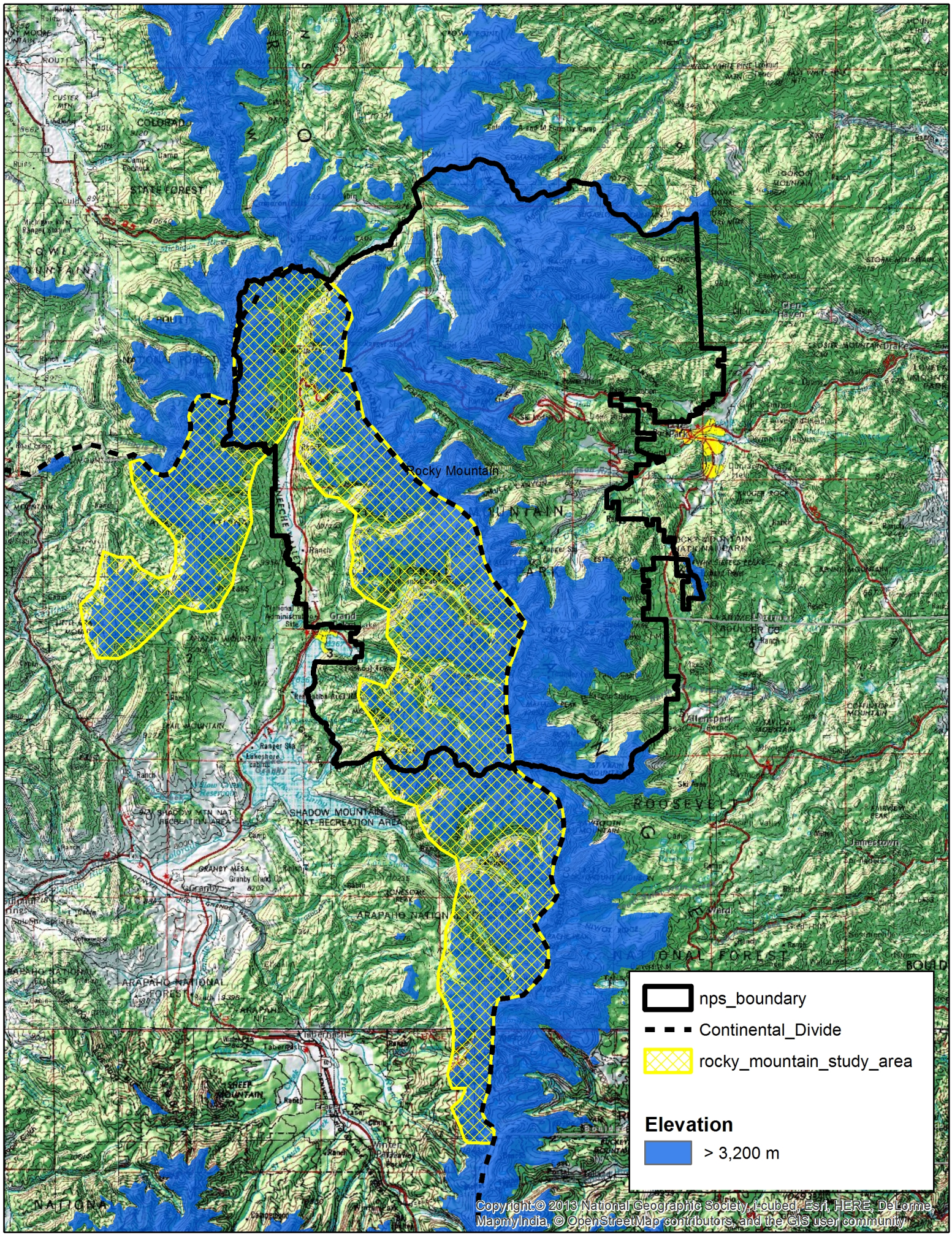
Rocky Mountain
nps_boundary
Continental_Divide
rocky_mountain_study_area
Elevation
> 3,200 m
Copyright © 2013 National Geographic Society, i-cubed, Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

From: Andrea Ray - NOAA Federal
To: Guinotte, John
Subject: Re: wolverine study areas
Date: Friday, September 1, 2017 10:59:07 AM

Thanks, John. yes, we realized that the original area was only the Colorado River basin, and missed east of the divide and north of it. thanks, Andrea

On Fri, Sep 1, 2017 at 8:22 AM, Guinotte, John <john_guinotte@fws.gov> wrote:

> Hi Andrea, Have a look at these maps re where we originally started for determining the study areas. approx 300m below treeline and above. elevations are in the map legends. Note though how much we expanded the Romo study area to the east
>
> John Guinotte
> Spatial Ecologist
> 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: **Guinotte, John** <john_guinotte@fws.gov>
> Date: Wed, Jul 6, 2016 at 1:03 PM
> Subject: wolverine study areas
> To: Stephen Torbit <Stephen_Torbit@fws.gov>, Jodi Bush <jodi_bush@fws.gov>, Marjorie Nelson <marjorie_nelson@fws.gov>, Justin Shoemaker <justin_shoemaker@fws.gov>
>
> Dear All,
>
> Quick update and potential maps of study areas attached. I spoke to Ben Livneh, one of the CU Co-PIs, about details on the 1000km2 study areas. Do these areas have to be by watershed, block, or can they be separate polygons dictated by elevation limits? He wasn't able to answer my question, but thought it was a good one and asked me to send him the polygons Steve and I drafted this am. Ben was going to run this by some of his people to see if running the model on elevation derived polygons was possible. If it is, it will maximize the amount of modeled area in potential wolverine habitat. If it isn't, we'll likely have to fall back on running the model on HUC 8 size watershed polygons. Ben's contact person is out until Monday so I don't think we'll hear anything back before then. See attached draft maps.
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> Best, John
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> John Guinotte
> Fish and Wildlife Biologist
> Ecological Services
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> Mountain Prairie Region 6
> 134 Union Blvd., Lakewood, CO 80228
> 303-236-4264
> john_guinotte@fws.gov

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Andrea J. Ray, Ph.D.
NOAA Earth System Research Lab, Mailcode R/PSD1
325 Broadway, Boulder, CO 80305-3328
(tel) 303-497-6434
(fax) 303-497-6449
andrea.ray@noaa.gov
www.researchgate.net/profile/Andrea_Ray2

From: Shoemaker, Justin
To: Grizzle, Betty; Jodi Bush; Guinotte, John; Stephen Torbit; Bryon Holt; Caitlin Snyder; Kit Hershey; Josh Hull; Madeline Drake; Gregg Kurz
Cc: Jacobsen, Dana; Marjorie Nelson
Subject: Agenda topics for Wolverine Core Team call today
Date: Tuesday, September 5, 2017 9:13:50 AM

Team,

Here's what we plan to discuss today. If you have topics to add, just let me know. Talk to you this afternoon.

1. Schedule (Justin/Betty)
2. SSA report status (Betty)
3. Genetic studies (Steve)
4. NOAA/CU snow study update (John)
5. Peer Review of the SSA report (Caitlin/Justin)

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

From: Guinotte, John
To: Stephen Torbit
Subject: Fwd: call
Date: Tuesday, September 5, 2017 9:55:18 AM

John Guinotte
Spatial Ecologist
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: **Andrea Ray - NOAA Federal** <andrea.ray@noaa.gov>
Date: Tue, Sep 5, 2017 at 9:50 AM
Subject: Re: call
To: "Guinotte, John" <john_guinotte@fws.gov>

I was just writing you an email -- we're doing final checks on numbers this morning (I just couldnt trust myself to see them anymore last night), and plan to send it off mid-day, Joe has to leave at 2 and I'd like it done before then, but I don't think we'll make 1145.

Andrea

On Tue, Sep 5, 2017 at 8:51 AM, Guinotte, John <john_guinotte@fws.gov> wrote:

> Hi Andrea,
> I sent you a call invite for later this am. Steve wants to know what the report status is before he leaves town today at 11:45am. FWS has a wolverine SSA core team call today at 2.
> Thanks John
>
> John Guinotte
> Spatial Ecologist
> 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

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Andrea J. Ray, Ph.D.
NOAA Earth System Research Lab, Mailcode R/PSD1
325 Broadway, Boulder, CO 80305-3328

(tel) 303-497-6434
(fax) 303-497-6449
andrea.ray@noaa.gov
www.researchgate.net/profile/Andrea_Ray2

From: Andrea Ray - NOAA Federal
To: Guinotte, John
Subject: Re: title
Date: Tuesday, September 5, 2017 5:09:33 PM

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thanks!

On Tue, Sep 5, 2017 at 5:01 PM, Guinotte, John <john_guinotte@fws.gov> wrote:

> Hi Andrea,
>
> I can't find it, but something along these lines is what I remember.
>
> Future snow persistence in Rocky Mountain and Glacier National Parks: An analysis to help inform the USFWS Wolverine Species Status Assessment
>
> John Guinotte
> Spatial Ecologist
> Ecological Services
> U.S. Fish and Wildlife Service
> Mountain Prairie Region 6
> 134 Union Blvd., Lakewood, CO 80228
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Andrea J. Ray, Ph.D.
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325 Broadway, Boulder, CO 80305-3328
(tel) 303-497-6434
(fax) 303-497-6449
andrea.ray@noaa.gov
www.researchgate.net/profile/Andrea_Ray2

From:	Andrea Ray - NOAA Federal
To:	John Guinotte; Steve Torbit
Cc:	Joseph Barsugli
Subject:	Wolverine Snow persistence report
Date:	Tuesday, September 5, 2017 5:24:32 PM
Attachments:	Wolverine Rept Text REVISION 5Sept17_AJR.docx

Hi John -- Here's the report with new title, and the figures are in the drive here, with today's date: https://drive.google.com/drive/folders/0ByT4y_bFYaBGem5kWENvSFc4eXM

Joe is going thru it now while on a plane, and expects that there will only be minor edits. If so, I'll do those first thing in the morning, but I want you to have this now.

I expect we'll be in touch in the next few days as questions/comments arise!

Andrea

--
--
Andrea J. Ray, Ph.D.
NOAA Earth System Research Lab, Mailcode R/PSD1
325 Broadway, Boulder, CO 80305-3328
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Future snow persistence in Rocky Mountain and Glacier National Parks: An analysis to inform the USFWS Wolverine Species Status Assessment

A Report to the U.S. Fish and Wildlife Service Region 6

5 September 2017

Andrea J. Ray[1], Joseph J. Barsugli[2], Ben Livneh[3] Candida F. Dewes[2], Imtiaz Rangwala[2], Aaron Heldmyer[3], Jenna Stewart[3]

[1]NOAA/ESRL/Physical Sciences Division
Boulder, CO
[2]CU/Cooperative Institute for Research in Environmental Sciences (CIRES)
[3]CU Civil, Environmental & Architectural Engineering

Corresponding Author:
Andrea J. Ray
303-497-6434
andrea.ray@noaa.gov

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5Sep2017

Executive Summary

Overview: This study is a fine-scale assessment of snow extent and depth at two areas in and in the vicinity of Glacier (GLAC) and Rocky Mountain (ROMO) National Parks. The analysis was done for both the recent past, using MODIS satellite-based remote sensing, and in historic simulations and projections of future snowpack using a high-resolution hydrologic model. The fine scale hydrologic modeling allows for the consideration of snow processes such as dependence on terrain slope and aspect that are important to understanding high elevation snow persistence in a changing climate and were not considered in previous work.

Methods: The report intentionally builds on previous work by McKelvey et al. (2011) extending that work by providing a higher resolution spatial scale analysis for two case study areas, and a broader range of future scenarios. Two areas were studied: a high latitude area near tree line within Glacier National Park, where tree line occurs at ~1200m (Figure 2-1) that is currently occupied by wolverines; and a lower latitude area within Rocky Mountain National Park, where tree line occurs at higher elevation (~ 2750 m) (ROMO, Figure 2-2). These sites were chosen to bracket the range of latitude and elevation wolverines currently occupy in the contiguous U.S. A detailed comparison of their methodologies and ours is provided in Table 2-1, and a discussion of results in Section 6. Note however that the primary difference between McKelvey et al. (2011) and this study is in the choice of study areas – west-wide vs. much smaller selected areas near treeline, which has implications for the biological hypotheses that may be addressed. Their work focused on May 1st snow depth as a proxy for May 15th snow disappearance, while we focus directly on May 15th snow disappearance. We also analyze our model results for the presence or absence of deeper snow (nominally greater than or equal to 0.5 meters depth) on April 15th and May 1st.[1]

The project uses methods from the peer-reviewed, published literature to:

- Explicitly model the effects of slope and aspect, using fine-scale spatial models to analyze topographic effects on snow
- Better represent the range of plausible future changes (climate scenarios)
- Analyze year-to-year variability during the main study period (2000-2013) including wet and dry extremes within that period. We selected representative wet, dry, and near normal years from the main study period for detailed analysis and assessed how these would change under different future climate scenarios. For the two areas, these are:
    - Representative years for GLAC: 2011 (cool wet), 2005 (warm dry), 2009 (near normal).
    - Representative years for ROMO: 2011 (cool wet), 2002 (warm dry), 2007 (near normal).
- Assessing change in snow persistence by elevation, with emphasis on elevations used by

[1] The study originally focused on May 15th to compare to the McKelvey, et al (2011) study, and June 1st to bracket the snowmelt season. However, as the study progressed, biologists because more interested in April snow.

Sept2017

wolverines for denning in GLAC, 1500m -2250. [2] Our analysis focusses on the 1800-2000m range, where most dens have been found. Linear regression of den site elevations and latitude in the contiguous U.S. indicated den sites in the ROMO study area would be located in an elevation range of 2700-3600 m, but documented den sites exist in ROMO (Guinotte, personal communication). In contrast to McKelvey's studies, our study areas are near tree line and above (962 m – 3166 m in GLAC, and 2563 – 4253 m in ROMO).

MODIS Observed Historic Snowpack Variability Analysis: Satellite-based MODIS snow cover data was used to assess the historical variability of snow cover in the study areas and as a basis for the spatial evaluation of the hydrologic model simulations. The historical observed snow cover was analyzed for its dependence on terrain elevation and aspect (compass direction that the slope faces).

- In GLAC, snow covered area 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; Section 4.3).
- Even in dry years, NE-facing slopes in GLAC tend to hold more snow and melt later in the season. There is > 80% snow cover above ~2000 m elevation on May 1 during dry years, and > 95% snow cover above ~1200 m during wet years (Figure 4-6).
- In ROMO, snow covered area also varies considerably by year (Section 4-4).
- NW-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 (Fig 4-13).

Future Snowpack Projections: The Distributed Hydrology Soil Vegetation (DHSVM) was run in historical simulations of the period 1998-2013. The model was validated against SNOTEL in-situ snow observations and MODIS snow cover. The model was then run for five scenarios of the future which represent a nominal 2055 climate. Scenarios were selected from CMIP5 global climate model (GCM) projections, and were chosen to span a large fraction of the range of the CMIP5 ensemble projections in each study area in terms of precipitation and temperature changes. Representative Wet, Near Normal, and Dry years were analyzed for the historical simulations and how each of these years plays out under these five future scenarios. The number of years (out of 16) with snow above 0.5m depth was also analyzed as was the change in Snow Covered Area (SCA) with depth greater than 0.5m. The average change in SCA and Snow Water Equivalent (SWE) was analyzed as a function of elevation, and for GLAC was overlayed with the elevations of wolverine den sites. (Section 5)

Sept 2017

[2] Actual den sites and elevations of specific dens are confidential and are not provided in this report. The full range in GLAC is ~1500m - ~2250. All but three of 14 documented dens in GLAC are between 1800 and 2000m (Fig. 5-22, 23); two are above 2000m and one is below ~1500m. Our analysis highlights this 1800-2000m band, although results are reported below and above that band.

For the study area in Glacier National Park (GLAC), projections for April 15th, May 1st, and May 15th Snow Covered Area and area with snow depth greater than 0.5 meters show declines on average in all scenarios, except for small increases in the Warm/Wet scenario and for almost all years (Section 5-11).

- For April 15th for the study area as a whole (Figure 2-1), there is a decline of 3-23 percent in snow covered area with light snow cover (depth ≥ 5 mm), and a 7-44% percent decline in area with significant snow (depth > 0.5 m) for the five scenarios considered, compared to the 2000-2013 historic average. For May 15th, the area with light snowcover declines 10-36 percent, and the area with significant snow cover declines 13-50 percent (Tables 5-4, 5-5)
- On April 15th, the Warm/Wet scenario shows the least change in average SCA (2121 Sq-km) compared to the historic snow cover (2609-7%) for significant (≥ 0.5 meter) snowpack. The largest decrease is the Hot/Wet scenario (1520 sq-km) with 44% decrease. Under the Hot/Wet scenario, the April 15th significant snowpack has been diminished below the level of the historic May 15th snowpack – a month shift (Figure 5-14).
- All projections show declines in the number of years with significant snow. In each study domain, the areas with frequent availability (at least 14 out of 16 years) of significant snow (≥ 0.5 m) become concentrated in smaller high elevation areas, as seen in the maps in Figures 5-13, 5-14 (GLAC), and 5-20, 5-21 (ROMO). In contrast, lower elevation areas had the largest changes, or decreases in significant snowcover.
- Most of the known den sites are located between 1800 and 2000m in GLAC. Below that elevation band large snow losses are predicted (40-70% decreases for two of the scenarios, 16-20% for the other three), above that elevation band there is little change in SCA for four of the five scenarios (2-8%) except in maximum warming scenario (-40%, Figure 5-22). In that 1800-2000m band, the snowpack change is sensitive to elevation and to the particular future climate scenario.
- This phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. Regonda et al. (2005) found little historical change in snowpack in the Western United States above approximately 2500m elevation despite observed warming trends.
- For representative wet years, the higher elevations of our study areas experience only 2-7% loss of snowpack under the scenarios with "least" change and the "central" change (Figure 5-8, 5-12), although for the dry years, losses range 18-57% (Table 5-5). This is in contrast to the McKelvey study, in which the large losses in the snow analysis included lower elevations that have not been considered likely denning areas.
- Modest declines in SWE may occur without affecting the area with significant snow depth. On May 1st, for areas at 1800m and above in GLAC, losses of ~10-30% SWE (Figure 5-23) result in losses of only ~10% snowcover. The implication is that the wet, cold climate of the GLAC study area could act as a "buffer" to change in the area of 0.5 m deep snow on May 1st, at least at the elevations above 1800m.

For the study area in and around Rocky Mountain National Park (ROMO), projections of May 15th Snow Covered Area in ROMO declines on average in all scenarios, except for small increases in the Warm/Wet scenario, and for almost all years (Section 5-12).

Sept 2017

- For April 15th for the study area as a whole (Figure 2-2), there is decline of 3-18% in area with light snow cover (depth ≥ 5 mm), and a change of -1 - +16 in area with significant snow cover (depth > 0.5 m) for the five scenarios considered, compared to the 2000-2013 historic average. For May 15th, the area with light snowcover declines 8-35 %, and the area with significant snow cover declines 6-38 percent (Tables 5-6, 5-7).
- Snow Covered Area in ROMO (≥0.5 m threshold on May 15) generally declines in wet years, shows a slight increase in (1-5%) in some years for the Warm/Wet scenarios with increased precipitation.
- One scenario with increased precipitation (Warm/Wet, giss) shows increases in April 15th SCA (Table 5-7). There are also slight increases in SWE for two scenarios at elevations at and above 3400m (Figure 5-25), but decreases in SWE for all scenarios below 3400m.
- Although no dens have been documented in ROMO, the elevation band for denning, modeled by regression analysis, is thought to be 2700-3600m. On May 1st, modest declines in SWE of ~15% and less for areas at 3400m and above result in losses of < result in losses of only ~10% snowcover (Figure 5-24, 25). 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 deep snow on May 1st. Below that band losses in SWE of ≥ 35% result in higher losses in SCA (20-65%), except in the scenario with least change (Warm/Wet, giss model). As in the denning band in GLAC, in that 2700-3600m band, the snowpack change is sensitive to elevation and to the particular future climate scenario.
- The phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. Regonda et al. (2005) found little historical change in snowpack in the Western United States above approximately 2500m elevation despite observed warming trends. Other literature on this topic is discussed in Section 5.13.
- ROMO exhibited more uncertainty in projections than GLAC
    - ROMO has more uncertainty as to whether precipitation will increase or decrease.
    - The beneficial effect of increased precipitation on snowpack is more prominent earlier in the Spring. In the Warm/Wet scenario, the area of significant snow on May1 increases on average, though it decreases on May 15.
    - For April 15th –May 15th, and for wet years, the high elevations of the ROMO study area as whole, there is only modest loss of snow cover under all scenarios of change (Table 5-7, see 2011 representative wet year). However even in wet years, the area of significant snowpack can decline by up to 26% for the Hot/Dry climate change scenario on May 15th (Table 5-7).

Elevation dependence of change (Section 5.13): **In general, and supported by the literature (e.g. Regonda et al, 2005), the snowpack at the higher elevations of both areas is more responsive to precipitation change, while at lower elevations it is more responsive to temperature change**. For GLAC, most of the observed and inferred den sites are located within the zone where temperature dominates the future effects of change, and therefore at elevations where the changes in snowpack are highly dependent on the climate scenario and also on elevation. For the elevation of den sites in GLAC (>1800m) loss of SCA on May 1st spans the range of 5-40% loss, with a 70% decreases for the Hot/Wet (miroc GCM) scenario (Fig 5-22). Above 2200m the losses are <5% for all but the Hot/Wet scenario. For ROMO, the range is at 3200 m elevation, the middle of the inferred range for wolverine there. However, at 3600m the loss of SCA in all scenarios is < 5% (Figure 5-24).

Sept2017

Comparison with McKelvey's results (Section 6): There are challenges in making a direct comparison between the studies due to differences in the goals and spatial scale. McKelvey investigated persistence of even a light snow cover to May 15th as a correlate of wolverine habitat, as noted in Aubry et al (2008). This study focuses on high-elevation terrain and on the persistence of deeper snowpack.

However, the following comparisons are valid:

- Snow cover persists in our study areas, even for the hotter of the two scenarios of change in the McKelvey study (miroc "2080's). The greatest loss of May 15th snow cover in McKelvey occurs at elevations lower than ~250m below treeline that were deliberately not included in the GLAC or ROMO study areas. (Figure 5-26).
- McKelvey focused exclusively on the persistence of even light snow cover on May 15th. Because of the increased resolution of our study we are able to consider whether any pockets of snow with depth greater than 0.5 meters will persist in these areas. Results vary according to scenario, but generally show declines of 13-50% in SCA in GLAC and 6-38% in ROMO for May 15th by the 2050s. We made projections for April 15th (which McKelvey did not), which shows declines of in SCA of 7-44% in GLAC and changes of -16 - +1% in ROMO for April 1st by the 2050s
- Our results may reasonably be generalized to the high mountain ranges within the Rockies that lie between GLAC and ROMO, with projections on average wetter in GLAC. However, without further study we cannot reasonably extend our results to say whether or not snow refugia may persist in the Central Rockies at below our study elevations (~1000m). Areas below our study areas are where McKelvey indicates the greatest snowpack losses. Nor can we extrapolate to the Cascades with its very different maritime climate.
- While it is difficult to compare the McKelvey et al (2011) results directly to the present study due to differences in methodology and focus, the qualitative picture remains – projected warming has a larger effect at lower elevations whereas projected precipitation changes may dominate the Springtime snowpack in the high country.

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1 Introduction

1.1 Motivation

This report responds to the United States Fish and Wildlife Service (FWS) need for information on potential climate impacts to snow persistence. The North American wolverine (*Gulo gulo luscus*) is currently being evaluated for listing as a threatened or endangered species under the Endangered Species Act (ESA) and climate change effects on snow persistence was identified as an important factor for the future viability of the wolverine. The species was considered for listing in 2014, but FWS concluded that it did not warrant listing. They further concluded that there is significant uncertainty about how the effects of climate change will affect wolverines and their habitat in the foreseeable future, and that this uncertainty includes information on how fine-scale changes in snow cover and persistence might affect denning site selection.

This report provides FWS with a finer scale assessment of snow extent and depth at which extends previous work by McKelvey et al. (2011). We believe the inclusion of finer scale analyses as well as additional snow processes such as slope and aspect are critical to understanding high elevation snow persistence in a changing climate.

By design, our methods and models are chosen from the peer-reviewed, published literature. What we find, particularly with regard to the elevation dependence of snowpack change, is consistent with past research.

Funding was provided by the U.S. Fish and Wildlife Service, Region 6 and the NOAA/Earth System Research Lab/Physical Sciences Division. This effort builds on work underway by the project team at NOAA/ESRL/PSD, the NOAA-University of Colorado (CU) Cooperative Institute for Research in Environmental Sciences (CIRES), and CU Department of Civil, Environmental & Architectural Engineering.

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1.2 Project Objectives

Persistent spring snowpack has been described as an important factor in determining suitable habitat for the wolverine, including Northern boreal forests and subarctic and alpine tundra (Aubry et al, 2007, Peacock et al, 2011). This relationship was the basis for the analysis by Copeland et al. (2010) and McKelvey et al. (2011) used in the previous FWS decision. In both studies, climate change projections of snowpack were used to characterize potential future wolverine habitat.

The goal of this effort is to identify the depth and persistence of spring snow in the future. Our primary objective is to advance scientific understanding of the current spatial extent of spring snow retention on the landscape, and the future temporal and spatial extent of snow retention through a thirty-year period, 2041-2070, centered on the year 2055. We aim to advance snow analysis and modeling to better support assessment of snow-related species, in the following ways:

- Explicitly model the effects of slope and aspect, using fine-scale spatial models to analyze topographic effects on snow
- Better represent the range of plausible future changes (climate scenarios)
- Analyze extremes from the current year to year variability: we selected representative wet, dry, and near normal years from the main study period for detailed analysis and assessed how these would change under different future climate scenarios.

Our strategy was to build on previous methods where possible to be comparable to work by McKelvey et al. (2011) and Copeland et al. (2010). We departed from their methods where necessary to take advantage of analysis techniques not feasible at the large scales used in the studies done by those authors. These include new scientific data and tools that are now available, including the following:

- Use of a longer time series of satellite and in situ observations.
- Analysis of historic snowpack variability to investigate the influences of topography on snow cover
- Use of more recent climate model output and improved criteria for choice of climate change scenarios
- Use of hydrologic modeling at highly resolved (250m) spatial scale for simulation and future projection of snow cover and depth for two case study areas in Glacier National Park and Rocky Mountain National Park.

5Sept2017

2 Project Overview and Background

2.1 Overview

We first reviewed the observed climate and variability, in order to provide context for future changes (Section 3). We next analyzed historic snow variability from satellite remote sensing of snow extent from the year 2000 to present to determine areas of greater and lesser sensitivity to climate drivers (temperature and precipitation), and identify possible snow refugia. Prior studies also show a relationship between terrain (slope and aspect) and persistence of snow (e.g. Lundquist and Flint, 2006) and thus this factor is potentially important under in a changed climate. (Section 4). We then did an intercomparison of the satellite observations of snow with that from the DHSVM hydrologic modeling study that includes a representation of slope and aspect (the compass direction that the slope faces) of the terrain and shading on the snowpack. Finally, the DSHVM hydrologic model was forced with five future scenarios of climate change for each of the two study regions (Section 5). These future climate scenarios were derived from the latest Coupled Model Inter-comparison Project Phase-5 runs (CMIP5, Taylor et al., 2012) which informed the latest Intergovernmental Panel on Climate Change (IPCC) report (IPCC AR5, 2013).

All methodologies were chosen to be consistent with those used in existing peer-reviewed work.

2.2 Study Areas

High-resolution hydrologic modeling was needed to provide fine scale analysis of snow. However, given time, funding and computational constraints, it was necessary to limit the study domain to two areas of about 1,500-3,000km^2 for high-resolution analysis. Two study areas representing core and peripheral habitat regions in the northern and central Rocky Mountains were identified in consultation with FWS Region 6 personnel (Figures 2-1 and 2-2). We bracketed the extent of wolverine habitat conditions in the lower 48, because we were restricted to smaller areas for analysis. The two sites chosen included a high latitude, low elevation area within Glacier National Park (Figure 2-1) that is currently occupied by wolverines and a lower latitude, high elevation area within Rocky Mountain National Park (Figure 2-2) that has had recent documented wolverine occurrence and could be a potential reintroduction site for wolverines. Both model areas encompassed elevations from ~250m below treeline to maximum elevation in each domain (962 m – 3166 m in GLAC, and 2563 – 4253 m in ROMO). This elevation threshold was chosen for the analysis by FWS to represent the areas with known denning activities by wolverines.

The analysis for the GLAC and ROMO study areas is presented in separate sections, repeating descriptions to make the material self-contained for the reader who may read about only one area; similarly, complete captions are given for each area.

Sept 2017

2.3 The West-wide context of future climate

Global climate models (GCMs) are the primary tools used by climate science to examine the nature of climate change during the 21st century. These models reveal both the uncertainty of climate projections as well as underlying regional patterns of change. This section provides a west-wide context for the specific choices of future climate scenarios that will be discussed later in the report.

Understanding the uncertainty of climate projections is commonly approached through comparison of the results from multiple climate models (e.g. IPCC, 2013). There are currently about 20 modeling centers worldwide that provide output from their best model or models to be considered in the Coupled Model Inter-comparison Project Phase-5 (CMIP5, Taylor et al., 2012), an international, coordinated modeling project which informed the most recent Intergovernmental Panel on Climate Change (IPCC) assessment report (IPCC AR5, 2013). When we quantify regional changes in climate variables such as temperature and precipitation by a particular time horizon in the 21st century, we find a large spread in the extent of warming and changes in precipitation, including both increases and decreases in precipitation, as shown in regional maps (Figure 2-4 and described later in Section 5). For temperature change, much of this spread (or uncertainty) is a result of the difference among the formulations of the GCMs (e.g., their climate sensitivities), whereas for precipitation it is both the differences among GCMs and internal climate variability. Some difference also comes out of the choice of future greenhouse gases (GHG) emission scenario. However, the differences among greenhouse gas emissions scenarios is less at mid-21st century compared to later in the century, and is much smaller than other sources of uncertainty at the regional scale (IPCC, 2013).

In addition to uncertainty, the CMIP5 climate models also reveal regional patterns of change. Figure 2-4 shows projected annual and seasonal temperature and precipitation changes by 2050 (2035–2064) over the western U.S., including the northern and central Rocky Mountains, from an ensemble of the 34 climate models used for this study under the RCP 8.5, a high-end emissions scenario. The large maps show the average change for all of the models (n=34) for that season, and the small maps show the average changes of the highest 20% and lowest 20% of the models, based on the statewide change for Colorado in temperature or precipitation. For much of the central and northern Rockies, all models show a substantial warming (of +2.5°F to +5.5°F). While fewer models agree about the direction of precipitation change west-wide, even the lower (drier) models show an increase in winter precipitation for the area around Glacier National Park, although there is less agreement for the central Rockies area including Rocky Mountain National Park.

The uncertainty of climate change motivates the choice of several future climate scenarios for each study region. The regional patterns of change indicate that the range of the climate scenarios chosen will differ somewhat from region to region. The GCM output, and the specific selection of future climate scenarios for this study are discussed further in Section 5.

Sept 2017

2.4 Comparison between our analysis and that of Copeland and McKelvey

The Copeland et al. (2010) and McKelvey et al. (2011) studies were an integral part of the previous FWS decision process. Therefore, we present here a detailed comparison of their methodologies and ours, to establish both how our methodologies followed theirs when appropriate, and diverged where new data or updated methods were available. A summary of the most salient similarities and differences between our work and the studies used previously is presented in Table 2-1.

Table 2-1: Modeling Methods Compared to McKelvey

	McKelvey (Littell)	This Study
Spatial Resolution (modeling)	VIC model – 1/16 degree (~5km x 7 km, ~37km^2 cell)	DHSVM model - 250m x 250m UTM grid (~0.0625 km^2 cell)
Spatial Extent	Westwide except California and Great Basin	ROMO and GLAC study areas, near and above treeline
Process differences	Slope and aspect were not modeled and the mountains were assumed to be flat from a solar radiation process, implicit elevation bands.	Slope, aspect, shading, explicit fine scale elevation effects.
Validation	None specific to snow	Comparison to SNOTEL (ground stations) and MODIS (satellite)
Future Scenarios	Delta Method; “2045”;”2085”; from 3 GCMs selected to span westwide temperature changes.	Delta Method: ”2055” from 5 GCMs spanning regional changes in temperature and precipitation
Analysis	Changes in long-term mean snowpack only	Means and variability, including wet, near normal and dry years.
Snow representation	Binary snow/no snow at 13 cm snow depth	Analyzed snow depth at two thresholds: 5mm of SWE (‘light snow’) and 0.5m depth (‘significant snow’)

Both Copeland et al (2010; hereafter, simply Copeland or the Copeland study) and McKelvey present analysis based on satellite remotely-sensed snow cover from the MODIS. For example, Copeland calculated the number of years with snowcover on May 15th as detected in the MODIS snowcover dataset, by calculating a snow disappearance date. They found that most (45 of 75) North American den sites were in areas that snow cover persisted with 6 or 7 out of 7 years on May 15th. We also provide a historical analysis of remotely sensed snow cover from MODIS. We also investigated the of number of years of snow persistence for our study areas, however, the new MODIS product has two advantages over that available at the time of their study, 1) improved snow detection (snow covered area, SCA), and 2) 17 years of MODIS data is now available vs the 7 available to Copeland and McKelvey. Furthermore, we investigated the relationships between snow cover persistence and both elevation and aspect (the compass direction of the slope face).

Both McKelvey et al. (2011) (hereafter, simply McKelvey or the McKelvey study) and the present study investigate projections of snow cover using a distributed hydrologic model. The McKelvey study focused its' analysis on May 1st snow depth simulated by the Variable Infiltration Capacity hydrologic (VIC) hydrology model (1/16 degree, ~5km x 7 km), "flat" gridboxes, or cells, with no slope aspect dependence). The May 1st snow depth was then converted into a proxy for May 15th snow disappearance by applying a threshold of 13 cm – a procedure they refer to as "cross-walking". All subsequent calculations of theirs were done using the May 15th snow cover proxy. The VIC model runs were documented in Littell et al. (2011) and were based on meteorological inputs from Elsner et al. (2010). The present study uses the Distributed Hydrology Soil Vegetation (DHSVM) model, which was developed by the same group at the University of Washington for fine-scale simulations, and shares many model components with the VIC model. The primary output of DHSVM is snow water equivalent (SWE). We investigate several thresholds for converting SWE to "snow cover". Conversion of SWE to snow depth is done using empirically derived conversion factor relevant to late Spring.

To generate future climate scenarios, Littell (on which McKelvey results are based) used the "delta method" (described later in Section 5) for the projected changes in climate compared to present day. This study also uses the "delta method," applied in a similar manner. The McKelvey study used a range of temperature change to select GCMs representing the range or spread of future scenarios. As shown below in Section 5.10 and Figure 5.7, their chosen future scenarios reflect a range of precipitation in GLAC, but in ROMO, the three scenarios have similar precipitation changes. This project selected a larger number of future scenarios selected based on changes in both temperature and precipitation, to be consistent with recommended strategies for incorporation of uncertainties into the assessment of impacts and developing adaptation strategies (e.g. Fisichelli et al, 2016 a,b, see Section 5-8).

Analysis metrics, including the time frames of the projections differ somewhat between the two studies. The McKelvey study calculated a metric for a historic period (1915-2005 average) and two futures, 30-year averages around "2045" and" 2085." This study focused on a 30-year period around mid-century, "2055" to focus on FWS' time horizons for the wolverine and due to time and computational constraints given the project budget. We also reproduce a single future scenario using one of the Littell (2011) "2080's scenarios for direct comparison. Calculations for a later period using the CMIP5 climate models (e.g. ~2100) could easily be made, but were

ESPEZ017

beyond the scope of this project. We provide analysis for two thresholds of snow amount, a "light" snow cover (5 mm of snow water equivalent [SWE]), and significant, or "heavy" snow cover (equivalent to 0.5 m of snow depth). Because the Littell dataset that McKelvey used only includes May 1st snow depth simulation (and not May 15th), McKelvey's study chose a 13 cm snow depth on May1st as a proxy for snow disappearance by May 15th. We instead chose to use a much lighter threshold for presence/absence of snow on May 15th itself. Note that SWE is a measure of the water content in the snowpack; to estimate depth, a density of the snow must be assumed, i.e. an approximation of whether the snow is heavy or light. Our threshold of 13mm SWE was originally chosen to be comparable to McKelvey's snow depth. Our assumptions are discussed further in Sec. 5.6.

For the purposes of determining the presence or absence of snow we use a 5mm SWE threshold. It is common modeling practice to use a low threshold for snow disappearance rather than using a strict criterion of zero, due to peculiarities with the model's numerical accounting for snow (Ben Livneh, pers. comm.) In addition, the effect of small dustings of springtime snowcover on previously bare ground were also minimized by this choice. In consultation with the biologists, also were concerned with analyzing the presence of "significant snow" which we defined as ≥ 0.5 m of snow depth. The value of ≥ 0.5 m was arrived at by an analysis of the modeled snow depth at known wolverine denning sites in Glacier National Park (Table 5-2). With the exception of one site that had melted out by May 15th, the other sites all have snowpack between 0.4 and 1.4 m. The conversion of SWE to snow depth assumes bulk density of the snowpack and is discussed in Section 5-5.

An important difference between this study and prior work by Copeland et al. (2010) and McKelvey et al. (2011) is the spatial scale of results. McKelvey and Copeland both presented results on a regular 1/16 degree latitude-longitude grid, in which each cell, or gridbox is ~5-7 km on a side. These cells were assumed to be flat in the model-- that is they do not incorporate slope or aspect information in their surface energy balance. The result of this is north-facing slopes are treated identically to south-facing slopes. Our study uses the Distributed Hydrology Soil Vegetation Model (DHSVM) originally developed by Wigmosta et al. (1994)[3] for simulating the snowpack at 250m x 250m resolution that incorporates other physical drivers of snowpack (a complete energy balance at the surface, a 2-layer snow model, and a 2-layer vegetation canopy model) and allows analysis of snow at different slopes and aspects (slope directions). The VIC modeling included the option for elevational snow bands within the VIC grid (Jeremy Littell, pers. comm.) but the snow band information was not explicitly used. Therefore, sub-grid scale elevational effects are implicit and approximate in the VIC model whereas it is explicitly modeled at the 250m-scale in DHSVM. A visual comparison of the gridbox sizes is shown in Figure 2-4 for further description of the terminology used to describe spatial resolution, see "resolution" in the Glossary. Neither VIC nor DHSVM include the effects of wind or avalanche redistribution of snow (see section 5-10 for additional modeling caveats).

[3] The most up-to-date documentation of the DHSVM model, including changes to the model subsequent to the original reference, is available from the following website: http://www.hydro.washington.edu/Lettenmaier/Models/DHSVM/documentation.shtml)

Sept 2017

It should be noted there are tradeoffs between our strategies and the methods of Copeland and McKelvey. The finer scale analysis presented in this report integrates slope and aspect with respect to snow accumulation and retention that are thought to be important for maintaining snow refugia for denning sites (see Fig 2 in McKelvey et al 2011), and for elevations where wolverine dens have been observed. The disadvantage of this improvement in spatial resolution is that the high-resolution modeling is computationally intensive. We were only able to analyze two study areas due to these computational constraints and the short time to meet FWS deadlines. The Copeland and McKelvey projects analyzed a much larger domain, including most of the wolverine range in the continental US, but does not provide detailed analysis of any habitat area.

5Sept2017

3 Observed Climate and Variability

Key Points:

- Both study areas show upward trends in both temperature and freezing level
- Surface Air Temperature and Atmospheric freezing level are related, with a stronger relationship in ROMO (that is, a greater change in freezing level for a given surface air temperature change)
- There is year-to-year variability in historic temperature, precipitation, and hence the snowpack, leading to some extreme wet and dry years that were chosen for study:
    - Representative years chosen for GLAC: 2011 (wet), 2005 (dry), 2009 (near normal).
    - Representative years chosen for ROMO: 2011 (wet), 2002 (dry), 2007 (near normal).

3.1 Introduction

This section presents a historical analysis of the winter and spring climate variability for the two study regions, GLAC and ROMO, in order to provide context for future changes. This section includes a discussion of trends in temperature and freezing level; historical year-to-year variability in cool season (October – May) temperature and precipitation for the study areas, choice of representative years during the simulation period for cool/wet, warm/dry, and near normal conditions for the two areas; and a ranking of the representative years in a longer climate record. Later in the report, we will assess what the wet, dry and near normal years of the future may be like. A complete description of regional climate is beyond the scope of this project, but may be found in e.g. McWethy et al (2010), Garfin et al (2014), Lukas et al (2014), Shafer et al (2014), and citations therein.

3.2 Background Material: Trends in Surface Temperature and Freezing Level in the Study Areas

Temperature strongly influences hydrologic processes such as snowpack accumulation, and timing of snowmelt. Here we present some background material on observed trends in surface air temperature and on the freezing level in the atmosphere, and how these two quantities are related.

Both the Glacier and Rocky Mountain areas show a trend of increasing surface air temperature in the winter season (October-May, Figure 3-1), consistent with trends that have been observed west-wide (Garfin et al 2014; Lukas et al 2014; Shafer et al 2014). While winter season temperatures vary inter-annually, linear regression of these data (not shown) indicates about a 1.4 ºC increase in temperature from 1948-2015 for an area around Glacier, and about a 1.2 ºC increase around Rocky Mountain National Park.

5Sept2017

Atmospheric freezing level height (FLH) represents the altitude in the free atmosphere (that is, away from the surface and its immediate influence) where the temperature is 0 °C. Above this level, the temperature of the air is typically below freezing. Freezing in the free atmosphere is indicative of the level above which precipitation falls as snow rather than rain. Freezing level height can have a strong influence on freeze-thaw processes in high-elevation regions (Bradley et al 2009). As with winter season temperatures, freezing level varies over time (Figures 3-2, 3-3), but linear regression (not shown) indicates about a 160m increase in the freezing level for Glacier (Fig 3-2), and about a 170 m increase in the freezing level for Rocky Mountain (Fig 3-3).

Figure 3-4 illustrates a strong relationship between freezing levels and surface air temperature change for both regions in October-May with explained variance (R^2) close to 0.8. For GLAC (3-1, left), a 1°C anomaly in temperature equates to about a 115 m increase in the freezing level, over the period. For ROMO, for 1°C increase in temperature there has been about a 180 m increase in the freezing level (3-1, right). If these historical relationships hold in the future, the larger change in freezing level for the ROMO study area could indicate a greater sensitivity of snow covered area to rising temperatures.

3.3 Exploring Weather Variability through the Choice of Representative Years for Detailed Analysis

One of the primary study goals is to extend the analysis to include the effects of climate change on extreme years both for years with high- and low- spring snowpack. This is in contrast to McKelvey et al (2011) who studied only the effect of climate change on the *long-term average* snowpack. Our historical snowpack analysis (Section 4) was performed for the entire period 2000-2013 and the hydrologic modeling (Section 5) for 1998-2013, and then assessed now these wet, dry, and near normal years might change under several climate change scenarios. To capture the weather variability within these periods we focus some of our analysis in Sections 4 and 5 on a representative wet, dry, and near normal year for each study area. Nonetheless, results from all years were computed.

Table 3-1: Historical Percentiles of precipitation and temperature for the representative dry, near normal, and wet years for GLAC and ROMO study areas.

	Year Type	Year	Oct. - May Precipitation Percentile	Oct. - May Temperature Percentile
GLAC	Dry	2005	6	83
	Near Normal	2009	45	42
	Wet	2011	98	6
ROMO	Dry	2002	4	45
	Near Normal	2007	56	69
	Wet	2011	96	36

Sept 2017

To drive our choice of representative years, we investigated historical cold-season (October-May) temperature and precipitation anomalies and MODIS-based snow covered area for 2000-2013. Years were chosen within that range to represent a cool/wet year with high spring snowpack, a "near normal" year, and a "dry" year with low snowpack. Figure 3-5 shows scatterplots of the anomalous precipitation (as % of average) and temperature (degrees Celsius) for each year of the primary study period (2000-2013) for the two study areas. For both study areas, the 2011 winter stands out as a particularly large (cool/wet) anomaly.

The choice a dry year for GLAC points to 2005. Examination of the time series of Snow Covered Area (SCA) derived from the MODIS satellite product (Figure 3-6) corroborates this choice. For ROMO the hot/dry year 2012 with exceptionally low snow cover was first chosen. However, modeling difficulties encountered in the model validation procedure described in section 5.4.2 led to the need to find an alternative "dry" year for ROMO. The scatter plot in Figure 3-5 indicates that 2004 or 2002 might both be good alternatives, and both of these years had adequate modeling success. Because 2002 had lower Spring snow cover (figure 3-6), and because it was a widely agreed upon drought year in Colorado, we chose to use 2002 as the representative "dry" year for ROMO.

For the choice of near-normal year, 2007 is indicated for ROMO, as that is closest to the center of the scatterplot in Figure 3-5. A number of choices would seem plausible for GLAC, however as no one year stands out as "most normal." To further guide our choices of representative years, we looked at the elevation profiles of SCA for the various years, and 2009 was chosen. We show the SCA as a function of elevation within the study areas (Figure 3-6cd) for the representative years. These plots indicate that the elevation profile of observed snow cover in our chosen near-normal years closely follow the median profile for 2000-2013.

3.4 The Study Period in the Longer Climate Record

Because the study period is 14 years long, the question arises as to how "extreme" the wet and dry years are in the longer climatological record. To address this question, we analyzed how often the temperature and precipitation anomalies for the study years are likely to occur in the longer (1950-2013) climatological record by computing their percentiles. Percentiles were calculated by ranking the data and using the following formula: percentile = (rank – 0.5)/(total number of years). Note that the exact rankings and percentiles may differ based on the underlying dataset and interpolation methods used, as the study areas have relatively few observing stations. However, percentiles calculated from the PRISM dataset (not shown) yield qualitatively similar results to those found below.

The percentiles of October – May precipitation and temperature averaged over the study areas are shown for the representative wet, near normal and dry in Table 3-1 for both study areas. The percentiles are calculated based on the 63 total years in the 1951-2013 period of the Livneh (2014) dataset. For GLAC, October – May 2011 was at the 98th percentile of precipitation and the 6th percentile of temperature, while 2005 was at the 6th percentile of precipitation and 83rd percentile of temperature. For ROMO, 2011 was in the 96th percentile of October – May precipitation, but only the 36th percentile of temperature, and while anomalously cold was not

FSept2017

extreme in temperature. 2002 was in the 4th percentile of precipitation, but only near the median in temperature.

For further reference, Tables 3-2 (GLAC) and 3-3 (ROMO) show the percentiles of precipitation and temperature for the entire study period, 2000-2013, as well as the percentiles for the April – June melt season. Even though the low precipitation was more extreme in 2002 than in 2012, the temperature was not. This is reflected in the MODIS spring snowcover (Figure 3-6), where 2002 was low, but not as nearly extreme as in 2012.

5Sept2017

Table 3-2: Percentile of temperature and precipitation anomalies for GLAC study area based on the 1951-2013 period. Percentiles are shown for both the October – May cold season and for the April – June melt season.

GLAC	Percentile 1951-2013			
	Oct. - May Precipitation	Oct. - May Temperature	Apr. - June Precipitation	Apr. - June Temperature
2000	31	96	7	66
2001	2	37	47	58
2002	61	31	91	12
2003	33	87	13	69
2004	13	63	33	61
2005	6	83	80	47
2006	37	82	53	93
2007	21	72	6	75
2008	39	47	60	17
2009	45	42	12	34
2010	12	55	85	13
2011	98	6	87	4
2012	40	74	72	53
2013	60	66	56	29

Table 3-3: Percentile of temperature and precipitation anomalies for ROMO study area based on the 1951-2013 period. Percentiles are shown for both the October – May cold season and for the April – June melt season.

ROMO	Percentile 1951-2013			
	Oct. - May Precipitation	Oct. - May Temperature	Apr. - June Precipitation	Apr. - June Temperature
2000	45	98	40	98
2001	29	33	23	91
2002	4	45	2	96
2003	75	80	77	64
2004	21	91	75	77
2005	50	82	82	53
2006	28	74	4	94
2007	56	69	6	75
2008	80	12	45	13
2009	77	93	88	44
2010	48	13	87	37
2011	96	36	93	25
2012	10	94	7	99
2013	64	26	79	42

Draft 2017

4 MODIS Observed Historic Snowpack Variability Analysis

Key points

- In GLAC, snow covered area 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; Section 4.3).
- Even in dry years, NE-facing slopes in GLAC tend to hold more snow and melt later in the season. There is > 80% snow cover above ~2000 m elevation on May 1 during dry years, and > 95% snow cover above ~1200 m during wet years (Figure 4-6).
- In ROMO, snow covered area also varies considerably by year (Section 4-4).
- NW-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 (Fig 4-13).

4.1 Introduction

In this section, we perform an analysis of the variability of snow cover in the historical period 2000-2016 using gridded snow cover data acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Terra satellite. The dataset and methodology of analysis is first described. The analysis for the GLAC and ROMO study areas are then presented in separate sections, repeating descriptions to make the material self-contained for the reader who may read about only one area. Each section consists of analysis of the following: a) total snow covered area (SCA), b) SCA fractional area as a function of eight compass directions of slope aspect (octants), and c) elevation dependence.

4.2 Dataset and Methods

4.2.1 Data sub-setting and re-projection

We downloaded selected MODIS/Terra daily snow cover data on a 500m grid from the recently released version 6 (MOD10A1.006) (Hall and Riggs, 2016). All data from geographic tiles h09v04 (ROMO) and h10v04 (GLAC) were downloaded for days between March 1 and July 1 for all years from 2000 to 2016.[4]

The data are available in daily files, one for each tile, and georeferenced to an equal-area sinusoidal projection. Each tile covers 10° x 10° at the equator or approximately 1200 km by 1200 km, with a nominal pixel resolution of 500 m (actual resolution 463.313 m). To bring the data to the same grid as used in the hydrologic modeling necessitated re-projection of the data

[4] Note that MODIS data was obtained for April, but FWS' interest in April arose after this part of the project was complete, so April is not shown in the graphics for this section.

ESep2017

onto a Universal Transverse Mercator Grid. We used the MODIS Reprojection Tool (https://lpdaac.usgs.gov/tools/modis_reprojection_tool) to subset the daily tiles to the areas of interest and re-project the subsetted areas to UTM grids with a pixel resolution of 250 m using nearest-neighbor resampling. The ROMO study area perimeter falls at the corner of tile h09v04, and extends slightly beyond the tile boundaries at its southern tip. We excluded this extension of the study from our analysis. Parameters for the MODIS data reprojection are provided in Table S4-1.

4.2.2 Converting Normalized Difference Snow Index to Binary (yes/no) Snow Cover

To better align our analysis with that in Copeland and McKelvey's work we wanted to use a daily binary (yes/no) snow cover value. However, one main obstacle had to be overcome -- snow cover was characterized differently in the versions of the MODIS data that Copeland used and in the current version. The prior work by McKelvey and Copeland both used Collection 4 of the MODIS data which provided them with a binary snow cover classification for each pixel on each day (clouds permitting). Collection 4 data are only available for the years 2000-2007, necessitating the use of the more recent MODIS Collection 6 products for the present study. However, Collection 6 does not include a binary daily snow cover product. Instead, snow cover is identified using the Normalized Difference Snow Index (NDSI).

NDSI is reported as a ratio, with values ranging from 0.00 to 1.00 (scaled and reported as 0 to 100 in the data files). The NASA guidance on conversion was not definitive: "If a user wants to make a binary SCA [Snow Covered Area] from the C6 [Collection 6] product they can set their own NDSI threshold for snow using the NDSI_Snow_Cover or the NDSI data or a combination of those data." (NASA, 2016). In lieu of a prescription, we chose to follow the procedure used by NASA to produce the 8-day composite snowcover product; we applied a threshold of NDSI > 0.1 to the daily MODIS NDSI values to indicate the presence of snow in a pixel on a given day.

4.2.3 Snow disappearance date and snow cover on a given date

As in Copeland et al (2010), we calculate a snow disappearance date for each year at each pixel. We define the Snow Disappearance Date (SDD) as the first day after March 1 in which NDSI/100 was less or equal to 0.1 (Cite NASA). The SDD is denoted by the Day of Year value, in which January 1 is 1, February 1 is 32, March 1 is 60 (or 61 in leap years), etc. Once SDD was defined at each grid point for each year (resulting in 17 annual maps of SDD for the period of record), we were able to derive snow cover maps for any given date. For example, snow cover on May 1 was inferred by marking grid points as "snow-covered" if their SDD was equal or greater than 121 (or 122 for leap years). We repeated the process to infer snow cover maps for May 15 and June 1. This indirect method to infer snow cover allowed us to circumvent the reality of several missing data points due to cloud cover, and offered a conservative estimate of snow disappearance.

4.2.4 Snow cover by elevation and aspect

A 250-m digital elevation model (DEM) was created using bilinear interpolation from the National Elevation Dataset (NED)10-m DEM products (USGS, 2009). Using this we obtained grids for elevation and aspect octants in both study regions. We reclassified the elevation values

6Sept2017

into 200 m bins. The elevation bins range from 1000 to 3000 m in GLAC and 2600 to 4200 m in ROMO. Both the slope magnitude and the aspect of the slope (that is the compass direction that the slope faces) were analyzed using functionality in the open source Quantum GIS software. We reclassified the aspect grids into eight 45°-wide directional bins (hereafter, octants) centered on the points of the compass. In both types of analyses (elevation and aspect), we computed snow covered area (SCA) on May1, May15, and June1, in terms of the total area in square kilometers and also in terms of the percentage of snow covered area in several elevation bands and aspect octants.

4.3 MODIS analysis for GLAC

This section presents some summary statistics of snow cover, including total snow covered area, and number of years during the period of study with snow cover on a given date. MODIS snow cover data was analyzed for March1 – July1 for all years 2000-2016. For more in depth analysis including aspect and elevation-based analyses the report focuses on the years representative of year-to-year variability defined in Section 3: 2011 ("wet"), 2009 ("near normal"), and 2005 ("dry").

4.3.1 Total Snow Covered Area

Total snow covered area was the primary metric that was analyzed in McKelvey et al (2011) and provides an overall summary of availability of snow. Figure 4-1 presents maps of May 15 snow cover for the GLAC study area and vicinity from MODIS. These maps clearly depict the regional character of the year-to-year variations in snowcover. Figure 4-2 shows the total snow covered area within the study area polygon, which is depicted in red on the previous figure. The year-to-year variations are shown for snowcover on three different dates during the melt season. The behavior in individual year varies considerably, 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). It is worth noting that 2015 and 2016, the last two years of the MODIS record, show low snowcover, although the modeling study period ends in 2013 because the Livneh dataset ends in that year (Section 5). Both these years had near-normal precipitation, but had anomalously warm temperatures. These years would be good candidates for future analysis.

To summarize all 17 years of the record, Figure 4-3 presents maps of the number of years with snow cover on April 1, April 15, May 1, May 15. These are similar to the analysis done by the Copeland and McKelvey studies. The primary difference is in the use of the newer MODIS products and the extension of the analysis from seven to seventeen years.

Figure 4-4 quantifies the maps in Figure 4-3, showing the area within the GLAC study area polygon with different numbers of years of snow cover. The three colored bars designate different days of the year. Because the study areas were chosen to be in the vicinity of tree line, it is no surprise that in the present climate there are large areas that see snow every year on May 1st.

4.3.2 Aspect Dependence of Snowpack: Fractional area

One of the primary goals of this study is to investigate topographic factors that influence the persistence of snow during the melt season. One such factor is the "slope aspect" or simply

ESP2017

"aspect" – the compass direction that the slope faces. The total land area within each aspect octant varies due to the orientation of ridges and valleys in the study area. As a result, the analysis of total snow covered area is dominated by the topography itself. These graphics are provided in the Supplementary Material.

To focus on the *relative* importance of the snow processes related to aspect, in we calculated the fraction of the total land area within each octant that is snow covered for each of the 17 years in the historical record (Figure 4-5), while in Figure 4-6 we focus on the representative wet and dry years. The asymmetric shape in Figure 4-5 clearly shows that in GLAC, the NE directions ranging from E to N have much larger fractional area covered by snow. Even in dry years, over 60 % of the NE facing slopes are snow-covered on May 15th (Figure 4-6).

One of the primary goals of this study is to investigate topographic factors that influence the persistence of snow during the melt season. One such factor is the "slope aspect" or simply "aspect" – the compass direction that the slope faces.

4.3.3 Elevation Dependence

Figure 4-7 shows the elevation dependence of MODIS snow cover for the wet, near-normal and dry years, with the median of all years as reference. The results are shown as a percentage of the total area within each 200-meter elevation band within the study area boundaries.

4.4 MODIS analysis for ROMO

MODIS snow cover data was analyzed for March1 – July 1 for the years 2000-2016. Data for all years was analyzed. We present here some summary statistics of snow cover, including total snow covered area, and number of years during the period of study with snow cover on a given date. For more in-depth analysis including aspect and elevation-based analyses the report focuses on the representative years defined in Section 3: 2011 ("wet"), 2007 ("near normal"), and 2012 ("dry").

4.4.1 Total Snow Covered Area

Total snow covered area was the primary metric that was analyzed in McKelvey et al (2011) and provides an overall summary of availability of snow. Figure 4-8 presents maps of May 15 snow cover for the ROMO study area and vicinity from MODIS. These maps clearly depict the regional character of the year-to-year variations in snowcover. Figure 4-9 shows the total snowcovered area within the study area polygon, which is depicted in red on the previous figure. The year-to-year variations are shown for snowcover on three different dates during the melt season. The behavior in individual year varies considerably, including "wet" years such as 2011 with very persistent snow, years with strong melt in early May, such as 2004, or in late May (2001, 2013), and "dry" years (2012).

To summarize all 17 years of the record, Figure 4-10 presents maps of the number of years with snow cover on May 1, May 15. These are similar to the analysis done by Copeland and McKelvey studies. The primary difference is in the use of the newer MODIS products and the extension of the analysis from seven to seventeen years.

Sept 2017

Figure 4-11 quantifies the maps shown in Figure 4-10, showing the area within the GLAC study area polygon with different numbers of years of snow cover. The three colored bars designate different days of the year. Because the study areas were chosen to be in the vicinity of tree line, it is no surprise that in the present climate there are large areas that see snow every year on May 1.

4.4.2 Slope Aspect Dependence of Snowpack: Fractional Area

One of the primary goals of this study is to investigate topographic factors that influence the persistence of snow during the melt season. One such factor is the "slope aspect" or simply "aspect" – the compass direction that the slope faces. The total land area within each aspect octant varies due to the orientation of ridges and valleys in the study area. As a result, the analysis of total snow covered area is dominated by the topography itself. These graphics are provided in the Supplementary Material.

The total land area within each aspect octant varies due to the orientation of ridges and valleys in the study area. As a result, the analysis of total snow covered area is dominated by the topography itself. To focus on the *relative* importance of the snow processes related to aspect, Figure 4-12 presents an analysis of the fraction of the total land area within each directional "bin" that is snow covered. The asymmetric shape shows that the NW-facing slopes have larger fractional area covered by snow. With the exception of 2012, even in dry years over 60 % of the NW facing slopes are snow-covered on May 15th. Figure 4-13 indicates that for the dry year 2012, snow cover was retained preferentially on NW-facing slopes.

4.4.3 Elevation Dependence

Figure 4-14 shows the elevation dependence of MODIS snow cover for the wet, near-normal and dry years, with the median of all years as reference. The results are shown as a percentage of the total elevation within each 200-meter elevation band within the study area boundaries. The ROMO area shows that the dry year, 2002 (as well as the other very dry year during the period, 2012), was significantly different from the other two, with a fractional area declining with altitude above 3400m. This may indicate that the meteorology in this region interacts differently with the topography in extremely dry years than in wetter years. The high-altitude snowpack may be particularly vulnerable in this region if conditions like those in 2002 recur.

5Sept2017

5 Future Snowpack Projections: DHSVM Modeling

Key Points - Methods

- In order to simulate snow cover under future climate conditions, we use a high-resolution snow/hydrology model with inputs derived from global climate model projections.
- The Distributed Hydrology Soil Vegetation (DHSVM) model was run for the historic period 1998-2013 and validated against available SNOTEL observing stations. The spatial patterns of snow were validated against MODIS satellite remotely sensed snow cover.
- Five scenarios of the future – for a thirty-year period, 2041-2070, centered on 2055 -- were selected from CMIP5 global climate model (GCM) projections based on a moderate (RCP 4.5) and high (RCP 8.5) emissions scenarios. These were chosen to represent a large fraction of the range of the CMIP5 ensemble projections in each study area in terms of precipitation and temperature changes. The scenarios differ somewhat between the two study areas to better represent the range of climate projections in each area.
- The selected GCM projections were downscaled using the "delta method" which applies change factors from the climate models to the historic temperature and precipitation that are used as inputs to the DHSVM model.
- Analysis is presented for light snow cover (Snow Water Equivalent > 5 mm) on May 15th for comparison with May 15th MODIS snow cover (as was used by McKelvey).
- To capture and assess year to year variability, Wet, Near Normal, and Dry representative case study years are shown for the historical simulations and how each of these years plays out under these five future scenarios.

Key Points – GLAC study area

For the study area in Glacier National Park (GLAC), projections for April 15th, May 1st, and May 15th Snow Covered Area and area with snow depth greater than 0.5 meters show declines on average in all scenarios, except for small increases in the Warm/Wet scenario and for all years (Section 5-11).

- For April 15th for the study area as a whole (Figure 2-1), there is a decline of 3-23 percent in snow covered area with light snow cover (depth ≥ 5 mm), and a 7-44% percent decline in area with significant snow (depth > 0.5 m) for the five scenarios considered, compared to the 2000-2013 historic average. For May 15th, the area with light snowcover declines 10-36 percent, and the area with significant snow cover declines 13-50 percent (Tables 5-4, 5-5). Under the Hot/Wet scenario, the April 15th significant snowpack has been diminished below the level of the historic May 15th snowpack – a month shift (Figure 5-14).
- On April 15th, the Warm/Wet scenario shows the least change in average SCA (2121 Sq-km) compared to the historic snow cover (2609-7%) for significant (≥ 0.5 meter) snowpack. The largest decrease is the Hot/Wet scenario (1520 sq-km) with 44% decrease.
- All projections show declines in the number of years with significant snow. In each study domain, the areas with frequent availability (at least 14 out of 16 years) of significant snow (≥ 0.5 m) become concentrated in smaller high elevation areas, as seen in the maps

Sept2017

in Figures 5-13, 5-14 (GLAC), and 5-20, 5-21 (ROMO). In contrast, lower elevation areas had the largest changes, or decreases in significant snowcover.

- Most of the known den sites are located between 1800 and 2000m in GLAC. Below that elevation band large snow losses are predicted (40-70% decreases for two of the scenarios, 16-20% for the other three), above that elevation band there is little change in SCA for four of the five scenarios (2-8%) except in maximum warming scenario (-40%, Figure 5-22). In that 1800-2000m band, the snowpack change is sensitive to elevation and to the particular future climate scenario.
- This phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. Regonda et al. (2005) found little historical change in snowpack in the Western United States above approximately 2500m elevation despite observed warming trends.
- For representative wet years, the higher elevations of our study areas experience only 2-7% loss of snowpack under the scenarios with "least" change and the "central" change (Figure 5-8, 5-12), although for the dry years, losses range 18-57% (Table 5-5). This is in contrast to the McKelvey study, in which the large losses in the snow analysis included lower elevations that have not been considered likely denning areas.
- Modest declines in SWE may occur without affecting the area with significant snow depth. On May 1st, for areas at 1800m and above in GLAC, losses of ~10-30% SWE (Figure 5-23) result in losses of only ~10% snowcover. The implication is that the wet, cold climate of the GLAC study area could act as a "buffer" to change in the area of 0.5 m deep snow on May 1st, at least at the elevations above 1800m.

Key Points – ROMO study area.

For the study area in and around Rocky Mountain National Park (ROMO), projections of May 15th Snow Covered Area in ROMO declines on average in all scenarios, except for small increases in the Warm/Wet scenario, and for almost all years (Section 5-12).

- For April 15th for the study area as a whole (Figure 2-2), there is decline of 3-18% in area with light snow cover (depth ≥ 5 mm), and a change of -1 - +16 in area with significant snow cover (depth > 0.5 m) for the five scenarios considered, compared to the 2000-2013 historic average. For May 15th, the area with light snowcover declines 8-35 %, and the area with significant snow cover declines 6-38 percent (Tables 5-6, 5-7).
- Snow Covered Area in ROMO (≥0.5 m threshold on May 15) generally declines in wet years, shows a slight increase in (1-5%) in some years for the Warm/Wet scenarios with increased precipitation.
- One scenario with increased precipitation (Warm/Wet, giss) shows increases in April 15th SCA (Table 5-7). There are also slight increases in SWE for two scenarios at elevations at and above 3400m (Figure 5-25), but decreases in SWE for all scenarios below 3400m.
- Although no dens have been documented in ROMO, the elevation band for denning, modeled by regression analysis, is thought to be 2700-3600m. On May 1st, modest declines in SWE of ~15% and less for areas at 3400m and above result in losses of < result in losses of only ~10% snowcover (Figure 5-24, 25). 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 deep snow on May 1st. Below that band losses in SWE of ≥ 35% result in higher losses in SCA (20-65%), except in the scenario with least change

Sept2017

(Warm/Wet, giss model). As in the denning band in GLAC, in that 2700-3600m band, the snowpack change is sensitive to elevation and to the particular future climate scenario.

- The phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. Regonda et al. (2005) found little historical change in snowpack in the Western United States above approximately 2500m elevation despite observed warming trends. Other literature on this topic is discussed in Section 5.13.
- ROMO exhibited more uncertainty in projections than GLAC
    - ROMO has more uncertainty as to whether precipitation will increase or decrease.
    - The beneficial effect of increased precipitation on snowpack is more prominent earlier in the Spring. In the Warm/Wet scenario, the area of significant snow on May1 increases on average, though it decreases on May 15.
    - For April 15th –May 15th, and for wet years, the high elevations of the ROMO study area as a whole, there are only modest loss of snow cover under all scenarios of change (Table 5-7, see 2011 representative wet year). However even in wet years, the area of significant snowpack can decline by up to 26% for the Hot/Dry climate change scenario on May 15th (Table 5-7).

5.1 Introduction

In this section we describe the hydrologic model along with various modeling assumptions, validation of the model, the choice of risk-spanning future climate scenarios, and present results of historical and projected snowpack for the two study areas.

To determine the projected effects of a changing climate on snowpack we ran a physically-based hydrology model. The physical basis of the model – using a full energy and water balance of the snowpack rather than a simple temperature-index model -- is critical to evaluate change in a non-stationary climate. While ambient temperature is a critical factor in whether precipitation falls as rain or snow, the subsequent evolution of the snowpack, and in particular the melt season, is driven primarily by the energy balance at the surface. The energy balance is the result of several processes, including solar and longwave radiation, sensible and latent heat fluxes, and heat flux into the ground, as well as storage of heat in the snowpack. Therefore, including a realistic energy balance helps to understand how the perturbations to climate will affect the snowpack.

5.2 Model Description

The Distributed Hydrology Soil Vegetation Model (DHSVM) provides a physically-based simulation of land surface hydrology, including snowpack. The physical processes include a full surface water and energy balance model, a 2-layer canopy model, a multi-layer soil model, a 2-layer snowpack model (Wigmosta et al. 1994). It has been used in many studies that have provided realistic hydrologic simulations in topographically complex areas (e.g. Livneh et al. 2015). The model has explicit treatment of topographic slope, and aspect (the compass direction that the slope faces).

5Sept2017

The model was selected for developing snowpack projections because it can be run at a fine spatial scale (250 m x 250m pixels) yet is able to be run over extensive domains. There are both finer-scale snow models, for which it would have been impractical to simulate such a large domain, and coarser-scale models, such as the 1/16 degree grid of the VIC model that the McKelvey study used (see section 2.3). Coarser-scale models do not explicitly model the effects of slope and aspect, which is one of the primary goals of this study. Both DHSVM and VIC were primarily developed at the University of Washington, and are available as open-source community models. The two models share many components in common, including similar snow and canopy models. As such it supports the project goal of building on McKelvey study by modelling at a finer scale and treating slope and aspect explicitly.

The model was set up for both study domains on a 250m grid in Universal Transverse Mercator (UTM) coordinates within the modeling domain defined within the polygons shown in Section 2. Soil properties and vegetation type as well as a digital elevation model (DEM) were adapted to the model grid. A soil hydraulic routing network was also determined from the DEM, though in this project we do not investigate the runoff. The effect of slope and aspect on incoming solar radiation is implemented through a computation of the degree of shading for each 250-m pixel that was variable throughout the day and differed from month to month based on the solar angle in the sky and from the DEM. The model requires inputs of time-varying meteorological fields on sub-daily time scales. Snow water equivalent was output on May 1, May 15, and June 1 for every year of the simulation. As noted below, snow depth was estimated using a typical snowpack density for late Spring. More details of the model will be included in the Section 5 Supplementary Material.

5Sept2017

5.3 Meteorological Inputs

The DHSVM model inputs were derived in a multi-step process. First, values of daily minimum temperature, daily maximum temperature, and precipitation were extracted from the Livneh (2015) dataset, which has a grid resolution of 1/16th degree in latitude and longitude. These daily values were disaggregated in time. Other forcing variables needed by the model, solar radiation, downwelling longwave radiation, specific humidity were derived from empirical relationships using the MTCLIM algorithms which were evaluated by Livneh et al. (2014) finding small overall biases. The Livneh et al (2015) data was then interpolated to the 250m DHSVM grid using an inverse-distance weighting algorithm along with assumed lapse rates (elevation dependence) in temperature and in precipitation. More details of the Livneh 2015 dataset will be included in the Section 5 Supplementary Material.

5.4 DHSVM Historical Validation

The goal of the model validation is to assess the overall magnitude, temporal, and spatial aspects of the modeled snowpack in the Spring and how these differ from observational estimates. Observational estimate of snow depth or snow water equivalent at the scales that we simulated are not available, leading to uncertainty about the “true” snowpack. For the overall magnitude

and temporal aspects of the snow simulation, we compared the historical model simulation to point observations at the few available SNOTEL sites, focusing on the duration and melt-out date of the snowpack. The spatial aspect of bias was evaluated by comparing the model output to the observed spatial patterns of snow cover obtained from the MODIS analysis (see Section 4), qualitatively for GLAC and quantitatively for ROMO. When interpreting the projections, future model biases are typically assumed to be similar to historical biases. With this assumption, the calculation of, for example, percentage change is less sensitive to biases and uncertainties in the historical simulation.

5.4.1 Comparison to SNOTEL

The DHSVM historical simulation was compared against the snow data from nine SNOTEL sites in the ROMO study area that were in operation during the full time-period of interest, and the 3 SNOTEL sites in and adjacent to the GLAC study area (Table 5-1). Validation against SNOTEL snow data was performed by running the DHSVM model in "point" mode so that it simulated the conditions at the SNOTEL locations only. Because the SNOTEL stations are deliberately sited in clearings, the canopy was assumed to be open for the validation runs, while the actual 250m grid canopy values were used for the production runs. Two metrics were chosen: the meltout day of year (defined as the date when SWE fell to less than 1mm), and the duration of snow cover (total number of days during the water year (October-September) when SWE > 10cm). Figure 5-1a shows the modeled and observed meltout dates for the GLAC and ROMO SNOTEL sites, and Figure 5-1b shows the duration of snowpack. One does not expect exact reproduction of the snowpack at the SNOTEL sites, but rather a scatter about the 1-to-1 line, which is seen. The Copeland Lake SNOTEL site, and to some extent the Many Glacier SNOTEL sites are outliers, with the model retaining snowpack significantly longer than in observations. Both these sites are at relatively low elevations, and are quite sensitive to potential temperature biases in the input data. The Livneh (2015) dataset is known to have a cool bias relative to other datasets, which may influence these sites disproportionately.

Table 5-1 SNOTEL Sites at Study Areas. Maps with SNOTEL sites are shown in Figs 2-1 and 2-2. Note that sites installed after 1997 were not used due to their short record.

	SNOTEL SITE NAME (Site Number, Abbreviation)
Glacier Study Area	Flattop Mountain (482, flat), Many Glacier (613, many), Pike Creek (693, pike)
Rocky Mountain Study Area (used for Validation)	Bear Lake (322, bear), Copeland Lake (412, cope), Joe Wright (551, joew), Lake Eldora (564, eldo), Lake Irene (565, iren), Niwot (663, niwo), Phantom Valley (688, phan), University Camp (838, univ), Willow Park (870, will)
Rocky Mountain Study Area (installed after 1997, not used)	Never Summer (1031), Wild Basin (1042), Hourglass Lake (1122), Long Draw Reservoir (1123), High Lonesome (1187), Sawtooth (1251)

The year-to-year variations of peak snowpack at the GLAC SNOTEL sites are well captured, as illustrated in Figure 5-2 that shows simulated and observed time series of SWE at these stations.

Sept 2017

Figure 5-3 shows selected SNOTEL sites in the ROMO area. As can be seen in Figure 5-2, the Copeland Lake site is less well simulated than other sites. We attribute this to being located at a lower elevation than other sites, and hence susceptible to small biases in temperature in the meteorological inputs. Other sites in ROMO are well simulated.

Based on this evaluation of DHSVM performance, the standard set of model parameters was adopted for the GLAC domain without modification.

The question arises of the independence of the SNOTEL data from the Livneh (2015) forcing data. The primary observing station data that were used for interpolation by Livneh (2015) did not include SNOTEL. However, a monthly adjustment factor was applied to the interpolated precipitation to reproduce the 1981-2000 climatology of PRISM. The temperature data in Livneh et al (2015) were entirely independent of SNOTEL data. Therefore, we expect that the errors revealed at the SNOTEL sites should be representative of errors at other, unobserved sites in the domain.

5.4.2 Comparison to MODIS Snow Cover

The spatial distribution of snow cover was assessed by comparison with MODIS data. Some care must be taken to compare observed NDSI, which indicated fractional snow cover, with modeled SWE, which does not account for fractional snow cover within a pixel. For this evaluation, a threshold to determine "snow covered ground" was chosen for both the MODIS NDSI (0.1) and for the DHSVM SWE. Figures 5-4 and 5-5 snow spatial overlays of the DHSVM simulated snow cover and the MODIS observed snow cover for the representative "dry" years in ROMO and GLAC. In terms of snow cover, dry years were more difficult to simulate than wet years, and the spatial agreement is good for these two examples.

However, initial attempts to model ROMO indicated biases in the spatial patterns of snow cover compared to MODIS. To overcome model errors at ROMO, an adjustment of two DHSVM snow parameters was conducted. The representative values of the physical quantities of these parameters can span a fairly large range, and hence an experiment was conducted to evaluate the appropriate settings of the model for ROMO based on minimizing differences between simulated and MODIS SCA for the historical period, as well as reducing biases with SNOTEL SWE.

The first parameter modified was the snow-surface roughness (SR), which affects the amount of turbulent heat fluxes that occur between the snow and the atmosphere, whereby a small number corresponds to a smoother snowpack that has less heat exchange with the overlying air, while the opposite is true for a large value. The second parameter was the liquid water capacity (LWC) that describes the volume of water that the snowpack can hold before water will leach out of the snowpack. This parameter is important, since it is common for snow to melt during the day and then for liquid water to refreeze at night.

Adjustments were made to SR and LWC within reasonable physical ranges and the DHSVM simulated SCA was compared with MODIS via a threat score. The threat score used, referred to as the Critical Success Index (CSI) by Zappa (2010), is defined as:

Sept 2017

$$CSI = \frac{a}{a + b + c}$$

Where a indicates a snow-covered pixel in both the simulation and observed data, b indicates a snow-covered pixel in the simulation but a bare pixel in the observed ("false positive"), and c is a bare pixel for the simulation and a snow-covered pixel shown by the observed data ("false negative"). The objective was to maximize the threat score. Approximately ten unique parameter settings were tested. Additionally, for each parameter setting the mean bias in meltout day and duration of snow cover between DHSVM simulated and SNOTEL SWE was calculated with the objective being a minimization of the bias between the two (bias = simulated – observed). The final DHSVM settings for ROMO were identified by the parameter values that corresponded with a combination of a high threat score and a low bias. The table and figure showing the parameter settings and ensuing objective values are included in the supplementary material (Figure S5.X).

5.5 Determination of Snow Depth from DHSVM model output

DHSVM does not compute snow depth as a separate quantity, but instead returns snow water equivalent (SWE). To estimate the snow depth from SWE. we adopt a uniform value of 2.5:1 for the SD:SWE ratio, corresponding to a snow density of 0.4 for May 1st and May 15th. We adopt a bulk density of 0.33 which yields a conversion factor of 3.0:1 for April 15th conditions. Further discussion can be found in the Section 5 Supplementary Material) appropriate for the May snowpack in the study areas. Several lines of evidence point to the reasonableness of this assumption. First, SNOTEL stations where both depth and SWE are measured show similar ratios for the two study areas. Second, we investigated the ratio of density from the SNODAS (Snow Data Assimilation System) product from the NOAA National Operational Hydrologic Remote Sensing Center, which points to a very narrow range around 2.6-2.7 for the ratio. Finally, for comparison with the McKelvey et al (2011) work we compared the May 1 Snow Depth and SWE products from the Littell et al (2011) hydrologic model runs (obtained separately from https://cig.uw.edu/datasets/wus/). These all point to an approximate value consistent with a density between 0.35 and 0.4. The results of this study do not depend on a precise value for snow density. The conclusions of the report are not sensitive to the choice of conversion factor within the ranges indicated by the above analysis.

5.6 Choice of thresholds for analysis

While the the McKelvey study analysis was for the presence or absence of snowcover, this modeling effort produces results in terms of SWE. This allows greater flexibility in evaluation of the depth of the snowpack, but presents a problem in comparison. To compare the model-generated SWE with both the McKelvey study results and our own MODIS historical snow cover analysis we used a threshold of 5mm SWE to define presence/absence of snow cover, also called "light snow". We also were concerned with analyzing the presence of "significant snow" which we defined as ≥ 0.5 m of snow depth. The value of ≥ 0.5 m was arrived at by an analysis of the modeled snow depth at known wolverine denning sites in Glacier National Park (Table 5-

5Sept2017

2). With the exception of one site that had melted out by May 15th, the other sites all have snowpack between 0.4 and 1.4 m.

Table 5-2: Modeled Snow Depth on May 15 at reported den sites in the Glacier Study Area (source: John Guinotte, FWS)

Den site	Date observed (month-yr)	Meltout Date (MODIS)	May 15 snow depth dhsvm (m)	May 01 snow depth dhsvm (m)	Notes
1	Apr-03	5/25/2003	1.036	1.068	Natal Den
2	May-03	5/25/2003	1.045	1.074	Maternal Den
3	Apr-04	6/4/2004	0.407	0.653	Natal Den
4	Apr-04	6/29/2004	0.539	0.753	Maternal Den
5	May-04	6/29/2004	0.653	0.832	Maternal Den
6	Mar-05	6/11/2005	0.531	0.797	Maternal Den
7	Apr-05	6/11/2005	0.531	0.797	Natal Den
8	May-05	6/11/2005	0.468	0.757	Maternal Den
9	Mar-06	5/25/2006	1.435	1.434	Unknown-materal or natal
10	Apr-06	5/14/2006	0	0.265	Meltout occurred before may 15 Unknown-maternal or natal
11	Apr-06	6/7/2006	1.233	1.237	Unknown-maternal or natal
12	May-06	5/31/2006	0.611	0.789	Maternal Den
13	May-06	5/31/2006	0.611	0.789	Natal Den
14	May-07	6/4/2007	0.176	0.568	Natal Den

5.7 Delta Method for Future Scenarios

The advantages and disadvantages of the delta method have been discussed extensively in the literature (e.g. Sofaer et al, 2016, for a recent review). The primary advantages of this method are its long history of use, its simplicity, and its use of the historical observed weather as the baseline. The simplicity allowed for the study to be completed in a short time-frame, while still reaching our primary objectives of finer spatial scale and a more complete exploration of future climate scenarios. The use of the historical baseline allows us to explore how wet, near normal, and dry "representative years" would play out under the different climate futures. However, it is important to keep in mind that we are "parameterizing the future variability in terms of the historical variability." This treatment of daily variability also leads to the primary disadvantage of the delta method: the assumptions that the changes in extremes follow the changes in the means, and that the pattern of daily weather is simply shifted without changing the sequences of weather. This aspect is less of a concern for this study, as snow accumulation and ablation are cumulative processes, so that the daily sequences of storms is less critical to simulate than the monthly and seasonal totals. Another assumption of the delta method is that the large-scale changes in temperature and precipitation apply uniformly to the study area. Equivalently we assume that change factors in ambient (free-air) temperature and precipitation will not depend on

Sept. Draft

the small scale spatial detail. Because we explicitly compute the surface energy balance, we are able to simulate surface temperature differences that depend on fine-scale terrain, mitigating to some extent this limitation of the delta method.

Following McKelvey (2011), we use the "delta method" to downscale the climate model data to the 250m modeling grid.

The steps in this method are as follows:

- Start with historical daily meteorological forcings (inputs to the DSHVM model) for the historical baseline period (1998-2013)
- Run DHSVM with the historical forcings to produce the simulated historical snow and hydrology.
- From climate model output, compute the change in 30-year average temperature for each calendar month over the time frame of interest. Do the same for the percent change in precipitation
- Apply these change factors to the historical daily meteorological inputs to DHSVM to generate future scenarios of meteorological inputs.
- Run DHSVM with these new inputs to generate the projected snow and hydrology.
- Compare the projected snow to the historic DHSVM model simulations to infer changes in snowpack.
- Repeat for a set of change factors from different climate models that adequately sample the uncertainty in climate projections.

The result of the delta method is a continuous-in-time simulation of the historical period (1998-2013), and an equal length simulation of how this sequence of years would play out in the future under five different scenarios of climate change. Figure 5-6 illustrates typical DHSVM model output using the delta method. Figure 5-6a shows a map of May 15, 2011 Snow Water Equivalent for the Glacier Study Area from the historical simulation, while Figure 5-6b shows a single projected future for what that year's SWE would look like under a particular scenario of climate change. The future scenario represents a year similar to 2011, that is, a relatively wet and cool year compared to other years in the future. However, in this example, the temperature and precipitation have been adjusted to be consistent with the 2041-2070 projected climate from the MIROC climate model, the model with the highest temperature increase and about 10% increase in precipitation.

5Sept2017

5.8 GCM Uncertainty and Scenario Planning Approach

As noted in Section 2, global climate models (GCMs) are our primary tools to examine the nature of climate change during the 21st century. There are currently about 20 modeling centers worldwide which provided output from their best model(s) to be considered in the Coupled Model Inter-comparison Project Phase-5 (CMIP5, Taylor et al., 2012) which informed the latest Intergovernmental Panel on Climate Change (IPCC) report (IPCC AR5). Here we quantify changes in temperature and precipitation for the two study areas for the 2041-2070 time frame, centered on 2055. We find a large spread in the extent of warming and changes in precipitation, including both increases and decreases in precipitation, as shown in Figure 5-7. The McKelvey study chose GCMs based on the range of temperature change (see Sec 2.2, also shown in Figure 5-7). For temperature, much of this spread (or uncertainty) is a result of the difference between GCMs (e.g., their climate sensitivities), whereas for precipitation it is both the difference between GCMs and internal climate variability. Some difference also comes from the choice of future greenhouse gases (GHG) emission scenario. However, these differences among mid-21st century climate responses are limited compared to later in the century (see a discussion in Ray et al., 2010).

For more robust planning and climate adaptation, experts recommend incorporation of these uncertainties into the assessment of impacts and developing adaptation strategies. The scenario planning approach has been one method that has been recommend and promoted by different entities and experts (National Park Service, 2013; Rowland et al., 2014; Maier et al., 2016; Murphy et al. 2016; Star et al., 2016, Fisichelli et al, 2016 a,b). Therefore, we adopted a strategy of selecting multiple divergent future scenarios challenging to the system of interest, following that in Fisichelli et al (2016 a, b).

5.9 Climate Projections Evaluation and Scenarios Selection

We compiled output for temperature and precipitation projections for 34 CMIP5 GCMs from the Reclamation (2013; http://gdo-dcp.ucllnl.org/) archive of 1-degree Regridded GCM dataset for Representative Concentration Pathways (RCP) 4.5 and 8.5, which are respectively the moderate and high GHG emissions scenarios --- therefore, a total of 68 GCM projections described in Supplementary Material. These data were then analyzed to quantify broad-scale projections for the two study regions by 2055 (i.e. a mid-point centered on the 2041-2070 period) – primarily changes in the cold season (Oct-May) temperature and precipitation by 2055 relative to the 1986-2015 period. Figures 5-7 show these changes for Rocky Mountain and Glacier National Parks, respectively, which are bounded by rectangular latitude/longitude values. As mentioned earlier, we found a large range in temperature increases (1-4 ºC) and changes in precipitation (-5% to +20%) for these regions by 2055. Table 5-3 shows GCM names, numbers and colors coded in later figures, and relative changes in temperature and precipitation. To incorporate the large range in climate projections, we worked with the ensemble of 68 CMIP5 temperature & precipitation projections, described by the red filled-circles in Figure 5-7, to select five future climate scenarios (black circles) that span the different parts of this projection space. Five GCMs representing these scenarios were identified for both RMNP and GNP. For each of these GCMs, we calculated changes in temperature and precipitation by 2055 for each month of the year,

Sept2017

which we call the “monthly delta”. These monthly deltas were used to perturb the hydrological models to simulate snow response in RMNP and GNP by 2055.

5Sept2017

Table 5-3. The six future scenarios used (five for each area) with changes in temperature and precipitation relative to other scenarios (See also Fig 5-7 for an alternate visualization of these changes), and the GCM used as the basis for the deltas for this scenario. More details on the GCMs are in the Glossary.

Future Scenario Name and #	Scenario Change in GLAC relative to other scenarios	Scenario Change in ROMO relative to other scenarios	Code and color for GCM used for this scenario
Central (#1)	+~2.2 ºC increase in temperature (close to the ensemble mean) and +~5% increase in precipitation	+~2.5 ºC increase in temperature (close to the ensemble mean) and +~8% increase in precipitation	cnrm, red
GLAC: **Hot/ Very Wet (**#2)	relatively higher increase in temperature (+~3.2 C) and the highest increase in precipitation (+20%) for the GLAC scenarios	N/A	canesm, green
ROMO: **Hot/Dry (**#2)	N/A	relatively higher temperature increase (+~ 3.5 ºC) and -~5% decrease in precipitation. This scenario results in the greatest change (reduction) in snow pack and snowcover.	hadgem, green
Hot/ Wet (#3)	the highest temperature increase of the GLAC scenarios (+~4.2 ºC) and +~10% increase in precipitation	the highest temperature increase of the ROMO scenarios (+~3.7 ºC) and the highest increase in precipitation (+~18%).	miroc, purple
Warm/ Wet (#4)	relatively lower temperature increase (+~1 ºC) and +~10% increase in precipitation	relatively lower temperature increase (+~1.3 ºC) and +~7% increase in precipitation that appears to partially offset the impacts of the temperature increase. This scenario results in the least change in snow pack and snowcover.	giss, aqua
Warm/ Dry (#5)	relatively lower temperature increase (+~1.6 ºC) and -~5% decrease in precipitation	relatively lower temperature increase (+~0.8 ºC) and -~5% decrease in precipitation	fio, orange

5.10 Modeling Caveats

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Some processes which may be of relevance not represented in the model include wind and avalanche re-distribution of snowpack. Snow depth is not explicitly modeled, and must be inferred (see below). The meteorological forcing does not take into account cold air pooling or how this may change in the future. Cold air pooling – the anomalously cold air that can collect in valley bottoms, particularly in Winter, could also act to prolong the duration of snow cover in those locations. While Curtis et al (2014) identify this as a potential process, they do not physically model cold air pooling, but merely include it in their present-day climatology as a simple "offset" from their unadjusted data. Nonetheless their work provides a complementary approach to the identification of potential snow refugia, though more work would need to be done to study the geographic and seasonal aspects for the study areas.

5.11 GLAC Study Area Results

This section presents SWE and SCA for representative years, area and number of years with snow depth ≥ 0.5 m. The elevation dependence of snow for GLAC is discussed in Section 5-13. **On average, the GLAC study area exhibits a 7 – 44 % decline in the area of snow depth ≥ 0.5 meters on April 15th, and a 13-50 % decline in the area on May 15 for the scenarios considered. Note that the Warm/Wet scenario projects a slight increase in the area of significant snowpack on April 15th, for the average of all years, and some individual years.**

5.11.1 SWE and Snow Covered Area for representative years

Figures 5-8 shows DHSVM model simulated snow water equivalent (SWE) on May 15 for the wet (2011) representative year. Maps of snow cover derived from SWE by applying a threshold of 13 mm are available in the Supplementary material. Results for thresholds of 1 mm and 5 mm of SWE were also investigated and show similar patterns. Snow covered area with a "light snow cover" threshold was computed primarily for comparison with both the MODIS results from Section 4, and with McKelvey. In Figure 5-8, the historical simulation is shown along with three of the five future scenarios, chosen to represent the central scenario (cnrm), the greatest change in snowpack on average (Hot/Wet (miroc) scenario) and the least change (Warm/Wet (giss) scenario). The projected snow maps answer the question "what would the snowpack in a wet year like 2011 look like in the 2040's through 2070's under these scenarios of climate change."

Figures 5-9 and 5-10 show SWE for the Near Normal (2009) and Dry (2005) representative years. The historical simulation and future scenarios are as in Figure 5-8. Figure 5-11 summarizes the results for snow covered area in terms of the total snow covered area (km^2) within the study area polygon. The numerical values of snow covered area for all years in the simulation, as well as percent changes for these quantities are shown in Table 5-4. Table 5-4 indicates that the snowcovered area decreases for all scenarios. On average, the GLAC study area exhibits a 7 – 44 % decline in the area of snow depth ≥ 0.5 meters on April 15th, and a 13-50 % decline in the area on May 15th for the scenarios considered.

- Comparing the Wet and Dry representative years we see that dry years are more vulnerable to climate change in terms of percent loss of snow covered area.
- For the Wet year, the high elevations of the study area result in little loss of snowpack in the study areas under most scenarios of change.

5Sept2017

- However, in Figures 5-10 and 5-11 we notice an anomaly – for the dry year, the Hot/Wet scenario does not have the greatest loss of snow covered area. The increase in precipitation in this scenario has somewhat compensated for the loss of snowpack due to warming.
- Snow changes at the elevations of known dens are discussed later in Section 5.13 and Figures 5-22 and 5-23.

5.11.2 Area and Number of years with ≥ 0.5 m Snow Depth

Because of interest in wolverine denning sites, we analyze snow depth ≥ 0.5 m, which we will also refer to as "significant snow" to contrast with the emphasis on light snow in McKelvey et al (2011) and in the previous section. Figure 5-12 shows the area with snow depth ≥ 0.5 m on April 15th and May 15th in the study area for the dry, near normal, and wet years. Because of the higher threshold for snow, the effects are somewhat larger than for the light snow threshold (see supplementary material). This is particularly evident in the dry year, which has a 50% decline on May 15 for four of the future scenarios. The numerical values of snow covered area at the ≥ 0.5 m threshold are shown in Table 5-5 for all years, as well as percent changes for these quantities. On average, the GLAC study area exhibits a 7 – 44 % decline in the area of snow depth ≥ 0.5 meters on April 15th, and a 13-50 % decline in the area on May 15th decline in the area of snow depth ≥ 0.5 meters for the scenarios considered. See discussion of changes at elevation in Section 5.13.

Figure 5-13 shows a map of the number of years (out of 16 possible) where each model pixel had ≥ 0.5 m of snow depth on May 15. This number-of-years statistic is analogous to that used by the Copeland study, except that there are more years of data, and these maps use a much higher threshold of snow. The projections show declines in the number of years with significant snow. The areas with frequent (14-16 years) availability of significant snow become concentrated in smaller high elevation areas.

The effects of climate change on snow melt have been presented as analogous to a "time shifting" of the melt season earlier in the year. For example, McKelvey used the May 31 vs. May 15 snow covered area as a proxy for a 2-week shift in the melt season. Figure 5-14 contrasts the evolution of the snowpack with respect to the number of years with significant snow from April 15th to May 15th in the historical simulations (Top Row) with the Warm/Wet scenario (Middle Row) and Hot/Wet (Bottom Row) scenarios. We see that the Warm/Wet scenario, shows the least change in the number of years compared to the historic snow cover in terms of the availability of significant snow. In contrast, under the Hot/Wet scenario, the number of years that significant snowpack occurs on April 15th has been diminished below the level of the historic May 15th snowpack – a month shift (Figure 5-14).

Sept 2017

GLAC	Snow Covered Area sq-km [5 mm SWE threshold]																	
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	2838	2876	2901	2886	2901	2869	2772	2615	2836	2784	2899	2900	2853	2901	2892	2890	2851	2881
	Central [cnrm]	2501	2732	2901	2804	2879	2708	2278	2067	2500	2297	2849	2870	2604	2897	2748	2743	2649	2737
	Hot/Very Wet [canesm]	2080	2342	2900	2589	2748	2288	1784	1630	1972	1714	2610	2695	2177	2839	2215	2405	2312	2315
	Hot/Wet [miroc]	2043	2069	2210	2326	2161	2419	1489	1593	2087	2020	2753	2245	2200	2591	1766	2700	2192	2181
	Warm/Wet [giss]	2697	2819	2901	2840	2887	2769	2578	2361	2677	2572	2881	2885	2706	2901	2827	2828	2758	2823
	Warm/Dry [fio]	2609	2735	2901	2839	2887	2808	2469	2176	2634	2490	2867	2883	2712	2900	2848	2785	2721	2797
1-May	historical	2625	2814	2707	2818	2892	2788	2608	2494	2694	2563	2888	2901	2538	2901	2775	2861	2745	2782
	Central [cnrm]	1949	2433	2160	2505	2820	2405	1948	1657	2072	1917	2773	2882	2008	2887	2202	2619	2327	2383
	Hot/Very Wet [canesm]	1578	2059	1815	1985	2580	1859	1400	1287	1633	1771	2499	2792	1419	2813	1730	2249	1938	1857
	Hot/Wet [miroc]	1828	1865	1806	1843	1731	2214	1324	2364	1721	1727	2655	2129	1845	2542	1374	2319	1965	1844
	Warm/Wet [giss]	2327	2653	2482	2647	2861	2556	2293	2142	2416	2204	2854	2896	2276	2901	2529	2739	2548	2543
	Warm/Dry [fio]	2256	2522	2301	2634	2832	2628	2214	1906	2337	2172	2824	2892	2257	2900	2531	2697	2494	2526
15-May	historical	1658	2756	2516	2413	2875	2695	2383	2211	2460	1865	2825	2838	2488	2900	2595	2597	2585	2595
	Central [cnrm]	918	2232	1832	1814	2664	2156	1572	1296	1652	1105	2457	2534	1813	2818	1816	1844	1908	1824
	Hot/Very Wet [canesm]	859	1948	1568	1409	2434	1703	1197	1002	1381	749	2241	2261	1259	2684	1468	1654	1614	1518
	Hot/Wet [miroc]	1414	1611	1273	1305	1476	2070	1053	1597	1396	1266	2391	1781	1731	2373	1119	1960	1618	1537
	Warm/Wet [giss]	1342	2562	2220	2109	2810	2413	2068	1829	2093	1455	2693	2714	2152	2883	2250	2342	2246	2235
	Warm/Dry [fio]	1166	2378	2045	1994	2729	2456	1870	1564	1953	1338	2588	2659	2073	2866	2171	2053	2119	2063

GLAC	Snow Covered Area % change [5 mm SWE threshold]																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central [cnrm]	-12	-5	0	-3	-1	-6	-18	-21	-12	-17	-2	-1	-9	0	-5	-5	-7	-5
	Hot/Very Wet [canesm]	-27	-19	0	-10	-5	-20	-36	-38	-30	-38	-10	-7	-24	-2	-23	-17	-19	-20
	Hot/Wet [miroc]	-28	-28	-24	-19	-25	-16	-46	-24	-26	-27	-5	-23	-23	-11	-39	-7	-23	-24
	Warm/Wet [giss]	-5	-2	0	-2	0	-3	-7	-10	-6	-8	-1	-1	-5	0	-2	-2	-3	-2
	Warm/Dry [fio]	-8	-5	0	-2	0	-2	-11	-17	-7	-11	-1	-1	-5	0	-2	-4	-5	-3
1-May	Central [cnrm]	-26	-14	-20	-11	-2	-14	-25	-34	-23	-25	-4	-1	-23	0	-21	-8	-15	-17
	Hot/Very Wet [canesm]	-40	-27	-33	-30	-11	-32	-46	-48	-39	-50	-13	-4	-45	-3	-38	-21	-29	-33
	Hot/Wet [miroc]	-30	-34	-33	-35	-40	-21	-49	-6	-36	-33	-8	-27	-29	-12	-50	-19	-29	-34
	Warm/Wet [giss]	-11	-6	-8	-6	-1	-8	-12	-14	-10	-14	-1	0	-12	0	-9	-4	-7	-9
	Warm/Dry [fio]	-14	-10	-15	-7	-2	-6	-15	-24	-13	-15	-2	0	-13	0	-9	-6	-9	-9
15-May	Central [cnrm]	-45	-19	-27	-25	-7	-20	-34	-41	-33	-41	-13	-11	-27	-3	-30	-29	-24	-29
	Hot/Very Wet [canesm]	-48	-29	-38	-42	-15	-37	-50	-55	-44	-60	-21	-20	-49	-7	-43	-36	-36	-41
	Hot/Wet [miroc]	-15	-42	-51	-46	-49	-23	-56	-28	-43	-32	-15	-37	-30	-18	-57	-25	-36	-48
	Warm/Wet [giss]	-19	-7	-12	-13	-2	-10	-13	-17	-15	-22	-5	-4	-13	-1	-13	-10	-10	-13
	Warm/Dry [fio]	-30	-14	-19	-17	-5	-9	-22	-29	-21	-28	-8	-6	-17	-1	-16	-21	-15	-19

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Table 5-4: GLAC Snow Covered Area (5 mm SWE threshold) Top: Area (km^2) in historical average (2000-2013) and five future scenarios. Bottom: percent change in future simulations compared to historical. Average and Median values also shown. The representative dry year is 2005, wet is 2011, and near normal is 2009.

GLAC	Snow Covered Area sq-km (0.5 m depth threshold)																	
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	2628	2801	2708	2826	2876	2733	2532	2338	2650	2484	2830	2866	2380	2901	2833	2797	2699	2765
	Central [canesm]	2047	2444	2202	2577	2753	2387	1889	1502	2077	1933	2574	2705	1858	2871	2454	2414	2293	2408
	Hot/Very Wet [canesm]	1730	2121	1904	2081	2515	1922	1403	1203	1674	1339	2365	2437	1298	2774	1932	2047	1922	1927
	Hot/Wet [miroc]	1406	1171	1539	1530	1265	1989	1078	1265	1354	1439	2349	1619	1176	2290	1280	1569	1520	1422
	Warm/Wet [giss]	2402	2647	2525	2683	2829	2530	2251	2004	2405	2197	2732	2785	2152	2899	2660	2633	2521	2581
	Warm/Dry [fio]	2269	2445	2279	2647	2730	2584	2084	1720	2278	2072	2588	2745	1874	2890	2662	2499	2398	2472
1-May	historical	1970	2688	2380	2468	2855	2537	2235	2062	2324	1906	2704	2777	2011	2901	2544	2680	2437	2543
	Central [canesm]	1296	2045	1744	2058	2588	1976	1481	1265	1569	1332	2371	2523	1393	2856	1791	2118	1980	1884
	Hot/Very Wet [canesm]	1139	1783	1470	1535	2313	1494	1056	970	1325	852	2152	2191	935	2725	1418	1811	1677	1682
	Hot/Wet [miroc]	1159	1142	1175	1089	1015	1767	922	1181	1037	1077	1826	1581	1056	2229	888	1582	1295	1158
	Warm/Wet [giss]	1621	2309	2060	2187	2726	2168	1845	1709	1941	1510	2537	2626	1707	2803	2167	2449	2159	2167
	Warm/Dry [fio]	1491	2153	1880	2105	2645	2249	1698	1435	1790	1446	2402	2560	1455	2880	2103	2237	2033	2104
15-May	historical	1043	2593	2152	1708	2778	2360	1922	1670	2035	1224	2479	2625	1556	2886	2274	2227	2121	2189
	Central [canesm]	496	1927	1457	1231	2377	1690	1160	927	1236	648	1882	2101	1312	2710	1459	1401	1581	1429
	Hot/Very Wet [canesm]	521	1724	1283	963	2151	1321	870	724	1116	450	1838	1922	975	2556	1179	1339	1388	1231
	Hot/Wet [miroc]	899	1046	761	706	908	1655	694	1035	818	770	1572	1208	1161	1975	748	1215	1069	972
	Warm/Wet [giss]	833	2346	1839	1455	2619	1990	1577	1374	1646	932	2270	2418	1683	2838	1861	1950	1951	1840
	Warm/Dry [fio]	623	2077	1611	1284	2506	2002	1382	1086	1437	778	2003	2261	1388	2785	1752	1528	1658	1570

GLAC	Snow Covered Area % change (0.5 m depth threshold)																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central [canesm]	-22	-13	-19	-9	-4	-13	-25	-36	-22	-22	-9	-6	-22	-1	-13	-14	-15	-13
	Hot/Very Wet [canesm]	-34	-24	-30	-26	-13	-30	-45	-49	-37	-46	-16	-15	-45	-4	-32	-27	-29	-30
	Hot/Wet [miroc]	-47	-58	-43	-46	-56	-27	-57	-46	-49	-42	-17	-44	-51	-21	-55	-44	-44	-45
	Warm/Wet [giss]	-9	-6	-7	-5	-2	-7	-11	-14	-9	-12	-3	-3	-10	0	-6	-6	-7	-7
	Warm/Dry [fio]	-14	-13	-16	-6	-5	-5	-18	-26	-14	-17	-9	-4	-21	0	-6	-11	-11	-11
1-May	Central [canesm]	-34	-22	-27	-17	-9	-22	-34	-39	-32	-30	-12	-9	-31	-2	-30	-21	-22	-25
	Hot/Very Wet [canesm]	-42	-32	-38	-38	-19	-41	-53	-53	-43	-55	-20	-21	-51	-6	-44	-32	-35	-41
	Hot/Wet [miroc]	-41	-57	-51	-56	-64	-30	-59	-43	-55	-43	-32	-43	-47	-23	-65	-41	-47	-54
	Warm/Wet [giss]	-18	-9	-13	-11	-5	-15	-17	-17	-16	-21	-6	-5	-15	0	-15	-9	-11	-13
	Warm/Dry [fio]	-24	-18	-21	-15	-7	-11	-24	-30	-23	-24	-11	-8	-28	-1	-17	-17	-17	-16
15-May	Central [canesm]	-52	-26	-32	-28	-14	-28	-40	-44	-39	-47	-24	-20	-33	-6	-36	-37	-29	-35
	Hot/Very Wet [canesm]	-50	-34	-40	-44	-23	-44	-55	-57	-45	-63	-26	-27	-50	-11	-48	-40	-38	-44
	Hot/Wet [miroc]	-14	-60	-65	-59	-67	-30	-67	-38	-60	-37	-37	-54	-41	-32	-67	-45	-50	-56
	Warm/Wet [giss]	-20	-10	-15	-15	-6	-16	-18	-18	-19	-24	-8	-8	-14	-2	-18	-12	-13	-16
	Warm/Dry [fio]	-40	-20	-25	-25	-10	-15	-28	-34	-29	-36	-19	-14	-29	-4	-23	-31	-22	-28

Table 5-5: GLAC Snow Covered Area (0.5 m snow depth threshold) Top: Area (km^2) in historical average (2000-2013) and five future scenarios. Bottom: percent change in future simulations compared to historical. Average and Median values also shown. The representative dry year is 2005, wet is 2011, and near normal is 2009.

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5.12 ROMO Study Area

This section presents SWE and SCA for representative years, area and number of years with snow depth ≥ 0.5 m. The elevation dependence of snow for GLAC is discussed in Section 5-13. **On aver**age, the ROMO study area exhibits a change of -1 - +16 in area with significant snow cover (depth > 0.5 m) for April 15th compared to the 2000-2013 historic average, and a decline of 6-38 percent for April 15th for the scenarios considered (Tables 5-6, 5-7).

5.12.1 SWE and Snow Covered Area for representative years

Figure 5-15 shows DHSVM model simulated SWE on May 15th for the wet representative year (2011). The historical simulation is shown along with three of the five future scenarios, chosen to represent the central scenario (cnrm), the greatest change in snowpack on average (Hot/Dry (hadgem2) scenario) and the least change (Warm/Wet (giss) scenario). The future scenarios answer the question "what would the snowpack in a wet year (like 2011) look like in the 2040's through 2070's under these scenarios of climate change." Note that the "greatest snowpack change" scenario is different for ROMO than for GLAC. We have included Hot/Dry in the choice of scenarios for ROMO because a significant number of climate models project drying conditions in ROMO, whereas in GLAC, the vast majority of climate models predict a wetter future.

Figures 5-16 and 5-17 shows SWE for the "Near Normal" (2009) and "Dry" (2002) year. One can see that in the dry year, the snow cover is already very sparse even in the historical simulation.

Figure 5-18 summarizes the results in terms of the total snow covered area (km^2) within the study area polygon. In this case, the threshold used is 13mm of SWE, representing a light snow cover, and comparable to the results in McKelvey. Comparing the Wet and Dry years we see, as with GLAC, that dry years are more vulnerable to climate change in terms of percentage of area lost. For the Wet year, the high elevations of the study area result in little loss of snowpack in the study areas under most scenarios of change. The numerical values of snow covered area for all years, as well as percent changes for these quantities are shown in Table 5-7. **On average, the ROMO study area exhibits a change of -1 - +16 in area with significant snow cover (depth > 0.5 m) for April 15th compared to the 2000-2013 historic average, and a decline of 6-38 percent for April 15th for the scenarios considered (Tables 5-6, 5-7).**

Sept 2017

ROMO	Snow Covered Area sq-km [5 mm SWE threshold]																	
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	1575	1522	1575	1593	1564	1536	1433	1593	1590	1587	1597	1583	1586	1594	1393	1595	1561	1587
	Central [comm]	1442	1348	1486	1519	1428	1590	1026	1550	1536	1447	1596	1495	1526	1582	1105	1590	1454	1507
	Hot/Dry [hadgem2]	1317	1199	1405	1491	1246	1575	917	1496	1530	1475	1595	1463	1485	1569	806	1578	1384	1480
	Hot/Very Wet [miroc]	1123	944	1248	1360	1208	1528	835	1418	1439	1094	1586	1275	1351	1505	1010	1589	1282	1313
	Warm/Wet [giss]	1539	1486	1555	1585	1507	1595	1253	1584	1586	1576	1597	1573	1582	1593	1251	1594	1528	1575
	Warm/Dry [ncar]	1509	1438	1562	1572	1508	1593	1122	1579	1580	1562	1597	1557	1567	1591	1206	1594	1507	1557
1-May	historical	1557	1519	1537	1546	1417	1592	1368	1596	1564	1568	1596	1573	1542	1594	1058	1593	1514	1560
	Central [comm]	1367	1274	1380	1256	1125	1559	957	1569	1394	1296	1590	1441	1387	1576	735	1538	1348	1384
	Hot/Dry [hadgem2]	1180	1073	1185	1096	900	1486	829	1306	1250	1265	1577	1341	1172	1547	570	1491	1201	1215
	Hot/Very Wet [miroc]	1058	873	1075	1030	928	1449	726	1555	1238	979	1563	1172	1217	1494	475	1457	1143	1124
	Warm/Wet [giss]	1496	1442	1459	1460	1233	1583	1154	1584	1515	1520	1595	1549	1496	1591	897	1587	1447	1505
	Warm/Dry [ncar]	1460	1429	1486	1448	1262	1577	1055	1591	1516	1494	1594	1536	1452	1590	830	1582	1431	1490
15-May	historical	1463	1452	1173	1281	1245	1587	1041	1536	1507	1481	1590	1512	1516	1591	915	1574	1484	1494
	Central [comm]	1122	1148	895	906	926	1527	667	1316	1153	1047	1553	1185	1302	1535	612	1424	1145	1151
	Hot/Dry [hadgem2]	840	912	565	679	661	1376	479	982	945	922	1410	891	1039	1431	427	1144	919	917
	Hot/Very Wet [miroc]	885	751	700	779	754	1371	484	1117	1032	816	1485	943	1163	1424	403	1304	963	914
	Warm/Wet [giss]	1306	1335	993	1109	1040	1570	841	1420	1380	1355	1579	1401	1441	1580	762	1542	1291	1367
	Warm/Dry [ncar]	1290	1316	1023	1084	1063	1562	817	1433	1385	1317	1582	1410	1444	1578	723	1534	1285	1351

ROMO	Snow Covered Area % change [5 mm SWE threshold]																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central [comm]	-8	-11	-6	-5	-9	0	-28	-3	-3	-9	0	-6	-4	-1	-21	0	-7	-5
	Hot/Dry [hadgem2]	-16	-21	-11	-6	-20	-1	-36	-6	-4	-7	0	-8	-6	-2	-42	-1	-11	-7
	Hot/Very Wet [miroc]	-29	-38	-21	-15	-23	-4	-42	-11	-10	-31	-1	-19	-15	-6	-27	0	-18	-17
	Warm/Wet [giss]	-2	-2	-1	0	-4	0	-13	-1	0	-1	0	-1	0	0	-10	0	-2	0
	Warm/Dry [ncar]	-4	-5	-1	-1	-4	0	-22	-1	-1	-2	0	-2	-2	0	-13	0	-3	-2
1-May	Central [comm]	-12	-16	-10	-19	-21	-2	-30	-2	-11	-17	0	-8	-10	-1	-31	-3	-11	-11
	Hot/Dry [hadgem2]	-24	-29	-26	-29	-36	-7	-39	-18	-20	-19	-1	-15	-24	-3	-46	-6	-21	-22
	Hot/Very Wet [miroc]	-32	-43	-30	-33	-34	-9	-47	-3	-21	-38	-2	-26	-21	-6	-55	-9	-24	-28
	Warm/Wet [giss]	-4	-5	-5	-6	-13	-1	-16	-1	-3	-3	0	-2	-3	0	-15	0	-4	-4
	Warm/Dry [ncar]	-6	-6	-3	-6	-11	-1	-23	0	-3	-5	0	-2	-6	0	-22	-1	-5	-5
15-May	Central [comm]	-23	-21	-24	-29	-26	-4	-36	-14	-23	-29	-2	-22	-14	-4	-33	-10	-18	-23
	Hot/Dry [hadgem2]	-43	-37	-52	-47	-47	-13	-54	-36	-37	-38	-11	-41	-31	-10	-53	-27	-35	-39
	Hot/Very Wet [miroc]	-40	-48	-40	-39	-39	-14	-53	-27	-32	-45	-7	-38	-23	-10	-56	-17	-31	-39
	Warm/Wet [giss]	-11	-8	-15	-13	-17	-1	-19	-8	-8	-9	-1	-7	-5	-1	-17	-2	-8	-9
	Warm/Dry [ncar]	-12	-9	-13	-15	-15	-2	-22	-7	-8	-11	-1	-7	-5	-1	-21	-3	-8	-10

Table 5-6: ROMO Snow Covered Area (5 mm SWE threshold) Top: Area (km^2) in historical average (2000-2013) and five future scenarios. Bottom: percent change in future simulations compared to historical. Average and Median values also shown. The representative dry year is 2002, wet is 2011, and near normal is 2007. The representative wet year is the same for both areas, but the wet and dry years are different.

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5.12.2 Area and Number of years with ≥ 0.5 m Snow Depth

Because of interest in wolverine denning sites, we analyze snow depth ≥ 0.5 m, which we will refer to here as "significant snow." Figure 5-19 shows the area with snow depth ≥ 0.5 m within the study area. Because of the more stringent threshold for snow, the effects are somewhat larger than for the light snow cover. The numerical values of snow covered area at the ≥ 0.5 m threshold are shown in Table 5-7 for all years, as well as percent changes for these quantities. In this table, we note that dry years such as 2002 see increases in snow covered area for the Hot/Very Wet and Warm/Wet scenarios. As in GLAC, dry years are somewhat buffered against change, and in fact can see increases in high-altitude "significant" snow for scenarios with increased precipitation. This is a result of the elevational dependence of snowpack change that will be discussed in the next sub-section. **On average, the ROMO study area exhibits change of -1 - +16 in area with significant snow cover (depth > 0.5 m) for April 15th compared to the 2000-2013 historic average, and a decline of 6-38 percent for April 15th for the scenarios considered (Tables 5-6, 5-7). Note that the Warm/Wet scenario projects a slight increase in the area of significant snowpack on April 15th, for the average of all years, and some individual years.**

Figure 5-20 shows a map of the number of years (out of 16 possible) where each model pixel had at least 0.5 m of snow depth on May 15th. This summary statistic is analogous to that used by the Copeland study, except that there are more years of data, and these maps use a much higher threshold of snow. The projections show declines in the number of years with significant snow. The areas with frequent (14-16 years) availability of significant snow become concentrated in smaller high elevation areas. The Hot/Dry "greatest change" scenario, illustrates that the combination of drying and warming leads to very large declines in the persistence of snow.

The effects of climate change on snow melt have been presented as analogous to a "time shifting" of the melt season earlier in the year. For example, McKelvey (2011) used the May 31st vs. May 15th snow covered area as a proxy for a 2-week shift in the melt season. Figure 5-21 contrasts the evolution of the snowpack with respect to the number of years with significant snow from April 15th to May 15th in the historical simulations (Top Row) with the Warm/Wet scenario (giss, Middle Row) and Hot/Wet (hadgem, Bottom Row) scenarios. We see that the Warm/Wet scenario, shows the least change in the number of years compared to the historic snow cover in terms of the availability of significant snow. In contrast, under the Hot/Wet scenario, the number of years that significant snowpack occurs on April 15th has been diminished below the level of the historic May 15th snowpack – a month shift (Figure 5-21).

5.13 Elevation Dependence of Snowpack Change in the DHSVM model

Snowpack accumulation and melt depends critically on temperature and hence on elevation. In the Warm/Dry and Hot/Dry scenarios, both the reduction in precipitation and the warming act to reduce Spring snowpack. For the scenarios with warming and increased precipitation there are two countervailing forces that play out along an elevational gradient. A warmer, wetter future is one in which the freezing level and snow line tends to be higher, but with the potential for

5SRP2017

greater snowpack accumulation during the cold season at high elevations. The warming also tends to lead to an earlier snowmelt, so that the increased high-elevation snowpack is more evident early in the Springtime than later

Figures 5-22 shows the percent change in May 1st snow covered area (SCA; ≥ 0.5 meters depth) for GLAC, computed for 200 m elevation bands. The elevation of observed den sites is noted by triangles, with den sites ranging from approximately 1500m to 2300 m. There is little change (<5%) in SCA for 4 of the 5 scenarios above 2200m. As in a mirror image there is greater than 95 % loss of SCA below 1400m for 4 of the 5 scenarios. Between these two elevations – and in the regions where most observations of dens have been noted – the snowpack change is very sensitive to elevation and to the particular future climate scenario. Most of the dens are at 1800 to 2000, below that band large losses predicted, above that elevation band minimal losses predicted accept in maximum warming scenario. Figure 5-23 shows the elevation dependence of the May 1st snowpack measured in terms of snow water equivalent (SWE). Viewing snowpack in terms of SWE illustrates more clearly that the Hot/Very Wet future scenario has a greater snowpack at high elevations despite completely losing its snowpack at 100m elevation. Figure 5-23 also illustrates that SWE can have modest declines without affecting the area with significant snow depth. The implications is that wet, cold climate of the GLAC study area can act as a "buffer" to change in the area of ≥ 0.5 meter deep snow on May 1st, at least at high elevations

Figure 5-24 shown the May 1st SCA (≥ 0.5 m depth) for ROMO. The high elevation areas show a loss of SCA for four of the five future scenarios, which an increase only in the Warm/Wet (giss) scenario. The climate of ROMO is, on average drier than that of GLAC, and the regions of the model simulations that have significant snow in most years is restricted to the two smaller areas within the domain (Figure 5-21). As a result the climate does not act to buffer change in the area of significant snow on May 1st.

This phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. Regonda et al. (2005) found little historical change in snowpack in the Western United States above approximately 2500m elevation despite observed warming trends. and Lettenmaier (2007) considered VIC hydrology model projections and reported as strong elevation dependence for snowpack loss in the Colorado River basin below 2500 m elevation (their data was visualized in Ray et al. 2008). Two recent studies are of special interest because they focus on areas near those considered here. Sospendra-Alfonso et al (2015), on an area near the GLAC study area, find that historically, temperature has been a larger driver of April 1st snowpack only below about 1560 m elevation, with precipitation the main driver of variability above that elevation. Scalzitti et al. (2016) investigated a single climate change scenario using a high-resolution weather model and found that the critical elevation below which temperature dominates snowpack rises by about 250m in the Colorado Rockies, and rises by about 191 m in the Northern Rockies hear the GLAC study area. While it is difficult to these results directly to the present study due to differences in methodology, the qualitative picture remains – projected warming has a larger effect at lower elevations whereas projected precipitation changes may dominate the Springtime snowpack in the high country.

Sept2017

ROMO	Snow Covered Area sq-km (0.5 m depth threshold)																	
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	1000	803	1176	1021	776	1571	924	1008	1178	1336	1536	1111	768	1529	710	935	1086	1014
	Central [comm]	914	727	1170	929	765	1475	757	1039	1023	999	1533	1035	747	1478	583	967	1009	983
	Hot/Dry [hardgcm2]	796	660	963	922	699	1372	692	891	1042	1076	1482	994	737	1417	485	887	945	906
	Hot/Very Wet [miroc]	781	588	948	897	724	1271	629	990	1071	811	1500	845	761	1361	426	1043	915	871
	Warm/Wet [gfdl]	1006	789	1184	1098	781	1553	862	1019	1217	1313	1569	1157	806	1531	677	1051	1100	1074
	Warm/Dry [ncar]	873	690	1062	821	728	1499	742	817	960	1123	1442	987	700	1462	565	826	953	825
1-May	historical	871	852	1029	819	719	1556	841	987	983	1147	1365	1148	837	1519	594	1119	1024	985
	Central [comm]	835	747	944	713	661	1423	710	888	811	847	1286	980	769	1454	472	1052	912	841
	Hot/Dry [hardgcm2]	742	636	742	672	561	1254	636	725	797	840	1136	817	703	1364	356	845	881	742
	Hot/Very Wet [miroc]	736	596	772	694	595	1182	583	819	845	706	1251	825	759	1326	315	1105	819	766
	Warm/Wet [gfdl]	890	822	960	799	691	1521	782	915	981	1110	1406	1093	837	1510	541	1141	1000	938
	Warm/Dry [ncar]	773	720	927	723	665	1464	716	792	800	965	1391	1004	762	1441	490	962	900	796
15-May	historical	852	864	705	712	681	1549	532	1017	943	995	1357	1005	981	1454	577	1041	954	962
	Central [comm]	738	699	569	556	569	1377	406	834	728	709	1151	744	854	1328	429	853	784	733
	Hot/Dry [hardgcm2]	584	546	296	398	406	1104	238	611	640	610	925	505	691	1080	262	635	596	597
	Hot/Very Wet [miroc]	636	558	451	534	497	1136	298	753	724	610	1110	627	818	1175	271	907	694	631
	Warm/Wet [gfdl]	809	797	629	670	632	1502	487	911	895	936	1320	902	957	1421	513	988	858	858
	Warm/Dry [ncar]	753	721	608	617	610	1455	402	826	778	832	1190	866	859	1343	484	897	828	882

ROMO	Snow Covered Area % change (0.5 m depth threshold)																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central [comm]	-9	-9	-1	-9	-1	-6	-18	3	-13	-25	0	-7	-3	-3	-18	3	-7	-3
	Hot/Dry [hardgcm2]	-20	-18	-18	-10	-10	-13	-25	-12	-12	-19	-4	-11	-4	-7	-32	-5	-13	-11
	Hot/Very Wet [miroc]	-22	-27	-19	-12	-7	-19	-32	-2	-9	-39	-2	-24	-1	-11	-40	12	-16	-14
	Warm/Wet [gfdl]	1	-2	1	8	1	-1	-7	1	3	-2	1	4	5	0	-5	12	1	6
	Warm/Dry [ncar]	-18	-14	-10	-20	-6	-5	-20	-19	-19	-16	-6	-11	-9	-4	-20	-12	-12	-19
1-May	Central [comm]	-4	-12	-8	-13	-8	-9	-16	-10	-17	-26	-6	-15	-8	-4	-21	-6	-11	-15
	Hot/Dry [hardgcm2]	-15	-25	-28	-18	-22	-19	-24	-27	-19	-27	-17	-29	-16	-11	-40	-24	-22	-25
	Hot/Very Wet [miroc]	-15	-30	-25	-15	-17	-24	-31	-17	-14	-38	-8	-28	-9	-13	-47	-1	-20	-22
	Warm/Wet [gfdl]	2	-3	-7	-3	-4	-2	-7	-7	0	-3	3	-5	0	-1	-9	2	-2	-5
	Warm/Dry [ncar]	-11	-15	-10	-12	-7	-6	-15	-20	-19	-16	-13	-13	-9	-5	-18	-14	-12	-19
15-May	Central [comm]	-13	-19	-19	-22	-17	-11	-24	-18	-23	-29	-15	-26	-13	-9	-26	-18	-18	-24
	Hot/Dry [hardgcm2]	-31	-37	-58	-44	-40	-29	-55	-40	-32	-39	-32	-50	-30	-26	-55	-39	-38	-38
	Hot/Very Wet [miroc]	-25	-35	-36	-25	-27	-27	-44	-26	-23	-39	-18	-38	-17	-19	-53	-13	-27	-34
	Warm/Wet [gfdl]	-5	-8	-11	-6	-7	-3	-9	-10	-5	-6	-3	-10	-2	-2	-11	-5	-6	-7
	Warm/Dry [ncar]	-12	-17	-14	-13	-10	-6	-25	-19	-17	-16	-12	-14	-12	-8	-16	-14	-13	-17

Table 5-7: ROMO Snow Covered Area (0.5 m snow depth threshold) Top: Area (km^2) in historical average (2000-2013) and five future scenarios. Bottom: percent change in future simulations compared to historical. Average and Median values also shown. The representative dry year is 2002, wet is 2011, and near normal is 2007.

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6 Comparing results with McKelvey

An overview of the methodological similarities and differences between this study and McKelvey et al (2011) was presented in section 2.2. The differences in aims of these studies leads to challenges in making a direct comparison. The primary difference is in the choice of study areas – west-wide vs. much smaller selected areas near treeline, which has implications for the biological hypotheses that may be addressed. Their work focused on May 1st snow depth as a proxy for May 15th snow disappearance, while we directly estimated the May 15th snow disappearance. McKelvey investigated persistence of even a snow cover to May 15th as a correlate of wolverine habitat, as noted in Aubry et al (2008). This study focuses on high-elevation terrain and on the persistence of deeper snowpack. We also analyze our model results for the presence or absence of deeper snow (nominally greater than or equal to 0.5 meters depth) on April 15th and May 1st. [5]

Nonetheless some general statements can be made relating the two studies. Figure 5-26 shows snowcover under McKelvey's historic and "miroc 2080's" (or hotter, greatest change) scenario. The GLAC and ROMO areas have been outlined. A close examination of this figure shows that snow cover persists in our study areas, even for their hotter scenario of change (miroc "2080's). The greatest loss of snow cover in McKelvey occurs at lower elevations than were included in GLAC or ROMO. Because of the increased resolution of our study we are able to consider whether any pockets of snow with depth ≥ 0.5 meters will persist.

The choice of future climate scenarios differs somewhat from McKelvey. We have intentionally included scenarios that represent the range of possibilities indicated by the CMIP5 climate models. McKelvey used climate model output from Littell, who chose scenarios based solely on projected warming. For GLAC, this choice fortuitously included a range of precipitation changes as well. For ROMO, however, McKelvey's scenarios include only a narrow range of precipitation change, where we include scenarios with significantly increased wintertime precipitation as well as scenarios with drying. This is a significant factor, given the buffering effect that increased precipitation has on snowpack loss at high elevations.

While McKelvey focused snowpack projections entirely on the long-term average, we investigate how climate variability – the sequences of wet and dry years -- intersects with scenarios of change. For ROMO in particular we find that dry years behave differently than wet years, with dry years benefitting from the increased precipitation in several of our future scenarios. This emphasizes the importance of planning for a range of possible climate scenarios, particularly regarding the direction of change in wintertime precipitation.

The question arises as to how the fine-scale projections of snow persistence in other areas might reasonably be inferred from the two study areas considered here. Figure 5-26 indicates many areas in the western United States that show persistence of snow cover in McKelvey's scenarios,

[5] The study originally focused on May 15th to compare to the McKelvey, et al (2011) study, and June 1st to bracket the snowmelt season. However, as the study progressed, biologists because more interested in April snow.

Sept 2017

even in the more extreme scenarios. We have investigated two study areas: a northern, relatively wet and low-elevation area GLAC, and a southern, relatively dry, and very high elevation area (ROMO). In both areas we find general declines in snow covered area under most future scenarios. The GLAC study area is broadly similar in its climate to much of the high northern Rockies, while ROMO shares features with the high mountain ranges of the Central Rockies. For areas in the McKelvey maps that show retention of snow on the higher mountain ranges it is physically reasonable to presume that a finer scale simulation would show the retention of areas of snow ≥ 0.5 m on May 15th. Extending this beyond the general area of the Rocky Mountains is problematic. Even within the Rockies, in regions where McKelvey's results show widespread loss of snowpack it is probably not reasonable to conclude one way or the other whether a finer scale analysis would identify snow refugia.

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Sept2017

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ESent2017

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Sept 2017

9 Glossary

- **Aspect:** compass direction that slope faces
- **Baseline period 1916-2000**: Deltas (changes) computed (monthly average delta) for "2040's and "2080's" compared to the 1916-2000 baseline.

- **CanESM:** A CMIP5 climate model the Canadian Centre for Climate Modeling and Analysis (canesm2.1.rcp85), forced with the RCP 8.5 higher emissions pathway, used in this report as a future scenario (Hot/Dry scenario for GLAC only) that has relatively higher increase in temperature (+~4.5 C) and about +20% increase in precipitation (See Figure 5-7)
- **Climate Sensitivity:** Regionally speaking, it is the response of a climate model for a given amount of greenhouse gas increase. More narrowly defined it is the global average temperature increase that results from a doubling of carbon dioxide over pre-industrial values.
- **CMIP3, CMIP5:** Coupled Model Intercomparison Project Phases 3 and 5. "Foundational" collections of climate model projections, used in the Intergovernmental panel on Climate Change (IPCC) 2007 and IPCC 2013 reports, respectively
- **CNRM:** A CMIP5 climate model from the French National Centre of Meteorological Research (cnrm-cm5.1.rcp85),used in this report as a future scenario (Central scenario for both GLAC and ROMO) that is relatively close to the ensemble mean in temperature increase (+~2.5 ºC) and +~5-8% increase in precipitation (See Figure 5-7).
- **DEM:** Digital elevation model
- **DSHVM:** Distributed Hydrology Soil Vegetation Model
- **ESM:** earth system models, see GCM.
- **FIO:** A CMIP5 earth system model from the First Institute of Oceanography, State Oceanic Administration of China (fio-esm.1.rcp85), used in this report as a future scenario (Warm/Dry scenario for both areas) that is relatively lower in temperature increase (+~0.8-1.6 ºC) and -~5% decrease in precipitation (See Figure 5-7).
- **FLH:** Atmospheric freezing level height is the altitude in the free atmosphere at which the temperature is 0 °C
- **GCM:** Global Climate Model, 6 were used for this report from the IPCC 2013 class of models; X of these are actually earth system models (ESM), an advanced type of GCM which have the added capability to explicitly represent biogeochemical processes that interact with the physical climate. GCM is used as a general term referring to both kinds of models, ESM is used specifically for earth system models.
- **GISS:** A CMIP5 climate model from the NASA Goddard Institute for Space Studies (giss-e2-r.1.rcp45), used in this report as a future scenario (Warm/Wet scenario for both areas). Referred to as the "Least Change" scenario because it that is relatively lower temperature increase (+~1-1.3 ºC) and +~7-10% increase in precipitation (See Figure 5-7).
- **GLAC:** An area in Glacier National Park used as a spatial unit of analysis in this report
- **HADGEM:** A CMIP5 earth system model from the United Kingdom Meteorological Office Hadley Center (hadgem2-es.1.rcp85) used in this report as a future scenario (Hot/Very Wet scenario for ROMO only) that has relatively higher temperature increase (+~ 3.5 ºC) and -~5% decrease in precipitation.
- **Internal climate variability**: The variations in the climate, even for 30-year and longer averages, that can occur due to the interactions of the atmosphere, ocean, inland surface and cryosphere. This occurs even in the absence of anthropogenic climate change.
- **MODIS:** Moderate Resolution Imaging Spectroradiometer, a satellite remote sensing instrument carried on the Terra satellite

Sept2017

- **MIROC:** A CMIP5 earth system model from the Japanese Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies (miroc-esm-chem.1.rcp85), used in this report as a future scenario (Hot/Wet scenario for both areas). Referred to as the "Greatest Change" scenario because it has the highest temperature increase of the scenarios (+~4 ºC) and +~10-18% increase in precipitation (see Figure 5-7). This ESM has an atmospheric chemistry (CHEM) component coupled to the MIROC-ESM (http://maca.northwestknowledge.net/GCMs.php).
- **NDSI:** Normalized Difference Snow Index, a measure of snow cover, has a has a linear relationship to fractional snow cover (FSC)
- **North American Freezing Level Tracker**: NCEP/NCAR Global Reanalysis 2.5º x 2.5º grid data (http://www.wrcc.dri.edu/cwd/products/)
- **Octants:** Topographic aspect, or compass direction, was classified into eight directional bins, each representing 45° of compass arc, e.g; NW, N, NE, E, SE, S, SW, and W
- **Resolution:** The VIC modeling that was the basis for McKelvey was performed on a regular grid in latitude and longitude, with a grid size of 1/16 degree on a side. The distance between degrees of longitude varies due to the curvature of the Earth, and the east-west dimension of a gridbox is smaller than the north-south distance by a factor of the cosine of latitude. At 40°N latitude, the southern extent of Rocky Mountain National Park, the gridbox is ~5km by 7 km (~37km^2). Grid boxes at Glacier National Park (~48°N) are slightly smaller. When referring to the McKelvey study we will use the "1/16 degree" notation. The DHSVM modeling used in this study was performed on a uniform grid in the Universal Transverse Mercator (UTM) map projection, which allows a near-uniform grid size of 250m by 250m (0.0625 km^2) in both of the study areas.
- **ROMO:** An area in and around Rocky Mountain NP used as a spatial unit of analysis in this report
- **SCA:** Snow Covered Area (km^2)
- **SDD:** Snow Disappearance Date, the first Day of Year after March 1 where pixel is snow-free, defined as the date which NDSI/100 was less or equal to 0.1.
- **SNODAS:** Snow Data Assimilation System, a product of the NOAA National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC)
- **SWE:** Snow water equivalent (mm). For May, snow depth is assumed to be ~ 2.5 *SWE
- **TopoWx:**
- **Snow covered area, total:**Total area covered by snow within the study boundaries in square kilometers (km^2)
- **Snow covered area, fractional:** Percentage of the total land area that is covered by snow; this can be within the study boundaries, aspect area, or elevation bands
- **VIC:** Variable Infiltration Capacity hydrologic model
- **UTM:** Universal Transverse Mercator spatial coordinates

FIGURES – see separate file

ESept2017

From: Andrea Ray - NOAA Federal
To: Guinotte, John
Cc: Joe Barsugli; Steve Torbit
Subject: Re: Wolverine Snow persistence report
Date: Wednesday, September 6, 2017 8:42:22 AM

John and Joe -- The exec summary had already been updated for new numbers (Joe and I have both double checked those in the ES and the text), and many bullets revised. Those were then copied to the bullets at the beginning of chapters in the text.

Joe -- if you're thinking it needs more changes based on what you saw as you looked through things yesterday (and our email exchange), call me so we can get that done ASAP,

Thanks! Andrea

On Wed, Sep 6, 2017 at 8:07 AM, Guinotte, John <john_guinotte@fws.gov> wrote:

> Thanks Joe, I'll read through the main body and figures this am. I will hold off on reading the exec summary/main points. When will you be sending the final version of the exec summary?
> Thanks John
>
> On Wed, Sep 6, 2017 at 5:01 AM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:
>
> > John,Andrea,
> >
> > I have made several changes to the text so you should look at this revised text document. Because of the increased amount of snow in ROMO in the corrected runs, we have had to remove some statements on the uniqueness of ROMO -- and on whether GLAC is really more buffered than ROMO. \
> >
> > The main body of the text has been carefully edited, but the main points and executive summary are not changed to reflect many of the details for GLAC and ROMO projections. They need to be updated according to the new text.
> >
> > Joe
> >
> > On 9/5/17 5:35 PM, Guinotte, John wrote:
> >
> > > Thanks Andrea. I'll read through it tomorrow and get back to you.
> > > Best, John
> > >
> > > John Guinotte
> > > Spatial Ecologist
> > > 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 Tue, Sep 5, 2017 at 5:22 PM, Andrea Ray - NOAA Federal <andrea.ray@noaa.gov> wrote:
>
> > Hi John -- Here's the report with new title, and the figures are in the drive here, with today's date: https://drive.google.com/drive/folders/0ByT4y_bFYaBGem5kWENvSFc4eXM
> >
> > Joe is going thru it now while on a plane, and expects that there will only be minor edits. If so, I'll do those first thing in the morning, but I want you to have this now.
> >
> > I expect we'll be in touch in the next few days as questions/comments arise!
> >
> > Andrea
> >
> > --
> > --
> > Andrea J. Ray, Ph.D.
> > NOAA Earth System Research Lab, Mailcode R/PSD1
> > 325 Broadway, Boulder, CO 80305-3328
> > (tel) 303-497-6434
> > (fax) 303-497-6449
> > andrea.ray@noaa.gov
> > www.researchgate.net/profile/Andrea_Ray2

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Joseph Barsugli
Research Scientist III
CIRES, UCB 216
University of Colorado at Boulder
cell:720-244-5922

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Andrea J. Ray, Ph.D.
NOAA Earth System Research Lab, Mailcode R/PSD1
325 Broadway, Boulder, CO 80305-3328
(tel) 303-497-6434
(fax) 303-497-6449
andrea.ray@noaa.gov
www.researchgate.net/profile/Andrea_Ray2

From: Guinotte, John
To: Joe Barsugli
Cc: Andrea Ray - NOAA Federal; Steve Torbit
Subject: Re: Wolverine Snow persistence report
Date: Wednesday, September 6, 2017 3:14:03 PM
Attachments: Wolverine Rept Text REVISION 5Sept17_AJR_JJB_JMGc.docx

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Here is the latest version of the text with table 5-2 updated. Some of the snow depths for the dens went up significantly using the new historical model runs. All of the known natal dens had > 1m of snow on April 15.
Best, John

John Guinotte
Spatial Ecologist
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 Wed, Sep 6, 2017 at 12:50 PM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:

> Yes, that table was one where I had a big question mark -- has it been done with the updated runs. thanks for updating the numbers. Joe
>
> On 9/6/17 11:47 AM, Andrea Ray - NOAA Federal wrote:
>
> > Hi John, yes would you update Table 2? I think you did the original Table. the small changes in the new DHSVM runs might make a difference, and you could add April 15th (I think we sent you all the data). And an idea, voulf you do a version of this table for ROMO and use the lower, middle and upper end of the inferred range (2700-3600)? or is that too speculative.
> >
> > I'll work on the changes you've sent after I talk to Joe later, tomorrow a.m. at the latest.
> >
> > Andrea
> >
> > On Wed, Sep 6, 2017 at 12:36 PM, Guinotte, John <john_guinotte@fws.gov> wrote:
> >
> > > Use this word doc instead. I changed the elevations for the study areas / treeline elevations.
> > >
> > > John Guinotte
> > > Spatial Ecologist
> > > 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

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> > >
> > > Joe is going thru it now while on a plane, and expects that there will only be minor edits. If so, I'll do those first thing in the morning, but I want you to have this now.
> > >
> > > I expect we'll be in touch in the next few days as questions/comments arise!
> > >
> > > Andrea

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Andrea J. Ray, Ph.D.
NOAA Earth System Research Lab, Mailcode R/PSD1
325 Broadway, Boulder, CO 80305-3328
(tel) 303-497-6434
(fax) 303-497-6449
andrea.ray@noaa.gov
www.researchgate.net/profile/Andrea_Ray2

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Joseph Barsugli
Research Scientist III
CIRES, UCB 216
University of Colorado at Boulder
cell:720-244-5922

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Andrea J. Ray, Ph.D.
NOAA Earth System Research Lab, Mailcode R/PSD1
325 Broadway, Boulder, CO 80305-3328
(tel) 303-497-6434
(fax) 303-497-6449
andrea.ray@noaa.gov
www.researchgate.net/profile/Andrea_Ray2

--
Joseph Barsugli
Research Scientist III
CIRES, UCB 216
University of Colorado at Boulder
cell:720-244-5922

Future snow persistence in Rocky Mountain and Glacier National Parks: An analysis to inform the USFWS Wolverine Species Status Assessment

A Report to the U.S. Fish and Wildlife Service Region 6

5 September 2017

Andrea J. Ray[1], Joseph J. Barsugli[2], Ben Livneh[3] Candida F. Dewes[2], Imtiaz Rangwala[2], Aaron Heldmyer[3], Jenna Stewart[3]

[1]NOAA/ESRL/Physical Sciences Division
Boulder, CO
[2]CU/Cooperative Institute for Research in Environmental Sciences (CIRES)
[3]CU Civil, Environmental & Architectural Engineering

Corresponding Author:
Andrea J. Ray
303-497-6434
andrea.ray@noaa.gov

Internal working document, do not cite, quote or distribute without permission of the authors, John Guinotte or Steve Torbit

Executive Summary

Overview: This study is a fine-scale assessment of snow extent and depth ~~at~~ for two areas within and ~~in the vicinity of~~surrounding Glacier (GLAC) and Rocky Mountain (ROMO) National Parks. The analysis was done for both the recent past, using MODIS satellite-based remote sensing, and in historic simulations and projections of future snowpack using a high-resolution hydrologic model. The fine scale hydrologic modeling allows for the consideration of snow processes such as dependence on terrain slope and aspect that are important to understanding high elevation snow persistence in a changing climate and were not considered in previous work.

Methods: The report intentionally builds on previous work by McKelvey et al. (2011) extending that work by providing a higher resolution spatial scale analysis for two case study areas, and a broader range of future scenarios. Two areas were studied: a high latitude area near tree line within Glacier National Park, where tree line occurs at ~~~1200m~~ 1800-2100m (Figure 2-1) that is currently occupied by wolverines; and a lower latitude area within Rocky Mountain National Park, where tree line occurs at higher elevation (~ ~~2750~~ 3500 m) (ROMO, Figure 2-2). These sites were chosen to bracket the range of latitude and elevation wolverines currently occupy in the contiguous U.S. A detailed comparison of their methodologies and ours is provided in Table 2-1, and a discussion of results in Section 6. Note however that the primary difference between McKelvey et al. (2011) and this study is in the choice of study areas – west-wide vs. much smaller selected areas near treeline, which has implications for the biological hypotheses that may be addressed. Their work focused on May 1st snow depth as a proxy for May 15th snow disappearance, while we focus directly on May 15th snow disappearance. We also analyze our model results for the presence or absence of deeper snow (nominally greater than or equal to 0.5 meters depth) on April 15th and May 1st.[1]

The project uses methods from the peer-reviewed, published literature to:

- Explicitly model the effects of slope and aspect, using fine-scale spatial models to analyze topographic effects on snow
- Better represent the range of plausible future changes (climate scenarios)
- Analyze year-to-year variability during the main study period (2000-2013, the years for which both MODIS satellite and hydrologic modeling were available) including wet and dry extremes within that period. We selected representative wet, dry, and near normal years from the main study period for detailed analysis and assessed how these would change under different future climate scenarios. For the two areas, these are:
    - Representative years for GLAC: 2011 (wet), 2005 (dry), 2009 (near normal).
    - Representative years for ROMO: 2011 (wet), 2002 (dry), 2007 (near normal).
- Assessing change in snow persistence by elevation, with emphasis on elevations used by wolverines for denning in GLAC, 1500m -2250.[2] Linear regression of den site elevations

Commented [GJM1]: Sentence fragment in #2 below

[1] The study originally focused on May 15th to compare to the McKelvey, et al (2011) study, and June 1st to bracket the snowmelt season. However, as the study progressed, biologists ~~because~~ became more interested in April snow covered area.

[2] Actual den sites and elevations of specific dens are confidential and are not provided in this report. The full range in GLAC is ~1500m - ~2250. All but three of 14 documented dens in

and latitude in the contiguous U.S. indicated den sites in the ROMO study area would be located in an elevation range of 2700-3600 m, but documented den sites do not exist in ROMO (Guinotte, personal communication). In contrast to McKelvey's studies, our study areas are near tree line and above (~~962~~ 1800 m – 3166 m in GLAC, and ~~2563~~ 3200 – 4253 m in ROMO).

Commented [GJM2]: Check these #s

Commented [GJM3]: Check these #s

MODIS Observed Historic Snowpack Variability Analysis: Satellite-based MODIS snow cover data was used to assess the historical variability of snow cover in the study areas and as a basis for the spatial evaluation of the hydrologic model simulations. The historical observed snow cover was analyzed for its dependence on terrain elevation and aspect (compass direction that the slope faces).

- In GLAC, snow covered area 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; Section 4.3).
- Even in dry years, NE-facing slopes in GLAC tend to hold more snow and melt later in the season. There is > 80% snow cover above ~2000 m elevation on May 1 during dry years, and > 95% snow cover above ~1200 m during wet years (Figure 4-6).
- In ROMO, snow covered area also varies considerably by year (Section 4-4).
- NW-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 (Fig 4-13).

Future Snowpack Projections (Section 5): The Distributed Hydrology Soil Vegetation (DHSVM) was run in historical simulations of the period 1998-2013. The model was validated against SNOTEL in-situ snow observations and MODIS snow cover. The model was then run for five scenarios of the future which represent a nominal 2055 climate. Scenarios were selected from CMIP5 global climate model (GCM) projections, and were chosen to span a large fraction of the range of the CMIP5 ensemble projections in each study area in terms of precipitation and temperature changes. Representative Wet, Near Normal, and Dry years were analyzed for the historical simulations and how each of these years plays out under these five future scenarios. The number of years (out of 16) with snow above 0.5m depth was also analyzed as was the change in Snow Covered Area (SCA) with depth greater than 0.5m. The average change in SCA and Snow Water Equivalent (SWE) was analyzed as a function of elevation, and for GLAC was overlayed with the elevations of wolverine den sites.

While SCA changes provide an overall metrics for the study areas, the interpretation of these reported changes should be done with care. The area-wide SCA results include snowcover changes in both forested and above-treeline terrain, which may have different implications for

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GLAC are between 1800 and 2000m (Fig. 5-22, 23); two are above 2000m and one is below ~1500m. Our analysis highlights this 1800-2000m band, although results are reported below and above that band.

wolverine biology. Acknowledging this limitation, SWE raster data was provided to the FWS for further analysis.

For the study area in Glacier National Park (GLAC):

- Projections for April 15th, May 1st, and May 15th Snow Covered Area and area with snow depth greater than 0.5 meters show declines on average in all scenarios, except for small increases in the Warm/Wet scenario and for almost all years (Section 5-11).
- For April 15th for the study area as a whole (Figure 2-1), there is a decline of 3-23 percent in snow covered area with light snow cover (depth ≥ 5 mm), and a 7-44% percent decline in area with significant snow (depth > 0.5 m) for the five scenarios considered, compared to the 2000-2013 historic average. For May 15th, the area with light snowcover declines 10-36 percent, and the area with significant snow cover declines 13-50 percent (Tables 5-4, 5-5)
- On April 15th, the Warm/Wet scenario shows the least change in average SCA (2121 Sq-km) compared to the historic snow cover (2609-7%) for significant (≥ 0.5 meter) snowpack. The largest decrease is the Hot/Wet scenario (1520 sq-km) with 44% decrease. Under the Hot/Wet scenario, the April 15th significant snowpack has been diminished below the level of the historic May 15th snowpack – a month shift (Figure 5-14).
- All projections show declines in the number of years with significant snow. In each study domain, the areas with frequent availability (at least 14 out of 16 years) of significant snow (≥ 0.5 m) become concentrated in smaller high elevation areas, as seen in the maps in Figures 5-13, 5-14 (GLAC), and 5-20, 5-21 (ROMO). In contrast, lower elevation areas had the largest changes, or decreases in the number of years with significant snowcover.
- Most of the known den sites are located between 1800 and 2000m in GLAC. Below that elevation band large snow losses are predicted (40-70% decreases for two of the scenarios, 16-20% for the other three), above that elevation band there is little change in SCA for four of the five scenarios (2-8%) except in maximum warming scenario (-40%, Figure 5-22). In that 1800-2000m band, the snowpack change is sensitive to elevation and to the particular future climate scenario.
- This phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. (Section 5-13)
- For representative wet years, the higher elevations of our study areas experience only 2-7% loss of snowpack under the scenarios with “least” change and the “central” change (Figure 5-8, 5-12), although for the dry years, losses range 18-57% (Table 5-5).
- Modest declines in SWE may occur without affecting the area with significant snow depth. On May 1st, for areas at 1800m and above in GLAC, losses of ~10-30% SWE (Figure 5-23) result in losses of only ~10% snowcover. The implication is that the wet, cold climate of the GLAC study area could act as a “buffer” to change in the area of 0.5 m deep snow on May 1st, at least at the elevations above 1800m.

For the study area in and around Rocky Mountain National Park (ROMO):

- Projections of May 15th Snow Covered Area in ROMO declines on average in all scenarios, except for small increases in the Warm/Wet scenario, and for almost all years (Section 5-12).
- For April 15th for the study area as a whole (Figure 2-2), there is decline of 3-18% in area with light snow cover (depth ≥ 5 mm), and a change of -1 - +16 in area with significant snow cover (depth > 0.5 m) for the five scenarios considered, compared to the 2000-2013 historic average. For May 15th, the area with light snowcover declines 8-35 %, and the area with significant snow cover declines 6-38 percent (Tables 5-6, 5-7).
- Snow Covered Area in ROMO (≥0.5 m threshold on May 15) generally declines in wet years, shows a slight increase in (1-5%) in some years for the Warm/Wet scenarios with increased precipitation.
- One scenario with increased precipitation (Warm/Wet, giss) shows increases in April 15th SCA (Table 5-7). There are also slight increases in SWE for two scenarios at elevations at and above 3400m (Figure 5-25), but decreases in SWE for all scenarios below 3400m.
- Although no dens have been documented in ROMO, the elevation band for denning, modeled by regression analysis, is thought to be ~2700-3600m. On May 1st, modest declines in SWE of ~15% and less for areas at 3400m and above result in losses of < result in losses of only ~10% snowcover (Figure 5-24, 25). 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 deep snow on May 1st. Below that band losses in SWE of ≥ 35% result in higher losses in SCA (20-65%), except in the scenario with least change (Warm/Wet, giss model). As in the denning band in GLAC, in that 2700-3600m band, the snowpack change is sensitive to elevation and to the particular future climate scenario.
- The phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. Regonda et al. (2005) found little historical change in snowpack in the Western United States above approximately 2500m elevation despite observed warming trends. Other literature on this topic is discussed in Section 5.13.
- ROMO exhibited more uncertainty in projections than GLAC
    - The GCM climate projections for ROMO are more uncertain as to whether precipitation will increase or decrease, compared to GLAC.
    - The beneficial effect of increased precipitation on snowpack is more prominent earlier in the Spring. In the Warm/Wet scenario, the area of significant snow on May1 increases on average, though it decreases on May 15.
    - For April 15th –May 15th, and for wet years, the high elevations of the ROMO study area as whole, there is only modest loss of snow cover under all scenarios of change (Table 5-7, see 2011 representative wet year). However even in wet years, the area of significant snowpack can decline by up to 26% for the Hot/Dry climate change scenario on May 15th (Table 5-7).

Elevation dependence of change (Section 5.13): **In general, and supported by the literature (e.g. Regonda et al, 2005), the snowpack at the higher elevations of both areas is more responsive to precipitation change, while at lower elevations it is more responsive to temperature change**. For GLAC, most of the observed and inferred den sites are located within the zone where temperature dominates the future effects of change, and therefore at elevations where the changes in snowpack are highly dependent on the climate scenario and also on elevation. For the elevation of den sites in GLAC (>1800m) loss of SCA on May 1st spans the

range of 5-40% loss, with a 70% decreases for the Hot/Wet (miroc GCM) scenario (Fig 5-22). Above 2200m the losses are <5% for all but the Hot/Wet scenario. For ROMO, the range is at 3200 m elevation, the middle of the inferred range for wolverine there. However, at 3600m the loss of SCA in all scenarios is < 5% (Figure 5-24).

Comparison with McKelvey's results (Section 6): There are challenges in making a direct comparison between the studies due to differences in the goals and spatial scale. McKelvey investigated persistence of even a light snow cover to May 15th as a correlate of wolverine habitat, as noted in Aubry et al (2008). This study focuses on high-elevation terrain and on the persistence of deeper snowpack.

However, the following comparisons are valid:

- Examining the data from McKelvey's study in detail reveals that snow cover persists in the GLAC and ROMO study areas, even for the hotter of the two scenarios of change in the their study ("miroc 2080's"). The greatest loss of May 15th snow cover in McKelvey occurs at elevations lower than ~250m below treeline that were deliberately not included in the GLAC or ROMO study areas. (Figure 5-26).
- McKelvey focused exclusively on the persistence of even light snow cover on May 15th. Because of the increased resolution of our study we are able to consider whether any pockets of snow with depth greater than 0.5 meters will persist in these areas. Results vary according to scenario, but generally show declines of 13-50% in SCA in GLAC and 6-38% in ROMO for May 15th by the 2050s. We made projections for April 15th (which McKelvey did not), which shows declines of in SCA of 7-44% in GLAC and changes of -16 - +1% in ROMO for April 1st by the 2050s.
- Our results may reasonably be generalized to the high mountain ranges within the Rockies that lie between GLAC and ROMO, with projections on average wetter in GLAC. However, without further study we cannot reasonably extend our results to say whether or not snow refugia may persist in the Central Rockies ~~at~~ below our study elevations (~1000m). Areas below our study areas are where McKelvey indicates the greatest snowpack losses. Nor can we extrapolate to the Cascades with its very different maritime climate.
- While it is difficult to compare the McKelvey et al (2011) results directly to the present study due to differences in methodology and focus, the qualitative picture remains – projected warming has a larger effect at lower elevations whereas projected precipitation changes may dominate the Springtime snowpack in the high country.

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1 Introduction

1.1 Motivation

This report responds to the United States Fish and Wildlife Service (FWS) need for information on potential climate impacts to snow persistence. The North American wolverine (*Gulo gulo luscus*) is currently being evaluated for listing as a threatened or endangered species under the Endangered Species Act (ESA) and climate change effects on snow persistence was identified as an important factor for the future viability of the wolverine. The species was considered for listing in 2014, but FWS concluded that it did not warrant listing. They further concluded that there is significant uncertainty about how the effects of climate change will affect wolverines and their habitat in the foreseeable future, and that this uncertainty includes information on how fine-scale changes in snow cover and persistence might affect denning site selection.

This report provides FWS with a finer scale assessment of snow extent and depth at which extends previous work by McKelvey et al. (2011). We believe the inclusion of finer scale analyses as well as additional snow processes such as slope and aspect are critical to understanding high elevation snow persistence in a changing climate.

By design, our methods and models are chosen from the peer-reviewed, published literature. What we find, particularly with regard to the elevation dependence of snowpack change, is consistent with past research.

Funding was provided by the U.S. Fish and Wildlife Service, Region 6 and the NOAA/Earth System Research Lab/Physical Sciences Division. This effort builds on work underway by the project team at NOAA/ESRL/PSD, the NOAA-University of Colorado (CU) Cooperative Institute for Research in Environmental Sciences (CIRES), and CU Department of Civil, Environmental & Architectural Engineering.

1.2 Project Objectives

Persistent spring snowpack has been described as an important factor in determining suitable habitat for the wolverine, including Northern boreal forests and subarctic and alpine tundra (Aubry et al, 2007, Peacock et al, 2011). This relationship was the basis for the analysis by Copeland et al. (2010) and McKelvey et al. (2011) used in the previous FWS decision. In both studies, climate change projections of snowpack were used to characterize potential future wolverine habitat.

The goal of this effort is to identify the depth and persistence of spring snow in the future. Our primary objective is to advance scientific understanding of the current spatial extent of spring snow retention on the landscape, and the future temporal and spatial extent of snow retention through a thirty-year period, 2041-2070, centered on the year 2055. We aim to advance snow analysis and modeling to better support assessment of snow-related species, in the following ways:

- Explicitly model the effects of slope and aspect, using fine-scale spatial models to analyze topographic effects on snow
- Better represent the range of plausible future changes (climate scenarios)
- Analyze extremes from the current year to year variability: we selected representative wet, dry, and near normal years from the main study period for detailed analysis and assessed how these would change under different future climate scenarios.

Our strategy was to build on previous methods where possible to be comparable to work by McKelvey et al. (2011) and Copeland et al. (2010). We departed from their methods where necessary to take advantage of analysis techniques not feasible at the large scales used in the studies done by those authors. These include new scientific data and tools that are now available, including the following:

- Use of a longer time series of satellite and in situ observations.
- Analysis of historic snowpack variability to investigate the influences of topography on snow cover
- Use of more recent climate model output and improved criteria for choice of climate change scenarios
- Use of hydrologic modeling at highly resolved (250m) spatial scale for simulation and future projection of snow cover and depth for two case study areas in Glacier National Park and Rocky Mountain National Park.

2 Project Overview and Background

2.1 Overview

We first reviewed the observed climate and variability, in order to provide context for future changes (Section 3). We next analyzed historic snow variability from satellite remote sensing of snow extent from the year 2000 to present to determine areas of greater and lesser sensitivity to climate drivers (temperature and precipitation), and identify possible snow refugia. Prior studies also show a relationship between terrain (slope and aspect) and persistence of snow (e.g. Lundquist and Flint, 2006) and thus this factor is potentially important under in a changed climate. (Section 4). We then did an intercomparison of the satellite observations of snow with that from the DHSVM hydrologic modeling study that includes a representation of slope and aspect (the compass direction that the slope faces) of the terrain and shading on the snowpack. Finally, the DSHVM hydrologic model was forced with five future scenarios of climate change for each of the two study regions (Section 5). These future climate scenarios were derived from the latest Coupled Model Inter-comparison Project Phase-5 runs (CMIP5, Taylor et al., 2012) which informed the latest Intergovernmental Panel on Climate Change (IPCC) report (IPCC AR5, 2013).

All methodologies were chosen to be consistent with those used in existing peer-reviewed work.

2.2 Study Areas

High-resolution hydrologic modeling was needed to provide fine scale analysis of snow. However, given time, funding and computational constraints, it was necessary to limit the study domain to two areas of about 1,500-3,000km^2 for high-resolution analysis. Two study areas representing core and peripheral habitat regions in the northern and central Rocky Mountains were identified in consultation with FWS Region 6 personnel (Figures 2-1 and 2-2). We bracketed the extent of wolverine habitat conditions in the lower 48, because we were restricted to smaller areas for analysis. The two sites chosen included a high latitude, (relatively) low elevation area within Glacier National Park (Figure 2-1) that is currently occupied by wolverines and a lower latitude, high elevation area within Rocky Mountain National Park (Figure 2-2) that has had recent documented wolverine occurrence and could be a potential reintroduction site for wolverines. Both model areas encompassed elevations from ~~250~~300 m below treeline to maximum elevation in each domain (2140~~962~~ m – 3166 m in GLAC, and 3200~~2563~~ – 4253 m in ROMO). This elevation threshold was chosen for the analysis by FWS to represent the areas with known denning activities by wolverines.

The analysis for the GLAC and ROMO study areas is presented in separate sections, repeating descriptions to make the material self-contained for the reader who may read about only one area; similarly, complete captions are given for each area.

2.3 The West-wide context of future climate

Global climate models (GCMs) are the primary tools used by climate scientistsee to examine the nature of climate change during the 21st century. These models reveal both the uncertainty of climate projections as well as underlying regional patterns of change. This section provides a west-wide context for the specific choices of future climate scenarios that will be discussed later in the report.

Understanding the uncertainty of climate projections is commonly approached through comparison of the results from multiple climate models (e.g. IPCC, 2013). There are currently about 20 modeling centers worldwide that provide output from their best model or models to be considered in the Coupled Model Inter-comparison Project Phase-5 (CMIP5, Taylor et al., 2012), an international, coordinated modeling project which informed the most recent Intergovernmental Panel on Climate Change (IPCC) assessment report (IPCC AR5, 2013). When we quantify regional changes in climate variables such as temperature and precipitation by a particular time horizon in the 21st century, we find a large spread in the extent of warming and changes in precipitation, including both increases and decreases in precipitation, as shown in regional maps (Figure 2-4 3 and described later in Section 5). For temperature change, much of this spread (or uncertainty) is a result of the difference among the formulations of the GCMs (e.g., their climate sensitivities), whereas for precipitation it is both the differences among GCMs and internal climate variability. Some difference also comes out of the choice of future greenhouse gases (GHG) emission scenario. However, the differences among greenhouse gas emissions scenarios is less at mid-21st century compared to later in the century, and is much smaller than other sources of uncertainty at the regional scale (IPCC, 2013).

In addition to uncertainty, the CMIP5 climate models also reveal regional patterns of change. Figure 2-4 3 shows projected annual and seasonal temperature and precipitation changes by 2050 (2035–2064) over the western U.S., including the northern and central Rocky Mountains, from an ensemble of the 34 climate models used for this study under the RCP 8.5, a high-end emissions scenario. The large maps show the average change for all of the models (n=34) for that season, and the small maps show the average changes of the highest 20% and lowest 20% of the models, based on the statewide change for Colorado in temperature or precipitation. For much of the central and northern Rockies, all models show a substantial warming (of +2.5°F to +5.5°F). While fewer models agree about the direction of precipitation change west-wide, even the lower (drier) models show an increase in winter precipitation for the area around Glacier National Park, although there is less agreement for the central Rockies area including Rocky Mountain National Park.

The uncertainty of climate change motivates the choice of several future climate scenarios for each study region. The regional patterns of change indicate that the range of the climate scenarios chosen will differ somewhat from region to region. The GCM output, and the specific selection of future climate scenarios for this study are discussed further in Section 5.

2.4 Comparison between our analysis and that of Copeland and McKelvey

The Copeland et al. (2010) and McKelvey et al. (2011) studies were an integral part of the previous FWS decision process. Therefore, we present here a detailed comparison of their methodologies and ours, to establish both how our methodologies followed theirs when appropriate, and diverged where new data or updated methods were available. A summary of the most salient similarities and differences between our work and the studies used previously is presented in Table 2-1.

Table 2-1: Modeling Methods Compared to McKelvey

	McKelvey (Littell)	This Study
Spatial Resolution (modeling)	VIC model – 1/16 degree (~5km x 7 km, ~37km^2 cell)	DHSVM model - 250m x 250m UTM grid (~0.0625 km^2 cell)
Spatial Extent	Westwide except California and Great Basin	ROMO and GLAC study areas, ~~near and above treeline~~300 m below treeline and above
Process differences	Slope and aspect were not modeled and the mountains were assumed to be flat from a solar radiation process, implicit elevation bands.	Slope, aspect, shading, explicit fine scale elevation effects.
Validation	None specific to snow	Comparison to SNOTEL (ground stations) and MODIS (satellite)
Future Scenarios	Delta Method; “2045”;”2085”; from 3 GCMs selected to span westwide temperature changes.	Delta Method: ”2055” from 5 GCMs spanning regional changes in temperature and precipitation
Analysis	Changes in long-term mean snowpack only	Means and variability, including wet, near normal and dry years.
Snow representation	Binary snow/no snow at 13 cm snow depth	Analyzed snow depth at two thresholds: 5mm of SWE (‘light snow’) and 0.5m depth (‘significant snow’)

Both Copeland et al (2010; hereafter, simply Copeland or the Copeland study) and McKelvey present analysis based on satellite remotely-sensed snow cover from the MODIS. For example, Copeland calculated the number of years with snowcover on May 15th as detected in the MODIS snowcover dataset, by calculating a snow disappearance date. They found that most (45 of 75) North American den sites were in areas that snow cover persisted with 6 or 7 out of 7 years on May 15th. We also provide a historical analysis of remotely sensed snow cover from MODIS. We also investigated the of number of years of snow persistence for our study areas, however, the new MODIS product has two advantages over that available at the time of their study, 1) improved snow detection (snow covered area, SCA), and 2) 17 years of MODIS data is now available vs the 7 available to Copeland and McKelvey. Furthermore, we investigated the relationships between snow cover persistence and both elevation and aspect (the compass direction of the slope face).

Both McKelvey et al. (2011) (hereafter, simply McKelvey or the McKelvey study) and the present study investigate projections of snow cover using a distributed hydrologic model. The McKelvey study focused its' analysis on May 1st snow depth simulated by the Variable Infiltration Capacity hydrologic (VIC) hydrology model (1/16 degree, ~5km x 7 km), "flat" gridboxes, or cells, with no slope aspect dependence). The May 1st snow depth was then converted into a proxy for May 15th snow disappearance by applying a threshold of 13 cm – a procedure they refer to as "cross-walking". All subsequent calculations of theirs were done using the May 15th snow cover proxy. The VIC model runs were documented in Littell et al. (2011) and were based on meteorological inputs from Elsner et al. (2010). The present study uses the Distributed Hydrology Soil Vegetation (DHSVM) model, which was developed by the same group at the University of Washington for fine-scale simulations, and shares many model components with the VIC model. The primary output of DHSVM is snow water equivalent (SWE). We investigate several thresholds for converting SWE to "snow cover". Conversion of SWE to snow depth is done using empirically derived conversion factors relevant to Spring.

To generate future climate scenarios, Littell (on which McKelvey results are based) used the "delta method" (described later in Section 5) for the projected changes in climate compared to present day. This study also uses the "delta method," applied in a similar manner. The McKelvey study used a range of temperature change to select GCMs representing the range or spread of future scenarios. As shown below in Section 5.10 and Figure 5.7, their chosen future scenarios reflect a range of precipitation in GLAC, but in ROMO, the three scenarios have similar precipitation changes. This project selected a larger number of future scenarios selected based on changes in both temperature and precipitation, to be consistent with recommended strategies for incorporation of uncertainties into the assessment of impacts and developing adaptation strategies (e.g. Fisichelli et al, 2016 a,b, see Section 5-8).

Analysis metrics, including the time frames of the projections differ somewhat between the two studies. The McKelvey study calculated a metric for a historic period (1915-2005 average) and two futures, 30-year averages around "2045" and" 2085." This study focused on a 30-year period around mid-century, "2055" to focus on FWS' time horizons for the wolverine and due to time and computational constraints given the project budget. Calculations for a later period using the CMIP5 climate models (e.g. ~2100) could easily be made, but were beyond the scope of this project.

We provide analysis for two thresholds of snow amount, a "light" snow cover (5 mm of snow water equivalent [SWE]), and significant, or "heavy" snow cover (equivalent to 0.5 m of snow depth). Because the Littell dataset that McKelvey used only includes May 1st snow depth simulation (and not May 15th), McKelvey's study chose a 13 cm snow depth on May1st as a proxy for snow disappearance by May 15th. We instead chose to use a much lighter threshold for presence/absence of snow on May 15th itself. Our threshold of 13mm SWE was originally chosen to be comparable to McKelvey's snow depth. Our assumptions are discussed further in Sec. 5.6.

For the purposes of determining the presence or absence of snow we use a 5mm SWE threshold. It is common modeling practice to use a low threshold for snow disappearance rather than using a strict criterion of zero, due to peculiarities with the model's numerical accounting for snow (Ben Livneh, pers. comm.) In addition, the effect of small dustings of springtime snowcover on previously bare ground were also minimized by this choice. In consultation with the biologists, also were concerned with analyzing the presence of "significant snow" which we defined as ≥ 0.5 m of snow depth. The value of ≥ 0.5 m was arrived at by an analysis of the modeled snow depth at known wolverine denning sites in Glacier National Park (Table 5-2). With the exception of one site that had melted out by May 15th, the other sites all have snowpack between 0.4 and 1.4 m. Note that SWE is a measure of the water content in the snowpack; to estimate depth, we assume a bulk density of the snowpack (see Section 5-5).

An important difference between this study and prior work by Copeland et al. (2010) and McKelvey et al. (2011) is the spatial scale of results. McKelvey and Copeland both presented results on a regular 1/16 degree latitude-longitude grid, in which each cell, or gridbox is ~5-7 km on a side. These cells were assumed to be flat in the model-- that is they do not incorporate slope or aspect information in their surface energy balance. The result of this is north-facing slopes are treated identically to south-facing slopes. Our study uses the Distributed Hydrology Soil Vegetation Model (DHSVM) originally developed by Wigmosta et al. (1994)[3] for simulating the snowpack at 250m x 250m resolution that incorporates other physical drivers of snowpack (a complete energy balance at the surface, a 2-layer snow model, and a 2-layer vegetation canopy model) and allows analysis of snow at different slopes and aspects (slope directions). The VIC modeling included the option for elevational snow bands within the VIC grid (Jeremy Littell, pers. comm.) but the snow band information was not explicitly used. Therefore, sub-grid scale elevational effects are implicit and approximate in the VIC model whereas it is explicitly modeled at the 250m-scale in DHSVM. A visual comparison of the gridbox sizes is shown in Figure 2-4 for further description of the terminology used to describe spatial resolution, see "resolution" in the Glossary. Neither VIC nor DHSVM include the effects of wind or avalanche redistribution of snow (see section 5-10 for additional modeling caveats).

It should be noted there are tradeoffs between our strategies and the methods of Copeland and McKelvey. The finer scale analysis presented in this report integrates slope and aspect with respect to snow accumulation and retention that are thought to be important for maintaining

[3] The most up-to-date documentation of the DHSVM model, including changes to the model subsequent to the original reference, is available from the following website: http://www.hydro.washington.edu/Lettenmaier/Models/DHSVM/documentation.shtml)

snow refugia for denning sites (see Fig 2 in McKelvey et al 2011), and for elevations where wolverine dens have been observed. The disadvantage of this improvement in spatial resolution is that the high-resolution modeling is computationally intensive. We were only able to analyze two study areas due to these computational constraints and the short time to meet FWS deadlines. The Copeland and McKelvey projects analyzed a much larger domain, including most of the wolverine range in the continental US, but does not provide detailed analysis of any habitat area.

3 Observed Climate and Variability

Key Points:

- Both study areas show upward trends in both temperature and freezing level
- Surface Air Temperature and Atmospheric freezing level are related, with a stronger relationship in ROMO (that is, a greater change in freezing level for a given surface air temperature change)
- There is year-to-year variability in historic temperature, precipitation, and hence the snowpack, leading to some extreme wet and dry years that were chosen for study:
    - Representative years chosen for GLAC: 2011 (wet), 2005 (dry), 2009 (near normal).
    - Representative years chosen for ROMO: 2011 (wet), 2002 (dry), 2007 (near normal).

3.1 Introduction

This section presents a historical analysis of the winter and spring climate variability for the two study regions, GLAC and ROMO, in order to provide context for future changes. This section includes a discussion of trends in temperature and freezing level; historical year-to-year variability in cool season (October – May) temperature and precipitation for the study areas, choice of representative years during the simulation period for cool/wet, warm/dry, and near normal conditions for the two areas; and a ranking of the representative years in a longer climate record. Later in the report, we will assess what the wet, dry and near normal years of the future may be like. A complete description of regional climate is beyond the scope of this project, but may be found in e.g. McWethy et al (2010), Garfin et al (2014), Lukas et al (2014), Shafer et al (2014), and citations therein.

3.2 Background Material: Trends in Surface Temperature and Freezing Level in the Study Areas

Temperature strongly influences hydrologic processes such as snowpack accumulation, and timing of snowmelt. Here we present some background material on observed trends in surface air temperature and on the freezing level in the atmosphere, and how these two quantities are related.

Both the Glacier and Rocky Mountain areas show a trend of increasing surface air temperature in the winter season (October-May, Figure 3-1), consistent with trends that have been observed west-wide (Garfin et al 2014; Lukas et al 2014; Shafer et al 2014). While winter season temperatures vary inter-annually, linear regression of these data (not shown) indicates about a 1.4 ºC increase in temperature from 1948-2015 for an area around Glacier, and about a 1.2 ºC increase around Rocky Mountain National Park.

Atmospheric freezing level height (FLH) represents the altitude in the free atmosphere (that is, away from the surface and its immediate influence) where the temperature is 0 °C. Above this level, the temperature of the air is typically below freezing. Freezing in the free atmosphere is indicative of the level above which precipitation falls as snow rather than rain. Freezing level height can have a strong influence on freeze-thaw processes in high-elevation regions (Bradley et al 2009). As with winter season temperatures, freezing level varies over time (Figures 3-2, 3-3), but linear regression (not shown) indicates about a 160m increase in the freezing level for Glacier (Fig 3-2), and about a 170 m increase in the freezing level for Rocky Mountain (Fig 3-3).

Figure 3-4 illustrates a strong relationship between freezing levels and surface air temperature change for both regions in October-May with explained variance (R^2) close to 0.8. For GLAC (3-1, left), a 1ºC anomaly in temperature equates to about a 115 m increase in the freezing level, over the period. For ROMO, for 1ºC increase in temperature there has been about a 180 m increase in the freezing level (3-1, right). If these historical relationships hold in the future, the larger change in freezing level for the ROMO study area could indicate a greater sensitivity of snow covered area to rising temperatures.

3.3 Exploring Year-to-Year Weather Variability through the Choice of Representative Years for Detailed Analysis

One of the primary study goals is to extend the analysis to include the effects of climate change on extreme years both for years with high- and low- spring snowpack. This is in contrast to McKelvey et al (2011) who studied only the effect of climate change on the *long-term average* snowpack. Our historical snowpack analysis (Section 4) was performed for the entire period 2000-2013 and the hydrologic modeling (Section 5) for 1998-2013, and then assessed now these wet, dry, and near normal years might change under several climate change scenarios. To capture the weather variability within these periods we focus some of our analysis in Sections 4 and 5 on a representative wet, dry, and near normal year for each study area. Nonetheless, results from all years were computed.

Table 3-1: Historical Percentiles of precipitation and temperature for the representative dry, near normal, and wet years for GLAC and ROMO study areas.

	Year Type	Year	Oct. - May Precipitation Percentile	Oct. - May Temperature Percentile
GLAC	Dry	2005	6	83
	Near Normal	2009	45	42
	Wet	2011	98	6
ROMO	Dry	2002	4	45
	Near Normal	2007	56	69
	Wet	2011	96	36

To drive our choice of representative years, we investigated historical cold-season (October-May) temperature and precipitation anomalies and MODIS-based snow covered area for 2000-2013. Years were chosen within that range to represent a cool/wet year with high spring snowpack, a "near normal" year, and a "dry" year with low snowpack. Figure 3-5 shows scatterplots of the anomalous precipitation (as % of average) and temperature (degrees Celsius) for each year of the primary study period (2000-2013) for the two study areas. For both study areas, the 2011 winter stands out as a particularly large (cool/wet) anomaly.

The choice a dry year for GLAC points to 2005. Examination of the time series of Snow Covered Area (SCA) derived from the MODIS satellite product (Figure 3-6) corroborates this choice. For ROMO the hot/dry year 2012 with exceptionally low snow cover was first chosen. However, modeling difficulties encountered in the model validation procedure described in section 5.4.2 led to the need to find an alternative "dry" year for ROMO. The scatter plot in Figure 3-5 indicates that 2004 or 2002 might both be good alternatives, and both of these years had adequate modeling success. Because 2002 had lower Spring snow cover (figure 3-6), and because it was a widely agreed upon drought year in Colorado, we chose to use 2002 as the representative "dry" year for ROMO.

For the choice of near-normal year, 2007 is indicated for ROMO, as that is closest to the center of the scatterplot in Figure 3-5. A number of choices would seem plausible for GLAC, however as no one year stands out as "most normal." To further guide our choices of representative years, we looked at the elevation profiles of SCA for the various years, and 2009 was chosen. We show the SCA as a function of elevation within the study areas (Figure 3-6cd) for the representative years. These plots indicate that the elevation profile of observed snow cover in our chosen near-normal years closely follow the median profile for 2000-2013.

3.4 The Study Period in the Longer Climate Record

Because the study period is 14 years long, the question arises as to how "extreme" the wet and dry years are in the longer climatological record. To address this question, we analyzed how often the temperature and precipitation anomalies for the study years are likely to occur in the longer (1950-2013) climatological record by computing their percentiles. Percentiles were calculated by ranking the data and using the following formula: percentile = (rank – 0.5)/(total number of years). Note that the exact rankings and percentiles may differ based on the underlying dataset and interpolation methods used, as the study areas have relatively few observing stations. However, percentiles calculated from the PRISM dataset (not shown) yield qualitatively similar results to those found below.

The percentiles of October – May precipitation and temperature averaged over the study areas are shown for the representative wet, near normal and dry in Table 3-1 for both study areas. The percentiles are calculated based on the 63 total years in the 1951-2013 period of the Livneh (2014) dataset. For GLAC, October – May 2011 was at the 98th percentile of precipitation and the 6th percentile of temperature, while 2005 was at the 6th percentile of precipitation and 83rd percentile of temperature. For ROMO, 2011 was in the 96th percentile of October – May precipitation, but only the 36th percentile of temperature, and while anomalously cold was not

extreme in temperature. 2002 was in the 4th percentile of precipitation, but only near the median in temperature.

For further reference, Tables 3-2 (GLAC) and 3-3 (ROMO) show the percentiles of precipitation and temperature for the entire study period, 2000-2013, as well as the percentiles for the April – June melt season. Even though the low precipitation was more extreme in 2002 than in 2012, the temperature was not. This is reflected in the MODIS spring snowcover (Figure 3-6), where 2002 was low, but not as nearly extreme as in 2012.

Table 3-2: Percentile of temperature and precipitation anomalies for GLAC study area based on the 1951-2013 period. Percentiles are shown for both the October – May cold season and for the April – June melt season.

GLAC	Percentile 1951-2013			
	Oct. - May Precipitation	Oct. - May Temperature	Apr. - June Precipitation	Apr. - June Temperature
2000	31	96	7	66
2001	2	37	47	58
2002	61	31	91	12
2003	33	87	13	69
2004	13	63	33	61
2005	6	83	80	47
2006	37	82	53	93
2007	21	72	6	75
2008	39	47	60	17
2009	45	42	12	34
2010	12	55	85	13
2011	98	6	87	4
2012	40	74	72	53
2013	60	66	56	29

Table 3-3: Percentile of temperature and precipitation anomalies for ROMO study area based on the 1951-2013 period. Percentiles are shown for both the October – May cold season and for the April – June melt season.

ROMO	Percentile 1951-2013			
	Oct. - May Precipitation	Oct. - May Temperature	Apr. - June Precipitation	Apr. - June Temperature
2000	45	98	40	98
2001	29	33	23	91
2002	4	45	2	96
2003	75	80	77	64
2004	21	91	75	77
2005	50	82	82	53
2006	28	74	4	94
2007	56	69	6	75
2008	80	12	45	13
2009	77	93	88	44
2010	48	13	87	37
2011	96	36	93	25
2012	10	94	7	99
2013	64	26	79	42

4 MODIS Observed Historic Snowpack Variability Analysis

Key points

- In GLAC, snow covered area 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; Section 4.3).
- Even in dry years, NE-facing slopes in GLAC tend to hold more snow and melt later in the season. There is > 80% snow cover above ~2000 m elevation on May 1 during dry years, and > 95% snow cover above ~1200 m during wet years (Figure 4-6).
- In ROMO, snow covered area also varies considerably by year (Section 4-4).
- NW-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 (Fig 4-13).

4.1 Introduction

In this section, we perform an analysis of the variability of snow cover in the historical period 2000-2016 using gridded snow cover data acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Terra satellite. The dataset and methodology of analysis is first described. The analysis for the GLAC and ROMO study areas are then presented in separate sections, repeating descriptions to make the material self-contained for the reader who may read about only one area. Each section consists of analysis of the following: a) total snow covered area (SCA), b) SCA fractional area as a function of eight compass directions of slope aspect (octants), and c) elevation dependence.

4.2 Dataset and Methods

4.2.1 Data sub-setting and re-projection

We downloaded selected MODIS/Terra daily snow cover data on a 500m grid from the recently released version 6 (MOD10A1.006) (Hall and Riggs, 2016). All data from geographic tiles h09v04 (ROMO) and h10v04 (GLAC) were downloaded for days between March 1 and July 1 for all years from 2000 to 2016.[4]

The data are available in daily files, one for each tile, and georeferenced to an equal-area sinusoidal projection. Each tile covers 10° x 10° at the equator or approximately 1200 km by 1200 km, with a nominal pixel resolution of 500 m (actual resolution 463.313 m). To bring the data to the same grid as used in the hydrologic modeling necessitated re-projection of the data

[4] Note that MODIS data was obtained for April, but FWS' interest in April arose after this part of the project was complete, so April is not shown in the graphics for this section.

onto a Universal Transverse Mercator Grid. We used the MODIS Reprojection Tool (https://lpdaac.usgs.gov/tools/modis_reprojection_tool) to subset the daily tiles to the areas of interest and re-project the subsetted areas to UTM grids with a pixel resolution of 250 m using nearest-neighbor resampling. The ROMO study area perimeter falls at the corner of tile h09v04, and extends slightly beyond the tile boundaries at its southern tip. We excluded this extension of the study from our analysis. Parameters for the MODIS data reprojection are provided in Table S4-1.

4.2.2 Converting Normalized Difference Snow Index to Binary (yes/no) Snow Cover

To better align our analysis with that in Copeland and McKelvey's work we wanted to use a daily binary (yes/no) snow cover value. However, one main obstacle had to be overcome -- snow cover was characterized differently in the versions of the MODIS data that Copeland used and in the current version. The prior work by McKelvey and Copeland both used Collection 4 of the MODIS data which provided them with a binary snow cover classification for each pixel on each day (clouds permitting). Collection 4 data are only available for the years 2000-2007, necessitating the use of the more recent MODIS Collection 6 products for the present study. However, Collection 6 does not include a binary daily snow cover product. Instead, snow cover is identified using the Normalized Difference Snow Index (NDSI).

NDSI is reported as a ratio, with values ranging from 0.00 to 1.00 (scaled and reported as 0 to 100 in the data files). The NASA guidance on conversion was not definitive: "If a user wants to make a binary SCA [Snow Covered Area] from the C6 [Collection 6] product they can set their own NDSI threshold for snow using the NDSI_Snow_Cover or the NDSI data or a combination of those data." (NASA, 2016). In lieu of a prescription, we chose to follow the procedure used by NASA to produce the 8-day composite snowcover product; we applied a threshold of NDSI > 0.1 to the daily MODIS NDSI values to indicate the presence of snow in a pixel on a given day.

4.2.3 Snow disappearance date and snow cover on a given date

As in Copeland et al (2010), we calculate a snow disappearance date for each year at each pixel. We define the Snow Disappearance Date (SDD) as the first day after March 1 in which NDSI/100 was less or equal to 0.1 (Cite NASA). The SDD is denoted by the Day of Year value, in which January 1 is 1, February 1 is 32, March 1 is 60 (or 61 in leap years), etc. Once SDD was defined at each grid point for each year (resulting in 17 annual maps of SDD for the period of record), we were able to derive snow cover maps for any given date. For example, snow cover on May 1 was inferred by marking grid points as "snow-covered" if their SDD was equal or greater than 121 (or 122 for leap years). We repeated the process to infer snow cover maps for May 15 and June 1. This indirect method to infer snow cover allowed us to circumvent the reality of several missing data points due to cloud cover, and offered a conservative estimate of snow disappearance.

4.2.4 Snow cover by elevation and aspect

A 250-m digital elevation model (DEM) was created using bilinear interpolation from the National Elevation Dataset (NED)10-m DEM products (USGS, 2009). Using this we obtained grids for elevation and aspect octants in both study regions. We reclassified the elevation values

into 200 m bins. The elevation bins range from 1000 to 3000 m in GLAC and 2600 to 4200 m in ROMO. Both the slope magnitude and the aspect of the slope (that is the compass direction that the slope faces) were analyzed using functionality in the open source Quantum GIS software. We reclassified the aspect grids into eight 45°-wide directional bins (hereafter, octants) centered on the points of the compass. In both types of analyses (elevation and aspect), we computed snow covered area (SCA) on May1, May15, and June1, in terms of the total area in square kilometers and also in terms of the percentage of snow covered area in several elevation bands and aspect octants.

4.3 MODIS analysis for GLAC

This section presents some summary statistics of snow cover, including total snow covered area, and number of years during the period of study with snow cover on a given date. MODIS snow cover data was analyzed for March1 – July1 for all years 2000-2016. For more in depth analysis including aspect and elevation-based analyses the report focuses on the years representative of year-to-year variability defined in Section 3: 2011 ("wet"), 2009 ("near normal"), and 2005 ("dry").

4.3.1 Total Snow Covered Area

Total snow covered area was the primary metric that was analyzed in McKelvey et al (2011) and provides an overall summary of availability of snow. Figure 4-1 presents maps of May 15 snow cover for the GLAC study area and vicinity from MODIS. These maps clearly depict the regional character of the year-to-year variations in snowcover. Figure 4-2 shows the total snow covered area within the study area polygon, which is depicted in red on the previous figure. The year-to-year variations are shown for snowcover on three different dates during the melt season. The behavior in individual year varies considerably, 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). It is worth noting that 2015 and 2016, the last two years of the MODIS record, show low snowcover, although the modeling study period ends in 2013 because the Livneh dataset ends in that year (Section 5). Both these years had near-normal precipitation, but had anomalously warm temperatures. These years would be good candidates for future analysis.

To summarize all 17 years of the record, Figure 4-3 presents maps of the number of years with snow cover on April 1, April 15, May 1, May 15. These are similar to the analysis done by the Copeland and McKelvey studies. The primary difference is in the use of the newer MODIS products and the extension of the analysis from seven to seventeen years.

Figure 4-4 quantifies the maps in Figure 4-3, showing the area within the GLAC study area polygon with different numbers of years of snow cover. The three colored bars designate different days of the year. Because the study areas were chosen to be in the vicinity of tree line, it is no surprise that in the present climate there are large areas that see snow every year on May 1st.

4.3.2 Aspect Dependence of Snowpack: Fractional area

One of the primary goals of this study is to investigate topographic factors that influence the persistence of snow during the melt season. One such factor is the "slope aspect" or simply

"aspect" – the compass direction that the slope faces. The total land area within each aspect octant varies due to the orientation of ridges and valleys in the study area. As a result, the analysis of total snow covered area is dominated by the topography itself. These graphics are provided in the Supplementary Material.

To focus on the *relative* importance of the snow processes related to aspect, ~~in~~ we calculated the fraction of the total land area within each octant that is snow covered for each of the 17 years in the historical record (Figure 4-5), while in Figure 4-6 we focus on the representative wet and dry years. The asymmetric shape in Figure 4-5 clearly shows that in GLAC, the NE directions ranging from E to N have much larger fractional area covered by snow. Even in dry years, over 60 % of the NE facing slopes are snow-covered on May 15th (Figure 4-6).

One of the primary goals of this study is to investigate topographic factors that influence the persistence of snow during the melt season. One such factor is the "slope aspect" or simply "aspect" – the compass direction that the slope faces.

4.3.3 Elevation Dependence

Figure 4-7 shows the elevation dependence of MODIS snow cover for the wet, near-normal and dry years, with the median of all years as reference. The results are shown as a percentage of the total area within each 200-meter elevation band within the study area boundaries.

4.4 MODIS analysis for ROMO

MODIS snow cover data was analyzed for March1 – July 1 for the years 2000-2016. Data for all years was analyzed. We present here some summary statistics of snow cover, including total snow covered area, and number of years during the period of study with snow cover on a given date. For more in-depth analysis including aspect and elevation-based analyses the report focuses on the representative years defined in Section 3: 2011 ("wet"), 2007 ("near normal"), and 2012 ("dry").

4.4.1 Total Snow Covered Area

Total snow covered area was the primary metric that was analyzed in McKelvey et al (2011) and provides an overall summary of availability of snow. Figure 4-8 presents maps of May 15 snow cover for the ROMO study area and vicinity from MODIS. These maps clearly depict the regional character of the year-to-year variations in snowcover. Figure 4-9 shows the total snowcovered area within the study area polygon, which is depicted in red on the previous figure. The year-to-year variations are shown for snowcover on three different dates during the melt season. The behavior in individual year varies considerably, including "wet" years such as 2011 with very persistent snow, years with strong melt in early May, such as 2004, or in late May (2001, 2013), and "dry" years (2012).

To summarize all 17 years of the record, Figure 4-10 presents maps of the number of years with snow cover on May 1, May 15. These are similar to the analysis done by Copeland and McKelvey studies. The primary difference is in the use of the newer MODIS products and the extension of the analysis from seven to seventeen years.

Figure 4-11 quantifies the maps shown in Figure 4-10, showing the area within the GLAC study area polygon with different numbers of years of snow cover. The three colored bars designate different days of the year. Because the study areas were chosen to be in the vicinity of tree line, it is no surprise that in the present climate there are large areas that see snow every year on May 1.

4.4.2 Slope Aspect Dependence of Snowpack: Fractional Area

One of the primary goals of this study is to investigate topographic factors that influence the persistence of snow during the melt season. One such factor is the "slope aspect" or simply "aspect" – the compass direction that the slope faces. The total land area within each aspect octant varies due to the orientation of ridges and valleys in the study area. As a result, the analysis of total snow covered area is dominated by the topography itself. These graphics are provided in the Supplementary Material.

The total land area within each aspect octant varies due to the orientation of ridges and valleys in the study area. As a result, the analysis of total snow covered area is dominated by the topography itself. To focus on the *relative* importance of the snow processes related to aspect, Figure 4-12 presents an analysis of the fraction of the total land area within each directional "bin" that is snow covered. The asymmetric shape shows that the NW-facing slopes have larger fractional area covered by snow. With the exception of 2012, even in dry years over 60 % of the NW facing slopes are snow-covered on May 15th. Figure 4-13 indicates that for the dry year 2012, snow cover was retained preferentially on NW-facing slopes.

4.4.3 Elevation Dependence

Figure 4-14 shows the elevation dependence of MODIS snow cover for the wet, near-normal and dry years, with the median of all years as reference. The results are shown as a percentage of the total elevation within each 200-meter elevation band within the study area boundaries. The ROMO area shows that the dry year, 2002 (as well as the other very dry year during the period, 2012), was significantly different from the other two, with a fractional area declining with altitude above 3400m. This may indicate that the meteorology in this region interacts differently with the topography in extremely dry years than in wetter years. The high-altitude snowpack may be particularly vulnerable in this region if conditions like those in 2002 recur.

5 Future Snowpack Projections: DHSVM Modeling

Key Points - Methods

- In order to simulate snow cover under future climate conditions, we use a high-resolution snow/hydrology model with inputs derived from historical observations and global climate model projections.
- The Distributed Hydrology Soil Vegetation (DHSVM) model was run for the historic period 1998-2013 and validated against available SNOTEL observing stations.[5] The spatial patterns of snow were validated against MODIS satellite remotely sensed snow cover.
- Five scenarios of the future – for a thirty-year period, 2041-2070, centered on 2055 -- were selected from CMIP5 global climate model (GCM) projections based on a moderate (RCP 4.5) and high (RCP 8.5) emissions scenarios. These were chosen to represent a large fraction of the range of the CMIP5 ensemble projections in each study area in terms of precipitation and temperature changes. The scenarios differ somewhat between the two study areas to better represent the range of climate projections in each area.
- The selected GCM projections were downscaled using the "delta method" which applies change factors from the climate models to the historic temperature and precipitation that are used as inputs to the DHSVM model.
- Analysis is presented for light snow cover (Snow Water Equivalent > 5 mm) on May 15th for comparison with May 15th MODIS snow cover (as was used by McKelvey).
- To capture and assess year to year variability, Wet, Near Normal, and Dry representative case study years are shown for the historical simulations and how each of these years plays out under these five future scenarios.

Key Points – GLAC study area

For the study area in Glacier National Park (GLAC), projections for April 15th, May 1st, and May 15th Snow Covered Area and area with snow depth greater than 0.5 meters show declines on average in all scenarios, except for small increases in the Warm/Wet scenario and for all years (Section 5-11).

- For April 15th for the study area as a whole (Figure 2-1), there is a decline of 3-23 percent in snow covered area with light snow cover (depth ≥ 5 mm), and a 7-44% percent decline in area with significant snow (depth > 0.5 m) for the five scenarios considered, compared to the 2000-2013 historic average. For May 15th, the area with light snowcover declines 10-36 percent, and the area with significant snow cover declines 13-50 percent (Tables 5-4, 5-5). Under the Hot/Wet scenario, the April 15th significant snowpack has been diminished below the level of the historic May 15th snowpack – a month shift (Figure 5-14).
- On April 15th, the Warm/Wet scenario shows the least change in average SCA (2121 Sq-km) compared to the historic snow cover (2609-7%) for significant (≥ 0.5 meter) snowpack. The largest decrease is the Hot/Wet scenario (1520 sq-km) with 44% decrease.

[5] Some results are presented only for the 2000-2013 period determined by the overlap of the DHSVM simulations with the MODIS satellite record.

- All projections show declines in the number of years with significant snow. In each study domain, the areas with frequent availability (at least 14 out of 16 years) of significant snow (≥ 0.5 m) become concentrated in smaller high elevation areas, as seen in the maps in Figures 5-13, 5-14 (GLAC), and 5-20, 5-21 (ROMO). In contrast, lower elevation areas had the largest changes, or decreases in significant snowcover.
    - Most of the known den sites are located between 1800 and 2000m in GLAC. Below that elevation band large snow losses are predicted (40-70% decreases for two of the scenarios, 16-20% for the other three), above that elevation band there is little change in SCA for four of the five scenarios (2-8%) except in maximum warming scenario (-40%, Figure 5-22). In that 1800-2000m band, the snowpack change is sensitive to elevation and to the particular future climate scenario.
    - This phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. Regonda et al. (2005) found little historical change in snowpack in the Western United States above approximately 2500m elevation despite observed warming trends.
    - For representative wet years, the higher elevations of our study areas experience only 2-7% loss of snowpack under the scenarios with "least" change and the "central" change (Figure 5-8, 5-12), although for the dry years, losses range 18-57% (Table 5-5). This is in contrast to the McKelvey study, in which the large losses in the snow analysis included lower elevations that have not been considered likely denning areas.
    - Modest declines in SWE may occur without affecting the area with significant snow depth. On May 1st, for areas at 1800m and above in GLAC, losses of ~10-30% SWE (Figure 5-23) result in losses of only ~10% snowcover. The implication is that the wet, cold climate of the GLAC study area could act as a "buffer" to change in the area of 0.5 m deep snow on May 1st, at least at the elevations above 1800m.

Key Points – ROMO study area.

For the study area in and around Rocky Mountain National Park (ROMO), projections of May 15th Snow Covered Area in ROMO declines on average in all scenarios, except for small increases in the Warm/Wet scenario, and for almost all years (Section 5-12).

- For April 15th for the study area as a whole (Figure 2-2), there is decline of 3-18% in area with light snow cover (depth ≥ 5 mm), and a change of -1 - +16 in area with significant snow cover (depth > 0.5 m) for the five scenarios considered, compared to the 2000-2013 historic average. For May 15th, the area with light snowcover declines 8-35 %, and the area with significant snow cover declines 6-38 percent (Tables 5-6, 5-7).

- Snow Covered Area in ROMO (≥0.5 m threshold on May 15) generally declines in wet years, shows a slight increase in (1-5%) in some years for the Warm/Wet scenarios with increased precipitation.
    - One scenario with increased precipitation (Warm/Wet, giss) shows increases in April 15th SCA (Table 5-7). There are also slight increases in SWE for two scenarios at elevations at and above 3400m (Figure 5-25), but decreases in SWE for all scenarios below 3400m.
    - Although no dens have been documented in ROMO, the elevation band for denning, modeled by regression analysis, is thought to be ~2700-3600m. On May 1st, modest declines in SWE of ~15% and less for areas at 3400m and above result in losses of < result in losses of only ~10% snowcover (Figure 5-24, 25). 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 deep snow on May 1st. Below that band losses in SWE of ≥ 35% result in higher losses in SCA (20-65%), except in the scenario with least change (Warm/Wet, giss model). As in the denning band in GLAC, in that 2700-3600m band, the snowpack change is sensitive to elevation and to the particular future climate scenario.

- The phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. Regonda et al. (2005) found little historical change in snowpack in the Western United States above approximately 2500m elevation despite observed warming trends. Other literature on this topic is discussed in Section 5.13.
- ROMO exhibited more uncertainty in projections than GLAC
    - ROMO has more uncertainty as to whether precipitation will increase or decrease.
    - The beneficial effect of increased precipitation on snowpack is more prominent earlier in the Spring. In the Warm/Wet scenario, the area of significant snow on May1 increases on average, though it decreases on May 15.
    - For April 15th –May 15th, and for wet years, the high elevations of the ROMO study area as a whole, there are only modest loss of snow cover under all scenarios of change (Table 5-7, see 2011 representative wet year). However even in wet years, the area of significant snowpack can decline by up to 26% for the Hot/Dry climate change scenario on May 15th (Table 5-7).

5.1 Introduction

In this section we describe the hydrologic model along with various modeling assumptions, validation of the model, the choice of risk-spanning future climate scenarios, and present results of historical and projected snowpack for the two study areas.

To determine the projected effects of a changing climate on snowpack we ran a physically-based hydrology model. The physical basis of the model – using a full energy and water balance of the snowpack rather than a simple temperature-index model -- is critical to evaluate change in a non-stationary climate. While ambient temperature is a critical factor in whether precipitation falls as rain or snow, the subsequent evolution of the snowpack, and in particular the melt season, is driven primarily by the energy balance at the surface. The energy balance is the result of several processes, including solar and longwave radiation, sensible and latent heat fluxes, and heat flux into the ground, as well as storage of heat in the snowpack. Therefore, including a realistic energy balance helps to understand how the perturbations to climate will affect the snowpack.

5.2 Model Description

The Distributed Hydrology Soil Vegetation Model (DHSVM) provides a physically-based simulation of land surface hydrology, including snowpack. The physical processes include a full surface water and energy balance model, a 2-layer canopy model, a multi-layer soil model, a 2-layer snowpack model (Wigmosta et al. 1994). It has been used in many studies that have provided realistic hydrologic simulations in topographically complex areas (e.g. Livneh et al.

2015). The model has explicit treatment of topographic slope, and aspect (the compass direction that the slope faces).

The model was selected for developing snowpack projections because it can be run at a fine spatial scale (250 m x 250m pixels) yet is able to be run over extensive domains. There are both finer-scale snow models, for which it would have been impractical to simulate such a large domain, and coarser-scale models, such as the 1/16 degree grid of the VIC model that the McKelvey study used (see section 2.3). Coarser-scale models do not explicitly model the effects of slope and aspect, which is one of the primary goals of this study. Both DHSVM and VIC were primarily developed at the University of Washington, and are available as open-source community models. The two models share many components in common, including similar snow and canopy models. As such it supports the project goal of building on McKelvey study by modelling at a finer scale and treating slope and aspect explicitly.

The model was set up for both study domains on a 250m grid in Universal Transverse Mercator (UTM) coordinates within the modeling domain defined within the polygons shown in Section 2. Soil properties and vegetation type as well as a digital elevation model (DEM) were adapted to the model grid. A soil hydraulic routing network was also determined from the DEM, though in this project we do not investigate the runoff. The effect of slope and aspect on incoming solar radiation is implemented through a computation of the degree of shading for each 250-m pixel that was variable throughout the day and differed from month to month based on the solar angle in the sky and from the DEM. The model requires inputs of time-varying meteorological fields on sub-daily time scales. Snow water equivalent was output on the 1st and 15th of the month from March 1st to June 1st for every year of the simulation and projections. As noted below, snow depth was estimated using a typical snowpack density for late Spring.

5.3 Meteorological Inputs

The DHSVM model inputs were derived in a multi-step process. First, values of daily minimum temperature, daily maximum temperature, and precipitation were extracted from the Livneh (2015) dataset, which has a grid resolution of 1/16th degree in latitude and longitude. These daily values were disaggregated in time. Other forcing variables needed by the model, solar radiation, downwelling longwave radiation, specific humidity were derived from empirical relationships using the MTCLIM algorithms which were evaluated by Livneh et al. (2014) finding small overall biases. The Livneh et al (2015) data was then interpolated to the 250m DHSVM grid using an inverse-distance weighting algorithm along with assumed lapse rates (elevation dependence) in temperature and in precipitation. More details of the Livneh 2015 dataset will be included in the Section 5 Supplementary Material.

5.4 DHSVM Historical Validation

The goal of the model validation is to assess the overall magnitude, temporal, and spatial aspects of the modeled snowpack in the Spring and how these differ from observational estimates.

Observational estimate of snow depth or snow water equivalent at the scales that we simulated are not available, leading to uncertainty about the "true" snowpack. For the overall magnitude and temporal aspects of the snow simulation, we compared the historical model simulation to point observations at the few available SNOTEL sites, focusing on the duration and melt-out date of the snowpack. The spatial aspect of bias was evaluated by comparing the model output to the observed spatial patterns of snow cover obtained from the MODIS analysis (see Section 4), qualitatively for GLAC and quantitatively for ROMO. When interpreting the projections, future model biases are typically assumed to be similar to historical biases. With this assumption, the calculation of, for example, percentage change is less sensitive to biases and uncertainties in the historical simulation.

5.4.1 Comparison to SNOTEL

The DHSVM historical simulation was compared against the snow data from nine SNOTEL sites in the ROMO study area that were in operation during the full time-period of interest, and the 3 SNOTEL sites in and adjacent to the GLAC study area (Table 5-1). Validation against SNOTEL snow data was performed by running the DHSVM model in "point" mode so that it simulated the conditions at the SNOTEL locations only. Because the SNOTEL stations are deliberately sited in clearings, the canopy was assumed to be open for the validation runs, while the actual 250m grid canopy values were used for the production runs. Two metrics were chosen: the meltout day of year (defined as the date when SWE fell to less than 1mm), and the duration of snow cover (total number of days during the water year (October-September) when SWE > 10cm). Figure 5-1a shows the modeled and observed meltout dates for the GLAC and ROMO SNOTEL sites, and Figure 5-1b shows the duration of snowpack. One does not expect exact reproduction of the snowpack at the SNOTEL sites, but rather a scatter about the 1-to-1 line, which is seen. The Copeland Lake SNOTEL site, and to some extent the Many Glacier SNOTEL sites are outliers, with the model retaining snowpack significantly longer than in observations. Both these sites are at relatively low elevations, and are quite sensitive to potential temperature biases in the input data. The Livneh (2015) dataset is known to have a cool bias relative to other datasets, which may influence these sites disproportionately.

Table 5-1 SNOTEL Sites at Study Areas. Maps with SNOTEL sites are shown in Figs 2-1 and 2-2. Note that sites installed after 1997 were not used due to their short record.

	SNOTEL SITE NAME (Site Number, Abbreviation)
Glacier Study Area	Flattop Mountain (482, flat), Many Glacier (613, many), Pike Creek (693, pike)
Rocky Mountain Study Area (used for Validation)	Bear Lake (322, bear), Copeland Lake (412, cope), Joe Wright (551, joew), Lake Eldora (564, eldo), Lake Irene (565, iren), Niwot (663, niwo), Phantom Valley (688, phan), University Camp (838, univ), Willow Park (870, will)
Rocky Mountain Study Area (installed after 1997, not used)	Never Summer (1031), Wild Basin (1042), Hourglass Lake (1122), Long Draw Reservoir (1123), High Lonesome (1187), Sawtooth (1251)

The year-to-year variations of peak snowpack at the GLAC SNOTEL sites are well captured, as illustrated in Figure 5-2 that shows simulated and observed time series of SWE at these stations. Figure 5-3 shows selected SNOTEL sites in the ROMO area. As can be seen in Figure 5-2, the Copeland Lake site is less well simulated than other sites. We attribute this to being located at a lower elevation than other sites, and hence susceptible to small biases in temperature in the meteorological inputs. Other sites in ROMO are well simulated.

Based on this evaluation of DHSVM performance, the standard set of model parameters was adopted for the GLAC domain without modification.

The question arises of the independence of the SNOTEL data from the Livneh (2015) forcing data. The primary observing station data that were used for interpolation by Livneh (2015) did not include SNOTEL. However, a monthly adjustment factor was applied to the interpolated precipitation to reproduce the 1981-2000 climatology of PRISM. The temperature data in Livneh et al (2015) were entirely independent of SNOTEL data. Therefore, we expect that the errors revealed at the SNOTEL sites should be representative of errors at other, unobserved sites in the domain.

5.4.2 Comparison to MODIS Snow Cover

The spatial distribution of snow cover was assessed by comparison with MODIS data. Some care must be taken to compare observed NDSI, which indicated fractional snow cover, with modeled SWE, which does not account for fractional snow cover within a pixel. For this evaluation, a threshold to determine "snow covered ground" was chosen for both the MODIS (NDSI >= 0.1) and for the DHSVM (SWE >= 5mm). Figures 5-4 and 5-5 snow spatial overlays of the DHSVM simulated snow cover and the MODIS observed snow cover for the representative dry years in ROMO and GLAC. In terms of snow cover, dry years were more difficult to simulate than wet years, and the spatial agreement is good for these two examples.

However, initial attempts to model ROMO indicated biases in the spatial patterns of snow cover compared to MODIS. To overcome model errors at ROMO, an adjustment of two DHSVM snow parameters was conducted. The representative values of the physical quantities of these parameters can span a fairly large range, and hence an experiment was conducted to evaluate the appropriate settings of the model for ROMO based on minimizing differences between simulated and MODIS SCA for the historical period, as well as reducing biases with SNOTEL SWE.

The first parameter modified was the snow-surface roughness (SR), which affects the amount of turbulent heat fluxes that occur between the snow and the atmosphere, whereby a small number corresponds to a smoother snowpack that has less heat exchange with the overlying air, while the opposite is true for a large value. The second parameter was the liquid water capacity (LWC) that describes the volume of water that the snowpack can hold before water will leach out of the snowpack. This parameter is important, since it is common for snow to melt during the day and then for liquid water to refreeze at night.

Adjustments were made to SR and LWC within reasonable physical ranges and the DHSVM simulated SCA was compared with MODIS via a threat score. The threat score used, referred to as the Critical Success Index (CSI) by Zappa (2010), is defined as:

$$CSI = \frac{a}{a + b + c}$$

Where a indicates a snow-covered pixel in both the simulation and observed data, b indicates a snow-covered pixel in the simulation but a bare pixel in the observed ("false positive"), and c is a bare pixel for the simulation and a snow-covered pixel shown by the observed data ("false negative"). The objective was to maximize the threat score. Approximately ten unique parameter settings were tested. Additionally, for each parameter setting the mean bias in meltout day and duration of snow cover between DHSVM simulated and SNOTEL SWE was calculated with the objective being a minimization of the bias between the two (bias = simulated – observed). The final DHSVM settings for ROMO were identified by the parameter values that corresponded with a combination of a high threat score and a low bias. The table and figure showing the parameter settings and ensuing objective values are included in the supplementary material.

5.5 Determination of Snow Depth from DHSVM model output

DHSVM does not compute snow depth as a separate quantity, but instead returns snow water equivalent (SWE). To estimate the snow depth from SWE we adopt a uniform value of 2.5:1 for the SD:SWE ratio, corresponding to a snow density of 0.4 for May 1st and May 15th. For april 15th conditions, we adopt a bulk density of 0.33 which yields a conversion factor of 3.0:1. Further discussion can be found in the Section 5 Supplementary Material. Several lines of evidence point to the reasonableness of this assumption. First, SNOTEL stations where both depth and SWE are measured show similar ratios for the two study areas. Second, we investigated the ratio of density from the SNODAS (Snow Data Assimilation System) product from the NOAA National Operational Hydrologic Remote Sensing Center, which points to a very narrow range around 2.6-2.7 for the ratio. Finally, for comparison with the McKelvey et al (2011) work we compared the May 1 Snow Depth and SWE products from the Littell et al (2011) hydrologic model runs (obtained separately from https://cig.uw.edu/datasets/wus/). These all point to an approximate value consistent with a density between 0.35 and 0.4. The results of this study do not depend on a precise value for snow density. The conclusions of the report are not sensitive to the choice of conversion factor within the ranges indicated by the above analysis.

5.6 Choice of thresholds for analysis

While the the McKelvey study analysis was for the presence or absence of snowcover, this modeling effort produces results in terms of SWE. This allows greater flexibility in evaluation of the depth of the snowpack, but presents a problem in comparison. To compare the model-generated SWE with both the McKelvey study results and our own MODIS historical snow cover analysis we used a threshold of 5mm SWE to define presence/absence of snow cover, also called "light snow". We also were concerned with analyzing the presence of "significant snow" which we defined as ≥ 0.5 m of snow depth. The value of ≥ 0.5 m was arrived at by an analysis of the modeled snow depth at known wolverine denning sites in Glacier National Park (Table 5-

2). With the exception of one site that had melted out by May 15th, the other sites all have snowpack between 0.4 and 1.4 m.

Table 5-2: Modeled Snow Depth on May 15 at reported den sites in the Glacier Study Area (source: John Guinotte, FWS)

Den site	Date observed (month-yr)	Meltout Date (MODIS)	April 15 snow depth dhsvm (m)	May 01 snow depth dhsvm	May 15 snow depth dhsvm (m)	Notes
1	Apr-03	5/25/2003	1.32	1.07	1.04	Natal Den
2	May-03	5/25/2003	1.32	1.07	1.05	Maternal Den
3	Apr-04	6/4/2004	1.96	1.46	1.13	Natal Den
4	Apr-04	6/29/2004	1.0	0.75	0.54	Maternal Den
5	May-04	6/29/2004	1.07	0.83	0.65	Maternal Den
6	Mar-05	6/11/2005	1.6	1.11	0.58	Maternal Den
7	Apr-05	6/11/2005	1.6	1.11	0.58	Natal Den
8	May-05	6/11/2005	1	0.76	0.47	Maternal Den
9	Mar-06	5/25/2006	3.05	2.56	2.44	Unknown-maternal or natal
10	Apr-06	5/14/2006	0.68	0.26	0	Meltout occurred before May 15 Unknown-maternal or natal
11	Apr-06	6/7/2006	2.83	2.4	2.38	Unknown-maternal or natal
12	May-06	5/31/2006	1.14	0.79	0.61	Maternal Den
13	May-06	5/31/2006	1.14	0.79	0.61	Natal Den
14	May-07	6/4/2007	1.82	1.28	0.68	Natal Den

5.7 Delta Method for Future Scenarios

The advantages and disadvantages of the delta method have been discussed extensively in the literature (e.g. Sofaer et al, 2016, for a recent review). The primary advantages of this method are its long history of use, its simplicity, and its use of the historical observed weather as the baseline. The simplicity allowed for the study to be completed in a short time-frame, while still reaching our primary objectives of finer spatial scale and a more complete exploration of future climate scenarios. The use of the historical baseline allows us to explore how wet, near normal, and dry "representative years" would play out under the different climate futures. However, it is important to keep in mind that we are "parameterizing the future variability in terms of the historical variability." This treatment of daily variability also leads to the primary disadvantage of the delta method: the assumptions that the changes in extremes follow the changes in the means, and that the pattern of daily weather is simply shifted without changing the sequences of weather (Sofaer et al, 2016). This aspect is less of a concern for this study, as snow accumulation and ablation are cumulative processes, so that the daily sequences of storms is less critical to

simulate than the monthly and seasonal totals. Another assumption of the delta method is that the large-scale changes in temperature and precipitation apply uniformly to the study area. Equivalently we assume that change factors in ambient (free-air) temperature and precipitation will not depend on the small scale spatial detail. Because we explicitly compute the surface energy balance, we are able to simulate surface temperature differences that depend on fine-scale terrain, mitigating to some extent this limitation of the delta method.

Following McKelvey (2011), we use the "delta method" to downscale the climate model data to the 250m modeling grid.

The steps in this method are as follows:

- Start with historical daily meteorological forcings (inputs to the DSHVM model) for the historical baseline period (1998-2013)
- Run DHSVM with the historical forcings to produce the simulated historical snow and hydrology.
- From climate model output, compute the change in 30-year average temperature for each calendar month over the time frame of interest. Do the same for the percent change in precipitation
- Apply these change factors to the historical daily meteorological inputs to DHSVM to generate future scenarios of meteorological inputs.
- Run DHSVM with these new inputs to generate the projected snow and hydrology.
- Compare the projected snow to the historic DHSVM model simulations to infer changes in snowpack.
- Repeat for a set of change factors from different climate models that adequately sample the uncertainty in climate projections.

The result of the delta method is a continuous-in-time simulation of the historical period (1998-2013), and an equal length simulation of how this sequence of years would play out in the future under five different scenarios of climate change. Figure 5-6 illustrates typical DHSVM model output using the delta method. Figure 5-6a shows a map of May 15, 2011 Snow Water Equivalent for the Glacier Study Area from the historical simulation, while Figure 5-6b shows a single projected future for what that year's SWE would look like under a particular scenario of climate change. The future scenario represents a year similar to 2011, that is, a relatively wet and cool year compared to other years in the future. However, in this example, the temperature and precipitation have been adjusted to be consistent with the 2041-2070 projected climate from the MIROC climate model, the model with the highest temperature increase and about 10% increase in precipitation.

5.8 GCM Uncertainty and Scenario Planning Approach

As noted in Section 2, global climate models (GCMs) are our primary tools to examine the nature of climate change during the 21st century. There are currently about 20 modeling centers worldwide which provided output from their best model(s) to be considered in the Coupled Model Inter-comparison Project Phase-5 (CMIP5, Taylor et al., 2012) which informed the latest Intergovernmental Panel on Climate Change (IPCC) report (IPCC AR5). Here we quantify changes in temperature and precipitation for the two study areas for the 2041-2070 time frame, centered on 2055. We find a large spread in the extent of warming and changes in precipitation, including both increases and decreases in precipitation, as shown in Figure 5-7. The McKelvey study chose GCMs based on the range of temperature change (see Sec 2.2, also shown in Figure 5-7). For temperature, much of this spread (or uncertainty) is a result of the difference between GCMs (e.g., their climate sensitivities), whereas for precipitation it is both the difference between GCMs and internal climate variability. Some difference also comes from the choice of future greenhouse gases (GHG) emission scenario. However, these differences among mid-21st century climate responses are limited compared to later in the century (see a discussion in Ray et al., 2010).

For more robust planning and climate adaptation, experts recommend incorporation of these uncertainties into the assessment of impacts and developing adaptation strategies. The scenario planning approach has been one method that has been recommend and promoted by different entities and experts (National Park Service, 2013; Rowland et al., 2014; Maier et al., 2016; Murphy et al. 2016; Star et al., 2016, Fisichelli et al, 2016 a,b). Therefore, we adopted a strategy of selecting multiple divergent future scenarios challenging to the system of interest, following that in Fisichelli et al (2016 a, b).

5.9 Climate Projections Evaluation and Scenarios Selection

We compiled output for temperature and precipitation projections for 34 CMIP5 GCMs from the Reclamation (2013; http://gdo-dcp.ucllnl.org/) archive of 1-degree Regridded GCM dataset for Representative Concentration Pathways (RCP) 4.5 and 8.5, which are respectively the moderate and high GHG emissions scenarios --- therefore, a total of 68 GCM projections described in Supplementary Material. These data were then analyzed to quantify broad-scale projections for the two study regions by 2055 (i.e. a mid-point centered on the 2041-2070 period) – primarily changes in the cold season (Oct-May) temperature and precipitation by 2055 relative to the 1986-2015 period. Figures 5-7 show these changes for Rocky Mountain and Glacier National Parks, respectively, which are bounded by rectangular latitude/longitude values. As mentioned earlier, we found a large range in temperature increases (1-4 ºC) and changes in precipitation (-5% to +20%) for these regions by 2055. Table 5-3 shows GCM names, numbers and colors coded in later figures, and relative changes in temperature and precipitation. To incorporate the large range in climate projections, we worked with the ensemble of 68 CMIP5 temperature & precipitation projections, described by the red filled-circles in Figure 5-7, to select five future climate scenarios (black circles) that span the different parts of this projection space. Five GCMs representing these scenarios were identified for both RMNP and GNP. For each of these GCMs, we calculated changes in temperature and precipitation by 2055 for each month of the year,

which we call the “monthly delta”. These monthly deltas were used to perturb the hydrological models to simulate snow response in RMNP and GNP by 2055.

Table 5-3. The future climate scenarios (five for each area) with changes in temperature and precipitation relative to other scenarios (See also Fig 5-7 for an alternate visualization of these changes), and the GCM used as the basis for the deltas for this scenario. More details on the GCMs are in the Glossary.

Future Scenario Name and #	Scenario Change in GLAC relative to other scenarios	Scenario Change in ROMO relative to other scenarios	Code and color for GCM used for this scenario
Central (#1)	+~2.2 °C increase in temperature (close to the ensemble mean) and +~5% increase in precipitation	+~2.5 °C increase in temperature (close to the ensemble mean) and +~8% increase in precipitation	cnrm, red
GLAC: **Hot/ Very Wet (**#2)	relatively higher increase in temperature (+~3.2 C) and the highest increase in precipitation (+20%) for the GLAC scenarios	N/A	canesm, green
ROMO: **Hot/Dry (**#2)	N/A	relatively higher temperature increase (+~ 3.5 °C) and -~5% decrease in precipitation. This scenario results in the greatest change (reduction) in snow pack and snowcover.	hadgem, green
Hot/ Wet (#3)	the highest temperature increase of the GLAC scenarios (+~4.2 °C) and +~10% increase in precipitation	the highest temperature increase of the ROMO scenarios (+~3.7 °C) and the highest increase in precipitation (+~18%).	miroc, purple
Warm/ Wet (#4)	relatively lower temperature increase (+~1 °C) and +~10% increase in precipitation	relatively lower temperature increase (+~1.3 °C) and +~7% increase in precipitation that appears to partially offset the impacts of the temperature increase. This scenario results in the least change in snow pack and snowcover.	giss, aqua
Warm/ Dry (#5)	relatively lower temperature increase (+~1.6 °C) and -~5% decrease in precipitation	relatively lower temperature increase (+~0.8 °C) and -~5% decrease in precipitation	fio, orange

5.10 Modeling Caveats

Some processes which may be of relevance not represented in the model include wind and avalanche re-distribution of snowpack. Snow depth is not explicitly modeled, and must be inferred (Section 5-5). The meteorological forcing does not take into account cold air pooling or how this may change in the future. Cold air pooling – the anomalously cold air that can collect in valley bottoms, particularly in Winter, could also act to prolong the duration of snow cover in those locations. While Curtis et al (2014) identify this as a potential process, they do not physically model cold air pooling, but merely include it in their present-day climatology as a simple "offset" from their unadjusted data. Nonetheless their work provides a complementary approach to the identification of potential snow refugia, though more work would need to be done to study the geographic and seasonal aspects for the study areas.

5.11 GLAC Study Area Results

This section presents SWE and SCA for representative years, area and number of years with snow depth ≥ 0.5 m. The elevation dependence of snow for GLAC is discussed in Section 5-13. **On average, the GLAC study area exhibits a 7 – 44 % decline in the area of snow depth ≥ 0.5 meters on April 15th, and a 13-50 % decline in the area on May 15 for the scenarios considered.**

5.11.1 SWE and Snow Covered Area for representative years

Figures 5-8 shows DHSVM model simulated snow water equivalent (SWE) on May 15 for the wet (2011) representative year. Maps of snow cover derived from SWE by applying a threshold of 5 mm are available in the Supplementary material. Results for thresholds of 1 mm of SWE were also investigated and show similar patterns. Snow covered area with a "light snow cover" threshold was computed primarily for comparison with both the MODIS results from Section 4, and with McKelvey. In Figure 5-8, the historical simulation is shown along with three of the five future scenarios, chosen to represent the central scenario (cnrm), the greatest change in snowpack on average (Hot/Wet (miroc) scenario) and the least change (Warm/Wet (giss) scenario). The projected snow maps answer the question "what would the snowpack in a wet year like 2011 look like in the 2040's through 2070's under these scenarios of climate change."

Figures 5-9 and 5-10 show SWE for the Near Normal (2009) and Dry (2005) representative years. The historical simulation and future scenarios are as in Figure 5-8. Figure 5-11 summarizes the results for snow covered area in terms of the total snow covered area (km^2) within the study area polygon. The numerical values of snow covered area for all years in the simulation, as well as percent changes for these quantities are shown in Table 5-4. Table 5-4 indicates that the snowcovered area decreases for all scenarios. On average, the GLAC study area exhibits a 7 – 44 % decline in the area of snow depth ≥ 0.5 meters on April 15th, and a 13-50 % decline in the area on May 15th for the scenarios considered.

- Comparing the Wet and Dry representative years we see that dry years are more vulnerable to climate change in terms of percent loss of snow covered area.
- For the Wet year, the high elevations of the study area result in little loss of snowpack in the study areas under most scenarios of change.

- However, in Figures 5-10 and 5-11 we notice an anomaly – for the dry year, the Hot/Wet (miroc) scenario does not have the greatest loss of snow covered area. The increase in precipitation in this scenario has somewhat compensated for the loss of snowpack due to warming. Instead the Hot/Very Wet (canesm) scenario, with its even larger warming shows the greatest loss of snow covered area.
- Snow changes at the elevations of known dens are discussed later in Section 5.13 and Figures 5-22 and 5-23.

5.11.2 Area and Number of years with ≥ 0.5 m Snow Depth

Because of interest in wolverine denning sites, we analyze snow depth ≥ 0.5 m, which we will also refer to as "significant snow" to contrast with the emphasis on light snow in McKelvey et al (2011) and in the previous section. Figure 5-12 shows the area with snow depth ≥ 0.5 m on April 15th and May 15th in the study area for the dry, near normal, and wet years. Because of the higher threshold for snow, the effects are somewhat larger than for the light snow threshold. This is particularly evident in the dry year, which has a 50% decline on May 15 for four of the future scenarios. The numerical values of snow covered area at the ≥ 0.5 m threshold are shown in Table 5-5 for all years, as well as percent changes for these quantities.

Figure 5-13 shows a map of the number of years (out of 16 possible) where each model pixel had ≥ 0.5 m of snow depth on May 15. This number-of-years statistic is analogous to that used by the Copeland study, except that there are more years of data, and these maps use a much higher threshold of snow. The projections show declines in the number of years with significant snow. The areas with frequent (14-16 years) availability of significant snow become concentrated in smaller, relatively higher elevation areas within the study domains.

The effects of climate change on snow melt have been presented as analogous to a "time shifting" of the melt season earlier in the year. For example, McKelvey used the May 31 vs. May 15 snow covered area as a proxy for a 2-week shift in the melt season. Figure 5-14 contrasts the evolution of the snowpack with respect to the number of years with significant snow from April 15th to May 15th in the historical simulations (Top Row) with the Warm/Wet scenario (Middle Row) and Hot/Wet (Bottom Row) scenarios. We see that the Warm/Wet scenario, shows the least change in the number of years compared to the historic snow cover in terms of the availability of significant snow. In contrast, under the Hot/Wet scenario, the number of years that significant snowpack occurs on April 15th has been diminished well below the level of the historic May 15th snowpack – more than a month shift (Figure 5-14).

GLAC	Snow Covered Area sq-km [5 mm SWE threshold]																	
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	2838	2876	2901	2886	2901	2869	2772	2615	2836	2784	2899	2900	2853	2901	2892	2890	2851	2881
	Central [comm]	2501	2732	2901	2804	2879	2708	2278	2067	2500	2297	2849	2870	2604	2897	2748	2743	2649	2737
	Hot/Very Wet [cancsm]	2080	2342	2900	2589	2748	2288	1784	1630	1972	1714	2610	2695	2177	2839	2235	2405	2312	2315
	Hot/Wet [miroc]	2043	2069	2210	2326	2161	2419	1489	1593	2087	2020	2753	2245	2200	2501	1766	2700	2192	2181
	Warm/Wet [gfdl]	2637	2819	2901	2840	2887	2769	2578	2361	2677	2572	2881	2885	2706	2901	2827	2828	2758	2823
	Warm/Dry [hir]	2604	2735	2901	2839	2887	2808	2469	2176	2634	2490	2867	2883	2712	2900	2848	2785	2721	2797
1-May	historical	2625	2814	2707	2818	2892	2788	2608	2494	2694	2563	2888	2901	2508	2901	2775	2861	2745	2782
	Central [comm]	1949	2433	2160	2505	2820	2405	1948	1657	2072	1917	2773	2882	2008	2887	2202	2619	2327	2383
	Hot/Very Wet [cancsm]	1578	2059	1835	1985	2580	1859	1400	1287	1633	1771	2499	2792	1419	2813	1730	2249	1938	1857
	Hot/Wet [miroc]	1828	1865	1806	1843	1731	2214	1324	1354	1721	1727	2655	2129	1845	2542	1374	2319	1955	1844
	Warm/Wet [gfdl]	2327	2653	2482	2647	2861	2556	2293	2142	2416	2204	2854	2896	2276	2901	2529	2739	2548	2543
	Warm/Dry [hir]	2256	2522	2301	2634	2832	2628	2214	1906	2337	2172	2824	2892	2257	2900	2531	2697	2494	2526
15-May	historical	1658	2756	2516	2413	2875	2635	2383	2211	2460	1865	2825	2838	2488	2900	2535	2597	2585	2555
	Central [comm]	918	2232	1832	1814	2664	2156	1572	1296	1652	1105	2457	2534	1813	2818	1816	1844	1988	1824
	Hot/Very Wet [cancsm]	859	1948	1568	1409	2434	1703	1197	1002	1381	749	2241	2261	1259	2684	1468	1664	1614	1518
	Hot/Wet [miroc]	1434	1611	1273	1305	1476	2070	1053	1537	1396	1266	2391	1781	1731	2373	1139	1960	1610	1537
	Warm/Wet [gfdl]	1342	2562	2220	2109	2810	2413	2068	1829	2093	1455	2693	2734	2152	2883	2250	2342	2246	2295
	Warm/Dry [hir]	1166	2378	2045	1994	2729	2456	1870	1564	1953	1338	2588	2659	2073	2866	2171	2053	2119	2063

GLAC	Snow Covered Area % change [5 mm SWE threshold]																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central [comm]	-12	-5	0	-3	-1	-6	-18	-21	-12	-17	-2	-1	-9	0	-5	-5	-7	-5
	Hot/Very Wet [cancsm]	-27	-19	0	-10	-5	-20	-36	-38	-30	-38	-10	-7	-24	-2	-23	-17	-19	-20
	Hot/Wet [miroc]	-28	-28	-24	-19	-25	-16	-46	-24	-26	-27	-5	-23	-23	-11	-39	-7	-23	-24
	Warm/Wet [gfdl]	-5	-2	0	-2	0	-3	-7	-10	-6	-8	-1	-1	-5	0	-2	-2	-3	-2
	Warm/Dry [hir]	-8	-5	0	-2	0	-2	-11	-17	-7	-11	-1	-1	-5	0	-2	-4	-5	-3
1-May	Central [comm]	-26	-14	-20	-11	-2	-14	-25	-34	-23	-25	-4	-1	-23	0	-21	-8	-15	-17
	Hot/Very Wet [cancsm]	-40	-27	-33	-30	-11	-32	-46	-48	-39	-50	-13	-4	-45	-3	-38	-21	-29	-33
	Hot/Wet [miroc]	-30	-34	-33	-35	-40	-21	-49	-6	-36	-33	-8	-27	-29	-12	-50	-19	-29	-34
	Warm/Wet [gfdl]	-11	-6	-8	-6	-1	-8	-12	-14	-10	-14	-1	0	-12	0	-9	-4	-7	-9
	Warm/Dry [hir]	-14	-10	-15	-7	-2	-6	-15	-24	-13	-15	-2	0	-13	0	-9	-6	-9	-9
15-May	Central [comm]	-45	-19	-27	-25	-7	-20	-34	-41	-33	-41	-13	-11	-27	-3	-30	-29	-24	-29
	Hot/Very Wet [cancsm]	-48	-29	-38	-42	-15	-37	-50	-55	-44	-60	-21	-20	-49	-7	-43	-36	-36	-41
	Hot/Wet [miroc]	-15	-42	-51	-46	-49	-23	-56	-28	-43	-32	-15	-37	-30	-18	-57	-25	-36	-40
	Warm/Wet [gfdl]	-19	-7	-12	-13	-2	-10	-13	-17	-15	-22	-5	-4	-13	-1	-13	-10	-10	-13
	Warm/Dry [hir]	-30	-14	-19	-17	-5	-9	-22	-29	-21	-28	-8	-6	-17	-1	-16	-21	-15	-19

Table 5-4: GLAC Snow Covered Area (5 mm SWE threshold) Top: Area (km^2) in historical average (2000-2013) and five future scenarios. Bottom: percent change in future simulations compared to historical. Average and Median values also shown. The representative dry year is 2005, wet is 2011, and near normal is 2009.

GLAC	Snow Covered Area sq km (0.5 m depth threshold)																	
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	2628	2801	2708	2826	2876	2733	2532	2338	2650	2484	2830	2866	2380	2901	2833	2797	2699	2765
	Central [canesm]	2047	2444	2202	2577	2753	2387	1889	1502	2077	1933	2574	2705	1858	2871	2454	2414	2293	2408
	Hot/Very Wet [canesm]	1730	2121	1904	2081	2515	1922	1403	1203	1674	1339	2365	2437	1298	2774	1932	2047	1922	1927
	Hot/Wet [miroc]	1406	1171	1539	1530	1265	1589	1078	1265	1354	1439	2349	1619	1176	2290	1280	1569	1528	1422
	Warm/Wet [gfdl]	2402	2647	2525	2683	2829	2530	2251	2004	2405	2197	2732	2785	2152	2899	2660	2633	2521	2581
	Warm/Dry [hir]	2269	2445	2279	2647	2730	2584	2084	1720	2278	2072	2588	2745	1874	2890	2662	2499	2398	2472
1-May	historical	1970	2638	2380	2468	2855	2537	2235	2062	2324	1906	2704	2777	2011	2901	2544	2680	2437	2543
	Central [canesm]	1296	2045	1744	2058	2588	1976	1481	1265	1503	1332	2371	2523	1393	2856	1791	2118	1900	1936
	Hot/Very Wet [canesm]	1139	1783	1470	1535	2313	1494	1056	970	1325	852	2152	2191	935	2725	1438	1811	1577	1482
	Hot/Wet [miroc]	1359	1142	1175	1089	1015	1767	922	1181	1037	1077	1826	1581	1056	2229	888	1582	1295	1158
	Warm/Wet [gfdl]	1621	2399	2060	2187	2726	2168	1845	1709	1941	1510	2537	2626	1707	2893	2167	2449	2159	2167
	Warm/Dry [hir]	1491	2353	1880	2105	2645	2249	1838	1435	1790	1446	2402	2560	1455	2880	2103	2737	2033	2104
15-May	historical	1043	2593	2152	1708	2778	2360	1922	1670	2035	1224	2479	2625	1956	2886	2274	2227	2121	2189
	Central [canesm]	496	1927	1457	1231	2377	1690	1360	927	1236	648	1882	2101	1312	2710	1493	1401	1581	1429
	Hot/Very Wet [canesm]	521	1724	1283	963	2151	1321	870	724	1116	450	1838	1922	975	2556	1179	1339	1382	1231
	Hot/Wet [miroc]	839	1046	761	706	908	1655	634	1035	838	770	1572	1208	1161	1975	748	1215	1059	972
	Warm/Wet [gfdl]	833	2346	1819	1455	2619	1990	1577	1374	1646	932	2270	2418	1683	2838	1861	1950	1851	1840
	Warm/Dry [hir]	623	2077	1611	1284	2506	2002	1382	1096	1437	778	2003	2261	1398	2785	1752	1528	1658	1578

GLAC	Snow Covered Area % change (0.5 m depth threshold)																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central [canesm]	-22	-13	-19	-9	-4	-13	-25	-36	-22	-22	-9	-6	-22	-1	-13	-14	-15	-13
	Hot/Very Wet [canesm]	-34	-24	-30	-26	-13	-30	-45	-49	-37	-46	-16	-15	-45	-4	-32	-27	-29	-30
	Hot/Wet [miroc]	-47	-58	-43	-46	-56	-27	-57	-46	-49	-42	-17	-44	-51	-21	-55	-44	-44	-45
	Warm/Wet [gfdl]	-9	-6	-7	-5	-2	-7	-11	-14	-9	-12	-3	-3	-10	0	-6	-6	-7	-7
	Warm/Dry [hir]	-14	-13	-16	-6	-5	-5	-18	-26	-14	-17	-9	-4	-21	0	-6	-11	-11	-11
1-May	Central [canesm]	-34	-22	-27	-17	-9	-22	-34	-39	-32	-30	-12	-9	-31	-2	-30	-21	-22	-25
	Hot/Very Wet [canesm]	-42	-32	-38	-38	-19	-41	-53	-53	-43	-55	-20	-21	-51	-6	-44	-32	-35	-41
	Hot/Wet [miroc]	-41	-57	-51	-56	-64	-30	-59	-43	-55	-43	-32	-43	-47	-23	-65	-41	-47	-54
	Warm/Wet [gfdl]	-18	-9	-13	-11	-5	-15	-17	-17	-16	-21	-6	-5	-15	0	-15	-9	-11	-13
	Warm/Dry [hir]	-24	-18	-21	-15	-7	-11	-24	-30	-23	-24	-11	-8	-28	-1	-17	-17	-17	-16
15-May	Central [canesm]	-52	-26	-32	-28	-14	-28	-40	-44	-39	-47	-24	-20	-33	-6	-36	-37	-29	-35
	Hot/Very Wet [canesm]	-50	-34	-40	-44	-23	-44	-55	-57	-45	-63	-26	-27	-50	-11	-48	-40	-38	-44
	Hot/Wet [miroc]	-14	-60	-65	-59	-67	-30	-67	-38	-60	-37	-37	-54	-41	-32	-67	-45	-50	-56
	Warm/Wet [gfdl]	-20	-10	-15	-15	-6	-16	-18	-18	-19	-24	-8	-8	-14	-2	-18	-12	-13	-16
	Warm/Dry [hir]	-40	-20	-25	-25	-10	-15	-28	-34	-29	-36	-19	-14	-29	-4	-23	-31	-22	-28

Table 5-5: GLAC Snow Covered Area (0.5 m snow depth threshold) Top: Area (km^2) in historical average (2000-2013) and five future scenarios. Bottom: percent change in future simulations compared to historical. Average and Median values also shown. The representative dry year is 2005, wet is 2011, and near normal is 2009.

5.12 ROMO Study Area

This section presents SWE and SCA for representative years, area and number of years with snow depth ≥ 0.5 m. The elevation dependence of snow for ROMO is discussed in Section 5-13. On average, the ROMO study area exhibits a change of +1% to -16% in the area with significant snow cover (depth > 0.5 m) on April 15th compared to the 2000-2013 historic average, and a decline of 6-38 percent for May 15th for the scenarios considered (Tables 5-6, 5-7).

5.12.1 SWE and Snow Covered Area for representative years

Figure 5-15 shows DHSVM model simulated SWE on May 15th for the wet representative year (2011). The historical simulation is shown along with three of the five future scenarios, chosen to represent the central scenario (cnrm), the greatest change in snowpack (Hot/Dry, hadgem2) and the least change (Warm/Wet, giss). The future scenarios answer the question "what would the snowpack in a wet year (like 2011) look like in the 2040's through 2070's under these scenarios of climate change." Note that the "greatest snowpack change" scenario is different for ROMO than for GLAC. We have included Hot/Dry as well as a Warm/Dry scenario in the choice of scenarios for ROMO because a significant number of climate models project drying conditions in ROMO, whereas in GLAC, the vast majority of climate models predict a wetter future.

Figures 5-16 and 5-17 shows SWE for the "Near Normal" (2009) and "Dry" (2002) year. One can see that in the dry year, the snow cover is already very low even in the historical simulation with maximum SWE in the domain approximately of ~0.5m on May 15th compared to values of ~1.0 m for the wet year.

Figure 5-18 summarizes the results in terms of the total snow covered area (km^2) within the study area polygon. In this case, the threshold used is 5mm of SWE, representing a light snow cover, and for May 15th, comparable to the results in McKelvey. Comparing the Wet and Dry years we see a more complicated pattern emerge. As in GLAC the wet year (2011) is less vulnerable to climate change in terms of percentage of area lost. Unlike GLAC, the near normal year (2007) shows large percentage declines, comparable to those of the dry year 2002. The numerical values of snow covered area for all years, as well as percent changes for these quantities are shown in Table 5-7. **On average, the ROMO study area exhibits a change of +1% to -16% in area with significant snow cover (depth > 0.5 m) for April 15th compared to the 2000-2013 historic average, and a decline of 6-38 percent for April 15th for the scenarios considered (Tables 5-6, 5-7).**

ROMO	Snow Covered Area sq-km [5 mm SWE threshold]																	
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	1575	1522	1575	1503	1564	1506	1433	1503	1500	1587	1507	1583	1586	1594	1393	1595	1561	1587
	Central [canesm]	1442	1348	1486	1519	1428	1530	1026	1550	1536	1447	1506	1495	1526	1582	1105	1500	1454	1487
	Hot/Dry [hadgem2]	1317	1199	1405	1491	1246	1575	917	1496	1530	1475	1595	1463	1485	1569	806	1578	1384	1480
	Hot/Very Wet [miroc]	1123	944	1248	1360	1208	1528	835	1418	1439	1094	1586	1275	1351	1505	1010	1589	1282	1313
	Warm/Wet [gfdl]	1539	1486	1555	1585	1507	1595	1253	1584	1586	1576	1597	1573	1582	1593	1251	1594	1528	1579
	Warm/Dry [ipsl]	1509	1438	1552	1572	1508	1593	1122	1579	1580	1552	1597	1557	1557	1591	1206	1594	1507	1557
1-May	historical	1557	1519	1537	1546	1417	1502	1368	1526	1564	1568	1506	1573	1542	1594	1058	1593	1514	1560
	Central [canesm]	1367	1274	1380	1256	1125	1559	957	1569	1394	1296	1590	1441	1387	1576	735	1538	1340	1384
	Hot/Dry [hadgem2]	1180	1073	1135	1096	900	1486	829	1306	1250	1265	1577	1341	1172	1547	570	1491	1201	1215
	Hot/Very Wet [miroc]	1058	873	1075	1030	928	1449	726	1555	1238	979	1563	1172	1217	1494	475	1457	1143	1124
	Warm/Wet [gfdl]	1496	1442	1459	1460	1233	1583	1154	1584	1515	1520	1595	1549	1496	1591	897	1587	1447	1485
	Warm/Dry [ipsl]	1460	1429	1486	1448	1262	1577	1055	1591	1516	1494	1594	1536	1452	1590	830	1582	1431	1490
15-May	historical	1463	1452	1173	1281	1245	1587	1041	1536	1507	1481	1590	1512	1516	1591	915	1574	1404	1494
	Central [canesm]	1122	1148	895	906	926	1527	667	1316	1353	1047	1553	1185	1302	1535	612	1424	1145	1151
	Hot/Dry [hadgem2]	840	912	565	679	661	1376	479	982	945	922	1410	891	1039	1431	427	1344	919	917
	Hot/Very Wet [miroc]	885	751	700	779	754	1371	484	1117	1032	816	1485	943	1163	1424	403	1304	963	914
	Warm/Wet [gfdl]	1306	1335	993	1309	1040	1570	841	1420	1380	1355	1579	1401	1441	1580	762	1542	1291	1367
	Warm/Dry [ipsl]	1290	1316	1023	1084	1063	1562	817	1433	1385	1317	1582	1410	1444	1578	723	1534	1285	1351
ROMO	Snow Covered Area % change [5 mm SWE threshold]																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central [canesm]	-8	-11	-6	-5	-9	0	-28	-3	-3	-9	0	-6	-4	-1	-21	0	-7	-5
	Hot/Dry [hadgem2]	-16	-21	-11	-6	-20	-1	-36	-6	-4	-7	0	-8	-6	-2	-42	-1	-11	-7
	Hot/Very Wet [miroc]	-29	-38	-21	-15	-23	-4	-42	-11	-10	-31	-1	-19	-15	-6	-27	0	-18	-17
	Warm/Wet [gfdl]	-2	-2	-1	0	-4	0	-13	-1	0	-1	0	-1	0	0	-10	0	-2	0
	Warm/Dry [ipsl]	-4	-5	-1	-1	-4	0	-22	-1	-1	-2	0	-2	-2	0	-13	0	-3	-2
1-May	Central [canesm]	-12	-16	-10	-19	-21	-2	-30	-2	-11	-17	0	-8	-10	-1	-31	-3	-11	-11
	Hot/Dry [hadgem2]	-24	-29	-26	-29	-36	-7	-39	-18	-20	-19	-1	-15	-24	-3	-46	-6	-21	-22
	Hot/Very Wet [miroc]	-32	-43	-30	-33	-34	-9	-47	-3	-21	-38	-2	-26	-21	-6	-55	-9	-24	-21
	Warm/Wet [gfdl]	-4	-5	-5	-6	-13	-1	-16	-1	-3	-3	0	-2	-3	0	-15	0	-4	-4
	Warm/Dry [ipsl]	-6	-6	-3	-6	-11	-1	-23	0	-3	-5	0	-2	-6	0	-22	-1	-5	-5
15-May	Central [canesm]	-23	-21	-24	-29	-26	-4	-36	-14	-23	-29	-2	-22	-14	-4	-33	-10	-18	-23
	Hot/Dry [hadgem2]	-43	-37	-52	-47	-47	-13	-54	-36	-37	-38	-11	-41	-31	-10	-53	-27	-35	-39
	Hot/Very Wet [miroc]	-40	-48	-40	-39	-39	-14	-53	-27	-32	-45	-7	-38	-23	-10	-56	-17	-31	-39
	Warm/Wet [gfdl]	-11	-8	-15	-13	-17	-1	-19	-8	-8	-9	-1	-7	-5	-1	-17	-2	-8	-9
	Warm/Dry [ipsl]	-12	-9	-13	-15	-15	-2	-22	-7	-8	-11	-1	-7	-5	-1	-21	-3	-8	-10

Table 5-6: ROMO Snow Covered Area (5 mm SWE threshold) Top: Area (km^2) in historical average (2000-2013) and five future scenarios. Bottom: percent change in future simulations compared to historical. Average and Median values also shown. The representative dry year is 2002, wet is 2011, and near normal is 2007. The representative wet year is the same for both areas, but the wet and dry years are different.

5.12.2 Area and Number of years with ≥ 0.5 m Snow Depth

Because of interest in wolverine denning sites, we analyze snow depth ≥ 0.5 m, which we will refer to here as "significant snow." Figure 5-19 shows the area with snow depth ≥ 0.5 m within the study area. Because of the more stringent threshold for snow, the effects are somewhat larger than for the light snow cover. The numerical values of snow covered area at the ≥ 0.5 m threshold are shown in Table 5-7 for all years, as well as percent changes for these quantities. In this table, we note that dry years such as 2002 see increases in snow covered area for the Hot/Very Wet and Warm/Wet scenarios. As in GLAC, dry years are somewhat buffered against change, and in fact can see increases in high-altitude "significant" snow for scenarios with increased precipitation. This is a result of the elevational dependence of snowpack change that will be discussed in the next sub-section.

Figure 5-20 shows a map of the number of years (out of 16 possible) where each model pixel had at least 0.5 m of snow depth on May 15th. This summary statistic is analogous to that used by the Copeland study, except that there are more years of data, and these maps use a much higher threshold of snow. The projections show declines in the number of years with significant snow. Visually, the changes depicted are more subtle than those for GLAC. The areas with frequent (14-16 years) availability of significant snow become concentrated in smaller, relatively higher elevation areas in the study area.

The effects of climate change on snow melt have been presented as analogous to a "time shifting" of the melt season earlier in the year. For example, McKelvey (2011) used the May 31st vs. May 15th snow covered area as a proxy for a 2-week shift in the melt season. Figure 5-21 contrasts the evolution of the snowpack with respect to the number of years with significant snow from April 15th to May 15th in the historical simulations (Top Row) with the Warm/Wet scenario (giss, Middle Row) and Hot/Wet (hadgem, Bottom Row) scenarios. We see that the Warm/Wet scenario, shows the least change in the number of years compared to the historic snow cover in terms of the availability of significant snow. The Hot/Dry "greatest change" scenario, illustrates that the combination of drying and warming leads to very large declines in the persistence of snow that are evident by May 15th, however with smaller changes on April 15th and May 1st.

5.13 Elevation Dependence of Snowpack Change in the DHSVM model

Snowpack accumulation and melt depends critically on temperature and hence on elevation. In the Warm/Dry and Hot/Dry scenarios, both the reduction in precipitation and the warming act to reduce Spring snowpack. For the scenarios with warming and increased precipitation there are two countervailing forces that play out along an elevational gradient. A warmer, wetter future is one in which the freezing level and snow line tends to be higher, but with the potential for greater snowpack accumulation during the cold season at high elevations. The warming also tends to lead to an earlier snowmelt, so that the increased high-elevation snowpack is more evident early in the Springtime than later

Figures 5-22 shows the percent change in May 1st snow covered area (SCA; ≥ 0.5 meters depth) for GLAC, computed for 200 m elevation bands. The elevation of observed den sites is noted by triangles, with den sites ranging from approximately 1500m to 2300 m. There is little change (<10%) in SCA for 4 of the 5 scenarios above 2000m. There is greater than 60 % loss of SCA below 1400m for 4 of the 5 scenarios. Between these two elevations – and in the regions where most observations of dens have been noted – the snowpack change is very sensitive to elevation and to the particular future climate scenario. Most of the dens are at 1800 to 2000, below that band large losses predicted, above that elevation band minimal losses predicted accept in maximum warming scenario. Figure 5-23 shows the elevation dependence of the May 1st snowpack measured in terms of snow water equivalent (SWE). Viewing snowpack in terms of SWE illustrates more clearly that the Hot/Very Wet future scenario has increased its snowpack between 2300 – 2900 m elevation despite completely losing its snowpack at 1000m elevation. Comparing Figure 5-22 (SCA) with Figure 5-23 (SWE) illustrates that SWE can have modest declines without affecting the area with significant snow depth. The implications is that wet, cold climate of the GLAC study area can act as a "buffer" to change in the area of ≥ 0.5 meter deep snow on May 1st, at least at relatively high elevations within the study area.

Figure 5-24 shown the May 1st SCA (≥ 0.5 m depth) for ROMO. For elevations above 3400m only modest (under 20%) losses of SCA are seen. Figure 5-25 shows only modest (under ~20%) losses in SWE for that elevation band as well with two scenarios (Warm/Wet (giss) and Hot Very Wet (miroc) having slight increases. Below 3400m the losses in SWE become much larger, the lower the elevation. Comparison of Figures 5-24 and 5-25 shows that the relationship between SWE loss and SCA loss is not always straightforward, with a more complicated elevation dependence for SCA than for SWE.

This phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. Regonda et al. (2005) found little historical change in snowpack in the Western United States above approximately 2500m elevation despite observed warming trends. and Lettenmaier (2007) considered VIC hydrology model projections and reported as strong elevation dependence for snowpack loss in the Colorado River basin below 2500 m elevation (their data was visualized in Ray et al. 2008). Two recent studies are of special interest because they focus on areas near those considered here. Sospendra-Alfonso et al (2015), on an area near the GLAC study area, find that historically, temperature has been a larger driver of April 1st snowpack only below about 1560 m elevation, with precipitation the main driver of variability above that elevation. Scalzitti et al. (2016) investigated a single climate change scenario using a high-resolution weather model and found that the critical elevation below which temperature dominates snowpack rises by about 250m in the Colorado Rockies, and rises by about 191 m in the Northern Rockies hear the GLAC study area. While it is difficult to these results directly to the present study due to differences in methodology, the qualitative picture remains – projected warming has a larger effect at lower elevations whereas projected precipitation changes may dominate the Springtime snowpack in the high country.

ROMO	Snow Covered Area sq-km [0.5 m depth threshold]																	
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	1000	803	1176	1021	776	1571	924	1008	1178	1336	1536	1111	768	1529	710	935	1086	1014
	Central [canm]	914	727	1170	929	765	1475	757	1039	1023	999	1533	1035	747	1478	583	967	1009	983
	Hot/Dry [hadgem2]	796	660	963	922	699	1372	692	891	1042	1076	1482	994	737	1417	485	887	945	906
	Hot/Very Wet [miroc]	781	588	948	897	724	1271	629	990	1071	811	1500	845	761	1361	426	1043	915	871
	Warm/Wet [giss]	1006	789	1184	1038	781	1553	862	1019	1217	1313	1559	1157	806	1531	677	1051	1100	1074
	Warm/Dry [ncc]	823	690	1062	821	728	1499	742	817	960	1123	1442	987	700	1462	565	826	953	825
1-May	historical	871	852	1029	819	719	1556	841	987	983	1147	1365	1148	837	1519	594	1119	1024	985
	Central [canm]	835	747	944	713	661	1423	710	888	811	847	1286	980	769	1454	472	1052	912	841
	Hot/Dry [hadgem2]	742	636	742	672	561	1254	636	725	797	840	1136	817	703	1364	356	845	801	742
	Hot/Very Wet [miroc]	736	596	772	694	595	1182	583	819	845	706	1251	825	759	1326	315	1105	819	766
	Warm/Wet [giss]	890	822	960	799	691	1521	782	915	981	1110	1406	1093	837	1510	541	1141	1000	938
	Warm/Dry [ncc]	773	720	927	723	665	1464	716	792	800	965	1191	1004	762	1441	490	962	900	796
15-May	historical	852	864	705	712	681	1549	532	1017	943	995	1357	1005	981	1454	577	1041	954	962
	Central [canm]	738	699	569	556	569	1377	406	834	728	709	1151	744	854	1328	429	853	784	733
	Hot/Dry [hadgem2]	584	546	296	398	406	1104	238	611	640	610	925	505	691	1080	262	635	596	597
	Hot/Very Wet [miroc]	636	558	451	534	497	1136	298	753	724	610	1110	627	818	1175	271	907	694	631
	Warm/Wet [giss]	809	797	629	670	632	1502	487	911	895	936	1320	902	957	1421	513	988	898	898
	Warm/Dry [ncc]	753	721	608	617	610	1455	402	826	778	832	1190	866	859	1343	484	897	828	882

ROMO	Snow Covered Area % change [0.5 m depth threshold]																	
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central [canm]	-9	-9	-1	-9	-1	-6	-18	3	-13	-25	0	-7	-3	-3	-18	3	-7	-3
	Hot/Dry [hadgem2]	-20	-18	-18	-10	-10	-13	-25	-12	-12	-19	-4	-11	-4	-7	-32	-5	-13	-11
	Hot/Very Wet [miroc]	-22	-27	-19	-12	-7	-19	-32	-2	-9	-39	-2	-24	-1	-11	-40	12	-16	-14
	Warm/Wet [giss]	1	-2	1	8	1	-1	-7	1	3	-2	1	4	5	0	-5	12	1	6
	Warm/Dry [ncc]	-18	-14	-10	-20	-6	-5	-20	-19	-19	-16	-6	-11	-9	-4	-20	-12	-12	-19
1-May	Central [canm]	-4	-12	-8	-13	-8	-9	-16	-10	-17	-26	-6	-15	-8	-4	-21	-6	-11	-15
	Hot/Dry [hadgem2]	-15	-25	-28	-18	-22	-19	-24	-27	-19	-27	-17	-29	-16	-11	-40	-24	-22	-25
	Hot/Very Wet [miroc]	-15	-30	-25	-15	-17	-24	-31	-17	-14	-38	-8	-28	-9	-13	-47	-1	-20	-22
	Warm/Wet [giss]	2	-3	-7	-3	-4	-2	-7	-7	0	-3	3	-5	0	-1	-9	2	-2	-5
	Warm/Dry [ncc]	-11	-15	-10	-12	-7	-6	-15	-20	-19	-16	-13	-13	-9	-5	-18	-14	-12	-19
15-May	Central [canm]	-13	-19	-19	-22	-17	-11	-24	-18	-23	-29	-15	-26	-13	-9	-26	-18	-18	-24
	Hot/Dry [hadgem2]	-31	-37	-58	-44	-40	-29	-55	-40	-32	-39	-32	-50	-30	-26	-55	-39	-38	-38
	Hot/Very Wet [miroc]	-25	-35	-36	-25	-27	-27	-44	-26	-23	-39	-18	-38	-17	-19	-53	-13	-27	-34
	Warm/Wet [giss]	-5	-8	-11	-6	-7	-3	-9	-10	-5	-6	-3	-10	-2	-2	-11	-5	-6	-7
	Warm/Dry [ncc]	-12	-17	-14	-13	-10	-6	-25	-19	-17	-16	-12	-14	-12	-8	-16	-14	-13	-17

Table 5-7: ROMO Snow Covered Area (0.5 m snow depth threshold) Top: Area (km^2) in historical average (2000-2013) and five future scenarios. Bottom: percent change in future simulations compared to historical. Average and Median values also shown. The representative dry year is 2002, wet is 2011, and near normal is 2007.

6 Comparing results with McKelvey

An overview of the methodological similarities and differences between this study and McKelvey et al (2011) was presented in section 2.2. The differences in aims of these studies leads to challenges in making a direct comparison. The primary difference is in the choice of study areas – west-wide vs. much smaller selected areas near treeline, which has implications for the biological hypotheses that may be addressed. Their work focused on May 1st snow depth as a proxy for May 15th snow disappearance, while we directly estimated the May 15th snow disappearance. McKelvey investigated persistence of even a snow cover to May 15th as a correlate of wolverine habitat, as noted in Aubry et al (2008). This study focuses on high-elevation terrain and on the persistence of deeper snowpack. We also analyze our model results for the presence or absence of deeper snow (nominally greater than or equal to 0.5 meters depth) on April 15th and May 1st. [6]

Nonetheless some general statements can be made relating the two studies. Figure 5-26 shows snowcover under McKelvey's historic and "miroc 2080's" (or hotter, greatest change) scenario. The GLAC and ROMO areas have been outlined. A close examination of this figure shows that snow cover persists in our study areas, even for their hotter scenario of change (miroc "2080's). The greatest loss of snow cover in McKelvey occurs at lower elevations than were included in GLAC or ROMO. Because of the increased resolution of our study we are able to consider whether any pockets of snow with depth ≥ 0.5 meters will persist.

The choice of future climate scenarios differs somewhat from McKelvey. We have intentionally included scenarios that represent the range of possibilities indicated by the CMIP5 climate models. McKelvey used climate model output from Littell, who chose scenarios based solely on projected warming. For GLAC, this choice fortuitously included a range of precipitation changes as well. For ROMO, however, McKelvey's scenarios include only a narrow range of precipitation change, where we include scenarios with significantly increased wintertime precipitation as well as scenarios with drying. This is a significant factor, given the buffering effect that increased precipitation has on snowpack loss at high elevations.

While McKelvey focused snowpack projections entirely on the long-term average, we investigate how climate variability – the sequences of wet and dry years -- intersects with scenarios of change. For ROMO in particular we find that dry years behave differently than wet years, with dry years benefitting from the increased precipitation in several of our future scenarios. This emphasizes the importance of planning for a range of possible climate scenarios, particularly regarding the direction of change in wintertime precipitation.

The question arises as to how the fine-scale projections of snow persistence in other areas might reasonably be inferred from the two study areas considered here. Figure 5-26 indicates many areas in the western United States that show persistence of snow cover in McKelvey's scenarios,

[6] The study originally focused on May 15th to compare to the McKelvey, et al (2011) study, and June 1st to bracket the snowmelt season. However, as the study progressed, biologists because more interested in April snow.

even in the more extreme scenarios. We have investigated two study areas: a northern, relatively wet and low-elevation area GLAC, and a southern, relatively dry, and very high elevation area (ROMO). In both areas we find general declines in snow covered area under most future scenarios. The GLAC study area is broadly similar in its climate to much of the high northern Rockies, while ROMO shares features with the high mountain ranges of the Central Rockies. For areas in the McKelvey maps that show retention of snow on the higher mountain ranges it is physically reasonable to presume that a finer scale simulation would show the retention of areas of snow $\geq$ 0.5 m on May 15th. Extending this beyond the general area of the Rocky Mountains is problematic. Even within the Rockies, in regions where McKelvey's results show widespread loss of snowpack it is probably not reasonable to conclude one way or the other whether a finer scale analysis would identify snow refugia.

7 Acknowledgements

The authors acknowledge funding from USFWS Region 6 and the NOAA Physical Sciences Division, and wish to acknowledge CU Support Scientist Leanne Lestak for her work in preparation of DEM, soils, and other input files for DHSVM. This project built on ongoing work at the NOAA Physical Sciences Division and the University of Colorado on snow hydrology. Finally, we thank Kevin McKelvey, Jeff Copeland, and Jeremy Littell for their willingness to discuss their earlier projects with us and share their data.

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9 Glossary

- **Aspect:** compass direction that slope faces
- **Baseline period 1916-2000**: Deltas (changes) computed (monthly average delta) for "2040's and "2080's" compared to the 1916-2000 baseline.

- **CanESM:** A CMIP5 climate model the Canadian Centre for Climate Modeling and Analysis (canesm2.1.rcp85), forced with the RCP 8.5 higher emissions pathway, used in this report as a future scenario (Hot/Dry scenario for GLAC only) that has relatively higher increase in temperature (+~4.5 C) and about +20% increase in precipitation (See Figure 5-7)
- **Climate Sensitivity:** Regionally speaking, it is the response of a climate model for a given amount of greenhouse gas increase. More narrowly defined it is the global average temperature increase that results from a doubling of carbon dioxide over pre-industrial values.
- **CMIP3, CMIP5:** Coupled Model Intercomparison Project Phases 3 and 5. "Foundational" collections of climate model projections, used in the Intergovernmental panel on Climate Change (IPCC) 2007 and IPCC 2013 reports, respectively
- **CNRM:** A CMIP5 climate model from the French National Centre of Meteorological Research (cnrm-cm5.1.rcp85),used in this report as a future scenario (Central scenario for both GLAC and ROMO) that is relatively close to the ensemble mean in temperature increase (+~2.5 ºC) and +~5-8% increase in precipitation (See Figure 5-7).
- **DEM:** Digital elevation model
- **DSHVM:** Distributed Hydrology Soil Vegetation Model
- **ESM:** earth system models, see GCM.
- **FIO:** A CMIP5 earth system model from the First Institute of Oceanography, State Oceanic Administration of China (fio-esm.1.rcp85), used in this report as a future scenario (Warm/Dry scenario for both areas) that is relatively lower in temperature increase (+~0.8-1.6 ºC) and -~5% decrease in precipitation (See Figure 5-7).
- **FLH:** Atmospheric freezing level height is the altitude in the free atmosphere at which the temperature is 0 °C
- **GCM:** Global Climate Model, 6 were used for this report from the IPCC 2013 class of models; X of these are actually earth system models (ESM), an advanced type of GCM which have the added capability to explicitly represent biogeochemical processes that interact with the physical climate. GCM is used as a general term referring to both kinds of models, ESM is used specifically for earth system models.
- **GISS:** A CMIP5 climate model from the NASA Goddard Institute for Space Studies (giss-e2-r.1.rcp45), used in this report as a future scenario (Warm/Wet scenario for both areas). Referred to as the "Least Change" scenario because it that is relatively lower temperature increase (+~1-1.3 ºC) and +~7-10% increase in precipitation (See Figure 5-7).
- **GLAC:** An area in Glacier National Park used as a spatial unit of analysis in this report
- **HADGEM:** A CMIP5 earth system model from the United Kingdom Meteorological Office Hadley Center (hadgem2-es.1.rcp85) used in this report as a future scenario (Hot/Very Wet scenario for ROMO only) that has relatively higher temperature increase (+~ 3.5 ºC) and -~5% decrease in precipitation.
- **Internal climate variability**: The variations in the climate, even for 30-year and longer averages, that can occur due to the interactions of the atmosphere, ocean, inland surface and cryosphere. This occurs even in the absence of anthropogenic climate change.
- **MODIS:** Moderate Resolution Imaging Spectroradiometer, a satellite remote sensing instrument carried on the Terra satellite

- **MIROC:** A CMIP5 earth system model from the Japanese Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies (miroc-esm-chem.1.rcp85), used in this report as a future scenario (Hot/Wet scenario for both areas). Referred to as the "Greatest Change" scenario because it has the highest temperature increase of the scenarios (+~4 ºC) and +~10-18% increase in precipitation (see Figure 5-7). This ESM has an atmospheric chemistry (CHEM) component coupled to the MIROC-ESM (http://maca.northwestknowledge.net/GCMs.php).
- **NDSI:** Normalized Difference Snow Index, a measure of snow cover, has a has a linear relationship to fractional snow cover (FSC)
- **North American Freezing Level Tracker**: NCEP/NCAR Global Reanalysis 2.5º x 2.5º grid data (http://www.wrcc.dri.edu/cwd/products/)
- **Octants:** Topographic aspect, or compass direction, was classified into eight directional bins, each representing 45° of compass arc, e.g; NW, N, NE, E, SE, S, SW, and W
- **Resolution:** The VIC modeling that was the basis for McKelvey was performed on a regular grid in latitude and longitude, with a grid size of 1/16 degree on a side. The distance between degrees of longitude varies due to the curvature of the Earth, and the east-west dimension of a gridbox is smaller than the north-south distance by a factor of the cosine of latitude. At 40°N latitude, the southern extent of Rocky Mountain National Park, the gridbox is ~5km by 7 km (~37km^2). Grid boxes at Glacier National Park (~48°N) are slightly smaller. When referring to the McKelvey study we will use the "1/16 degree" notation. The DHSVM modeling used in this study was performed on a uniform grid in the Universal Transverse Mercator (UTM) map projection, which allows a near-uniform grid size of 250m by 250m (0.0625 km^2) in both of the study areas.
- **ROMO:** An area in and around Rocky Mountain NP used as a spatial unit of analysis in this report
- **SCA:** Snow Covered Area (km^2)
- **SDD:** Snow Disappearance Date, the first Day of Year after March 1 where pixel is snow-free, defined as the date which NDSI/100 was less or equal to 0.1.
- **SNODAS:** Snow Data Assimilation System, a product of the NOAA National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC)
- **SWE:** Snow water equivalent (mm). For May, snow depth is assumed to be ~ 2.5 *SWE
- **TopoWx:**
- **Snow covered area, total:**Total area covered by snow within the study boundaries in square kilometers (km^2)
- **Snow covered area, fractional:** Percentage of the total land area that is covered by snow; this can be within the study boundaries, aspect area, or elevation bands
- **VIC:** Variable Infiltration Capacity hydrologic model
- **UTM:** Universal Transverse Mercator spatial coordinates

FIGURES – see separate file

From: Joe Barsugli
To: Andrea Ray - NOAA Federal; Guinotte, John
Cc: Steve Torbit
Subject: Re: Wolverine Snow persistence report
Date: Wednesday, September 6, 2017 3:57:22 PM

Andrea, can talk. call 323-465-2371 for the landline. Joe

On 9/6/17 2:32 PM, Andrea Ray - NOAA Federal wrote:

> thanks! will take a look...
>
> On Wed, Sep 6, 2017 at 3:14 PM, Guinotte, John <john_guinotte@fws.gov> wrote:
>
> > Here is the latest version of the text with table 5-2 updated. Some of the snow depths for the dens went up significantly using the new historical model runs. All of the known natal dens had > 1m of snow on April 15.
> > Best, John
> >
> > John Guinotte
> > Spatial Ecologist
> > 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 Wed, Sep 6, 2017 at 12:50 PM, Joe Barsugli <joseph.barsugli@noaa.gov> wrote:
> >
> > > Yes, that table was one where I had a big question mark -- has it been done with the updated runs. thanks for updating the numbers. Joe
> > >
> > > On 9/6/17 11:47 AM, Andrea Ray - NOAA Federal wrote:
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Andrea

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> John Guinotte
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> Ecological Services
> U.S. Fish and Wildlife Service
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> 134 Union Blvd., Lakewood, CO 80228
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Joseph Barsugli
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CIRES, UCB 216
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From: Joe Barsugli
To: Guinotte, John
Cc: Andrea Ray - NOAA Federal; Steve Torbit
Subject: Re: Wolverine Snow persistence report
Date: Wednesday, September 6, 2017 4:10:15 PM
Attachments: SCA_values.xlsx

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SCA Comparison (km2) - ROMO				0.5 m SD
Date	Year	Historical	hadgem2-es.1.rcp85	cnrm-cm5.1.rcp85
	1998	1000.3	795.6875	913.8125
	1999	803.38	659.5625	727.25
	2000	1175.8	963.4375	1169.75
	2001	1020.9	922.3125	929.125
	2002	775.69	699.4375	764.625
	2003	1570.6	1371.8125	1474.75
	2004	923.81	691.5625	756.5625
	2005	1007.6	890.5625	1038.625
15-Apr	2006	1178.1	1042.1875	1023.125
	2007	1336.4	1076.375	999.0625
	2008	1536.1	1482.25	1532.5625
	2009	1110.9	993.5	1035.25
	2010	767.88	736.5	747.25
	2011	1528.6	1416.9375	1478.375
	2012	710.25	485.125	583
	2013	934.94	887.0625	966.8125
	Avg	1086.3	944.6445313	1008.746094
	1998	870.69	742.4375	834.9375
	1999	851.69	635.875	746.5625
	2000	1028.6	742.1875	944.0625
	2001	819.06	672.0625	712.5
	2002	719	561.3125	661.1875
	2003	1555.9	1253.875	1423.3125
	2004	840.69	635.9375	710.375
	2005	986.63	724.5	888.375
1-May	2006	982.69	797	810.75
	2007	1146.9	839.9375	846.8125
	2008	1365.4	1136.25	1286.1875
	2009	1148.4	816.5625	980.0625
	2010	837.25	703.125	769.4375
	2011	1518.9	1354.1875	1453.625
	2012	594.44	355.75	472.125
	2013	1119	845.1875	1051.9375
	Avg	1024.1	801.0117188	912.015625
	1998	851.56	583.875	738
	1999	863.63	545.9375	698.8125
	2000	704.5	295.8125	569.0625
	2001	712	397.6875	555.6875
	2002	681.06	405.6875	568.625
	2003	1549.4	1103.875	1377.0625

15-May

2004	532.31	237.5625	406.1875
2005	1017.1	610.875	833.5625
2006	943.38	640.25	728.4375
2007	994.75	609.5	708.5625
2008	1356.9	925	1150.625
2009	1004.5	505.0625	743.5
2010	980.63	691.25	853.9375
2011	1453.7	1080.0625	1327.5
2012	577.25	262.3125	429.0625
2013	1041	634.625	852.5625
Avg	953.98	595.5859375	783.8242188

1-Jun

1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013

) Threshold		
fio-esm.1.rcp45	giss-e2-r.1.rcp45	miroc-esm.1.rcp85
822.5625	1006.375	780.5
689.75	788.5	587.75
1061.75	1184.0625	947.6875
820.875	1097.6875	897.375
728.4375	780.875	723.8125
1498.875	1552.8125	1270.6875
742.1875	861.5625	629.0625
817.375	1018.9375	990.4375
959.6875	1216.8125	1071.4375
1123.0625	1313.1875	811.4375
1442.0625	1558.5	1499.9375
986.625	1157.125	845.125
700.3125	805.75	760.625
1462.3125	1531.375	1360.625
565.125	677.1875	426.125
826.4375	1051.125	1043.4375
952.9648438	1100.117188	915.3789063
772.625	889.6875	736.3125
720.375	821.9375	596.1875
927.3125	959.8125	772.4375
723.0625	798.5625	694.3125
665.3125	691.25	595.0625
1463.625	1520.875	1181.5
715.5	782.1875	583.375
792.0625	915.1875	819.25
800.1875	981.3125	844.5
964.8125	1109.75	706.125
1190.9375	1406.1875	1250.8125
1003.5	1092.625	825.125
762.1875	837.25	759.4375
1441.125	1510	1326.0625
489.8125	541.25	314.625
962.0625	1141.4375	1105
899.65625	999.9570313	819.3828125
753.25	809.1875	635.5
721	796.625	558.25
607.5625	628.5	450.5625
617.25	669.5	534.0625
609.8125	631.8125	497.4375
1455.3125	1501.75	1136.125

401.8125	486.8125	298.3125
825.625	910.6875	752.5
778.375	894.6875	723.6875
831.75	936.125	609.6875
1189.75	1319.5625	1110.125
866.4375	901.9375	627.375
859.125	957.375	818.375
1343.0625	1421.125	1174.5
484.4375	512.75	271
897.3125	987.625	907.375
827.6171875	897.8789063	694.0546875

From: Andrea Ray - NOAA Federal
To: Guinotte, John
Subject: Re: Wolverine Snow persistence report
Date: Thursday, September 7, 2017 10:54:29 AM

Thanks, John. I talked to Joe last night and I'm making some edits now, including yours. It turns out that he really only had concerns with a couple of the bullets, and I'm adjusting those now

A note on this sentence that you edited -- the elevations we had put in were for the modeling itself. Bc we were modeling hydrologic basins, some of them are a bit lower than tree line. The numbers I put in were for the elevation of the lowest & highest pixel in the modeling -- and those lower elevations are shown on graphics. However, the min pixels were't the same around the edges of the study area, but the top is the top. that's too many weeds for the report, esp the ES. So I'll clarify the text with ~1000-3100m and ~2500-4253.

Linear regression of den site elevations[GJM1] and latitude in the contiguous U.S. indicated den sites in the ROMO study area would be located in an elevation range of 2700-3600 m, but documented den sites do not exist in ROMO (Guinotte, personal communication). In contrast to McKelvey's studies, our study areas are near tree line and above (~~962~~ 1800 m – 3166 m[GJM2] in GLAC, and ~~2563~~ 3200 – 4253 m[GJM3] in ROMO).

[GJM1]Sentence fragment in #2 below

[GJM2]Check these #s

[GJM3]Check these #s

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From: Guinotte, John
To: Betty Grizzle
Subject: Fwd: Wolverine Snow persistence report
Date: Thursday, September 7, 2017 5:09:33 PM
Attachments: Wolverine Rept Text FINAL 7Sept17.docx

Betty, NOAA just sent this updated report. I haven't had a chance to look at it.
Best, John

---------- Forwarded message ----------
From: **Andrea Ray - NOAA Federal** <andrea.ray@noaa.gov>
Date: Thu, Sep 7, 2017 at 4:59 PM
Subject: Re: Wolverine Snow persistence report
To: Joe Barsugli <joseph.barsugli@noaa.gov>
Cc: "Guinotte, John" <john_guinotte@fws.gov>, Steve Torbit <Stephen_Torbit@fws.gov>

Hi John and Steve, Here's the full report in both word (separate files for text and figures), and a combined PDF (Wolverine Rept Text and Figures_7 Sept 17.pdf). all have today's date at the end of the filename. I'm attaching the word file for the text only.

Even the PDF is too large to email, so they're all in a new "final report" subfolder in the Report folder on googledrive: https://drive.google.com/drive/folders/0B6ksrl3lWQI4cld4NVF4VEppRE0

As Joe pointed out, some of the findings don't lend themselves very well to a short bullet -- they're just more complicated than that. Here's how we summarized our findings in the context of McKelvey, one of the bullets in the comparison section on p 6 of the executive summary:

"McKelvey reported a 33% decline in snow cover for western North America for the 2030-2059 period in their ensemble mean climate change scenario ("ensemble2040s"), and a 63% decline for the 2070-2099 period ("ensemble2080s"). The closest comparison with this study is to look at May 15th "light snow cover" (>= 5 mm SWE) for the Central scenario, compared to the Ensemble 2040s results. The Central scenario is not an ensemble mean, but similar to an ensemble mean, was chosen to represent the central tendency of GCM projections in the period 2041-2070. For this scenario, we find losses in >= 5 mm SWE of 24% in GLAC and 18% in ROMO (Tables 5-4 and 5-6). Because our modeling used smaller, higher elevation areas focused on denning, we would not expect our results to replicate the snow loss reported in McKelvey. We show smaller losses a decade further in the future. A similar discrepancy holds of one compares only to the Montana and Colorado statewide snow loss reported in McKelvey."

And yes, the ES stretches to a total of 5 pages (title page is first) -- but as we kept adding actual numbers and elevations, etc, it kept getting longer. Those bullets are copied to the beginning of each section.

Standing by for any other questions.

Andrea

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> > John,Andrea,
> >
> > I have made several changes to the text so you should look at this revised text document. Because of the increased amount of snow in ROMO in the corrected runs, we have had to remove some statements on the uniqueness of ROMO -- and on whether GLAC is really more buffered than ROMO.
> > \
> >
> > The main body of the text has been carefully edited, but the main points and executive summary are not changed to reflect many of the details for GLAC and ROMO projections. They need to be updated according to the new text.
> >
> > Joe
> >
> > On 9/5/17 5:35 PM, Guinotte, John wrote:
> >
> > > Thanks Andrea. I'll read through it tomorrow and get back to you.
> > > Best, John
> > >
> > > John Guinotte
> > > Spatial Ecologist
> > > 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 Tue, Sep 5, 2017 at 5:22 PM, Andrea Ray - NOAA Federal <andrea.ray@noaa.gov> wrote:

> Hi John -- Here's the report with new title, and the figures are in the drive here, with today's date: https://drive.google.com/drive/folders/0ByT4y_bFYaBGem5kWENvSFc4eXM
>
> Joe is going thru it now while on a plane, and expects that there will only be minor edits. If so, I'll do those first thing in the morning, but I want you to have this now.
>
> I expect we'll be in touch in the next few days as questions/comments arise!
>
> Andrea
>
> --
> --
> Andrea J. Ray, Ph.D.
> NOAA Earth System Research Lab, Mailcode R/PSD1
> 325 Broadway, Boulder, CO 80305-3328
> (tel) 303-497-6434
> (fax) 303-497-6449
> andrea.ray@noaa.gov
> www.researchgate.net/profile/Andrea_Ray2

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Joseph Barsugli
Research Scientist III
CIRES, UCB 216
University of Colorado at Boulder
cell:720-244-5922

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Andrea J. Ray, Ph.D.
NOAA Earth System Research Lab, Mailcode R/PSD1
325 Broadway, Boulder, CO 80305-3328
(tel) 303-497-6434
(fax) 303-497-6449
andrea.ray@noaa.gov
www.researchgate.net/profile/Andrea_Ray2

--
Joseph Barsugli
Research Scientist III
CIRES, UCB 216
University of Colorado at Boulder
cell:720-244-5922

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Joseph Barsugli
Research Scientist III
CIRES, UCB 216
University of Colorado at Boulder
cell:720-244-5922

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--
Andrea J. Ray, Ph.D.
NOAA Earth System Research Lab, Mailcode R/PSD1
325 Broadway, Boulder, CO 80305-3328
(tel) 303-497-6434
(fax) 303-497-6449
andrea.ray@noaa.gov
www.researchgate.net/profile/Andrea_Ray2

Future snow persistence in Rocky Mountain and Glacier National Parks: An analysis to inform the USFWS Wolverine Species Status Assessment

A Report to the U.S. Fish and Wildlife Service Region 6

7 September 2017

Andrea J. Ray[1], Joseph J. Barsugli[2], Ben Livneh[3] Candida F. Dewes[2], Imtiaz Rangwala[2], Aaron Heldmyer[3], Jenna Stewart[3]

[1]NOAA/ESRL/Physical Sciences Division
Boulder, CO
[2]CU/Cooperative Institute for Research in Environmental Sciences (CIRES)
[3]CU Civil, Environmental & Architectural Engineering

Corresponding Author:
Andrea J. Ray, Ph.D.
303-497-6434
andrea.ray@noaa.gov

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Executive Summary

Overview: This study is a fine-scale assessment of snow extent and depth for two areas within and surrounding Glacier (GLAC) and Rocky Mountain (ROMO) National Parks. The analysis was done for both the recent past, using MODIS satellite-based remote sensing, and in historic simulations and projections of future snowpack using a high-resolution hydrologic model. The fine scale hydrologic modeling allows for the consideration of snow processes such as dependence on terrain slope and aspect that are important to understanding high elevation snow persistence in a changing climate and were not considered in previous work.

Methods: The report intentionally builds on previous work by McKelvey et al. (2011) extending that work by providing a higher resolution spatial scale analysis for two case study areas, and a broader range of future scenarios. Two areas were studied: a high latitude area near tree line within Glacier National Park, where tree line occurs at ~1800-2100 m (Figure 2-1) that is currently occupied by wolverines; and a lower latitude area within Rocky Mountain National Park, where tree line occurs at higher elevation (~ 3500 m) (ROMO, Figure 2-2). These sites were chosen to bracket the range of latitude and elevation wolverines currently occupy in the contiguous U.S. A detailed comparison of their methodologies and ours is provided in Table 2-1, and a discussion of results in Section 6. Note however that the primary difference between McKelvey et al. (2011) and this study is in the choice of study areas – west-wide vs. much smaller selected areas near treeline, which has implications for the biological hypotheses that may be addressed. Their work focused on May 1st snow depth as a proxy for May 15th snow disappearance, while we focus directly on May 15th snow disappearance. We also analyze our model results for the presence or absence of deeper snow (nominally greater than or equal to 0.5 meters depth) on April 15th and May 1st.[1]

The project uses methods from the peer-reviewed, published literature to:

- Explicitly model the effects of slope and aspect, using fine-scale spatial models to analyze topographic effects on snow
- Better represent the range of plausible future changes (climate scenarios)
- Analyze year-to-year variability during the main study period (2000-2013, the years for which both MODIS satellite and hydrologic modeling were available) including wet and dry extremes within that period. We selected representative wet, dry, and near normal years from the main study period for detailed analysis and assessed how these would change under different future climate scenarios. For the two areas, these are:
    - Representative years for GLAC: 2011 (wet), 2005 (dry), 2009 (near normal).
    - Representative years for ROMO: 2011 (wet), 2002 (dry), 2007 (near normal).
- Assessing change in snow persistence by elevation, with emphasis on elevations used by wolverines for denning in GLAC, 1500m -2250. [2] Linear regression of den site elevations

[1] The study originally focused on May 15th to compare to the McKelvey, et al (2011) study, and June 1st to bracket the snowmelt season. However, as the study progressed, biologists became more interested in April snowcovered area.

[2] Actual den locations and elevations of specific dens are confidential and are not provided in this report. The full range in GLAC is ~1500m - ~2250. All but three of 14 documented dens in

and latitude in the contiguous U.S. indicated den sites in the ROMO study area would be located in an elevation range of 2700-3600 m, but documented den sites do not exist in ROMO (Guinotte, personal communication). In contrast to McKelvey's study, which included , the modeling for our study areas are near tree line and above (~1000m – 3166 m in GLAC, and ~2500 m – 4253 m in ROMO).

MODIS Observed Historic Snowpack Variability Analysis: Satellite-based MODIS snowcover data was used to assess the historical variability of snowcover in the study areas and as a basis for the spatial evaluation of the hydrologic model simulations. The historical observed snowcover was analyzed for its dependence on terrain elevation and aspect (compass direction that the slope faces).

- In GLAC, snowcovered area 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; Section 4.3).
- Even in dry years, NE-facing slopes in GLAC tend to hold more snow and melt later in the season. There is > 80% snowcover above ~2000 m elevation on May 1 during dry years, and > 95% snowcover above ~1200 m during wet years (Figure 4-6).
- In ROMO, snowcovered area also varies considerably by year (Section 4-4).
- NW-facing slopes in ROMO tend to hold more snow even during dry years. In very dry years, snowcover peaks at intermediate elevations, suggesting that the high-altitude snowpack may be particularly vulnerable in this region under warm/dry conditions (Fig 4-13).

Future Snowpack Projections (Section 5): The Distributed Hydrology Soil Vegetation (DHSVM) was run in historical simulations of the period 1998-2013. The model was validated against SNOTEL in-situ snow observations and MODIS snowcover. The model was then run for five scenarios of the future which represent a nominal 2055 climate. Scenarios were selected from CMIP5 global climate model (GCM) projections, and were chosen to span a large fraction of the range of the CMIP5 ensemble projections in each study area in terms of precipitation and temperature changes. Representative Wet, Near Normal, and Dry years were analyzed for the historical simulations and how each of these years plays out under these five future scenarios. The number of years (out of 16) with snow above 0.5m depth was also analyzed as was the change in Snowcovered Area (SCA) with depth greater than 0.5m. The average change in SCA and Snow Water Equivalent (SWE) was analyzed as a function of elevation, and for GLAC was overlayed with the elevations of wolverine den sites.

While SCA changes provide an overall metrics for the study areas, the interpretation of these reported changes should be done with care. The area-wide SCA results include snowcover changes in both forested and above-treeline terrain, which may have different implications for wolverine biology. Acknowledging this limitation, SWE raster data was provided to the FWS for further analysis.

GLAC are between 1800 and 2000m (Fig. 5-22, 23); two are above 2000m and one is below ~1500m. Our analysis highlights this 1800-2000m band, although results are reported below and above that band.

For the study area in Glacier National Park (GLAC):

- Projections for April 15th, May 1st, and May 15th Snowcovered Area and area with snow depth greater than 0.5 meters show declines on average in all scenarios, except for small increases in the Warm/Wet scenario and for almost all years (Section 5-11).
- For April 15th for the study area as a whole (Figure 2-1), there is a decline of 3-23 percent in snowcovered area with light snowcover (depth ≥ 5 mm), and a 7-44% percent decline in area with significant snow (depth > 0.5 m) for the five scenarios considered, compared to the 2000-2013 historic average. For May 15th, the area with light snowcover declines 10-36 percent, and the area with significant snowcover declines 13-50 percent (Tables 5-4, 5-5)
- On April 15th, the Warm/Wet scenario shows the least change in average SCA (2121 Sq-km) compared to the historic snowcover (2609 sq-km, 7% decline) for significant (≥ 0.5 meter) snowcover. The largest decrease is the Hot/Wet scenario (1520 sq-km) with 44% decrease. Under the Hot/Wet scenario, the April 15th significant snowpack has been diminished below the level of the historic May 15th snowpack – a month shift (Figure 5-14).
- All projections show declines in the number of years with significant snow. In each study domain, the areas with frequent availability (at least 14 out of 16 years) of significant snow (≥ 0.5 m) become concentrated in smaller high elevation areas, as seen in the maps in Figures 5-13, 5-14 (GLAC), and 5-20, 5-21 (ROMO). In contrast, lower elevation areas had the largest changes, or decreases in the number of years with significant snowcover.
- Most of the known den sites are located between 1800 and 2000m in GLAC. Below that elevation band large snow losses are predicted (40-70% decreases for two of the scenarios, 16-20% for the other three), above that elevation band there is little change in SCA for four of the five scenarios (2-8%) except in maximum warming scenario (-40%, Figure 5-22). In that 1800-2000m band, the snowpack change is sensitive to elevation and to the particular future climate scenario.
- This phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. (Section 5-13)
- For representative wet years, the higher elevations of our study areas experience only 2-7% loss of snowpack under the scenarios with "least" change and the "central" change (Figure 5-8, 5-12), although for the dry years, losses range 18-57% (Table 5-5).
- Modest declines in SWE may occur without affecting the area with significant snow depth. On May 1st, for areas at 1800m and above in GLAC, losses of ~10-30% SWE (Figure 5-23) result in losses of only ~10% snowcover. The implication is that the wet, cold climate of the GLAC study area could act as a "buffer" to change in the area of 0.5 m deep snow on May 1st, at least at the elevations above 1800m.

For the study area in and around Rocky Mountain National Park (ROMO):

- Projections of May 15th Snowcovered Area in ROMO declines on average in all scenarios, except for small increases in the Warm/Wet scenario, and for almost all years (Section 5-12).

- For April 15th for the study area as a whole (Figure 2-2), there is decline of 3-18% in area with light snowcover (depth ≥ 5 mm), and a change of -1 - +16 in area with significant snowcover (depth > 0.5 m) for the five scenarios considered, compared to the 2000-2013 historic average. For May 15th, the area with light snowcover declines 8-35 %, and the area with significant snowcover declines 6-38 percent (Tables 5-6, 5-7).
- Snowcovered Area in ROMO (≥0.5 m threshold on May 15) generally declines in wet years, shows a slight increase in (1-5%) in some years for the Warm/Wet scenarios with increased precipitation.
- One scenario with increased precipitation (Warm/Wet, giss) shows increases in April 15th SCA (Table 5-7). There are also slight increases in SWE for two scenarios at elevations at and above 3400m (Figure 5-25), but decreases in SWE for all scenarios below 3400m.
- Although no dens have been documented in ROMO, the elevation band for denning, modeled by regression analysis, is thought to be 2700-3600m. On May 1st, modest declines in SWE of ~15% and less for areas at 3400m and above result in losses of < result in losses of only ~10% snowcover (Figure 5-24, 25). 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 deep snow on May 1st. Below that band losses in SWE of ≥35% result in higher losses in SCA (20-65%), except in the scenario with least change (Warm/Wet, giss model). As in the denning band in GLAC, in that 2700-3600m band, the snowpack change is sensitive to elevation and to the particular future climate scenario.
- The phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. Studies have found little historical change in snowpack in the Western United States above approximately 2500m elevation despite observed warming trends. Other literature on this topic is discussed in Section 5.13.
- ROMO exhibited more uncertainty in projections than GLAC, because compared to GLAC, the GCM climate projections for ROMO are more uncertain, i.e. have a larger spread, as to whether precipitation will increase or decrease (Figure 5-7).
    - For April 15th –May 15th, and for wet years, at the high elevations of the ROMO study area as whole, there is only modest loss of snowcover (<13%) under most scenarios of change (Table 5-7, see 2011 representative wet year). However even in wet years, the area of significant snowpack can decline by up to 26% for the Hot/Dry climate change scenario on May 15th (Table 5-7).

Elevation dependence of change (Section 5.13): **In general, and supported by the literature (see section 5.13), the snowpack at the higher elevations of both areas is more responsive to precipitation change, while at lower elevations it is more responsive to temperature change**. For GLAC, most of the observed and inferred den sites are located within the zone where temperature dominates the future effects of change, and therefore at elevations where the changes in snowpack are highly dependent on the climate scenario and also on elevation. For the elevation of den sites in GLAC (>1800m) loss of SCA on May 1st spans the range of 5-40% loss, with a 70% decreases for the Hot/Wet (miroc GCM) scenario (Fig 5-22). Above 2200m the losses are <5% for all but the Hot/Wet scenario. For ROMO, the range is at 3200 m elevation, the middle of the inferred range for wolverine there. However, at 3600m the loss of SCA in all scenarios is < 5% (Figure 5-24).

Comparison with McKelvey's results (Section 6): There are challenges in making a direct

comparison between the studies due to differences in the goals and spatial scale. McKelvey investigated persistence of even a light snowcover to May 15th as a correlate of wolverine habitat, as noted in Aubry et al (2008). This study focuses on high-elevation terrain and on the persistence of deeper snowpack.

However, the following comparisons are valid:

- McKelvey reported a 33% decline in snow cover for western North America for the 2030-2059 period in their ensemble mean climate change scenario ("ensemble2040s"), and a 63% decline for the 2070-2099 period ("ensemble2080s"). The closest comparison with this study is to look at May 15th "light snow cover" (>= 5 mm SWE) for the Central scenario, compared to the Ensemble 2040s results. The Central scenario is not an ensemble mean, but similar to an ensemble mean, was chosen to represent the central tendency of GCM projections in the period 2041-2070. For this scenario, we find losses in >= 5 mm SWE of 24% in GLAC and 18% in ROMO (Tables 5-4 and 5-6). Because our modeling used smaller, higher elevation areas focused on denning, we would not expect our results to replicate the snow loss reported in McKelvey. We show smaller losses a decade further in the future. A similar discrepancy holds of one compares only to the Montana and Colorado statewide snow loss reported in McKelvey. Comparable scenarios for the 2080's were beyond the scope of this project.
- Examining the data from McKelvey's study in detail reveals that snowcover persists in the GLAC and ROMO study areas, even for the hotter of the two scenarios of change in their study ("miroc 2080's"). The greatest loss of May 15th snowcover in McKelvey occurs at elevations lower than ~250m below treeline that were deliberately not included in the GLAC or ROMO study areas. (Figure 5-26).
- McKelvey focused exclusively on the persistence of even light snowcover on May 15th. Because of the increased resolution of our study we are able to consider whether any pockets of snow with depth greater than 0.5 meters will persist in these areas. Results vary according to scenario, but generally show declines of 13-50% in SCA in GLAC and 6-38% in ROMO for May 15th by the 2050s. We made projections for April 15th (which McKelvey did not), which shows declines of in SCA of 7-44% in GLAC and changes of -16 - +1% in ROMO for April 1st by the 2050s.
- Our results may reasonably be generalized to the high mountain ranges within the Rockies that lie between GLAC and ROMO, with projections on average wetter in GLAC. However, without further study we cannot reasonably extend our results to say whether or not snow refugia may persist in the Central Rockies below our study elevations (~1000m). Areas below our study areas are where McKelvey indicates the greatest snowpack losses. Nor can we extrapolate to the Cascades with its very different maritime climate.
- While it is difficult to compare the McKelvey et al (2011) results directly to the present study due to differences in methodology and focus, the qualitative picture remains – projected warming has a larger effect at lower elevations whereas projected precipitation changes may dominate the Springtime snowpack in the high country.

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1 Introduction

1.1 Motivation

This report responds to the United States Fish and Wildlife Service (FWS) need for information on potential climate impacts to snow persistence. The North American wolverine (*Gulo gulo luscus*) is currently being evaluated for listing as a threatened or endangered species under the Endangered Species Act (ESA) and climate change effects on snow persistence was identified as an important factor for the future viability of the wolverine. The species was considered for listing in 2014, but FWS concluded that it did not warrant listing. They further concluded that there is significant uncertainty about how the effects of climate change will affect wolverines and their habitat in the foreseeable future, and that this uncertainty includes information on how fine-scale changes in snowcover and persistence might affect denning site selection.

This report provides FWS with a finer scale assessment of snow extent and depth at which extends previous work by McKelvey et al. (2011). We believe the inclusion of finer scale analyses as well as additional snow processes such as slope and aspect are critical to understanding high elevation snow persistence in a changing climate.

By design, our methods and models are chosen from the peer-reviewed, published literature. What we find, particularly with regard to the elevation dependence of snowpack change, is consistent with past research.

Funding was provided by the U.S. Fish and Wildlife Service, Region 6 and the NOAA/Earth System Research Lab/Physical Sciences Division. This effort builds on work underway by the project team at NOAA/ESRL/PSD, the NOAA-University of Colorado (CU) Cooperative Institute for Research in Environmental Sciences (CIRES), and CU Department of Civil, Environmental & Architectural Engineering.

1.2 Project Objectives

Persistent spring snowpack has been described as an important factor in determining suitable habitat for the wolverine, including Northern boreal forests and subarctic and alpine tundra (Aubry et al, 2007, Peacock et al, 2011). This relationship was the basis for the analysis by Copeland et al. (2010) and McKelvey et al. (2011) used in the previous FWS decision. In both studies, climate change projections of snowpack were used to characterize potential future wolverine habitat.

The goal of this effort is to identify the depth and persistence of spring snow in the future. Our primary objective is to advance scientific understanding of the current spatial extent of spring snow retention on the landscape, and the future temporal and spatial extent of snow retention through a thirty-year period, 2041-2070, centered on the year 2055. We aim to advance snow analysis and modeling to better support assessment of snow-related species, in the following ways:

- Explicitly model the effects of slope and aspect, using fine-scale spatial models to analyze topographic effects on snow
- Better represent the range of plausible future changes (climate scenarios)
- Analyze extremes from the current year to year variability: we selected representative wet, dry, and near normal years from the main study period for detailed analysis and assessed how these would change under different future climate scenarios.

Our strategy was to build on previous methods where possible to be comparable to work by McKelvey et al. (2011) and Copeland et al. (2010). We departed from their methods where necessary to take advantage of analysis techniques not feasible at the large scales used in the studies done by those authors. These include new scientific data and tools that are now available, including the following:

- Use of a longer time series of satellite and in situ observations.
- Analysis of historic snowpack variability to investigate the influences of topography on snowcover
- Use of more recent climate model output and improved criteria for choice of climate change scenarios
- Use of hydrologic modeling at highly resolved (250m) spatial scale for simulation and future projection of snowcover and depth for two case study areas in Glacier National Park and Rocky Mountain National Park.

2 Project Overview and Background

2.1 Overview

We first reviewed the observed climate and variability, in order to provide context for future changes (Section 3). We next analyzed historic snow variability from satellite remote sensing of snow extent from the year 2000 to present to determine areas of greater and lesser sensitivity to climate drivers (temperature and precipitation), and identify possible snow refugia. Prior studies also show a relationship between terrain (slope and aspect) and persistence of snow (e.g. Lundquist and Flint, 2006) and thus this factor is potentially important under in a changed climate. (Section 4). We then did an intercomparison of the satellite observations of snow with that from the DHSVM hydrologic modeling study that includes a representation of slope and aspect (the compass direction that the slope faces) of the terrain and shading on the snowpack. Finally, the DSHVM hydrologic model was forced with five future scenarios of climate change for each of the two study regions (Section 5). These future climate scenarios were derived from the latest Coupled Model Inter-comparison Project Phase-5 runs (CMIP5, Taylor et al., 2012) which informed the latest Intergovernmental Panel on Climate Change (IPCC) report (IPCC AR5, 2013).

All methodologies were chosen to be consistent with those used in existing peer-reviewed work.

2.2 Study Areas

High-resolution hydrologic modeling was needed to provide fine scale analysis of snow. However, given time, funding and computational constraints, it was necessary to limit the study domain to two areas of about 1,500-3,000km^2 for high-resolution analysis. Two study areas representing core and peripheral habitat regions in the northern and central Rocky Mountains were identified in consultation with FWS Region 6 personnel (Figures 2-1 and 2-2). We bracketed the extent of wolverine habitat conditions in the lower 48, because we were restricted to smaller areas for analysis. The two sites chosen included a high latitude, (relatively) low elevation area within Glacier National Park (Figure 2-1) that is currently occupied by wolverines and a lower latitude, high elevation area within Rocky Mountain National Park (Figure 2-2) that has had recent documented wolverine occurrence and could be a potential reintroduction site for wolverines. Both model areas encompassed elevations from ~250m below treeline to maximum elevation in each domain (962 m – 3166 m in GLAC, and 2563 – 4253 m in ROMO).[3] This elevation threshold was chosen for the analysis by FWS to represent the areas with known denning activities by wolverines.

The analysis for the GLAC and ROMO study areas is presented in separate sections, repeating descriptions to make the material self-contained for the reader who may read about only one area; similarly, complete captions are given for each area.

[3] The lowest elevation of each area was not a fixed elevation, but varied somewhat depending on the elevation of the lowest pixel in each hydrologic basin modeled, 962m for GLAC and 4253m.

2.3 The West-wide context of future climate

Global climate models (GCMs) are the primary tools used by climate scientists to examine the nature of climate change during the 21st century. These models reveal both the uncertainty of climate projections as well as underlying regional patterns of change. This section provides a west-wide context for the specific choices of future climate scenarios that will be discussed later in the report.

Understanding the uncertainty of climate projections is commonly approached through comparison of the results from multiple climate models (e.g. IPCC, 2013). There are currently about 20 modeling centers worldwide that provide output from their best model or models to be considered in the Coupled Model Inter-comparison Project Phase-5 (CMIP5, Taylor et al., 2012), an international, coordinated modeling project which informed the most recent Intergovernmental Panel on Climate Change (IPCC) assessment report (IPCC AR5, 2013). When we quantify regional changes in climate variables such as temperature and precipitation by a particular time horizon in the 21st century, we find a large spread in the extent of warming and changes in precipitation, including both increases and decreases in precipitation, as shown in regional maps (Figure 2-4 and described further in Section 5). For temperature change, much of this spread (or uncertainty) is a result of the difference among the formulations of the GCMs (e.g., their climate sensitivities), whereas for precipitation it is both the differences among GCMs and internal climate variability. Some difference also comes out of the choice of future greenhouse gases (GHG) emission scenario. However, the differences among greenhouse gas emissions scenarios is less at mid-21st century compared to later in the century, and is much smaller than other sources of uncertainty at the regional scale (IPCC, 2013).

In addition to uncertainty, the CMIP5 climate models also reveal regional patterns of change. Figure 2-3 shows projected annual and seasonal temperature and precipitation changes by 2050 (2035–2064) over the western U.S., including the northern and central Rocky Mountains, from an ensemble of the 34 climate models used for this study under the RCP 8.5, a high-end emissions scenario. The large maps show the average change for all of the models (n=34) for that season, and the small maps show the average changes of the highest 20% and lowest 20% of the models, based on the statewide change for Colorado in temperature or precipitation. For much of the central and northern Rockies, all models show a substantial warming (+2.5°F to +5.5°F). While fewer models agree about the direction of precipitation change west-wide, even the lower (drier) 20% of the models show an increase in winter precipitation for the area around Glacier National Park, although there is less agreement for the central Rockies area including Rocky Mountain National Park.

The uncertainty of climate change motivates the choice of several future climate scenarios for each study region. The regional patterns of change indicate that the range of the climate scenarios chosen will differ somewhat from region to region. The GCM output, and the specific selection of future climate scenarios for this study are discussed further in Section 5.

2.4 Comparison between our analysis and that of Copeland and McKelvey

The Copeland et al. (2010) and McKelvey et al. (2011) studies were an integral part of the previous FWS decision process. Therefore, we present here a detailed comparison of their methodologies and ours, to establish both how our methodologies followed theirs when appropriate, and diverged where new data or updated methods were available. A summary of the most salient similarities and differences between our work and the studies used previously is presented in Table 2-1.

Table 2-1: Modeling Methods Compared to McKelvey

	McKelvey (Littell)	**This Study**
Spatial Resolution (modeling)	VIC model – 1/16 degree (~5km x 7 km, ~37km^2 cell)	DHSVM model - 250m x 250m UTM grid (~0.0625 km^2 cell)
Spatial Extent	Westwide except California and Great Basin	ROMO and GLAC study areas, ~300 m below treeline and above
Process differences	Slope and aspect were not modeled and the mountains were assumed to be flat from a solar radiation process, implicit elevation bands.	Slope, aspect, shading, explicit fine scale elevation effects.
Validation	None specific to snow	Comparison to SNOTEL (ground stations) and MODIS (satellite)
Future Scenarios	Delta Method; “2045”;”2085”; from 3 GCMs selected to span westwide temperature changes.	Delta Method: ”2055” from 5 GCMs spanning regional changes in temperature and precipitation
Analysis	Changes in long-term mean snowpack only	Means and variability, including wet, near normal and dry years.
Snow representation	Binary snow/no snow at 13 cm snow depth	Analyzed snow depth at two thresholds: 5mm of SWE (‘light snow’) and 0.5m depth (‘significant snow’)

Both Copeland et al (2010; hereafter, simply Copeland or the Copeland study) and McKelvey present analysis based on satellite remotely-sensed snowcover from the MODIS. For example, Copeland calculated the number of years with snowcover on May 15th as detected in the MODIS snowcover dataset, by calculating a snow disappearance date. They found that most (45 of 75) North American den sites were in areas that snowcover persisted with 6 or 7 out of 7 years on May 15th. We also provide a historical analysis of remotely sensed snowcover from MODIS. We also investigated the of number of years of snow persistence for our study areas, however, the new MODIS product has two advantages over that available at the time of their study, 1) improved snow detection (snowcovered area, SCA), and 2) 17 years of MODIS data is now available vs the 7 available to Copeland and McKelvey. Furthermore, we investigated the relationships between snowcover persistence and both elevation and aspect (the compass direction of the slope face).

Both McKelvey et al. (2011) (hereafter, simply McKelvey or the McKelvey study) and the present study investigate projections of snowcover using a distributed hydrologic model. The McKelvey study focused its' analysis on May 1st snow depth simulated by the Variable Infiltration Capacity hydrologic (VIC) hydrology model (1/16 degree, ~5km x 7 km), "flat" gridboxes, or cells, with no slope aspect dependence). The May 1st snow depth was then converted into a proxy for May 15th snow disappearance by applying a threshold of 13 cm – a procedure they refer to as "cross-walking". All subsequent calculations of theirs were done using the May 15th snowcover proxy. The VIC model runs were documented in Littell et al. (2011) and were based on meteorological inputs from Elsner et al. (2010). The present study uses the Distributed Hydrology Soil Vegetation (DHSVM) model, which was developed by the same group at the University of Washington for fine-scale simulations, and shares many model components with the VIC model. The primary output of DHSVM is snow water equivalent (SWE). We investigate several thresholds for converting SWE to "snowcover". Conversion of SWE to snow depth is done using empirically derived conversion factors relevant to Spring.

To generate future climate scenarios, Littell (on which McKelvey results are based) used the "delta method" (described later in Section 5) for the projected changes in climate compared to present day. This study also uses the "delta method," applied in a similar manner. The McKelvey study used a range of temperature change to select GCMs representing the range or spread of future scenarios. As shown below in Section 5.10 and Figure 5.7, their chosen future scenarios reflect a range of precipitation in GLAC, but in ROMO, the three scenarios have similar precipitation changes. This project selected a larger number of future scenarios selected based on changes in both temperature and precipitation, to be consistent with recommended strategies for incorporation of uncertainties into the assessment of impacts and developing adaptation strategies (e.g. Fisichelli et al, 2016 a, b, see Section 5-8).

Analysis metrics, including the time frames of the projections differ somewhat between the two studies. The McKelvey study calculated a metric for a historic period (1915-2005 average) and two futures, 30-year averages around "2045" and" 2085." This study focused on a 30-year period around mid-century, "2055" to focus on FWS' time horizons for the wolverine and due to time and computational constraints given the project budget. Calculations for a later period using the CMIP5 climate models (e.g. ~2100) could easily be made, but were beyond the scope of this project.

We provide analysis for two thresholds of snow amount, a "light" snowcover (5 mm of snow water equivalent [SWE]), and significant, or "heavy" snowcover (equivalent to 0.5 m of snow depth). Because the Littell dataset that McKelvey used only includes May 1st snow depth simulation (and not May 15th), McKelvey's study chose a 13 cm snow depth on May1st as a proxy for snow disappearance by May 15th. We instead chose to use a much lighter threshold for presence/absence of snow on May 15th itself. Our threshold of 13mm SWE was originally chosen to be comparable to McKelvey's snow depth. Our assumptions are discussed further in Sec. 5.6.

For the purposes of determining the presence or absence of snow we use a 5mm SWE threshold. It is common modeling practice to use a low threshold for snow disappearance rather than using a strict criterion of zero, due to peculiarities with the model's numerical accounting for snow (Ben Livneh, pers. comm.) In addition, the effect of small dustings of springtime snowcover on previously bare ground were also minimized by this choice. The biologists we worked with also were concerned with analyzing the presence of "significant snow" which we defined as ≥ 0.5 m of snow depth. The value of ≥ 0.5 m was arrived at by an analysis of the modeled snow depth at known wolverine denning sites in Glacier National Park (Table 5-2). With the exception of one site that had melted out by May 15th, the other sites all have snowpack between 0.4 and 1.4 m. Note that SWE is a measure of the water content in the snowpack; to estimate depth, we assume a bulk density of the snowpack (see Section 5-5).

An important difference between this study and prior work by Copeland et al. (2010) and McKelvey et al. (2011) is the spatial scale of results. McKelvey and Copeland both presented results on a regular 1/16 degree latitude-longitude grid, in which each cell, or gridbox is ~5-7 km on a side. These cells were assumed to be flat in the model-- that is they do not incorporate slope or aspect information in their surface energy balance. The result of this is north-facing slopes are treated identically to south-facing slopes. Our study uses the Distributed Hydrology Soil Vegetation Model (DHSVM) originally developed by Wigmosta et al. (1994)[4] for simulating the snowpack at 250m x 250m resolution that incorporates other physical drivers of snowpack (a complete energy balance at the surface, a 2-layer snow model, and a 2-layer vegetation canopy model) and allows analysis of snow at different slopes and aspects (slope directions). The VIC modeling included the option for elevational snow bands within the VIC grid (Jeremy Littell, pers. comm.) but the snow band information was not explicitly used. Therefore, sub-grid scale elevational effects are implicit and approximate in the VIC model whereas it is explicitly modeled at the 250m-scale in DHSVM. A visual comparison of the gridbox sizes is shown in Figure 2-4 for further description of the terminology used to describe spatial resolution, see "resolution" in the Glossary. Neither VIC nor DHSVM include the effects of wind or avalanche redistribution of snow (see section 5-10 for additional modeling caveats).

It should be noted there are tradeoffs between our strategies and the methods of Copeland and McKelvey. The finer scale analysis presented in this report integrates slope and aspect with respect to snow accumulation and retention that are thought to be important for maintaining snow refugia for denning sites (see Fig 2 in McKelvey et al 2011), and for elevations where

[4] The most up-to-date documentation of the DHSVM model, including changes to the model subsequent to the original reference, is available from the following website: http://www.hydro.washington.edu/Lettenmaier/Models/DHSVM/documentation.shtml)

wolverine dens have been observed. The disadvantage of this improvement in spatial resolution is that the high-resolution modeling is computationally intensive. We were only able to analyze two study areas due to these computational constraints and the short time to meet FWS deadlines. The Copeland and McKelvey projects analyzed a much larger domain, including most of the wolverine range in the continental US, but does not provide detailed analysis of any habitat area.

3 Observed Climate and Variability

Key Points:

- Both study areas show upward trends in both temperature and freezing level
- Surface Air Temperature and Atmospheric freezing level are related, with a stronger relationship in ROMO (that is, a greater change in freezing level for a given surface air temperature change)
- There is year-to-year variability in historic temperature, precipitation, and hence the snowpack, leading to some extreme wet and dry years that were chosen for study:
    - Representative years chosen for GLAC: 2011 (wet), 2005 (dry), 2009 (near normal).
    - Representative years chosen for ROMO: 2011 (wet), 2002 (dry), 2007 (near normal).

3.1 Introduction

This section presents a historical analysis of the winter and spring climate variability for the two study regions, GLAC and ROMO, in order to provide context for future changes. This section includes a discussion of trends in temperature and freezing level; historical year-to-year variability in cool season (October – May) temperature and precipitation for the study areas, choice of representative years during the simulation period for cool/wet, warm/dry, and near normal conditions for the two areas; and a ranking of the representative years in a longer climate record. Later in the report, we will assess what the wet, dry and near normal years of the future may be like. A complete description of regional climate is beyond the scope of this project, but may be found in e.g. McWethy et al (2010), Garfin et al (2014), Lukas et al (2014), Shafer et al (2014), and citations therein.

3.2 Background Material: Trends in Surface Temperature and Freezing Level in the Study Areas

Temperature strongly influences hydrologic processes such as snowpack accumulation, and timing of snowmelt. Here we present some background material on observed trends in surface air temperature and on the freezing level in the atmosphere, and how these two quantities are related.

Both the Glacier and Rocky Mountain areas show a trend of increasing surface air temperature in the winter season (October-May, Figure 3-1), consistent with trends that have been observed west-wide (Garfin et al 2014; Lukas et al 2014; Shafer et al 2014). While winter season temperatures vary inter-annually, linear regression of these data (not shown) indicates about a 1.4 ºC increase in temperature from 1948-2015 for an area around Glacier, and about a 1.2 ºC increase around Rocky Mountain National Park.

Atmospheric freezing level height (FLH) represents the altitude in the free atmosphere (that is, away from the surface and its immediate influence) where the temperature is 0 °C. Above this level, the temperature of the air is typically below freezing. Freezing in the free atmosphere is indicative of the level above which precipitation falls as snow rather than rain. Freezing level height can have a strong influence on freeze-thaw processes in high-elevation regions (Bradley et al 2009). As with winter season temperatures, freezing level varies over time (Figures 3-2, 3-3), but linear regression (not shown) indicates about a 160m increase in the freezing level for Glacier (Fig 3-2), and about a 170 m increase in the freezing level for Rocky Mountain (Fig 3-3).

Figure 3-4 illustrates a strong relationship between freezing levels and surface air temperature change for both regions in October-May with explained variance (R^2) close to 0.8. For GLAC (3-1, left), a 1°C anomaly in temperature equates to about a 115 m increase in the freezing level, over the period. For ROMO, for 1°C increase in temperature there has been about a 180 m increase in the freezing level (3-1, right). If these historical relationships hold in the future, the larger change in freezing level for the ROMO study area could indicate a greater sensitivity of snowcovered area to rising temperatures.

3.3 Exploring Year-to-Year Weather Variability through the Choice of Representative Years for Detailed Analysis

One of the primary study goals is to extend the analysis to include the effects of climate change on extreme years both for years with high- and low- spring snowpack. This is in contrast to McKelvey et al (2011) who studied only the effect of climate change on the *long-term average* snowpack. Our historical snowpack analysis (Section 4) was performed for the entire period 2000-2013 and the hydrologic modeling (Section 5) for 1998-2013, and then assessed now these wet, dry, and near normal years might change under several climate change scenarios. To capture the weather variability within these periods we focus some of our analysis in Sections 4 and 5 on a representative wet, dry, and near normal year for each study area. Nonetheless, results from all years were computed.

Table 3-1: Historical Percentiles of precipitation and temperature for the representative dry, near normal, and wet years for GLAC and ROMO study areas.

	Year Type	Year	Oct. - May Precipitation Percentile	Oct. - May Temperature Percentile
GLAC	Dry	2005	6	83
	Near Normal	2009	45	42
	Wet	2011	98	6
ROMO	Dry	2002	4	45
	Near Normal	2007	56	69
	Wet	2011	96	36

To drive our choice of representative years, we investigated historical cold-season (October-May) temperature and precipitation anomalies and MODIS-based snowcovered area for 2000-2013. Years were chosen within that range to represent a cool/wet year with high spring snowpack, a "near normal" year, and a "dry" year with low snowpack. Figure 3-5 shows scatterplots of the anomalous precipitation (as % of average) and temperature (degrees Celsius) for each year of the primary study period (2000-2013) for the two study areas. For both study areas, the 2011 winter stands out as a particularly large (cool/wet) anomaly.

The choice a dry year for GLAC points to 2005. Examination of the time series of Snowcovered Area (SCA) derived from the MODIS satellite product (Figure 3-6) corroborates this choice. For ROMO the hot/dry year 2012 with exceptionally low snowcover was first chosen. However, modeling difficulties encountered in the model validation procedure described in section 5.4.2 led to the need to find an alternative "dry" year for ROMO. The scatter plot in Figure 3-5 indicates that 2004 or 2002 might both be good alternatives, and both of these years had adequate modeling success. Because 2002 had lower Spring snowcover (figure 3-6), and because it was a widely agreed upon drought year in Colorado, we chose to use 2002 as the representative "dry" year for ROMO.

For the choice of near-normal year, 2007 is indicated for ROMO, as that is closest to the center of the scatterplot in Figure 3-5. A number of choices would seem plausible for GLAC, however as no one year stands out as "most normal." To further guide our choices of representative years, we looked at the elevation profiles of SCA for the various years, and 2009 was chosen. We show the SCA as a function of elevation within the study areas (Figure 3-6cd) for the representative years. These plots indicate that the elevation profile of observed snowcover in our chosen near-normal years closely follow the median profile for 2000-2013.

3.4 The Study Period in the Longer Climate Record

Because the study period is 14 years long, the question arises as to how "extreme" the wet and dry years are in the longer climatological record. To address this question, we analyzed how often the temperature and precipitation anomalies for the study years are likely to occur in the longer (1950-2013) climatological record by computing their percentiles. Percentiles were calculated by ranking the data and using the following formula: percentile = (rank – 0.5)/(total number of years). Note that the exact rankings and percentiles may differ based on the underlying dataset and interpolation methods used, as the study areas have relatively few observing stations. However, percentiles calculated from the PRISM dataset (not shown) yield qualitatively similar results to those found below.

The percentiles of October – May precipitation and temperature averaged over the study areas are shown for the representative wet, near normal and dry in Table 3-1 for both study areas. The percentiles are calculated based on the 63 total years in the 1951-2013 period of the Livneh (2014) dataset. For GLAC, October – May 2011 was at the 98th percentile of precipitation and the 6th percentile of temperature, while 2005 was at the 6th percentile of precipitation and 83rd percentile of temperature. For ROMO, 2011 was in the 96th percentile of October – May precipitation, but only the 36th percentile of temperature, and while anomalously cold was not

extreme in temperature. 2002 was in the 4th percentile of precipitation, but only near the median in temperature.

For further reference, Tables 3-2 (GLAC) and 3-3 (ROMO) show the percentiles of precipitation and temperature for the entire study period, 2000-2013, as well as the percentiles for the April – June melt season. Even though the low precipitation was more extreme in 2002 than in 2012, the temperature was not. This is reflected in the MODIS spring snowcover (Figure 3-6), where 2002 was low, but not as nearly extreme as in 2012.

Table 3-2: Percentile of temperature and precipitation anomalies for GLAC study area based on the 1951-2013 period. Percentiles are shown for both the October – May cold season and for the April – June melt season.

GLAC	Percentile 1951-2013			
	Oct. - May Precipitation	Oct. - May Temperature	Apr. - June Precipitation	Apr. - June Temperature
2000	31	96	7	66
2001	2	37	47	58
2002	61	31	91	12
2003	33	87	13	69
2004	13	63	33	61
2005	6	83	80	47
2006	37	82	53	93
2007	21	72	6	75
2008	39	47	60	17
2009	45	42	12	34
2010	12	55	85	13
2011	98	6	87	4
2012	40	74	72	53
2013	60	66	56	29

Table 3-3: Percentile of temperature and precipitation anomalies for ROMO study area based on the 1951-2013 period. Percentiles are shown for both the October – May cold season and for the April – June melt season.

ROMO	Percentile 1951-2013			
	Oct. - May Precipitation	Oct. - May Temperature	Apr. - June Precipitation	Apr. - June Temperature
2000	45	98	40	98
2001	29	33	23	91
2002	4	45	2	96
2003	75	80	77	64
2004	21	91	75	77
2005	50	82	82	53
2006	28	74	4	94
2007	56	69	6	75
2008	80	12	45	13
2009	77	93	88	44
2010	48	13	87	37
2011	96	36	93	25
2012	10	94	7	99
2013	64	26	79	42

4 MODIS Observed Historic Snowpack Variability Analysis

Key points

- In GLAC, snowcovered area 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; Section 4.3).
- Even in dry years, NE-facing slopes in GLAC tend to hold more snow and melt later in the season. There is > 80% snowcover above ~2000 m elevation on May 1 during dry years, and > 95% snowcover above ~1200 m during wet years (Figure 4-6).
- In ROMO, snowcovered area also varies considerably by year (Section 4-4).
- NW-facing slopes in ROMO tend to hold more snow even during dry years. In very dry years, snowcover peaks at intermediate elevations, suggesting that the high-altitude snowpack may be particularly vulnerable in this region under warm/dry conditions (Fig 4-13).

4.1 Introduction

In this section, we perform an analysis of the variability of snowcover in the historical period 2000-2016 using gridded snowcover data acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS) on board the Terra satellite. The dataset and methodology of analysis is first described. The analysis for the GLAC and ROMO study areas are then presented in separate sections, repeating descriptions to make the material self-contained for the reader who may read about only one area. Each section consists of analysis of the following: a) total snowcovered area (SCA), b) SCA fractional area as a function of eight compass directions of slope aspect (octants), and c) elevation dependence.

4.2 Dataset and Methods

4.2.1 Data sub-setting and re-projection

We downloaded selected MODIS/Terra daily snowcover data on a 500m grid from the recently released version 6 (MOD10A1.006) (Hall and Riggs, 2016). All data from geographic tiles h09v04 (ROMO) and h10v04 (GLAC) were downloaded for days between March 1 and July 1 for all years from 2000 to 2016.[5]

The data are available in daily files, one for each tile, and georeferenced to an equal-area sinusoidal projection. Each tile covers 10° x 10° at the equator or approximately 1200 km by 1200 km, with a nominal pixel resolution of 500 m (actual resolution 463.313 m). To bring the data to the same grid as used in the hydrologic modeling necessitated re-projection of the data

[5] Note that MODIS data was obtained for April, but FWS' interest in April arose after this part of the project was complete, so June 1st but not April dates are shown in the graphics for this section.

onto a Universal Transverse Mercator Grid. We used the MODIS Reprojection Tool (https://lpdaac.usgs.gov/tools/modis_reprojection_tool) to subset the daily tiles to the areas of interest and re-project the subsetted areas to UTM grids with a pixel resolution of 250 m using nearest-neighbor resampling. The ROMO study area perimeter falls at the corner of tile h09v04, and extends slightly beyond the tile boundaries at its southern tip. We excluded this extension of the study from our analysis. Parameters for the MODIS data reprojection are provided in Table S4-1.

4.2.2 Converting Normalized Difference Snow Index to Binary (yes/no) Snowcover

To better align our analysis with that in Copeland and McKelvey's work we wanted to use a daily binary (yes/no) snowcover value. However, one main obstacle had to be overcome -- snowcover was characterized differently in the versions of the MODIS data that Copeland used and in the current version. The prior work by McKelvey and Copeland both used Collection 4 of the MODIS data which provided them with a binary snowcover classification for each pixel on each day (clouds permitting). Collection 4 data are only available for the years 2000-2007, necessitating the use of the more recent MODIS Collection 6 products for the present study. However, Collection 6 does not include a binary daily snowcover product. Instead, snowcover is identified using the Normalized Difference Snow Index (NDSI).

NDSI is reported as a ratio, with values ranging from 0.00 to 1.00 (scaled and reported as 0 to 100 in the data files). The NASA guidance on conversion was not definitive: "If a user wants to make a binary SCA [Snowcovered Area] from the C6 [Collection 6] product they can set their own NDSI threshold for snow using the NDSI_Snow_Cover or the NDSI data or a combination of those data." (NASA, 2016). In lieu of a prescription, we chose to follow the procedure used by NASA to produce the 8-day composite snowcover product; we applied a threshold of NDSI > 0.1 to the daily MODIS NDSI values to indicate the presence of snow in a pixel on a given day.

4.2.3 Snow disappearance date and snowcover on a given date

As in Copeland et al (2010), we calculate a snow disappearance date for each year at each pixel. We define the Snow Disappearance Date (SDD) as the first day after March 1 in which NDSI/100 was less or equal to 0.1 (Cite NASA). The SDD is denoted by the Day of Year value, in which January 1 is 1, February 1 is 32, March 1 is 60 (or 61 in leap years), etc. Once SDD was defined at each grid point for each year (resulting in 17 annual maps of SDD for the period of record), we were able to derive snowcover maps for any given date. For example, snowcover on May 1 was inferred by marking grid points as "snow-covered" if their SDD was equal or greater than 121 (or 122 for leap years). We repeated the process to infer snowcover maps for May 15 and June 1. This indirect method to infer snowcover allowed us to circumvent the reality of several missing data points due to cloud cover, and offered a conservative estimate of snow disappearance.

4.2.4 Snowcover by elevation and aspect

A 250-m digital elevation model (DEM) was created using bilinear interpolation from the National Elevation Dataset (NED)10-m DEM products (USGS, 2009). Using this we obtained grids for elevation and aspect octants in both study regions. We reclassified the elevation values

into 200 m bins. The elevation bins range from 1000 to 3000 m in GLAC and 2600 to 4200 m in ROMO. Both the slope magnitude and the aspect of the slope (that is the compass direction that the slope faces) were analyzed using functionality in the open source Quantum GIS software. We reclassified the aspect grids into eight 45°-wide directional bins (hereafter, octants) centered on the points of the compass. In both types of analyses (elevation and aspect), we computed snowcovered area (SCA) on May 1st, May 15th, and June 1st, in terms of the total area in square kilometers and also in terms of the percentage of snowcovered area in several elevation bands and aspect octants.

4.3 MODIS analysis for GLAC

This section presents some summary statistics of snowcover, including total snowcovered area, and number of years during the period of study with snowcover on a given date. MODIS snowcover data was analyzed for March1 – July1 for all years 2000-2016. For more in-depth analysis including aspect and elevation-based analyses the report focuses on the years representative of year-to-year variability defined in Section 3: 2011 ("wet"), 2009 ("near normal"), and 2005 ("dry").

4.3.1 Total Snowcovered Area

Total snowcovered area was the primary metric that was analyzed in McKelvey et al (2011) and provides an overall summary of availability of snow. Figure 4-1 presents maps of May 15 snowcover for the GLAC study area and vicinity from MODIS. These maps clearly depict the regional character of the year-to-year variations in snowcover. Figure 4-2 shows the total snowcovered area within the study area polygon, which is depicted in red on the previous figure. The year-to-year variations are shown for snowcover on three different dates during the melt season. The behavior in individual year varies considerably, 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). It is worth noting that 2015 and 2016, the last two years of the MODIS record, show low snowcover, although the modeling study period ends in 2013 because the Livneh dataset ends in that year (Section 5). Both these years had near-normal precipitation, but had anomalously warm temperatures. These years would be good candidates for future analysis.

To summarize all 17 years of the record, Figure 4-3 presents maps of the number of years with snowcover on April 1, April 15, May 1, May 15. These are similar to the analysis done by the Copeland and McKelvey studies. The primary difference is in the use of the newer MODIS products and the extension of the analysis from seven to seventeen years.

Figure 4-4 quantifies the maps in Figure 4-3, showing the area within the GLAC study area polygon with different numbers of years of snowcover. The three colored bars designate different days of the year. Because the study areas were chosen to be in the vicinity of tree line, it is no surprise that in the present climate there are large areas that see snow every year on May 1st.

4.3.2 Aspect Dependence of Snowpack: Fractional area

One of the primary goals of this study is to investigate topographic factors that influence the persistence of snow during the melt season. One such factor is the "slope aspect" or simply "aspect" – the compass direction that the slope faces. The total land area within each aspect

octant varies due to the orientation of ridges and valleys in the study area. As a result, the analysis of total snowcovered area is dominated by the topography itself. These graphics are provided in the Supplementary Material.

To focus on the *relative* importance of the snow processes related to aspect, we calculated the fraction of the total land area within each octant that is snowcovered for each of the 17 years in the historical record (Figure 4-5), while in Figure 4-6 we focus on the representative wet and dry years. The asymmetric shape in Figure 4-5 clearly shows that in GLAC, the NE directions ranging from E to N have much larger fractional area covered by snow. Even in dry years, over 60 % of the NE facing slopes are snow-covered on May 15th (Figure 4-6).

One of the primary goals of this study is to investigate topographic factors that influence the persistence of snow during the melt season. One such factor is the "slope aspect" or simply "aspect" – the compass direction that the slope faces.

4.3.3 Elevation Dependence

Figure 4-7 shows the elevation dependence of MODIS snowcover for the wet, near-normal and dry years, with the median of all years as reference. The results are shown as a percentage of the total area within each 200-meter elevation band within the study area boundaries.

4.4 MODIS analysis for ROMO

MODIS snowcover data was analyzed for March1 – July 1 for the years 2000-2016. Data for all years was analyzed. We present here some summary statistics of snowcover, including total snowcovered area, and number of years during the period of study with snowcover on a given date. For more in-depth analysis including aspect and elevation-based analyses the report focuses on the representative years defined in Section 3: 2011 ("wet"), 2007 ("near normal"), and 2012 ("dry").

4.4.1 Total Snowcovered Area

Total snowcovered area was the primary metric that was analyzed in McKelvey et al (2011) and provides an overall summary of availability of snow. Figure 4-8 presents maps of May 15 snowcover for the ROMO study area and vicinity from MODIS. These maps clearly depict the regional character of the year-to-year variations in snowcover. Figure 4-9 shows the total snowcovered area within the study area polygon, which is depicted in red on the previous figure. The year-to-year variations are shown for snowcover on three different dates during the melt season. The behavior in individual year varies considerably, including "wet" years such as 2011 with very persistent snow, years with strong melt in early May, such as 2004, or in late May (2001, 2013), and "dry" years (2012).

To summarize all 17 years of the record, Figure 4-10 presents maps of the number of years with snowcover on May 1, May 15. These are similar to the analysis done by Copeland and McKelvey studies. The primary difference is in the use of the newer MODIS products and the extension of the analysis from seven to seventeen years.

Figure 4-11 quantifies the maps shown in Figure 4-10, showing the area within the GLAC study area polygon with different numbers of years of snowcover. The three colored bars designate

different days of the year. Because the study areas were chosen to be in the vicinity of tree line, it is no surprise that in the present climate there are large areas that see snow every year on May 1.

4.4.2 Slope Aspect Dependence of Snowpack: Fractional Area

One of the primary goals of this study is to investigate topographic factors that influence the persistence of snow during the melt season. One such factor is the "slope aspect" or simply "aspect" – the compass direction that the slope faces. The total land area within each aspect octant varies due to the orientation of ridges and valleys in the study area. As a result, the analysis of total snowcovered area is dominated by the topography itself. These graphics are provided in the Supplementary Material.

The total land area within each aspect octant varies due to the orientation of ridges and valleys in the study area. As a result, the analysis of total snowcovered area is dominated by the topography itself. To focus on the *relative* importance of the snow processes related to aspect, Figure 4-12 presents an analysis of the fraction of the total land area within each directional "bin" that is snowcovered. The asymmetric shape shows that the NW-facing slopes have larger fractional area covered by snow. With the exception of 2012, even in dry years over 60 % of the NW facing slopes are snow-covered on May 15th. Figure 4-13 indicates that for the dry year 2012, snowcover was retained preferentially on NW-facing slopes.

4.4.3 Elevation Dependence

Figure 4-14 shows the elevation dependence of MODIS snowcover for the wet, near-normal and dry years, with the median of all years as reference. The results are shown as a percentage of the total elevation within each 200-meter elevation band within the study area boundaries. The ROMO area shows that the dry year, 2002 (as well as the other very dry year during the period, 2012), was significantly different from the other two, with a fractional area declining with altitude above 3400m. This may indicate that the meteorology in this region interacts differently with the topography in extremely dry years than in wetter years. The high-altitude snowpack may be particularly vulnerable in this region if conditions like those in 2002 recur.

5 Future Snowpack Projections: DHSVM Modeling

Key Points - Methods

- In order to simulate snowcover under future climate conditions, we use a high-resolution snow/hydrology model with inputs derived from historical observations and global climate model projections.
- The Distributed Hydrology Soil Vegetation (DHSVM) model was run for the historic period 1998-2013 and validated against available SNOTEL observing stations.[6] The spatial patterns of snow were validated against MODIS satellite remotely sensed snowcover.
- Five scenarios of the future – for a thirty-year period, 2041-2070, centered on 2055 -- were selected from CMIP5 global climate model (GCM) projections based on a moderate (RCP 4.5) and high (RCP 8.5) emissions scenarios. These were chosen to represent a large fraction of the range of the CMIP5 ensemble projections in each study area in terms of precipitation and temperature changes. The scenarios differ somewhat between the two study areas to better represent the range of climate projections in each area.
- The selected GCM projections were downscaled using the "delta method" which applies change factors from the climate models to the historic temperature and precipitation that are used as inputs to the DHSVM model.
- Analysis is presented for light snowcover (Snow Water Equivalent > 5 mm) on May 15th for comparison with May 15th MODIS snowcover (as was used by McKelvey).
- To capture and assess year to year variability, Wet, Near Normal, and Dry representative case study years are shown for the historical simulations and how each of these years plays out under these five future scenarios.

Key Points – GLAC study area

- Projections for April 15th, May 1st, and May 15th Snowcovered Area and area with snow depth greater than 0.5 meters show declines on average in all scenarios, except for small increases in the Warm/Wet scenario and for almost all years (Section 5-11).
- For April 15th for the study area as a whole (Figure 2-1), there is a decline of 3-23 percent in snowcovered area with light snowcover (depth ≥ 5 mm), and a 7-44% percent decline in area with significant snow (depth > 0.5 m) for the five scenarios considered, compared to the 2000-2013 historic average. For May 15th, the area with light snowcover declines 10-36 percent, and the area with significant snowcover declines 13-50 percent (Tables 5-4, 5-5)
- On April 15th, the Warm/Wet scenario shows the least change in average SCA (2121 Sq-km) compared to the historic snowcover (2609 sq-km, 7% decline) for significant (≥ 0.5 meter) snowcover. The largest decrease is the Hot/Wet scenario (1520 sq-km) with 44% decrease. Under the Hot/Wet scenario, the April 15th significant snowpack has been diminished below the level of the historic May 15th snowpack – a month shift (Figure 5-

[6] Some results are presented only for the 2000-2013 period determined by the overlap of the DHSVM simulations with the MODIS satellite record.

14).

- All projections show declines in the number of years with significant snow. In each study domain, the areas with frequent availability (at least 14 out of 16 years) of significant snow (≥ 0.5 m) become concentrated in smaller high elevation areas, as seen in the maps in Figures 5-13, 5-14 (GLAC), and 5-20, 5-21 (ROMO). In contrast, lower elevation areas had the largest changes, or decreases in the number of years with significant snowcover.
- Most of the known den sites are located between 1800 and 2000m in GLAC. Below that elevation band large snow losses are predicted (40-70% decreases for two of the scenarios, 16-20% for the other three), above that elevation band there is little change in SCA for four of the five scenarios (2-8%) except in maximum warming scenario (-40%, Figure 5-22). In that 1800-2000m band, the snowpack change is sensitive to elevation and to the particular future climate scenario.
- This phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. (Section 5-13)
- For representative wet years, the higher elevations of our study areas experience only 2-7% loss of snowpack under the scenarios with "least" change and the "central" change (Figure 5-8, 5-12), although for the dry years, losses range 18-57% (Table 5-5).
- Modest declines in SWE may occur without affecting the area with significant snow depth. On May 1st, for areas at 1800m and above in GLAC, losses of ~10-30% SWE (Figure 5-23) result in losses of only ~10% snowcover. The implication is that the wet, cold climate of the GLAC study area could act as a "buffer" to change in the area of 0.5 m deep snow on May 1st, at least at the elevations above 1800m.

Key Points – ROMO study area

- Projections of May 15th Snowcovered Area in ROMO declines on average in all scenarios, except for small increases in the Warm/Wet scenario, and for almost all years (Section 5-12).
- For April 15th for the study area as a whole (Figure 2-2), there is decline of 3-18% in area with light snowcover (depth ≥ 5 mm), and a change of -1 - +16 in area with significant snowcover (depth > 0.5 m) for the five scenarios considered, compared to the 2000-2013 historic average. For May 15th, the area with light snowcover declines 8-35 %, and the area with significant snowcover declines 6-38 percent (Tables 5-6, 5-7).
- Snowcovered Area in ROMO (≥0.5 m threshold on May 15) generally declines in wet years, shows a slight increase in (1-5%) in some years for the Warm/Wet scenarios with increased precipitation.
- One scenario with increased precipitation (Warm/Wet, giss) shows increases in April 15th SCA (Table 5-7). There are also slight increases in SWE for two scenarios at elevations at and above 3400m (Figure 5-25), but decreases in SWE for all scenarios below 3400m.
- Although no dens have been documented in ROMO, the elevation band for denning, modeled by regression analysis, is thought to be 2700-3600m. On May 1st, modest declines in SWE of ~15% and less for areas at 3400m and above result in losses of only ~10% snowcover (Figure 5-24, 25). 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 deep snow on May 1st. Below that band losses in SWE of ≥35% result in higher

losses in SCA (20-65%), except in the scenario with least change (Warm/Wet, giss model). As in GLAC, the snowpack change in that 2700-3600m band is sensitive to elevation and to the particular future climate scenario.

- The phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. Studies have found little historical change in snowpack in the Western United States above approximately 2500m elevation despite observed warming trends. Other literature on this topic is discussed in Section 5.13.
- ROMO exhibited more uncertainty in projections than GLAC, because compared to GLAC, the GCM climate projections for ROMO are more uncertain, i.e. have a larger spread, as to whether precipitation will increase or decrease (Figure 5-7).
    - For April 15th –May 15th, and for wet years, at the high elevations of the ROMO study area as whole, there is only modest loss of snowcover (<13%) under most scenarios of change (Table 5-7, see 2011 representative wet year). However even in wet years, the area of significant snowpack can decline by up to 26% for the Hot/Dry climate change scenario on May 15th (Table 5-7).

5.1 Introduction

In this section we describe the hydrologic model along with various modeling assumptions, validation of the model, the choice of risk-spanning future climate scenarios, and present results of historical and projected snowpack for the two study areas.

To determine the projected effects of a changing climate on snowpack we ran a physically-based hydrology model. The physical basis of the model – using a full energy and water balance of the snowpack rather than a simple temperature-index model -- is critical to evaluate change in a non-stationary climate. While ambient temperature is a critical factor in whether precipitation falls as rain or snow, the subsequent evolution of the snowpack, and in particular the melt season, is driven primarily by the energy balance at the surface. The energy balance is the result of several processes, including solar and longwave radiation, sensible and latent heat fluxes, and heat flux into the ground, as well as storage of heat in the snowpack. Therefore, including a realistic energy balance helps to understand how the perturbations to climate will affect the snowpack.

5.2 Model Description

The Distributed Hydrology Soil Vegetation Model (DHSVM) provides a physically-based simulation of land surface hydrology, including snowpack. The physical processes include a full surface water and energy balance model, a 2-layer canopy model, a multi-layer soil model, a 2-layer snowpack model (Wigmosta et al. 1994). It has been used in many studies that have provided realistic hydrologic simulations in topographically complex areas (e.g. Livneh et al. 2015). The model has explicit treatment of topographic slope, and aspect (the compass direction that the slope faces).

The model was selected for developing snowpack projections because it can be run at a fine spatial scale (250 m x 250m pixels) yet is able to be run over extensive domains. There are both

finer-scale snow models, for which it would have been impractical to simulate such a large domain, and coarser-scale models, such as the 1/16 degree grid of the VIC model that the McKelvey study used (see section 2.3). Coarser-scale models do not explicitly model the effects of slope and aspect, which is one of the primary goals of this study. Both DHSVM and VIC were primarily developed at the University of Washington, and are available as open-source community models. The two models share many components in common, including similar snow and canopy models. As such it supports the project goal of building on McKelvey study by modelling at a finer scale and treating slope and aspect explicitly.

The model was set up for both study domains on a 250m grid in Universal Transverse Mercator (UTM) coordinates within the modeling domain defined within the polygons shown in Section 2. Soil properties and vegetation type as well as a digital elevation model (DEM) were adapted to the model grid. A soil hydraulic routing network was also determined from the DEM, though in this project we do not investigate the runoff. The effect of slope and aspect on incoming solar radiation is implemented through a computation of the degree of shading for each 250-m pixel that was variable throughout the day and differed from month to month based on the solar angle in the sky and from the DEM. The model requires inputs of time-varying meteorological fields on sub-daily time scales. Snow water equivalent was output on the 1st and 15th of the month from March 1st to June 1st for every year of the simulation and projections.[7] As noted below, snow depth was estimated using a typical snowpack density for late Spring.

5.3 Meteorological Inputs

The DHSVM model inputs were derived in a multi-step process. First, values of daily minimum temperature, daily maximum temperature, and precipitation were extracted from the Livneh (2015) dataset, which has a grid resolution of 1/16th degree in latitude and longitude. These daily values were disaggregated in time. Other forcing variables needed by the model, solar radiation, downwelling longwave radiation, specific humidity were derived from empirical relationships using the MTCLIM algorithms which were evaluated by Livneh et al. (2014) finding small overall biases. The Livneh et al (2015) data was then interpolated to the 250m DHSVM grid using an inverse-distance weighting algorithm along with assumed lapse rates (elevation dependence) in temperature and in precipitation. More details of the Livneh 2015 dataset will be included in the Section 5 Supplementary Material.

5.4 DHSVM Historical Validation

The goal of the model validation is to assess the overall magnitude, temporal, and spatial aspects of the modeled snowpack in the Spring and how these differ from observational estimates. Observational estimate of snow depth or snow water equivalent at the scales that we simulated are not available, leading to uncertainty about the "true" snowpack. For the overall magnitude and temporal aspects of the snow simulation, we compared the historical model simulation to

[7] All data has been provided to FWS.

point observations at the few available SNOTEL sites, focusing on the duration and melt-out date of the snowpack. The spatial aspect of bias was evaluated by comparing the model output to the observed spatial patterns of snowcover obtained from the MODIS analysis (see Section 4), qualitatively for GLAC and quantitatively for ROMO. When interpreting the projections, future model biases are typically assumed to be similar to historical biases. With this assumption, the calculation of, for example, percentage change is less sensitive to biases and uncertainties in the historical simulation.

5.4.1 Comparison to SNOTEL

The DHSVM historical simulation was compared against the snow data from nine SNOTEL sites in the ROMO study area that were in operation during the full time-period of interest, and the 3 SNOTEL sites in and adjacent to the GLAC study area (Table 5-1). Validation against SNOTEL snow data was performed by running the DHSVM model in "point" mode so that it simulated the conditions at the SNOTEL locations only. Because the SNOTEL stations are deliberately sited in clearings, the canopy was assumed to be open for the validation runs, while the actual 250m grid canopy values were used for the production runs. Two metrics were chosen: the meltout day of year (defined as the date when SWE fell to less than 1mm), and the duration of snowcover (total number of days during the water year (October-September) when SWE > 10cm). Figure 5-1a shows the modeled and observed meltout dates for the GLAC and ROMO SNOTEL sites, and Figure 5-1b shows the duration of snowpack. One does not expect exact reproduction of the snowpack at the SNOTEL sites, but rather a scatter about the 1-to-1 line, which is seen. The Copeland Lake SNOTEL site, and to some extent the Many Glacier SNOTEL sites are outliers, with the model retaining snowpack significantly longer than in observations. Both these sites are at relatively low elevations, and are quite sensitive to potential temperature biases in the input data. The Livneh (2015) dataset is known to have a cool bias relative to other datasets, which may influence these sites disproportionately.

Table 5-1 SNOTEL Sites at Study Areas. Maps with SNOTEL sites are shown in Figs 2-1 and 2-2. Note that sites installed after 1997 were not used due to their short record.

	SNOTEL SITE NAME (Site Number, Abbreviation)
Glacier Study Area	Flattop Mountain (482, flat), Many Glacier (613, many), Pike Creek (693, pike)
Rocky Mountain Study Area (used for Validation)	Bear Lake (322, bear), Copeland Lake (412, cope), Joe Wright (551, joew), Lake Eldora (564, eldo), Lake Irene (565, iren), Niwot (663, niwo), Phantom Valley (688, phan), University Camp (838, univ), Willow Park (870, will)
Rocky Mountain Study Area (installed after 1997, not used)	Never Summer (1031), Wild Basin (1042), Hourglass Lake (1122), Long Draw Reservoir (1123), High Lonesome (1187), Sawtooth (1251)

The year-to-year variations of peak snowpack at the GLAC SNOTEL sites are well captured, as illustrated in Figure 5-2 that shows simulated and observed time series of SWE at these stations. Figure 5-3 shows selected SNOTEL sites in the ROMO area. As can be seen in Figure 5-2, the

Copeland Lake site is less well simulated than other sites. We attribute this to being located at a lower elevation than other sites, and hence susceptible to small biases in temperature in the meteorological inputs. Other sites in ROMO are well simulated.

Based on this evaluation of DHSVM performance, the standard set of model parameters was adopted for the GLAC domain without modification.

The question arises of the independence of the SNOTEL data from the Livneh (2015) forcing data. The primary observing station data that were used for interpolation by Livneh (2015) did not include SNOTEL. However, a monthly adjustment factor was applied to the interpolated precipitation to reproduce the 1981-2000 climatology of PRISM. The temperature data in Livneh et al (2015) were entirely independent of SNOTEL data. Therefore, we expect that the errors revealed at the SNOTEL sites should be representative of errors at other, unobserved sites in the domain.

5.4.2 Comparison to MODIS Snowcover

The spatial distribution of snowcover was assessed by comparison with MODIS data. Some care must be taken to compare observed NDSI, which indicated fractional snowcover, with modeled SWE, which does not account for fractional snowcover within a pixel. For this evaluation, a threshold to determine "snowcovered ground" was chosen for both the MODIS (NDSI >= 0.1) and for the DHSVM (SWE >= 5mm). Figures 5-4 and 5-5 snow spatial overlays of the DHSVM simulated snowcover and the MODIS observed snowcover for the representative dry years in ROMO and GLAC. In terms of snowcover, dry years were more difficult to simulate than wet years, and the spatial agreement is good for these two examples.

However, initial attempts to model ROMO indicated biases in the spatial patterns of snowcover compared to MODIS. To overcome model errors at ROMO, an adjustment of two DHSVM snow parameters was conducted. The representative values of the physical quantities of these parameters can span a fairly large range, and hence an experiment was conducted to evaluate the appropriate settings of the model for ROMO based on minimizing differences between simulated and MODIS SCA for the historical period, as well as reducing biases with SNOTEL SWE.

The first parameter modified was the snow-surface roughness (SR), which affects the amount of turbulent heat fluxes that occur between the snow and the atmosphere, whereby a small number corresponds to a smoother snowpack that has less heat exchange with the overlying air, while the opposite is true for a large value. The second parameter was the liquid water capacity (LWC) that describes the volume of water that the snowpack can hold before water will leach out of the snowpack. This parameter is important, since it is common for snow to melt during the day and then for liquid water to refreeze at night.

Adjustments were made to SR and LWC within reasonable physical ranges and the DHSVM simulated SCA was compared with MODIS via a threat score. The threat score used, referred to as the Critical Success Index (CSI) by Zappa (2010), is defined as:

$$CSI = \frac{a}{a + b + c}$$

Where a indicates a snow-covered pixel in both the simulation and observed data, b indicates a snow-covered pixel in the simulation but a bare pixel in the observed ("false positive"), and c is a bare pixel for the simulation and a snow-covered pixel shown by the observed data ("false negative"). The objective was to maximize the threat score. Approximately ten unique parameter settings were tested. Additionally, for each parameter setting the mean bias in meltout day and duration of snowcover between DHSVM simulated and SNOTEL SWE was calculated with the objective being a minimization of the bias between the two (bias = simulated – observed). The final DHSVM settings for ROMO were identified by the parameter values that corresponded with a combination of a high threat score and a low bias. The table and figure showing the parameter settings and ensuing objective values are included in the supplementary material.

5.5 Determination of Snow Depth from DHSVM model output

DHSVM does not compute snow depth as a separate quantity, but instead returns snow water equivalent (SWE). To estimate the snow depth from SWE we adopt a uniform value of 2.5:1 for the SD:SWE ratio, corresponding to a snow density of 0.4 for May 1st and May 15th. For April 15th conditions, we adopt a bulk density of 0.33 which yields a conversion factor of 3.0:1. Further discussion can be found in the Section 5 Supplementary Material. Several lines of evidence point to the reasonableness of this assumption. First, SNOTEL stations where both depth and SWE are measured show similar ratios for the two study areas. Second, we investigated the ratio of density from the SNODAS (Snow Data Assimilation System) product from the NOAA National Operational Hydrologic Remote Sensing Center, which points to a very narrow range around 2.6-2.7 for the ratio. Finally, for comparison with the McKelvey et al (2011) work we compared the May 1 Snow Depth and SWE products from the Littell et al (2011) hydrologic model runs (obtained separately from https://cig.uw.edu/datasets/wus/). These all point to an approximate value consistent with a density between 0.35 and 0.4. The results of this study do not depend on a precise value for snow density. The conclusions of the report are not sensitive to the choice of conversion factor within the ranges indicated by the above analysis.

5.6 Choice of thresholds for analysis

While the the McKelvey study analysis was for the presence or absence of snowcover, this modeling effort produces results in terms of SWE. This allows greater flexibility in evaluation of the depth of the snowpack, but presents a problem in comparison. To compare the model-generated SWE with both the McKelvey study results and our own MODIS historical snowcover analysis we used a threshold of 5mm SWE to define presence/absence of snowcover, also called "light snow". We also were concerned with analyzing the presence of "significant snow" which we defined as ≥ 0.5 m of snow depth. The value of ≥ 0.5 m was arrived at by an analysis of the modeled snow depth at known wolverine denning sites in Glacier National Park (Table 5-2). With the exception of one site that had melted out by May 15th, the other sites all have snowpack between 0.4 and 1.4 m.

Table 5-2: Modeled Snow Depth on May 15 at reported den sites in the Glacier Study Area (source: John Guinotte, FWS)

Den site	Date observed (month-yr)	Meltout Date (MODIS)	April 15 snow depth dhsvm (m)	May 01 snow depth dhsvm (m)	May 15 snow depth dhsvm (m)	Notes
1	Apr-03	5/25/2003	1.32	1.07	1.04	Natal Den
2	May-03	5/25/2003	1.32	1.07	1.05	Maternal Den
3	Apr-04	6/4/2004	1.96	1.46	1.13	Natal Den
4	Apr-04	6/29/2004	1.0	0.75	0.54	Maternal Den
5	May-04	6/29/2004	1.07	0.83	0.65	Maternal Den
6	Mar-05	6/11/2005	1.6	1.11	0.58	Maternal Den
7	Apr-05	6/11/2005	1.6	1.11	0.58	Natal Den
8	May-05	6/11/2005	1	0.76	0.47	Maternal Den
9	Mar-06	5/25/2006	3.05	2.56	2.44	Unknown-maternal or natal
10	Apr-06	5/14/2006	0.68	0.26	0	Meltout occurred before May 15 Unknown-maternal or natal
11	Apr-06	6/7/2006	2.83	2.4	2.38	Unknown-maternal or natal
12	May-06	5/31/2006	1.14	0.79	0.61	Maternal Den
13	May-06	5/31/2006	1.14	0.79	0.61	Natal Den
14	May-07	6/4/2007	1.82	1.28	0.68	Natal Den

5.7 Delta Method for Future Scenarios

The advantages and disadvantages of the delta method have been discussed extensively in the literature (e.g. Sofaer et al, 2016, for a recent review). The primary advantages of this method are its long history of use, its simplicity, and its use of the historical observed weather as the baseline. The simplicity allowed for the study to be completed in a short time-frame, while still reaching our primary objectives of finer spatial scale and a more complete exploration of future climate scenarios. The use of the historical baseline allows us to explore how wet, near normal, and dry "representative years" would play out under the different climate futures. However, it is important to keep in mind that we are "parameterizing the future variability in terms of the historical variability." This treatment of daily variability also leads to the primary disadvantage of the delta method: the assumptions that the changes in extremes follow the changes in the means, and that the pattern of daily weather is simply shifted without changing the sequences of weather (Sofaer et al, 2016). This aspect is less of a concern for this study, as snow accumulation and ablation are cumulative processes, so that the daily sequences of storms is less critical to simulate than the monthly and seasonal totals. Another assumption of the delta method is that the

large-scale changes in temperature and precipitation apply uniformly to the study area. Equivalently we assume that change factors in ambient (free-air) temperature and precipitation will not depend on the small scale spatial detail. Because we explicitly compute the surface energy balance, we are able to simulate surface temperature differences that depend on fine-scale terrain, mitigating to some extent this limitation of the delta method.

Following McKelvey (2011), we use the "delta method" to downscale the climate model data to the 250m modeling grid.

The steps in this method are as follows:

- Start with historical daily meteorological forcings (inputs to the DSHVM model) for the historical baseline period (1998-2013)
- Run DHSVM with the historical forcings to produce the simulated historical snow and hydrology.
- From climate model output, compute the change in 30-year average temperature for each calendar month over the time frame of interest. Do the same for the percent change in precipitation
- Apply these change factors to the historical daily meteorological inputs to DHSVM to generate future scenarios of meteorological inputs.
- Run DHSVM with these new inputs to generate the projected snow and hydrology.
- Compare the projected snow to the historic DHSVM model simulations to infer changes in snowpack.
- Repeat for a set of change factors from different climate models that adequately sample the uncertainty in climate projections.

The result of the delta method is a continuous-in-time simulation of the historical period (1998-2013), and an equal length simulation of how this sequence of years would play out in the future under five different scenarios of climate change. Figure 5-6 illustrates typical DHSVM model output using the delta method. Figure 5-6a shows a map of May 15, 2011 Snow Water Equivalent for the Glacier Study Area from the historical simulation, while Figure 5-6b shows a single projected future for what that year's SWE would look like under a particular scenario of climate change. The future scenario represents a year similar to 2011, that is, a relatively wet and cool year compared to other years in the future. However, in this example, the temperature and precipitation have been adjusted to be consistent with the 2041-2070 projected climate from the MIROC climate model, the model with the highest temperature increase and about 10% increase in precipitation.

5.8 GCM Uncertainty and Scenario Planning Approach

As noted in Section 2, global climate models (GCMs) are our primary tools to examine the nature of climate change during the 21st century. There are currently about 20 modeling centers worldwide which provided output from their best model(s) to be considered in the Coupled Model Inter-comparison Project Phase-5 (CMIP5, Taylor et al., 2012) the basis for the latest Intergovernmental Panel on Climate Change (IPCC) report (IPCC AR5). Figure 5-7 shows the changes in temperature and precipitation for the two study areas for the 2041-2070 period, centered on 2055. We find a large spread in the extent of warming and changes in precipitation, including both increases and decreases in precipitation. The McKelvey study chose GCMs based on the range of temperature change (see Sec 2.2, and Figure 5-7). For temperature, much of this spread (or uncertainty) is a result of the difference between GCMs (e.g., their climate sensitivities), whereas for precipitation it is both the difference between GCMs and internal climate variability. Some difference also comes from the choice of future greenhouse gases (GHG) emission scenario. However, these differences among mid-21st century climate responses are limited compared to later in the century (see discussion in Ray et al., 2010).

For more robust planning and climate adaptation, experts recommend incorporation of these uncertainties into the assessment of impacts and developing adaptation strategies. The scenario planning approach has been one method that has been recommend and promoted by different entities and experts (National Park Service, 2013; Rowland et al., 2014; Maier et al., 2016; Murphy et al. 2016; Star et al., 2016, Fisichelli et al, 2016 a,b). Therefore, we adopted a strategy of selecting multiple divergent future scenarios challenging to the system of interest, following that in Fisichelli et al (2016 a, b).

5.9 Climate Projections Evaluation and Scenarios Selection

We compiled output for temperature and precipitation projections for 34 CMIP5 GCMs from the Reclamation (2013; http://gdo-dcp.ucllnl.org/) archive of 1-degree Regridded GCM dataset for Representative Concentration Pathways (RCP) 4.5 and 8.5, which are respectively the moderate and high GHG emissions scenarios --- therefore, a total of 68 GCM projections described in Supplementary Material. These data were then analyzed to quantify broad-scale projections for the two study regions by 2055 (i.e. a mid-point centered on the 2041-2070 period) – primarily changes in the cold season (Oct-May) temperature and precipitation by 2055 relative to the 1986-2015 period. Figures 5-7 show these changes for Rocky Mountain and Glacier National Parks, respectively, which are bounded by rectangular latitude/longitude values. As mentioned earlier, we found a large range in temperature increases (1-4 ºC) and changes in precipitation (-5% to +20%) for these regions by 2055. Table 5-3 shows GCM names, numbers and colors coded in later figures, and relative changes in temperature and precipitation. To incorporate the large range in climate projections, we worked with the ensemble of 68 CMIP5 temperature & precipitation projections, described by the red filled-circles in Figure 5-7, to select five future climate scenarios (black circles) that span the different parts of this projection space. Five GCMs representing these scenarios were identified for both RMNP and GNP. For each of these GCMs, we calculated changes in temperature and precipitation by 2055 for each month of the year,

which we call the “monthly delta”. These monthly deltas were used to perturb the hydrological models to simulate snow response in RMNP and GNP by 2055.

Table 5-3. The future climate scenarios (five for each area) with changes in temperature and precipitation relative to other scenarios (See also Fig 5-7 for an alternate visualization of these changes), and the GCM used as the basis for the deltas for this scenario. More details on the GCMs are in the Glossary.

Future Scenario Name and #	Scenario Change in GLAC relative to other scenarios	Scenario Change in ROMO relative to other scenarios	Code and color for GCM used for this scenario
Central (#1)	+~2.2 °C increase in temperature (close to the ensemble mean) and +~5% increase in precipitation	+~2.5 °C increase in temperature (close to the ensemble mean) and +~8% increase in precipitation	cnrm, red
GLAC: **Hot/ Very Wet (**#2)	relatively higher increase in temperature (+~3.2 C) and the highest increase in precipitation (+20%) for the GLAC scenarios	N/A	canesm, green
ROMO: **Hot/Dry (**#2)	N/A	relatively higher temperature increase (+~ 3.5 °C) and -~5% decrease in precipitation. This scenario results in the greatest change (reduction) in snow pack and snowcover.	hadgem, green
Hot/ Wet (#3)	the highest temperature increase of the GLAC scenarios (+~4.2 °C) and +~10% increase in precipitation	the highest temperature increase of the ROMO scenarios (+~3.7 °C) and the highest increase in precipitation (+~18%).	miroc, purple
Warm/ Wet (#4)	relatively lower temperature increase (+~1 °C) and +~10% increase in precipitation	relatively lower temperature increase (+~1.3 °C) and +~7% increase in precipitation that appears to partially offset the impacts of the temperature increase. This scenario results in the least change in snow pack and snowcover.	giss, aqua
Warm/ Dry (#5)	relatively lower temperature increase (+~1.6 °C) and -~5% decrease in precipitation	relatively lower temperature increase (+~0.8 °C) and -~5% decrease in precipitation	fio, orange

5.10 Modeling Caveats

Some processes which may be of relevance not represented in the model include wind and avalanche re-distribution of snowpack. Snow depth is not explicitly modeled, and must be inferred (Section 5-5). The meteorological forcing does not take into account cold air pooling or how this may change in the future. Cold air pooling – the anomalously cold air that can collect in valley bottoms, particularly in Winter, could also act to prolong the duration of snowcover in those locations. While Curtis et al (2014) identify this as a potential process, they do not physically model cold air pooling, but merely include it in their present-day climatology as a simple "offset" from their unadjusted data. Nonetheless their work provides a complementary approach to the identification of potential snow refugia, though more work would need to be done to study the geographic and seasonal aspects for the study areas.

5.11 GLAC Study Area Results

This section presents SWE and SCA for representative years, area and number of years with snow depth ≥ 0.5 m. The elevation dependence of snow for GLAC is discussed in Section 5-13. **On average, the GLAC study area exhibits a 7 – 44 % decline in the area of snow depth ≥ 0.5 meters on April 15th, and a 13-50 % decline in the area on May 15 for the scenarios considered.**

5.11.1 SWE and Snowcovered Area for representative years

Figures 5-8 shows DHSVM model simulated snow water equivalent (SWE) on May 15 for the wet (2011) representative year. Maps of snowcover derived from SWE by applying a threshold of 5 mm are available in the Supplementary material. Results for thresholds of 1 mm of SWE were also investigated and show similar patterns. Snowcovered area with a "light snowcover" threshold was computed primarily for comparison with both the MODIS results from Section 4, and with McKelvey. In Figure 5-8, the historical simulation is shown along with three of the five future scenarios, chosen to represent the central scenario (cnrm), the greatest change in snowpack on average (Hot/Wet (miroc) scenario) and the least change (Warm/Wet (giss) scenario). The projected snow maps answer the question "what would the snowpack in a wet year like 2011 look like in the 2040's through 2070's under these scenarios of climate change."

Figures 5-9 and 5-10 show SWE for the Near Normal (2009) and Dry (2005) representative years. The historical simulation and future scenarios are as in Figure 5-8. Figure 5-11 summarizes the results for snowcovered area in terms of the total snowcovered area (km^2) within the study area polygon. The numerical values of snowcovered area for all years in the simulation, as well as percent changes for these quantities are shown in Table 5-4. Table 5-4 indicates that the snowcovered area decreases for all scenarios. On average, the GLAC study area exhibits a 7 – 44 % decline in the area of snow depth ≥ 0.5 meters on April 15th, and a 13-50 % decline in the area on May 15th for the scenarios considered.

- Comparing the Wet and Dry representative years we see that dry years are more vulnerable to climate change in terms of percent loss of snowcovered area.
- For the Wet year, the high elevations of the study area result in little loss of snowpack in the study areas under most scenarios of change.

- However, in Figures 5-10 and 5-11 we notice an anomaly – for the dry year, the Hot/Wet (miroc) scenario does not have the greatest loss of snowcovered area. The increase in precipitation in this scenario has somewhat compensated for the loss of snowpack due to warming. Instead the Hot/Very Wet (cnsm) scenario, with its even larger warming shows the greatest loss of snowcovered area.
- Snow changes at the elevations of known dens are discussed later in Section 5.13 and Figures 5-22 and 5-23.

5.11.2 Area and Number of years with ≥ 0.5 m Snow Depth

Because of interest in wolverine denning sites, we analyze snow depth ≥ 0.5 m, which we will also refer to as "significant snow" to contrast with the emphasis on light snow in McKelvey et al (2011) and in the previous section. Figure 5-12 shows the area with snow depth ≥ 0.5 m on April 15th and May 15th in the study area for the dry, near normal, and wet years. Because of the higher threshold for snow, the effects are somewhat larger than for the light snow threshold. This is particularly evident in the dry year, which has a 50% decline on May 15 for four of the future scenarios. The numerical values of snowcovered area at the ≥ 0.5 m threshold are shown in Table 5-5 for all years, as well as percent changes for these quantities.

Figure 5-13 shows a map of the number of years (out of 16 possible) where each model pixel had ≥ 0.5 m of snow depth on May 15. This number-of-years statistic is analogous to that used by the Copeland study, except that there are more years of data, and these maps use a much higher threshold of snow. The projections show declines in the number of years with significant snow. The areas with frequent (14-16 years) availability of significant snow become concentrated in smaller, relatively higher elevation areas within the study domains.

The effects of climate change on snow melt have been presented as analogous to a "time shifting" of the melt season earlier in the year. For example, McKelvey used the May 31 vs. May 15 snowcovered area as a proxy for a 2-week shift in the melt season. Figure 5-14 contrasts the evolution of the snowpack with respect to the number of years with significant snow from April 15th to May 15th in the historical simulations (Top Row) with the Warm/Wet scenario (Middle Row) and Hot/Wet (Bottom Row) scenarios. We see that the Warm/Wet scenario, shows the least change in the number of years compared to the historic snowcover in terms of the availability of significant snow. In contrast, under the Hot/Wet scenario, the number of years that significant snowpack occurs on April 15th has been diminished well below the level of the historic May 15th snowpack – more than a month shift (Figure 5-14).

GLAC	Snow Covered Area sq-km (5 mm SWE threshold)																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	2838	2876	2901	2886	2901	2869	2772	2615	2836	2784	2899	2900	2853	2901	2892	2890	**2851**	**2881**
	Central (cnrm)	2501	2732	2901	2804	2879	2708	2278	2067	2500	2297	2849	2870	2604	2897	2748	2743	**2649**	**2737**
	Hot/Very Wet (canesm)	2080	2342	2900	2589	2748	2288	1784	1630	1972	1714	2610	2695	2177	2839	2215	2405	**2312**	**2315**
	Hot/Wet (miroc)	2043	2069	2210	2326	2161	2419	1489	1993	2087	2020	2753	2245	2200	2591	1766	2700	**2192**	**2181**
	Warm/Wet (giss)	2697	2819	2901	2840	2887	2769	2578	2361	2677	2572	2881	2885	2706	2901	2827	2828	**2758**	**2823**
	Warm/Dry (fio)	2604	2735	2901	2839	2887	2808	2469	2176	2634	2490	2867	2883	2712	2900	2848	2785	**2721**	**2797**
1-May	historical	2625	2814	2707	2818	2892	2788	2608	2494	2694	2563	2888	2901	2598	2901	2775	2861	**2745**	**2782**
	Central (cnrm)	1949	2433	2160	2505	2820	2405	1948	1657	2072	1917	2773	2882	2008	2887	2202	2619	**2327**	**2303**
	Hot/Very Wet (canesm)	1578	2059	1815	1985	2580	1899	1400	1287	1633	1271	2499	2792	1419	2813	1730	2249	**1938**	**1857**
	Hot/Wet (miroc)	1828	1865	1806	1843	1731	2214	1324	2354	1721	1727	2655	2129	1845	2542	1374	2319	**1955**	**1844**
	Warm/Wet (giss)	2327	2653	2482	2647	2861	2556	2293	2142	2416	2204	2854	2896	2276	2901	2529	2739	**2548**	**2543**
	Warm/Dry (fio)	2256	2522	2301	2634	2832	2628	2214	1906	2337	2172	2824	2892	2257	2900	2531	2697	**2494**	**2526**
15-May	historical	1658	2756	2516	2413	2875	2695	2383	2211	2460	1865	2825	2838	2488	2900	2595	2597	**2505**	**2555**
	Central (cnrm)	918	2232	1832	1814	2664	2156	1572	1296	1652	1105	2457	2534	1813	2818	1816	1844	**1908**	**1824**
	Hot/Very Wet (canesm)	859	1948	1568	1409	2434	1703	1197	1002	1381	749	2241	2261	1259	2684	1468	1664	**1614**	**1518**
	Hot/Wet (miroc)	1414	1611	1223	1305	1476	2070	1053	1597	1396	1266	2391	1781	1731	2373	1119	1960	**1610**	**1537**
	Warm/Wet (giss)	1342	2562	2220	2109	2810	2413	2068	1829	2099	1455	2693	2714	2152	2883	2250	2342	**2246**	**2235**
	Warm/Dry (fio)	1166	2378	2045	1994	2729	2456	1870	1564	1953	1338	2588	2659	2073	2866	2171	2053	**2119**	**2063**

GLAC	Snow Covered Area % change (5 mm SWE threshold)																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central (cnrm)	-12	-5	0	-3	-1	-6	-18	-21	-12	-17	-2	-1	-9	0	-5	-5	**-7**	**-5**
	Hot/Very Wet (canesm)	-27	-19	0	-10	-5	-20	-36	-38	-30	-38	-10	-7	-24	-2	-23	-17	**-19**	**-20**
	Hot/Wet (miroc)	-28	-28	-24	-19	-25	-16	-46	-24	-26	-27	-5	-23	-23	-11	-39	-7	**-23**	**-24**
	Warm/Wet (giss)	-5	-2	0	-2	0	-3	-7	-10	-6	-8	-1	-1	-5	0	-2	-2	**-3**	**-2**
	Warm/Dry (fio)	-8	-5	0	-2	0	-2	-11	-17	-7	-11	-1	-1	-5	0	-2	-4	**-5**	**-3**
1-May	Central (cnrm)	-26	-14	-20	-11	-2	-14	-25	-34	-23	-25	-4	-1	-23	0	-21	-8	**-15**	**-17**
	Hot/Very Wet (canesm)	-40	-27	-33	-30	-11	-32	-46	-48	-39	-50	-13	-4	-45	-3	-38	-21	**-29**	**-33**
	Hot/Wet (miroc)	-30	-34	-33	-35	-40	-21	-49	-6	-36	-33	-8	-27	-29	-12	-50	-19	**-29**	**-34**
	Warm/Wet (giss)	-11	-6	-8	-6	-1	-8	-12	-14	-10	-14	-1	0	-12	0	-9	-4	**-7**	**-9**
	Warm/Dry (fio)	-14	-10	-15	-7	-2	-6	-15	-24	-13	-15	-2	0	-13	0	-9	-6	**-9**	**-9**
15-May	Central (cnrm)	-45	-19	-27	-25	-7	-20	-34	-41	-33	-41	-13	-11	-27	-3	-30	-29	**-24**	**-29**
	Hot/Very Wet (canesm)	-48	-29	-38	-42	-15	-37	-50	-55	-44	-60	-21	-20	-49	-7	-43	-36	**-36**	**-41**
	Hot/Wet (miroc)	-15	-42	-51	-46	-49	-23	-56	-28	-43	-32	-15	-37	-30	-18	-57	-25	**-36**	**-40**
	Warm/Wet (giss)	-19	-7	-12	-13	-2	-10	-13	-17	-15	-22	-5	-4	-13	-1	-13	-10	**-10**	**-13**
	Warm/Dry (fio)	-30	-14	-19	-17	-5	-9	-22	-29	-21	-28	-8	-6	-17	-1	-16	-21	**-15**	**-19**

Table 5-4: GLAC Snowcovered Area (5 mm SWE threshold) Top: Area (km^2) in historical average (2000-2013) and five future scenarios. Bottom: percent change in future simulations compared to historical. Average and Median values also shown. The representative dry year is 2005, wet is 2011, and near normal is 2009.

GLAC	Snow Covered Area sq-km (0.5 m depth threshold)																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	2628	2801	2708	2826	2876	2733	2532	2338	2650	2484	2830	2866	2380	2901	2833	2797	**2699**	**2765**
	Central (cnrm)	2047	2444	2202	2577	2753	2387	1889	1502	2077	1933	2574	2705	1858	2871	2454	2414	**2293**	**2400**
	Hot/Very Wet (canesm)	1730	2121	1904	2081	2515	1922	1403	1203	1674	1339	2365	2437	1298	2774	1932	2047	**1922**	**1927**
	Hot/Wet (miroc)	1406	1171	1539	1530	1265	1989	1078	1265	1354	1439	2349	1619	1176	2290	1280	1569	**1520**	**1422**
	Warm/Wet (giss)	2402	2647	2525	2683	2829	2530	2251	2004	2405	2197	2732	2785	2152	2899	2660	2633	**2521**	**2581**
	Warm/Dry (fio)	2269	2445	2279	2647	2730	2584	2084	1720	2278	2072	2588	2745	1874	2890	2662	2499	**2398**	**2472**
1-May	historical	1970	2638	2380	2468	2855	2537	2235	2062	2324	1906	2704	2777	2011	2901	2544	2680	**2437**	**2503**
	Central (cnrm)	1296	2045	1744	2058	2588	1976	1481	1265	1569	1332	2371	2523	1393	2856	1791	2118	**1900**	**1884**
	Hot/Very Wet (canesm)	1139	1783	1470	1535	2313	1494	1056	970	1325	852	2152	2191	995	2725	1418	1811	**1577**	**1482**
	Hot/Wet (miroc)	1159	1142	1175	1089	1015	1767	922	1181	1037	1077	1826	1581	1056	2229	888	1582	**1295**	**1150**
	Warm/Wet (giss)	1621	2399	2060	2187	2726	2168	1845	1709	1941	1510	2537	2626	1707	2893	2167	2449	**2159**	**2167**
	Warm/Dry (fio)	1491	2153	1880	2105	2645	2249	1698	1435	1790	1446	2402	2560	1455	2880	2103	2237	**2033**	**2104**
15-May	historical	1043	2593	2152	1708	2778	2360	1922	1670	2035	1224	2479	2625	1956	2886	2274	2227	**2121**	**2189**
	Central (cnrm)	496	1927	1457	1231	2377	1690	1160	927	1236	648	1882	2101	1312	2710	1459	1401	**1501**	**1429**
	Hot/Very Wet (canesm)	521	1724	1283	963	2151	1321	870	724	1116	450	1838	1922	975	2556	1179	1339	**1308**	**1231**
	Hot/Wet (miroc)	899	1046	761	706	908	1655	634	1035	818	770	1572	1208	1161	1975	748	1215	**1069**	**972**
	Warm/Wet (giss)	833	2346	1819	1455	2619	1990	1577	1374	1646	932	2270	2418	1683	2838	1861	1950	**1851**	**1840**
	Warm/Dry (fio)	623	2077	1611	1284	2506	2002	1382	1096	1437	778	2003	2261	1398	2785	1752	1528	**1658**	**1570**

GLAC	Snow Covered Area % change (0.5 m depth threshold)																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central (cnrm)	-22	-13	-19	-9	-4	-13	-25	-36	-22	-22	-9	-6	-22	-1	-13	-14	**-15**	**-13**
	Hot/Very Wet (canesm)	-34	-24	-30	-26	-13	-30	-45	-49	-37	-46	-16	-15	-45	-4	-32	-27	**-29**	**-30**
	Hot/Wet (miroc)	-47	-58	-43	-46	-56	-27	-57	-46	-49	-42	-17	-44	-51	-21	-55	-44	**-44**	**-49**
	Warm/Wet (giss)	-9	-6	-7	-5	-2	-7	-11	-14	-9	-12	-3	-3	-10	0	-6	-6	**-7**	**-7**
	Warm/Dry (fio)	-14	-13	-16	-6	-5	-5	-18	-26	-14	-17	-9	-4	-21	0	-6	-11	**-11**	**-11**
1-May	Central (cnrm)	-34	-22	-27	-17	-9	-22	-34	-39	-32	-30	-12	-9	-31	-2	-30	-21	**-22**	**-25**
	Hot/Very Wet (canesm)	-42	-32	-38	-38	-19	-41	-53	-53	-43	-55	-20	-21	-51	-6	-44	-32	**-35**	**-41**
	Hot/Wet (miroc)	-41	-57	-51	-56	-64	-30	-59	-43	-55	-43	-32	-43	-47	-23	-65	-41	**-47**	**-54**
	Warm/Wet (giss)	-18	-9	-13	-11	-5	-15	-17	-17	-16	-21	-6	-5	-15	0	-15	-9	**-11**	**-13**
	Warm/Dry (fio)	-24	-18	-21	-15	-7	-11	-24	-30	-23	-24	-11	-8	-28	-1	-17	-17	**-17**	**-16**
15-May	Central (cnrm)	-52	-26	-32	-28	-14	-28	-40	-44	-39	-47	-24	-20	-33	-6	-36	-37	**-29**	**-35**
	Hot/Very Wet (canesm)	-50	-34	-40	-44	-23	-44	-55	-57	-45	-63	-26	-27	-50	-11	-48	-40	**-38**	**-44**
	Hot/Wet (miroc)	-14	-60	-65	-59	-67	-30	-67	-38	-60	-37	-37	-54	-41	-32	-67	-45	**-50**	**-56**
	Warm/Wet (giss)	-20	-10	-15	-15	-6	-16	-18	-18	-19	-24	-8	-8	-14	-2	-18	-12	**-13**	**-16**
	Warm/Dry (fio)	-40	-20	-25	-25	-10	-15	-28	-34	-29	-36	-19	-14	-29	-4	-23	-31	**-22**	**-28**

Table 5-5: GLAC Snowcovered Area (0.5 m snow depth threshold) Top: Area (km^2) in historical average (2000-2013) and five future scenarios. Bottom: percent change in future simulations compared to historical. Average and Median values also shown. The representative dry year is 2005, wet is 2011, and near normal is 2009.

5.12 ROMO Study Area

This section presents SWE and SCA for representative years, area and number of years with snow depth ≥ 0.5 m. The elevation dependence of snow for ROMO is discussed in Section 5-13. On average, the ROMO study area exhibits a change of +1% to -16% in the area with significant snowcover (depth > 0.5 m) on April 15th compared to the 2000-2013 historic average, and a decline of 6-38 percent for May 15th for the scenarios considered (Tables 5-6, 5-7).

5.12.1 SWE and Snowcovered Area for representative years

Figure 5-15 shows DHSVM model simulated SWE on May 15th for the wet representative year (2011). The historical simulation is shown along with three of the five future scenarios, chosen to represent the central scenario (cnrm), the greatest change in snowpack (Hot/Dry, hadgem2) and the least change (Warm/Wet, giss). The future scenarios answer the question "what would the snowpack in a wet year (like 2011) look like in the 2040's through 2070's under these scenarios of climate change." Note that the "greatest snowpack change" scenario is different for ROMO than for GLAC. We have included Hot/Dry as well as a Warm/Dry scenario in the choice of scenarios for ROMO because a significant number of climate models project drying conditions in ROMO, whereas in GLAC, the vast majority of climate models predict a wetter future.

Figures 5-16 and 5-17 shows SWE for the "Near Normal" (2009) and "Dry" (2002) year. One can see that in the dry year, the snowcover is already very low even in the historical simulation with maximum SWE in the domain approximately of ~0.5m on May 15th compared to values of ~1.0 m for the wet year.

Figure 5-18 summarizes the results in terms of the total snowcovered area (km^2) within the study area polygon. In this case, the threshold used is 5mm of SWE, representing a light snowcover, and for May 15th, comparable to the results in McKelvey. Comparing the Wet and Dry years we see a more complicated pattern emerge. As in GLAC the wet year (2011) is less vulnerable to climate change in terms of percentage of area lost. Unlike GLAC, the near normal year (2007) shows large percentage declines, comparable to those of the dry year 2002. The numerical values of snowcovered area for all years, as well as percent changes for these quantities are shown in Table 5-7. **On average, the ROMO study area exhibits a change of +1% to -16% in area with significant snowcover (depth > 0.5 m) for April 15th compared to the 2000-2013 historic average, and a decline of 6-38 percent for April 15th for the scenarios considered (Tables 5-6, 5-7).**

ROMO	Snow Covered Area sq-km (5 mm SWE threshold)																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	1575	1522	1575	1593	1564	1596	1433	1593	1590	1587	1597	1583	1586	1594	1393	1595	**1561**	**1587**
	Central (cnrm)	1442	1348	1486	1519	1428	1590	1026	1550	1536	1447	1596	1495	1526	1582	1105	1590	**1454**	**1507**
	Hot/Dry (hadgem2)	1317	1199	1405	1491	1246	1575	917	1496	1530	1475	1595	1463	1485	1569	806	1578	**1384**	**1480**
	Hot/Very Wet (miroc)	1123	944	1248	1360	1208	1528	835	1418	1439	1094	1586	1275	1351	1505	1010	1589	**1282**	**1313**
	Warm/Wet (giss)	1539	1486	1555	1585	1507	1595	1253	1584	1586	1576	1597	1573	1582	1593	1251	1594	**1528**	**1579**
	Warm/Dry (fio)	1509	1438	1552	1572	1508	1593	1122	1579	1580	1552	1597	1557	1557	1591	1206	1594	**1507**	**1557**
1-May	historical	1557	1519	1537	1546	1417	1592	1368	1596	1564	1568	1596	1573	1542	1594	1058	1593	**1514**	**1560**
	Central (cnrm)	1367	1274	1380	1256	1125	1559	957	1569	1394	1296	1590	1441	1387	1576	735	1538	**1340**	**1384**
	Hot/Dry (hadgem2)	1180	1073	1135	1096	900	1486	829	1306	1250	1265	1577	1341	1172	1547	570	1491	**1201**	**1215**
	Hot/Very Wet (miroc)	1058	873	1075	1030	928	1449	726	1555	1238	979	1563	1172	1217	1494	475	1457	**1143**	**1124**
	Warm/Wet (giss)	1496	1442	1459	1460	1233	1583	1154	1584	1515	1520	1595	1549	1496	1591	897	1587	**1447**	**1505**
	Warm/Dry (fio)	1460	1429	1486	1448	1262	1577	1055	1591	1516	1494	1594	1536	1452	1590	830	1582	**1431**	**1490**
15-May	historical	1463	1452	1173	1281	1245	1587	1041	1536	1507	1481	1590	1512	1516	1591	915	1574	**1404**	**1494**
	Central (cnrm)	1122	1148	895	906	926	1527	667	1316	1153	1047	1553	1185	1302	1535	612	1424	**1145**	**1151**
	Hot/Dry (hadgem2)	840	912	565	679	661	1376	479	982	945	922	1410	891	1039	1431	427	1144	**919**	**917**
	Hot/Very Wet (miroc)	885	751	700	779	754	1371	484	1117	1032	816	1485	943	1163	1424	403	1304	**963**	**914**
	Warm/Wet (giss)	1306	1335	993	1109	1040	1570	841	1420	1380	1355	1579	1401	1441	1580	762	1542	**1291**	**1367**
	Warm/Dry (fio)	1290	1316	1023	1084	1063	1562	817	1433	1385	1317	1582	1410	1444	1578	723	1534	**1285**	**1351**

ROMO	Snow Covered Area % change (5 mm SWE threshold)																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central (cnrm)	-8	-11	-6	-5	-9	0	-28	-3	-3	-9	0	-6	-4	-1	-21	0	**-7**	**-5**
	Hot/Dry (hadgem2)	-16	-21	-11	-6	-20	-1	-36	-6	-4	-7	0	-8	-6	-2	-42	-1	**-11**	**-7**
	Hot/Very Wet (miroc)	-29	-38	-21	-15	-23	-4	-42	-11	-10	-31	-1	-19	-15	-6	-27	0	**-18**	**-17**
	Warm/Wet (giss)	-2	-2	-1	0	-4	0	-13	-1	0	-1	0	-1	0	0	-10	0	**-2**	**0**
	Warm/Dry (fio)	-4	-5	-1	-1	-4	0	-22	-1	-1	-2	0	-2	-2	0	-13	0	**-3**	**-2**
1-May	Central (cnrm)	-12	-16	-10	-19	-21	-2	-30	-2	-11	-17	0	-8	-10	-1	-31	-3	**-11**	**-11**
	Hot/Dry (hadgem2)	-24	-29	-26	-29	-36	-7	-39	-18	-20	-19	-1	-15	-24	-3	-46	-6	**-21**	**-22**
	Hot/Very Wet (miroc)	-32	-43	-30	-33	-34	-9	-47	-3	-21	-38	-2	-26	-21	-6	-55	-9	**-24**	**-28**
	Warm/Wet (giss)	-4	-5	-5	-6	-13	-1	-16	-1	-3	-3	0	-2	-3	0	-15	0	**-4**	**-4**
	Warm/Dry (fio)	-6	-6	-3	-6	-11	-1	-23	0	-3	-5	0	-2	-6	0	-22	-1	**-5**	**-5**
15-May	Central (cnrm)	-23	-21	-24	-29	-26	-4	-36	-14	-23	-29	-2	-22	-14	-4	-33	-10	**-18**	**-23**
	Hot/Dry (hadgem2)	-43	-37	-52	-47	-47	-13	-54	-36	-37	-38	-11	-41	-31	-10	-53	-27	**-35**	**-39**
	Hot/Very Wet (miroc)	-40	-48	-40	-39	-39	-14	-53	-27	-32	-45	-7	-38	-23	-10	-56	-17	**-31**	**-39**
	Warm/Wet (giss)	-11	-8	-15	-13	-17	-1	-19	-8	-8	-9	-1	-7	-5	-1	-17	-2	**-8**	**-9**
	Warm/Dry (fio)	-12	-9	-13	-15	-15	-2	-22	-7	-8	-11	-1	-7	-5	-1	-21	-3	**-8**	**-10**

Table 5-6: ROMO Snowcovered Area (5 mm SWE threshold) Top: Area (km^2) in historical average (2000-2013) and five future scenarios. Bottom: percent change in future simulations compared to historical. Average and Median values also shown. The representative dry year is 2002, wet is 2011, and near normal is 2007. The representative wet year is the same for both areas, but the wet and dry years are different.

Area and Number of years with ≥ 0.5 m Snow Depth

Because of interest in wolverine denning sites, we analyze snow depth ≥ 0.5 m, which we will refer to here as "significant snow." Figure 5-19 shows the area with snow depth ≥ 0.5 m within the study area. Because of the more stringent threshold for snow, the effects are somewhat larger than for the light snowcover. The numerical values of snowcovered area at the ≥ 0.5 m threshold are shown in Table 5-7 for all years, as well as percent changes for these quantities. In this table, we note that dry years such as 2002 see increases in snowcovered area for the Hot/Very Wet and Warm/Wet scenarios. As in GLAC, dry years are somewhat buffered against change, and in fact can see increases in high-altitude "significant" snow for scenarios with increased precipitation. This is a result of the elevational dependence of snowpack change that will be discussed in the next sub-section.

Figure 5-20 shows a map of the number of years (out of 16 possible) where each model pixel had at least 0.5 m of snow depth on May 15th. This summary statistic is analogous to that used by the Copeland study, except that there are more years of data, and these maps use a much higher threshold of snow. The projections show declines in the number of years with significant snow. Visually, the changes depicted are more subtle than those for GLAC. The areas with frequent (14-16 years) availability of significant snow become concentrated in smaller, relatively higher elevation areas in the study area.

The effects of climate change on snow melt have been presented as analogous to a "time shifting" of the melt season earlier in the year. For example, McKelvey (2011) used the May 31st vs. May 15th snowcovered area as a proxy for a 2-week shift in the melt season. Figure 5-21 contrasts the evolution of the snowpack with respect to the number of years with significant snow from April 15th to May 15th in the historical simulations (Top Row) with the Warm/Wet scenario (giss, Middle Row) and Hot/Wet (hadgem, Bottom Row) scenarios. We see that the Warm/Wet scenario, shows the least change in the number of years compared to the historic snowcover in terms of the availability of significant snow. The Hot/Dry "greatest change" scenario, illustrates that the combination of drying and warming leads to very large declines in the persistence of snow that are evident by May 15th, however with smaller changes on April 15th and May 1st.

5.13 Elevation Dependence of Snowpack Change in the DHSVM model

Snowpack accumulation and melt depends critically on temperature and hence on elevation. In the Warm/Dry and Hot/Dry scenarios, both the reduction in precipitation and the warming act to reduce Spring snowpack. For the scenarios with warming and increased precipitation there are two countervailing forces that play out along an elevational gradient. A warmer, wetter future is one in which the freezing level and snow line tends to be higher, but with the potential for greater snowpack accumulation during the cold season at high elevations. The warming also tends to lead to an earlier snowmelt, so that the increased high-elevation snowpack is more evident early in the Springtime than later

Figures 5-22 shows the percent change in May 1st snowcovered area (SCA; ≥ 0.5 meters depth) for GLAC, computed for 200 m elevation bands. The elevation of observed den sites is noted by triangles, with den sites ranging from approximately 1500m to 2300 m. There is little change (<10%) in SCA for 4 of the 5 scenarios above 2000m. There is greater than 60 % loss of SCA below 1400m for 4 of the 5 scenarios. Between these two elevations – and in the regions where most observations of dens have been noted – the snowpack change is very sensitive to elevation and to the particular future climate scenario. Most of the dens are at 1800 to 2000, below that band large losses predicted, above that elevation band minimal losses predicted accept in maximum warming scenario. Figure 5-23 shows the elevation dependence of the May 1st snowpack measured in terms of snow water equivalent (SWE). Viewing snowpack in terms of SWE illustrates more clearly that the Hot/Very Wet future scenario has increased its snowpack between 2300 – 2900 m elevation despite completely losing its snowpack at 1000m elevation. Comparing Figure 5-22 (SCA) with Figure 5-23 (SWE) illustrates that SWE can have modest declines without affecting the area with significant snow depth. The implications is that wet, cold climate of the GLAC study area can act as a "buffer" to change in the area of ≥ 0.5 meter deep snow on May 1st, at least at relatively high elevations within the study area.

Figure 5-24 shown the May 1st SCA (≥ 0.5 m depth) for ROMO. For elevations above 3400m only modest (under 20%) losses of SCA are seen. Figure 5-25 shows only modest (under ~20%) losses in SWE for that elevation band as well with two scenarios (Warm/Wet (giss) and Hot Very Wet (miroc) having slight increases. Below 3400m the losses in SWE become much larger, the lower the elevation. Comparison of Figures 5-24 and 5-25 shows that the relationship between SWE loss and SCA loss is not always straightforward, with a more complicated elevation dependence for SCA than for SWE.

This phenomenon of elevation-dependent snowpack change in the Western US is well supported in the literature. Regonda et al. (2005) found little historical change in snowpack in the Western United States above approximately 2500m elevation despite observed warming trends. and Lettenmaier (2007) considered VIC hydrology model projections and reported as strong elevation dependence for snowpack loss in the Colorado River basin below 2500 m elevation (their data was visualized in Ray et al. 2008). Two recent studies are of special interest because they focus on areas near those considered here. Sospendra-Alfonso et al (2015), on an area near the GLAC study area, find that historically, temperature has been a larger driver of April 1st snowpack only below about 1560 m elevation, with precipitation the main driver of variability above that elevation. Scalzitti et al. (2016) investigated a single climate change scenario using a high-resolution weather model and found that the critical elevation below which temperature dominates snowpack rises by about 250m in the Colorado Rockies, and rises by about 191 m in the Northern Rockies hear the GLAC study area. While it is difficult to these results directly to the present study due to differences in methodology, the qualitative picture remains – projected warming has a larger effect at lower elevations whereas projected precipitation changes may dominate the Springtime snowpack in the high country.

ROMO	Snow Covered Area sq-km (0.5 m depth threshold)																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	historical	1000	803	1176	1021	776	1571	924	1008	1178	1336	1536	1111	768	1529	710	935	**1086**	**1014**
	Central (cnrm)	914	727	1170	929	765	1475	757	1039	1023	999	1533	1035	747	1478	583	967	**1009**	**983**
	Hot/Dry (hadgem2)	796	660	963	922	699	1372	692	891	1042	1076	1482	994	737	1417	485	887	**945**	**906**
	Hot/Very Wet (miroc)	781	588	948	897	724	1271	629	990	1071	811	1500	845	761	1361	426	1043	**915**	**871**
	Warm/Wet (giss)	1006	789	1184	1098	781	1553	862	1019	1217	1313	1559	1157	806	1531	677	1051	**1100**	**1074**
	Warm/Dry (fio)	823	690	1062	821	728	1499	742	817	960	1123	1442	987	700	1462	565	826	**953**	**825**
1-May	historical	871	852	1029	819	719	1556	841	987	983	1147	1365	1148	837	1519	594	1119	**1024**	**985**
	Central (cnrm)	835	747	944	713	661	1423	710	888	811	847	1286	980	769	1454	472	1052	**912**	**841**
	Hot/Dry (hadgem2)	742	636	742	672	561	1254	636	725	797	840	1136	817	703	1354	356	845	**801**	**742**
	Hot/Very Wet (miroc)	736	596	772	694	595	1182	583	819	845	706	1251	825	759	1326	315	1105	**819**	**766**
	Warm/Wet (giss)	890	822	960	799	691	1521	782	915	981	1110	1406	1093	837	1510	541	1141	**1000**	**938**
	Warm/Dry (fio)	773	720	927	723	665	1464	716	792	800	965	1191	1004	762	1441	490	962	**900**	**796**
15-May	historical	852	864	705	712	681	1549	532	1017	943	995	1357	1005	981	1454	577	1041	**954**	**962**
	Central (cnrm)	738	699	569	556	569	1377	406	834	728	709	1151	744	854	1328	429	853	**784**	**733**
	Hot/Dry (hadgem2)	584	546	296	398	406	1104	238	611	640	610	925	505	691	1080	262	635	**596**	**597**
	Hot/Very Wet (miroc)	636	558	451	534	497	1136	298	753	724	610	1110	627	818	1175	271	907	**694**	**631**
	Warm/Wet (giss)	809	797	629	670	632	1502	487	911	895	936	1320	902	957	1421	513	988	**898**	**898**
	Warm/Dry (fio)	753	721	608	617	610	1455	402	826	778	832	1190	866	859	1343	484	897	**828**	**802**

ROMO	Snow Covered Area % change (0.5 m depth threshold)																		
	Scenario	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average	Median
15-Apr	Central (cnrm)	-9	-9	-1	-9	-1	-6	-18	3	-13	-25	0	-7	-3	-3	-18	3	**-7**	**-3**
	Hot/Dry (hadgem2)	-20	-18	-18	-10	-10	-13	-25	-12	-12	-19	-4	-11	-4	-7	-32	-5	**-13**	**-11**
	Hot/Very Wet (miroc)	-22	-27	-19	-12	-7	-19	-32	-2	-9	-39	-2	-24	-1	-11	-40	12	**-16**	**-14**
	Warm/Wet (giss)	1	-2	1	8	1	-1	-7	1	3	-2	1	4	5	0	-5	12	**1**	**6**
	Warm/Dry (fio)	-18	-14	-10	-20	-6	-5	-20	-19	-19	-16	-6	-11	-9	-4	-20	-12	**-12**	**-19**
1-May	Central (cnrm)	-4	-12	-8	-13	-8	-9	-16	-10	-17	-26	-6	-15	-8	-4	-21	-6	**-11**	**-15**
	Hot/Dry (hadgem2)	-15	-25	-28	-18	-22	-19	-24	-27	-19	-27	-17	-29	-16	-11	-40	-24	**-22**	**-25**
	Hot/Very Wet (miroc)	-15	-30	-25	-15	-17	-24	-31	-17	-14	-38	-8	-28	-9	-13	-47	-1	**-20**	**-22**
	Warm/Wet (giss)	2	-3	-7	-3	-4	-2	-7	-7	0	-3	3	-5	0	-1	-9	2	**-2**	**-5**
	Warm/Dry (fio)	-11	-15	-10	-12	-7	-6	-15	-20	-19	-16	-13	-13	-9	-5	-18	-14	**-12**	**-19**
15-May	Central (cnrm)	-13	-19	-19	-22	-17	-11	-24	-18	-23	-29	-15	-26	-13	-9	-26	-18	**-18**	**-24**
	Hot/Dry (hadgem2)	-31	-37	-58	-44	-40	-29	-55	-40	-32	-39	-32	-50	-30	-26	-55	-39	**-38**	**-38**
	Hot/Very Wet (miroc)	-25	-35	-36	-25	-27	-27	-44	-26	-23	-39	-18	-38	-17	-19	-53	-13	**-27**	**-34**
	Warm/Wet (giss)	-5	-8	-11	-6	-7	-3	-9	-10	-5	-6	-3	-10	-2	-2	-11	-5	**-6**	**-7**
	Warm/Dry (fio)	-12	-17	-14	-13	-10	-6	-25	-19	-17	-16	-12	-14	-12	-8	-16	-14	**-13**	**-17**

Table 5-7: ROMO Snowcovered Area (0.5 m snow depth threshold) Top: Area (km^2) in historical average (2000-2013) and five future scenarios. Bottom: percent change in future simulations compared to historical. Average and Median values also shown. The representative dry year is 2002, wet is 2011, and near normal is 2007.

6 Comparing results with McKelvey

An overview of the methodological similarities and differences between this study and McKelvey et al (2011) was presented in section 2.2. The differences in aims of these studies leads to challenges in making a direct comparison. The primary difference is in the choice of study areas – west-wide vs. much smaller selected areas near treeline, which has implications for the biological hypotheses that may be addressed. Their work focused on May 1st snow depth as a proxy for May 15th snow disappearance, while we directly estimated the May 15th snow disappearance. McKelvey investigated persistence of even a snowcover to May 15th as a correlate of wolverine habitat, as noted in Aubry et al (2008). This study focuses on high-elevation terrain and on the persistence of deeper snowpack. We also analyze our model results for the presence or absence of deeper snow (nominally greater than or equal to 0.5 meters depth) on April 15th and May 1st. [8]

Nonetheless some general statements can be made relating the two studies. Figure 5-26 shows snowcover under McKelvey's historic and "miroc 2080's" (or hotter, greatest change) scenario. The GLAC and ROMO areas have been outlined. A close examination of this figure shows that snowcover persists in our study areas, even for their hotter scenario of change (miroc "2080's). The greatest loss of snowcover in McKelvey occurs at lower elevations than were included in GLAC or ROMO. Because of the increased resolution of our study we are able to consider whether any pockets of snow with depth ≥ 0.5 meters will persist.

The choice of future climate scenarios differs somewhat from McKelvey. We have intentionally included scenarios that represent the range of possibilities indicated by the CMIP5 climate models. McKelvey used climate model output from Littell, who chose scenarios based solely on projected warming. For GLAC, this choice fortuitously included a range of precipitation changes as well. For ROMO, however, McKelvey's scenarios include only a narrow range of precipitation change, where we include scenarios with significantly increased wintertime precipitation as well as scenarios with drying. This is a significant factor, given the buffering effect that increased precipitation has on snowpack loss at high elevations.

While McKelvey focused snowpack projections entirely on the long-term average, we investigate how climate variability – the sequences of wet and dry years -- intersects with scenarios of change. For ROMO in particular we find that dry years behave differently than wet years, with dry years benefitting from the increased precipitation in several of our future scenarios. This emphasizes the importance of planning for a range of possible climate scenarios, particularly regarding the direction of change in wintertime precipitation.

The question arises as to how the fine-scale projections of snow persistence in other areas might reasonably be inferred from the two study areas considered here. Figure 5-26 indicates many areas in the western United States that show persistence of snowcover in McKelvey's scenarios, even in the more extreme scenarios. We have investigated two study areas: a northern, relatively

[8] The study originally focused on May 15th to compare to the McKelvey, et al (2011) study, and June 1st to bracket the snowmelt season. However, as the study progressed, biologists because more interested in April snow.

wet and low-elevation area GLAC, and a southern, relatively dry, and very high elevation area (ROMO). In both areas we find general declines in snowcovered area under most future scenarios. The GLAC study area is broadly similar in its climate to much of the high northern Rockies, while ROMO shares features with the high mountain ranges of the Central Rockies. For areas in the McKelvey maps that show retention of snow on the higher mountain ranges it is physically reasonable to presume that a finer scale simulation would show the retention of areas of snow ≥ 0.5 m on May 15th. Extending this beyond the general area of the Rocky Mountains is problematic. Even within the Rockies, in regions where McKelvey's results show widespread loss of snowpack it is probably not reasonable to conclude one way or the other whether a finer scale analysis would identify snow refugia.

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9 Glossary

- **Aspect:** compass direction that slope faces
- **Baseline period 1916-2000**: Deltas (changes) computed (monthly average delta) for "2040's and "2080's" compared to the 1916-2000 baseline.
- **CanESM or cnsm:** A CMIP5 climate model the Canadian Centre for Climate Modeling and Analysis (canesm2.1.rcp85), forced with the RCP 8.5 higher emissions pathway, used in this report as a future scenario (Hot/Dry scenario for GLAC only) that has relatively higher increase in temperature (+~4.5 C) and about +20% increase in precipitation (See Figure 5-7)
- **Climate Sensitivity:** Regionally speaking, it is the response of a climate model for a given amount of greenhouse gas increase. More narrowly defined it is the global average temperature increase that results from a doubling of carbon dioxide over pre-industrial values.
- **CMIP3, CMIP5:** Coupled Model Intercomparison Project Phases 3 and 5. "Foundational" collections of climate model projections, used in the Intergovernmental panel on Climate Change (IPCC) 2007 and IPCC 2013 reports, respectively
- **CNRM:** A CMIP5 climate model from the French National Centre of Meteorological Research (cnrm-cm5.1.rcp85),used in this report as a future scenario (Central scenario for both GLAC and ROMO) that is relatively close to the ensemble mean in temperature increase (+~2.5 ºC) and +~5-8% increase in precipitation (See Figure 5-7).
- **DEM:** Digital elevation model
- **DSHVM:** Distributed Hydrology Soil Vegetation Model
- **ESM:** earth system models, see GCM.
- **FIO:** A CMIP5 earth system model from the First Institute of Oceanography, State Oceanic Administration of China (fio-esm.1.rcp85), used in this report as a future scenario (Warm/Dry scenario for both areas) that is relatively lower in temperature increase (+~0.8-1.6 ºC) and -~5% decrease in precipitation (See Figure 5-7).
- **FLH:** Atmospheric freezing level height is the altitude in the free atmosphere at which the temperature is 0 °C
- **GCM:** Global Climate Model, 6 were used for this report from the IPCC 2013 class of models; X of these are actually earth system models (ESM), an advanced type of GCM which have the added capability to explicitly represent biogeochemical processes that interact with the physical climate. GCM is used as a general term referring to both kinds of models, ESM is used specifically for earth system models.
- **GISS:** A CMIP5 climate model from the NASA Goddard Institute for Space Studies (giss-e2-r.1.rcp45), used in this report as a future scenario (Warm/Wet scenario for both areas). Referred to as the "Least Change" scenario because it that is relatively lower temperature increase (+~1-1.3 ºC) and +~7-10% increase in precipitation (See Figure 5-7).
- **GLAC:** An area in Glacier National Park used as a spatial unit of analysis in this report
- **HADGEM:** A CMIP5 earth system model from the United Kingdom Meteorological Office Hadley Center (hadgem2-es.1.rcp85) used in this report as a future scenario

(Hot/Very Wet scenario for ROMO only) that has relatively higher temperature increase (+~ 3.5 ºC) and -~5% decrease in precipitation.

- **Internal climate variability**: The variations in the climate, even for 30-year and longer averages, that can occur due to the interactions of the atmosphere, ocean, inland surface and cryosphere. This occurs even in the absence of anthropogenic climate change.
- **MODIS:** Moderate Resolution Imaging Spectroradiometer, a satellite remote sensing instrument carried on the Terra satellite
- **MIROC:** A CMIP5 earth system model from the Japanese Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies (miroc-esm-chem.1.rcp85), used in this report as a future scenario (Hot/Wet scenario for both areas). Referred to as the "Greatest Change" scenario because it has the highest temperature increase of the scenarios (+~4 ºC) and +~10-18% increase in precipitation (see Figure 5-7). This ESM has an atmospheric chemistry (CHEM) component coupled to the MIROC-ESM (http://maca.northwestknowledge.net/GCMs.php).
- **NDSI:** Normalized Difference Snow Index, a measure of snowcover, has a has a linear relationship to fractional snowcover (FSC)
- **North American Freezing Level Tracker**: NCEP/NCAR Global Reanalysis 2.5º x 2.5º grid data (http://www.wrcc.dri.edu/cwd/products/)
- **Octants:** Topographic aspect, or compass direction, was classified into eight directional bins, each representing 45° of compass arc, e.g; NW, N, NE, E, SE, S, SW, and W
- **Resolution:** The VIC modeling that was the basis for McKelvey was performed on a regular grid in latitude and longitude, with a grid size of 1/16 degree on a side. The distance between degrees of longitude varies due to the curvature of the Earth, and the east-west dimension of a gridbox is smaller than the north-south distance by a factor of the cosine of latitude. At 40°N latitude, the southern extent of Rocky Mountain National Park, the gridbox is ~5km by 7 km (~37km^2). Grid boxes at Glacier National Park (~48°N) are slightly smaller. When referring to the McKelvey study we will use the "1/16 degree" notation. The DHSVM modeling used in this study was performed on a uniform grid in the Universal Transverse Mercator (UTM) map projection, which allows a near-uniform grid size of 250m by 250m (0.0625 km^2) in both of the study areas.
- **ROMO:** An area in and around Rocky Mountain NP used as a spatial unit of analysis in this report
- **SCA:** Snowcovered Area (km^2)
- **SDD:** Snow Disappearance Date, the first Day of Year after March 1 where pixel is snow-free, defined as the date which NDSI/100 was less or equal to 0.1.
- **SNODAS:** Snow Data Assimilation System, a product of the NOAA National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC)
- **SWE:** Snow water equivalent (mm). For May, snow depth is assumed to be ~ 2.5 *SWE
- **TopoWx:**
- **Snowcovered area, total:**Total area covered by snow within the study boundaries in square kilometers (km^2)
- **Snowcovered area, fractional:** Percentage of the total land area that is covered by snow; this can be within the study boundaries, aspect area, or elevation bands
- **VIC:** Variable Infiltration Capacity hydrologic model
- **UTM:** Universal Transverse Mercator spatial coordinates

From:	Snyder, Caitlin
To:	Justin Shoemaker; Grizzle, Betty
Subject:	Draft SOW and peer review plan for wolverine peer review
Date:	Friday, September 8, 2017 8:37:26 AM
Attachments:	20170907_Wolverine peer review Statement of Work.docx 20170906_Wolverine_SSA_PeerReviewPlan.docx

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Hi Justin and Betty,

Attached is a draft Statement of Work for the wolverine peer review and a draft peer review plan.

The SOW will be submitted to contracting and they will put it out to the contractor to get a bid on the peer review process. There is template language in the SOW, so please only look at the specific language related to wolverine and the schedule (number of days for each task).

The peer review plan will be posted on the Service's Peer Review page -- I'm assuming it should go under Region 6.

The peer review plan draws from the language in the SOW, so I recommend focusing your review on the SOW, because I can easily incorporate the language from the SOW into the peer review plan later.

Please let me know if you have any questions.

Thanks,
Caitlin

Caitlin Snyder
Unified Listing Team
U.S. Fish & Wildlife Service
MS: ES
5275 Leesburg Pike
Falls Church, VA 22041-3803
phone: 703 358 2673

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

Date: September 7, 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.

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 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 later 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, Oregon (Wallowa Range), and Wyoming. Individual wolverines have also moved into historic 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 an M.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 large carnivore management, especially wolverines;

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

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 small populations;

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 personally, or 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, none of the reviewers should have served as participants in the April 2-3, 2014 facilitated wolverine workshop held by the Service. 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 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 them into the final recovery plan, 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. Individual reviewers should, at their own discretion, provide comments,

criticisms, and ideas about any of the topics they feel qualified to comment on. Not all reviewers are required to address all issues noted below. Reviewers should comment on areas within their expertise, and may choose to abstain from other areas.

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 are how are they relevant?

(2) Provide advice on the overall strengths and limitations of the scientific data used in the document. Have the authors been 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 viability 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 present given the data and the analyses conducted been clearly identified and has the degree of uncertainty been appropriately characterized? If not, please identify any specifics 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 services 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 (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 Contracting Officer Representative 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: FWS Project Lead will provide the Contractor access to materials needed by the Contractor to determine the scope of the activity and identify appropriate peer reviewers, such as an early draft of the biological report (Note: the final draft biological report will not be ready at the time of award to provide to the Contractor.)	1 day after award (estimated as DATE)
Task 2: The Contractor(s) will provide the Project Lead the names and resumes of 5 qualified, expert peer reviewers.	21 days from task 1 (estimated as DATE)
Task 3: The Project Lead will review the names and resumes of the peer reviewers and provide feedback to Contractor – acceptable / non-acceptable. If a peer reviewer is determined by the government to be non-acceptable the Contractor has 10 days from notification to submit new names and resumes for government review. Government will review within 7 days.	7 days from Task 2 (estimated as DATE)
	CALENDAR DAYS AFTER FINAL DRAFT SSA HAS BEEN PROVIDED TO CONTRACTOR (estimated as DATE – subject to change)
Task 4: The Contractor(s) shall conduct a thorough, objective 30-day peer review of the draft SSA.	30 days (estimated as DATE); Provide reviews to the Service within 5 calendar days after the 30 days) (estimated as DATE).
Task 5: The Project Lead facilitates specific follow-up questions/answers between the Service and the reviewers.	46 days (estimated as DATE)
Task 6: The Contractor(s) will provide all applicable official records to the Service Project Lead.	5 days (estimated as DATE)

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 background information including, but not limited to: ADD LIST HERE.

9. Payment Schedule:

The payment schedule is as follows: 100 percent upon completion of Task 6 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

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 (wolverine ecologist/statistician/modeler having performed similar reviews) (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).

A Peer Review Plan for
the Wolverine
Species Status Assessment draft Report

U.S. Fish and Wildlife Service, Region 6

About the Document:

The format of this peer review plan reflects the necessary items enumerated in the 2004 Office of Management and Budget memorandum M-05-03 entitled "Final Information Quality Bulletin for Peer Review" (p. 29 i-x; https://www.whitehouse.gov/omb/memoranda_fy2005_m05-03). Further, in accordance with the Service's 2016 memorandum entitled "Peer Review Process" (https://www.fws.gov/endangered/improving_ESA/peer_review_process.html) an independent office, otherwise not associated with the dissemination, will select peer reviewers and coordinate the process.

Subject and purpose. The Service's Carlsbad Fish and Wildlife Office (and others) is drafting 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. The SSA report will be used to comply with a court order and inform a decision (to later be published in the *Federal Register*) to classify the North American wolverine as threatened, endangered or "not warranted" under the Act. Public inquiries may be directed to the agency contact listed below.

Importance of the "dissemination". The SSA report will disseminate likely "influential scientific information" and provide the scientific foundation to inform any subsequent listing determination and/or recovery plan under the Act.

About the Peer Review Process:

Timing of the review: The peer review will take place between October and December 2017.

Type of review: The Service is contracting the solicitation and coordination of the independent scientific review. The purpose of seeking independent peer review is to ensure that the best biological and scientific data are being used in the SSA, as well as to ensure that reviews by recognized experts are incorporated into the SSA. Peer reviewers were asked to consider, but not limit their responses, to the following questions and provide any other relevant comments, criticisms, or ideas:

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 are how are they relevant?

2. Provide advice on the overall strengths and limitations of the scientific data used in the document. Have the authors been 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 viability 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 present given the data and the analyses conducted been clearly identified and has the degree of uncertainty been appropriately characterized? If not, please identify any specifics concerns.

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

About public participation: If the SSA report is used to support a classification determination, the public will then have the opportunity to comment on that proposed rule or finding when it is published. The Service will not be providing public comments to the peer reviewers before they conduct their review. The public is invited to submit comments on this peer review plan by sending emails to the agency contact listed below. The Service will summarize in the final decision document, and make publicly available, copies of each individual independent peer review letter.

Number of reviewers: The Service will use five (5) individual independent subject matter expert peer reviewers.

Necessary expertise. The Service requests that the contractor seeks peer reviewers with expertise in the following topics of scientific investigation including:

1. Each reviewer must have a Ph.D. or an M.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 large carnivore management, especially wolverines;

   b. Expert knowledge of wildlife biology, wildlife management, demographic management of mammals (especially carnivores), genetics, population modeling, small population

management, and/or scientific literature on wolverines or other musteleds;

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 small populations;

e. Experience as a peer reviewer for scientific publications;

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

Scope of the review. Peer reviewers will be advised that they should not provide advice on policy, including a decision-maker's tolerances for risk and uncertainty.

Selection of peer reviewers. The contractor will be responsible for assigning an experienced, senior and well-qualified manager to lead this review and for the selection of 5 well-qualified, independent reviewers.

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 personally, or 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, none of the reviewers should have served as participants in the April 2-3, 2014 facilitated wolverine workshop held by the Service. Finally, the reviewers should have no financial or other conflicts of interest with the outcome or implications of the report.

Each reviewer will submit a conflict of interest disclosure that will be posted along with the peer review plan on the Service's Science Excellence website (https://www.fws.gov/science) and made publicly available.

Agency contact: Justin Shoemaker, Classification and Recovery Biologist, 309-757-5800 ext. 214 or email: justin_shoemaker@fws.gov

From: Grizzle, Betty
To: Snyder, Caitlin; Justin Shoemaker
Cc: Bush, Jodi
Subject: Re: Draft SOW and peer review plan for wolverine peer review
Date: Tuesday, September 12, 2017 11:46:37 AM
Attachments: 20170906_Wolverine_SSA_PeerReviewPlan_BJG.docx
20170907_Wolverine peer review Statement of Work_JS_BJG.docx

Please see attached documents with my comments/suggestions.

On Fri, Sep 8, 2017 at 7:36 AM, Snyder, Caitlin <caitlin_snyder@fws.gov> wrote:

> Hi Justin and Betty,
>
> Attached is a draft Statement of Work for the wolverine peer review and a draft peer review plan.
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>
> Please let me know if you have any questions.
>
> Thanks,
> Caitlin
>
> Caitlin Snyder
> Unified Listing Team
> U.S. Fish & Wildlife Service
> MS: ES
> 5275 Leesburg Pike
> Falls Church, VA 22041-3803
> phone: 703 358 2673

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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

A Peer Review Plan for
the North American
Wolverine
Species Status Assessment draft Report

U.S. Fish and Wildlife Service, Region 6

About the Document:

The format of this peer review plan reflects the necessary items enumerated in the 2004 Office of Management and Budget memorandum M-05-03 entitled "Final Information Quality Bulletin for Peer Review" (p. 29 i-x; https://www.whitehouse.gov/omb/memoranda_fy2005_m05-03). Further, in accordance with the Service's 2016 memorandum entitled "Peer Review Process" (https://www.fws.gov/endangered/improving_ESA/peer_review_process.html) an independent office, otherwise not associated with the dissemination, will select peer reviewers and coordinate the process.

Subject and purpose. The Service's Montana Ecological Services Office (in coordination with other Field Offices) is drafting 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 projected future conditions for the species. 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. Public inquiries may be directed to the agency contact listed below.

Importance of the "dissemination". The SSA report will disseminate likely "influential scientific information" and provide the scientific foundation to inform any subsequent listing determination and/or recovery plan under the Act.

About the Peer Review Process:

Timing of the review: The peer review will take place between October and December 2017.

Type of review: The Service is contracting the solicitation and coordination of the independent scientific review. The purpose of seeking independent peer review is to ensure that the best biological and scientific data are being used in the SSA, as well as to ensure that reviews by recognized experts are incorporated into the SSA. Peer reviewers are asked to consider, but not limit their responses, to the following questions and provide any other relevant comments, criticisms, or ideas:

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 the viability of this species and not repetitive of other information or studies already included? What are they and how are they relevant?

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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 viability 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.

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

About public participation: If the SSA report is used to support a classification determination, the public will then have the opportunity to comment on that proposed rule or finding when it is published. The Service will not be providing public comments to the peer reviewers before they conduct their review. The public is invited to submit comments on this peer review plan by sending emails to the agency contact listed below. The Service will summarize in the final decision document, and make publicly available, copies of each individual independent peer review letter.

Number of reviewers: The Service will use five (5) individual independent subject matter expert peer reviewers.

Necessary expertise. The Service requests that the contractor seeks peer reviewers with expertise in the following topics of scientific investigation including:

1. Each reviewer must have a Ph.D. or an M.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

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mammals (especially mesocarnivores), genetics, population modeling, population management and conservation, 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.

Scope of the review. Peer reviewers will be advised that they should not provide advice on policy, including a decision-maker's tolerances for risk and uncertainty.

Selection of peer reviewers. The contractor will be responsible for assigning an experienced, senior and well-qualified manager to lead this review and for the selection of 5 well-qualified, independent reviewers.

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.

Each reviewer will submit a conflict of interest disclosure that will be posted along with the peer review plan on the Service's Science Excellence website (https://www.fws.gov/science) and made publicly available.

Agency contact: Justin Shoemaker, Classification and Recovery Biologist, 309-757-5800 ext. 214 or email: justin_shoemaker@fws.gov

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

Date: September 7, 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 threatened or endangered 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 Northern Rocky Mountains in Idaho, Montana, Oregon, parts of Washington and Oregon, and Wyoming. Individual wolverines have recently dispersed into their historic 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 an M.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:

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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 conservation management, 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;

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e. Experience as a peer reviewer for scientific publications;

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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 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 final SSA report recovery plan, 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,

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criticisms, or thoughts. Collectively, the review should cover, but not be limited to, the topics listed below. Individual reviewers should, at their own discretion, provide comments, criticisms, and ideas about any of the topics they feel qualified to comment on. Not all reviewers are required to address all issues noted below. Reviewers should comment on areas within their expertise, and may choose to abstain from other areas.

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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 the viability of this species and not repetitive of other information or studies already included? What are they and how are they relevant?

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(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 viability of the North American wolverine? Are there any inconsistencies in how the data are presented or assessed?

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Analysis of Available Data

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(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**:**

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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 (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 Contracting Officer Representative will be provided to the contractor via the Contracting Officer.

6. Task Schedule

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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:

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TASK/DELIVERABLE	CALENDAR DAYS AFTER AWARD

Task 1: FWS ULT Lead or Field Office? will provide the Contractor access to materials needed by the Contractor to determine the scope of the activity and identify appropriate peer reviewers, such as an early draft of the biological report (Note: the final draft SSA biological report will not be available at the time of award to provide to the Contractor.)	1 day after award (estimated as DATE)
Task 2: The Contractor(s) will provide the Lead Field Office?? the names and resumes of 5 qualified, expert peer reviewers.	21 days from task 1 (estimated as DATE)
Task 3: The Project Lead will review the names and resumes of the peer reviewers and provide feedback to Contractor – acceptable / not acceptable. If a peer reviewer is determined by the government to be not acceptable, the Contractor has 10 days from notification to submit new names and resumes for government review. Government will review within 7 days.	7 days from Task 2 (estimated as DATE)
	CALENDAR DAYS AFTER FINAL DRAFT SSA REPORT HAS BEEN PROVIDED TO CONTRACTOR (estimated as DATE – subject to change)
Task 4: The Contractor(s) shall conduct a thorough, objective 30-day peer review of the draft SSA.	30 days (estimated as DATE); Provide reviews to the Service within 5 calendar days after the 30 days) (estimated as DATE).
Task 5: The Project Lead facilitates specific follow-up questions/answers between the Service and the reviewers.	46 days (estimated as DATE)
Task 6: The Contractor(s) will provide all applicable official records to the Service Project Lead.	5 days (estimated as DATE)

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Commented [SJ13]: If this were to happen, it really pushes things back. Not sure how likely it is to happen though.

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Commented [BJG15]: Not sure I understand. The contractor is coordinating the peer review, not conducting it, right?

Commented [SJ16]: Betty wants to get the draft SSA Report to peer reviewers no later than Oct. 13. All other dates in this table can be calculated from that date. But I think we allow too much time for task 2. Thoughts?

Commented [BJG17]: Yes, this timeline is a little problematic. But as I mentioned on Core Team call, if you want to "hold" the draft document so that it is sent out on the original timeline (Oct 21, though this is a Saturday??), then that will help. I will not be available Oct 13 and for most of the week of Oct 16.

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 background information including, but not limited to: ADD LIST HERE.

9. Payment Schedule:

The payment schedule is as follows: 100 percent upon completion of Task 6 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

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 (wildlife biologist/ecologist/statistician/modeler having performed similar reviews) (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).

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From: Bush, Jodi
To: Grizzle, Betty
Cc: Snyder, Caitlin; Justin Shoemaker
Subject: Re: Draft SOW and peer review plan for wolverine peer review
Date: Tuesday, September 12, 2017 12:34:32 PM
Attachments: 20170906_Wolverine_SSA_PeerReviewPlan_BJG_JBeds.docx
20170907_Wolverine peer review Statement of Work_JS_BJG_JB.docx

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Betty and others. My review on top of Betty's. Generally I agree with her suggested edits. 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, Sep 12, 2017 at 11:46 AM, Grizzle, Betty <betty_grizzle@fws.gov> wrote:

> Please see attached documents with my comments/suggestions.
>
> On Fri, Sep 8, 2017 at 7:36 AM, Snyder, Caitlin <caitlin_snyder@fws.gov> wrote:
>
> > Hi Justin and Betty,
> >
> > Attached is a draft Statement of Work for the wolverine peer review and a draft peer review plan.
> >
> > The SOW will be submitted to contracting and they will put it out to the contractor to get a bid on the peer review process. There is template language in the SOW, so please only look at the specific language related to wolverine and the schedule (number of days for each task).
> >
> > The peer review plan will be posted on the Service's Peer Review page -- I'm assuming it should go under Region 6.
> >
> > The peer review plan draws from the language in the SOW, so I recommend focusing your review on the SOW, because I can easily incorporate the language from the SOW into the peer review plan later.
> >
> > Please let me know if you have any questions.
> >
> > Thanks,
> > Caitlin
> >
> > Caitlin Snyder
> > Unified Listing Team
> > U.S. Fish & Wildlife Service
> > MS: ES

5275 Leesburg Pike
Falls Church, VA 22041-3803
phone: 703 358 2673

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Betty J. Grizzle, D.Env.
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2177 Salk Ave, Suite 250
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mammals (especially mesocarnivores), genetics, population modeling, population management and conservation, 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.

Scope of the review. Peer reviewers will be advised that they should not provide advice on policy, including a decision-maker's tolerances for risk and uncertainty.

Selection of peer reviewers. The contractor will be responsible for assigning an experienced, senior and well-qualified manager to lead this review and for the selection of at least 3 and up to 5 well-qualified, independent reviewers.

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.

Each reviewer will submit a conflict of interest disclosure that will be posted along with the peer review plan on the Service's Science Excellence website (https://www.fws.gov/science) and made publicly available.

Agency contact: Justin Shoemaker, Classification and Recovery Biologist, 309-757-5800 ext. 214 or email: justin_shoemaker@fws.gov

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

Date: September 7, 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 threatened or endangered 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 Northern Rocky Mountains in Idaho, Montana, and, parts of Washington and Oregon, and Wyoming. Individual wolverines have recently dispersed into their historic 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 an M.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:

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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 conservation management, 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 at least 3 and up to 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 final 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,

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Commented [JB6]: I agree. We only need 3.

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criticisms, or thoughts. Collectively, the review should cover, but not be limited to, the topics listed below. Individual reviewers should, at their own discretion, provide comments, criticisms, and ideas about any of the topics they feel qualified to comment on. Not all reviewers are required to address all issues noted below. Reviewers should comment on areas within their expertise, and should abstain from commenting in areas outside of their expertise.

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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?

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Commented [BJG9]: Is this question necessary? It seems to indicate that focus in only on viability, but we are asking for assessment of all information?
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(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?

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Commented [BJG10]: See comment above. #6 below provides appropriate question for this issue.
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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 specifics concerns.

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(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**:**

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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 (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 Contracting Officer Representative will be provided to the contractor via the Contracting Officer.

6. Task Schedule

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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:

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TASK/DELIVERABLE	CALENDAR DAYS AFTER AWARD

Task 1: FWS ULT Lead or Field Office? will provide the Contractor access to materials needed by the Contractor to determine the scope of the activity and identify appropriate peer reviewers, such as an early draft of the biological report (Note: the final draft SSA biological report will not be available at the time of award to provide to the Contractor.)	1 day after award (estimated as DATE)
Task 2: The Contractor(s) will provide the Lead Field Office?? the names and resumes of 5 qualified, expert peer reviewers.	14 days from task 1 (estimated as DATE)
Task 3: The Project Lead will review the names and resumes of the peer reviewers and provide feedback to Contractor – acceptable / not acceptable. If a peer reviewer is determined by the government to be not acceptable, the Contractor has 10 days from notification to submit new names and resumes for government review. Government will review within 7 days.	7 days from Task 2 (estimated as DATE)
	CALENDAR DAYS AFTER FINAL DRAFT SSA REPORT HAS BEEN PROVIDED TO CONTRACTOR (estimated as DATE – subject to change)
Task 4: The Contractor(s) through use of Peer Reviewers, shall conduct a thorough, objective 30-day peer review of the draft SSA.	30 days (estimated as DATE); Provide reviews to the Service within 5 calendar days after the 30 days) (estimated as DATE).
Task 5: The Project Lead facilitates specific follow-up questions/answers between the Service and the reviewers.	46 days (estimated as DATE)
Task 6: The Contractor(s) will provide all applicable official records to the Service Project Lead.	5 days (estimated as DATE)

Commented [BJG11]: Not sure what this should be. This is important – who is the primary contact?

Commented [JB12]: This should be project lead – Betty.

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Commented [SJ13]: Should we call it a species status assessment report?

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Commented [SJ15]: If this were to happen, it really pushes things back. Not sure how likely it is to happen though.

Commented [BJG16]: I would recommend that each peer reviewer complete and sign a conflict of interest form, which should be submitted to Service by the Contractor. I have an example form, if needed

Commented [JB17]: I don't think we need to do this. I don't recall that we have done this for the last 3 peer reviews we have completed.

Commented [BJG18]: Not sure I understand. The contractor is coordinating the peer review, not conducting it, right?

Commented [JB19]: Also. They almost never meeting the 30 day timeline. 45 days is what typically happens.

Commented [SJ20]: Betty wants to get the draft SSA Report to peer reviewers no later than Oct. 13. All other dates in this table can be calculated from that date. But I think we allow too much time for task 2. Thoughts?

Commented [BJG21]: Yes, this timeline is a little problematic. But as I mentioned on Core Team call, if you want to "hold" the draft document so that it is sent out on the original timeline (Oct 21, though this is a Saturday??), then that will help. I will not be available Oct 13 and for most of the week of Oct 16.

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 background information including, but not limited to: ADD LIST HERE.

9. Payment Schedule:

The payment schedule is as follows: 100 percent upon completion of Task 6 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

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 (wildlife biologist/ecologist/statistician/modeler having performed similar reviews) (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).

Commented [SJ22]: Betty?

Commented [BJG23]: Is this necessary? They will receive list of or complete references cited in SSA report. This list of citations is at 20 pages+ in current draft. No easy way to summarize all of those.

Commented [JB24]: By list here, they just mean what other docs. Like lit cited. Not an itemized list of lit cited. Or if we wanted them to see the proposed rule or the withdrawal if we

Commented [BJG25]: See notes above. I'm not clear on who is responsible for what regarding communicating with or providing documents to contractor.

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Commented [SJ26]: Is this relevant? Didn't see this in 3.2. above.

Commented [BJG27]: I would remove statistician.

From: Shoemaker, Justin
To: Snyder, Caitlin
Cc: Grizzle, Betty
Subject: Re: Draft SOW and peer review plan for wolverine peer review
Date: Tuesday, September 12, 2017 8:34:13 AM
Attachments: 20170907_Wolverine peer review Statement of Work_JS.docx

---

Thanks for putting this together Caitlin. I have a few edits and questions/comments in the attached SOW.

In the peer review plan, we might say the Montana FO instead of Carlsbad. I think Betty is actually working for Jodi on this project?

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 Fri, Sep 8, 2017 at 9:36 AM, Snyder, Caitlin <caitlin_snyder@fws.gov> wrote:

> Hi Justin and Betty,
>
> Attached is a draft Statement of Work for the wolverine peer review and a draft peer review plan.
>
> The SOW will be submitted to contracting and they will put it out to the contractor to get a bid on the peer review process. There is template language in the SOW, so please only look at the specific language related to wolverine and the schedule (number of days for each task).
>
> The peer review plan will be posted on the Service's Peer Review page -- I'm assuming it should go under Region 6.
>
> The peer review plan draws from the language in the SOW, so I recommend focusing your review on the SOW, because I can easily incorporate the language from the SOW into the peer review plan later.
>
> Please let me know if you have any questions.
>
> Thanks,
> Caitlin
>
> Caitlin Snyder
> Unified Listing Team
> U.S. Fish & Wildlife Service
> MS: ES
> 5275 Leesburg Pike
> Falls Church, VA 22041-3803

phone: 703 358 2673

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

Date: September 7, 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*) in the contiguous United States 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.

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 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 later be published in the *Federal Register*) to classify the North American wolverine as threatened, endangered or "not warranted" under the Act.

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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 an M.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:

Commented [SJ1]: …in the contiguous United States. ? We're not really evaluating all North American wolverine.

Commented [SJ2]: This is a mouthful, but I think we need to make this clear. Could say contiguous US population of NA wolverine also.

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

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

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 small populations;

e. Experience as a peer reviewer for scientific publications;

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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 personally, or 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, none of the reviewers should have served as participants in the April 2-3, 2014 facilitated wolverine workshop held by the Service. 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 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 them into the final recovery plan, as appropriate.

Commented [SJ3]: Rule?

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. Individual reviewers should, at their own discretion, provide comments,

criticisms, and ideas about any of the topics they feel qualified to comment on. Not all reviewers are required to address all issues noted below. Reviewers should comment on areas within their expertise, and may choose to abstain from other areas.

Available Data

(1) Please identify any oversights or omissions of data or information, and their relevance to the assessment. Are there other~~s~~ 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 ~~are~~ and how are they relevant?

(2) Provide advice on the overall strengths and limitations of the scientific data used in the document. Have the authors been 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 viability 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 present given the data and the analyses conducted been clearly identified and has the degree of uncertainty been appropriately characterized? If not, please identify any specifics 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 services 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 (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.

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6. Task Schedule.
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TASK/DELIVERABLE	**CALENDAR DAYS AFTER AWARD**

Task 1: FWS Project Lead will provide the Contractor access to materials needed by the Contractor to determine the scope of the activity and identify appropriate peer reviewers, such as an early draft of the biological report (Note: the final draft biological report will not be ready at the time of award to provide to the Contractor.)	1 day after award (estimated as DATE)
Task 2: The Contractor(s) will provide the Project Lead the names and resumes of 5 qualified, expert peer reviewers.	21 days from task 1 (estimated as DATE)
Task 3: The Project Lead will review the names and resumes of the peer reviewers and provide feedback to Contractor – acceptable / non-acceptable. If a peer reviewer is determined by the government to be non-acceptable the Contractor has 10 days from notification to submit new names and resumes for government review. Government will review within 7 days.	7 days from Task 2 (estimated as DATE)
	CALENDAR DAYS AFTER FINAL DRAFT SSA REPORT HAS BEEN PROVIDED TO CONTRACTOR (estimated as DATE – subject to change)
Task 4: The Contractor(s) shall conduct a thorough, objective 30-day peer review of the draft SSA.	30 days (estimated as DATE); Provide reviews to the Service within 5 calendar days after the 30 days) (estimated as DATE).
Task 5: The Project Lead facilitates specific follow-up questions/answers between the Service and the reviewers.	46 days (estimated as DATE)
Task 6: The Contractor(s) will provide all applicable official records to the Service Project Lead.	5 days (estimated as DATE)

Commented [SJ4]: Should we call it a species status assessment report?

Commented [SJ5]: Seems like a lot of time to find reviewers.

Commented [SJ6]: If this were to happen, it really pushes things back. Not sure how likely it is to happen though.

Commented [SJ7]: Betty wants to get the draft SSA Report to peer reviewers no later than Oct. 13. All other dates in this table can be calculated from that date. But I think we allow too much time for task 2. Thoughts?

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 background information including, but not limited to: ADD LIST HERE.

Commented [SJ8]: Betty?

9. Payment Schedule:

The payment schedule is as follows: 100 percent upon completion of Task 6 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

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 (wolverine ecologist/statistician/modeler having performed similar reviews) (reference paragraph 3).

Commented [SJ9]: Is this relevant? Didn't see this in 3.2. above.

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).

From: Grizzle, Betty
To: Snyder, Caitlin
Cc: Shoemaker, Justin
Subject: Re: Draft SOW and peer review plan for wolverine peer review
Date: Tuesday, September 12, 2017 8:57:48 AM

Thanks Caitlin. I am busy reviewing and incorporating info from NOAA report.
I will try to get formal comments to you by tomorrow.
Betty

On Tue, Sep 12, 2017 at 7:33 AM, Shoemaker, Justin <justin_shoemaker@fws.gov> wrote:

> Thanks for putting this together Caitlin. I have a few edits and questions/comments in the attached SOW.
>
> In the peer review plan, we might say the Montana FO instead of Carlsbad. I think Betty is actually working for Jodi on this project?
>
> 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 Fri, Sep 8, 2017 at 9:36 AM, Snyder, Caitlin <caitlin_snyder@fws.gov> wrote:
>
> > Hi Justin and Betty,
> >
> > Attached is a draft Statement of Work for the wolverine peer review and a draft peer review plan.
> >
> > The SOW will be submitted to contracting and they will put it out to the contractor to get a bid on the peer review process. There is template language in the SOW, so please only look at the specific language related to wolverine and the schedule (number of days for each task).
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> > The peer review plan will be posted on the Service's Peer Review page -- I'm assuming it should go under Region 6.
> >
> > The peer review plan draws from the language in the SOW, so I recommend focusing your review on the SOW, because I can easily incorporate the language from the SOW into the peer review plan later.
> >
> > Please let me know if you have any questions.
> >
> > Thanks,
> > Caitlin
> >
> > Caitlin Snyder
> > Unified Listing Team

U.S. Fish & Wildlife Service
MS: ES
5275 Leesburg Pike
Falls Church, VA 22041-3803
phone: 703 358 2673

--

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: Snyder, Caitlin
Cc: Grizzle, Betty
Subject: Re: Draft SOW and peer review plan for wolverine peer review
Date: Tuesday, September 12, 2017 9:20:34 AM
Attachments: 20170907_Wolverine peer review Statement of Work_JS.docx

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Caitlin,

After communicating w/ Betty, I've rethought some of my edits. The analysis is looking at North American wolverine, not just wolverine in lower 48 States.

Use this one.

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 Tue, Sep 12, 2017 at 9:33 AM, Shoemaker, Justin <justin_shoemaker@fws.gov> wrote:

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Please let me know if you have any questions.

Thanks,
Caitlin

Caitlin Snyder
Unified Listing Team
U.S. Fish & Wildlife Service
MS: ES
5275 Leesburg Pike
Falls Church, VA 22041-3803
phone: 703 358 2673

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

Date: September 7, 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.

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 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 later 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, Oregon (Wallowa Range), and Wyoming. Individual wolverines have also moved into historic 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 an M.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 large carnivore management, especially wolverines;

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

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 small populations;

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 personally, or 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, none of the reviewers should have served as participants in the April 2-3, 2014 facilitated wolverine workshop held by the Service. 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 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 them into the final recovery plan, as appropriate.

Commented [SJ1]: Rule?

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. Individual reviewers should, at their own discretion, provide comments,

criticisms, and ideas about any of the topics they feel qualified to comment on. Not all reviewers are required to address all issues noted below. Reviewers should comment on areas within their expertise, and may choose to abstain from other areas.

Available Data

(1) Please identify any oversights or omissions of data or information, and their relevance to the assessment. Are there other~~s~~ 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 ~~are~~ and how are they relevant?

(2) Provide advice on the overall strengths and limitations of the scientific data used in the document. Have the authors been 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 viability 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 present given the data and the analyses conducted been clearly identified and has the degree of uncertainty been appropriately characterized? If not, please identify any specifics 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 services 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 (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 Contracting Officer Representative 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: FWS Project Lead will provide the Contractor access to materials needed by the Contractor to determine the scope of the activity and identify appropriate peer reviewers, such as an early draft of the biological report (Note: the final draft biological report will not be ready at the time of award to provide to the Contractor.)	1 day after award (estimated as DATE)
Task 2: The Contractor(s) will provide the Project Lead the names and resumes of 5 qualified, expert peer reviewers.	21 days from task 1 (estimated as DATE)
Task 3: The Project Lead will review the names and resumes of the peer reviewers and provide feedback to Contractor – acceptable / non-acceptable. If a peer reviewer is determined by the government to be non-acceptable the Contractor has 10 days from notification to submit new names and resumes for government review. Government will review within 7 days.	7 days from Task 2 (estimated as DATE)
	CALENDAR DAYS AFTER FINAL DRAFT SSA REPORT HAS BEEN PROVIDED TO CONTRACTOR (estimated as DATE – subject to change)
Task 4: The Contractor(s) shall conduct a thorough, objective 30-day peer review of the draft SSA.	30 days (estimated as DATE); Provide reviews to the Service within 5 calendar days after the 30 days) (estimated as DATE).
Task 5: The Project Lead facilitates specific follow-up questions/answers between the Service and the reviewers.	46 days (estimated as DATE)
Task 6: The Contractor(s) will provide all applicable official records to the Service Project Lead.	5 days (estimated as DATE)

Commented [SJ2]: Should we call it a species status assessment report?

Commented [SJ3]: Seems like a lot of time to find reviewers.

Commented [SJ4]: If this were to happen, it really pushes things back. Not sure how likely it is to happen though.

Commented [SJ5]: Betty wants to get the draft SSA Report to peer reviewers no later than Oct. 13. All other dates in this table can be calculated from that date. But I think we allow too much time for task 2. Thoughts?

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 background information including, but not limited to: ADD LIST HERE.

Commented [SJ6]: Betty?

9. Payment Schedule:

The payment schedule is as follows: 100 percent upon completion of Task 6 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

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 (wolverine ecologist/statistician/modeler having performed similar reviews) (reference paragraph 3).

Commented [SJ7]: Is this relevant? Didn't see this in 3.2. above.

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).

From: Grizzle, Betty
To: Snyder, Caitlin; Justin Shoemaker
Cc: Bush, Jodi
Subject: Re: Draft SOW and peer review plan for wolverine peer review
Date: Tuesday, September 12, 2017 11:46:13 AM
Attachments: 20170906_Wolverine_SSA_PeerReviewPlan_BJG.docx
20170907_Wolverine peer review Statement of Work_JS_BJG.docx

Please see attached documents with my comments/suggestions.

On Fri, Sep 8, 2017 at 7:36 AM, Snyder, Caitlin <caitlin_snyder@fws.gov> wrote:

> Hi Justin and Betty,
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> Please let me know if you have any questions.
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> Thanks,
> Caitlin
>
> Caitlin Snyder
> Unified Listing Team
> U.S. Fish & Wildlife Service
> MS: ES
> 5275 Leesburg Pike
> Falls Church, VA 22041-3803
> phone: 703 358 2673

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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

A Peer Review Plan for
the North American
Wolverine
Species Status Assessment draft Report

U.S. Fish and Wildlife Service, Region 6

About the Document:

The format of this peer review plan reflects the necessary items enumerated in the 2004 Office of Management and Budget memorandum M-05-03 entitled "Final Information Quality Bulletin for Peer Review" (p. 29 i-x; https://www.whitehouse.gov/omb/memoranda_fy2005_m05-03). Further, in accordance with the Service's 2016 memorandum entitled "Peer Review Process" (https://www.fws.gov/endangered/improving_ESA/peer_review_process.html) an independent office, otherwise not associated with the dissemination, will select peer reviewers and coordinate the process.

Subject and purpose. The Service's Montana Ecological Services ~~Carlsbad Fish and Wildlife~~ Office (in coordination with ~~and~~ other Field Offices) is drafting 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~~ projected future conditions for the species. The SSA report will be used to ~~comply with a court order and~~ inform a decision (to ~~later~~ be published in the *Federal Register*) to classify the North American wolverine as threatened, endangered or "not warranted" under the Act. Public inquiries may be directed to the agency contact listed below.

Importance of the "dissemination". The SSA report will disseminate likely "influential scientific information" and provide the scientific foundation to inform any subsequent listing determination and/or recovery plan under the Act.

About the Peer Review Process:

Timing of the review: The peer review will take place between October and December 2017[BJG1].

Type of review: The Service is contracting the solicitation and coordination of the independent scientific review. The purpose of seeking independent peer review is to ensure that the best biological and scientific data are being used in the SSA, as well as to ensure that reviews by recognized experts are incorporated into the SSA. Peer reviewers ~~were~~ are asked to consider, but not limit their responses, to the following questions and provide any other relevant comments, criticisms, or ideas:

Available Data

1. Please identify any oversights or omissions of data or information, and their relevance to the assessment. Are there other~~s~~ 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?[BJG2] What are they and~~are~~ 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 ~~Have the authors been~~ 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 viability 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 ~~given the data~~ and the analyses conducted been clearly identified and has the degree of uncertainty been appropriately characterized? If not, please identify any specifics concerns.

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

About public participation: If the SSA report is used to support a classification determination, the public will then have the opportunity to comment on that proposed rule or finding when it is published. The Service will not be providing public comments to the peer reviewers before they conduct their review. The public is invited to submit comments on this peer review plan by sending emails to the agency contact listed below. The Service will summarize in the final decision document, and make publicly available, copies of each individual independent peer review letter.

Number of reviewers: The Service will use five (5)[BJG3] individual independent subject matter expert peer reviewers.

Necessary expertise. The Service requests that the contractor seeks peer reviewers with expertise in the following topics of scientific investigation including:

1. Each reviewer must have a Ph.D. or an M.S[BJG4]. 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 ~~large~~ carnivore management, especially wolverines;

b. Expert knowledge of wildlife biology, wildlife management, demographic management of mammals (especially mesocarnivores), genetics, population modeling, ~~, small~~ population management and conservation, and/or scientific literature on wolverines or other mustel~~i~~eds;

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 ~~small~~ metapopulations;

e. Experience as a peer reviewer for scientific publications;

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

Scope of the review. Peer reviewers will be advised that they should not provide advice on policy, including a decision-maker's tolerances for risk and uncertainty.

Selection of peer reviewers. The contractor will be responsible for assigning an experienced, senior and well-qualified manager to lead this review and for the selection of 5[BJG5] well-qualified, independent reviewers.

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 personally, or~~ 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, ~~none of the reviewers~~ individuals who served as peer reviewers for previous proposed rules or who were ~~should have served as~~ 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.

Each reviewer will submit a conflict of interest disclosure that will be posted along with the peer review plan on the Service's Science Excellence website (https://www.fws.gov/science) and made publicly available.

Agency contact: Justin Shoemaker, Classification and Recovery Biologist, 309-757-5800 ext. 214 or email: justin_shoemaker@fws.gov

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

Date: September 7, 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[BJG1] 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 threatened or endangered 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 ~~later~~ 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, Oregon ~~(Wallowa Range)~~, parts of Washington and Oregon, and Wyoming. Individual wolverines have recently~~also moved~~ dispersed into their historic 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.[BJG2]

3. Methods, Protocols and/or Scientific Standards

1. Each reviewer must have a Ph.D. or an M.S[BJG3]. 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 ~~large~~ carnivore management, especially wolverines;

b. Expert knowledge of wildlife biology, wildlife management, demographic management of mammals (especially meso carnivores), genetics, population modeling and~~, small population~~ conservation management[BJG4], and/or scientific literature on wolverines or other mustel~~ie~~ids;

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 meta~~small~~ populations;

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 personally, or~~ 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, ~~none of the reviewers~~ individuals who served as peer reviewers for previous proposed rules or who were ~~should have served as~~ 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 5 well-qualified reviewers. [BJG5]

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~~m~~ in ~~into~~ the final SSA report recovery plan[SJ6], 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. -Individual reviewers should, at their own discretion, provide comments, criticisms, and ideas about any of the topics they feel qualified to comment on. -Not all reviewers are required to address all issues noted below. -Reviewers should comment on areas within their expertise, and may choose [BJG7]to abstain from other areas.

Available Data

(1) Please identify any oversights or omissions of data or information, and their relevance to the assessment. Are there other~~s~~ sources of information or studies that were not included that are relevant to assessing the viability of this species [BJG8]and not repetitive of other information or studies already included? What are they ~~are~~ and how are they relevant?

(2) Provide advice on the overall strengths and limitations of the scientific data used in the document. ~~Have the authors been~~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 viability [BJG9]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 ~~given the data~~ and the analyses conducted been clearly identified and has the degree of uncertainty been appropriately characterized? If not, please identify any specifics 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 (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 Contracting Officer Representative 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: FWS ~~Project~~ ULT Lead or Field Office? [BJG10]will provide the Contractor access to materials needed by the Contractor to determine the scope of the activity and identify appropriate peer reviewers, such as an early draft of the biological report (Note: the final draft SSA biological [SJ11]report will not be ~~ready~~ available at the time of award to provide to the Contractor.)	1 day after award (estimated as DATE)
Task 2: The Contractor(s) will provide the ~~Project~~ Lead Field Office?? the names and resumes of 5 qualified, expert peer reviewers.	21[SJ12] days from task 1 (estimated as DATE)
Task 3: The Project Lead will review the names and resumes of the peer reviewers and provide feedback to Contractor – acceptable / not ~~non~~ acceptable. If a peer reviewer is determined by the government to be not~~n~~ acceptable, the Contractor has 10 days[SJ13] from notification to submit new names and resumes for government review. Government will review within 7	7 days from Task 2 (estimated as DATE)
	CALENDAR DAYS AFTER FINAL DRAFT SSA REPORT HAS BEEN PROVIDED TO CONTRACTOR (estimated as DATE – subject to change)
Task 4: The Contractor(s) shall conduct a thorough[BJG15], objective 30-day peer review of the draft SSA.	30 days (estimated as DATE[SJ16][BJG17]); Provide reviews to the Service within 5 calendar days after the 30 days) (estimated as DATE).
Task 5: The Project Lead facilitates specific follow-up questions/answers between the Service and the reviewers.	46 days (estimated as DATE)
Task 6: The Contractor(s) will provide all applicable official records to the Service Project Lead.	5 days (estimated as DATE)

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 background information including, but not limited to: ADD LIST HERE.[SJ18][BJG19]

9. Payment Schedule:

The payment schedule is as follows: 100 percent upon completion of Task 6 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[BJG20], 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

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 (~~wolverine~~ wildlife biologist/ecologist/statistician[SJ21][BJG22]/modeler having performed similar reviews) (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).

From: Bush, Jodi
To: Grizzle, Betty
Cc: Snyder, Caitlin; Justin Shoemaker
Subject: Re: Draft SOW and peer review plan for wolverine peer review
Date: Tuesday, September 12, 2017 12:34:32 PM
Attachments: 20170906_Wolverine_SSA_PeerReviewPlan_BJG_JBeds.docx
20170907_Wolverine peer review Statement of Work_JS_BJG_JB.docx

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Betty and others. My review on top of Betty's. Generally I agree with her suggested edits. 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, Sep 12, 2017 at 11:46 AM, Grizzle, Betty <betty_grizzle@fws.gov> wrote:

> Please see attached documents with my comments/suggestions.
>
> On Fri, Sep 8, 2017 at 7:36 AM, Snyder, Caitlin <caitlin_snyder@fws.gov> wrote:
>
> > Hi Justin and Betty,
> >
> > Attached is a draft Statement of Work for the wolverine peer review and a draft peer review plan.
> >
> > The SOW will be submitted to contracting and they will put it out to the contractor to get a bid on the peer review process. There is template language in the SOW, so please only look at the specific language related to wolverine and the schedule (number of days for each task).
> >
> > The peer review plan will be posted on the Service's Peer Review page -- I'm assuming it should go under Region 6.
> >
> > The peer review plan draws from the language in the SOW, so I recommend focusing your review on the SOW, because I can easily incorporate the language from the SOW into the peer review plan later.
> >
> > Please let me know if you have any questions.
> >
> > Thanks,
> > Caitlin
> >
> > Caitlin Snyder
> > Unified Listing Team
> > U.S. Fish & Wildlife Service
> > MS: ES

5275 Leesburg Pike
Falls Church, VA 22041-3803
phone: 703 358 2673

--

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

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

Date: September 7, 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 threatened or endangered 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 ~~later~~ 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, ~~Oregon~~ and ~~(Wallowa Range)~~, parts of Washington and Oregon, and Wyoming. Individual wolverines have recently ~~also moved~~ dispersed into their historic 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 an M.S. with significant experience in Wildlife Ecology, Ecology, or Wildlife Management; and

Commented [BJG1]: Note: I changed spacing between sentences to single space below to be consistent with the style presented in the first paragraph.

Commented [BJG2]: This is repeated below, delete here?

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Commented [BJG3]: Should we say Master's (some of these are M.Sc., etc.)

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 ~~large~~ carnivore management, especially wolverines;

b. Expert knowledge of wildlife biology, wildlife management, demographic management of mammals (especially meso carnivores), genetics, population modeling and~~, small population~~ conservation management, and/or scientific literature on wolverines or other mustel~~ie~~ds;

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 meta~~small~~ populations;

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 personally, or~~ 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, ~~none of the reviewers~~ individuals who served as peer reviewers for previous proposed rules or who were ~~should have served as~~ 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 at least 3 and up to 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~~n~~ in ~~into~~ the final SSA report ~~recovery plan~~, 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

Commented [BJG4]: Conservation?

Commented [BJG5]: Not sure there will be 5. Can we say up to 5?

Commented [JB6]: I agree. We only need 3.

Commented [SJ7]: Rule?

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. Individual reviewers should, at their own discretion, provide comments, criticisms, and ideas about any of the topics they feel qualified to comment on. Not all reviewers are required to address all issues noted below. Reviewers should comment on areas within their expertise, and ~~may choose to~~ should abstain from commenting in areas outside of their expertise~~other areas~~.

Available Data

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

(2) Provide advice on the overall strengths and limitations of the scientific data used in the document. ~~Have the authors been~~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 viability~~ 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 ~~given the data~~ and the analyses conducted been clearly identified and has the degree of uncertainty been appropriately characterized? If not, please identify any specifics 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

Commented [BJG8]: Should?

Commented [BJG9]: Is this question necessary? It seems to indicate that focus in only on viability, but we are asking for assessment of all information?

Commented [BJG10]: See comment above. #6 below provides appropriate question for this issue.

(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**:**

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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 (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 Contracting Officer Representative 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: FWS ~~Project~~ ULT Lead or Field Office? will provide the Contractor access to materials needed by the Contractor to determine the scope of the activity and identify appropriate peer reviewers, such as an early draft of the biological report (Note: the final draft SSA biological report will not be ~~ready~~ available at the time of award to provide to the Contractor.)	1 day after award (estimated as DATE)
Task 2: The Contractor(s) will provide the ~~Project~~ Lead Field Office?? the names and resumes of 5 qualified, expert peer reviewers.	14~~21~~ days from task 1 (estimated as DATE)
Task 3: The Project Lead will review the names and resumes of the peer reviewers and provide feedback to Contractor – acceptable / not ~~non~~ acceptable. If a peer reviewer is determined by the government to be not~~n~~ acceptable, the Contractor has 10 days from notification to submit new names and resumes for government review. Government will review within 7 days.	7 days from Task 2 (estimated as DATE)
	CALENDAR DAYS AFTER FINAL DRAFT SSA REPORT HAS BEEN PROVIDED TO CONTRACTOR (estimated as DATE – subject to change)
Task 4: The Contractor(s) through use of Peer Reviewers, shall conduct a thorough, objective 30-day peer review of the draft SSA.	30 days (estimated as DATE); Provide reviews to the Service within 5 calendar days after the 30 days) (estimated as DATE).
Task 5: The Project Lead facilitates specific follow-up questions/answers between the Service and the reviewers.	46 days (estimated as DATE)
Task 6: The Contractor(s) will provide all applicable official records to the Service Project Lead.	5 days (estimated as DATE)

Commented [BJG11]: Not sure what this should be. This is important – who is the primary contact?

Commented [JB12]: This should be project lead – Betty.

Commented [SJ13]: Should we call it a species status assessment report?

Commented [SJ14]: Seems like a lot of time to find reviewers.

Commented [SJ15]: If this were to happen, it really pushes things back. Not sure how likely it is to happen though.

Commented [BJG16]: I would recommend that each peer reviewer complete and sign a conflict of interest form, which should be submitted to Service by the Contractor. I have an example form, if needed

Commented [JB17]: I don't think we need to do this. I don't recall that we have done this for the last 3 peer reviews we have completed.

Commented [BJG18]: Not sure I understand. The contractor is coordinating the peer review, not conducting it, right?

Commented [JB19]: Also. They almost never meeting the 30 day timeline. 45 days is what typically happens.

Commented [SJ20]: Betty wants to get the draft SSA Report to peer reviewers no later than Oct. 13. All other dates in this table can be calculated from that date. But I think we allow too much time for task 2. Thoughts?

Commented [BJG21]: Yes, this timeline is a little problematic. But as I mentioned on Core Team call, if you want to "hold" the draft document so that it is sent out on the original timeline (Oct 21, though this is a Saturday??), then that will help. I will not be available Oct 13 and for most of the week of Oct 16.

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 background information including, but not limited to: ADD LIST HERE.

9. Payment Schedule:

The payment schedule is as follows: 100 percent upon completion of Task 6 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

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 (~~wolverine~~ wildlife biologist/ecologist/statistician/modeler having performed similar reviews) (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).

Commented [SJ22]: Betty?

Commented [BJG23]: Is this necessary? They will receive list of or complete references cited in SSA report. This list of citations is at 20 pages+ in current draft. No easy way to summarize all of those.

Commented [JB24]: By list here, they just mean what other docs. Like lit cited. Not an itemized list of lit cited. Or if we wanted them to see the proposed rule or the withdrawal if we

Commented [BJG25]: See notes above. I'm not clear on who is responsible for what regarding communicating with or providing documents to contractor.

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Commented [SJ26]: Is this relevant? Didn't see this in 3.2. above.

Commented [BJG27]: I would remove statistician.

A Peer Review Plan for
the North American
Wolverine
Species Status Assessment draft Report

U.S. Fish and Wildlife Service, Region 6

About the Document:

The format of this peer review plan reflects the necessary items enumerated in the 2004 Office of Management and Budget memorandum M-05-03 entitled "Final Information Quality Bulletin for Peer Review" (p. 29 i-x; https://www.whitehouse.gov/omb/memoranda_fy2005_m05-03). Further, in accordance with the Service's 2016 memorandum entitled "Peer Review Process" (https://www.fws.gov/endangered/improving_ESA/peer_review_process.html) an independent office, otherwise not associated with the dissemination, will select peer reviewers and coordinate the process.

Subject and purpose. The Service's Montana Ecological Services ~~Carlsbad Fish and Wildlife~~ Office (in coordination with ~~and~~ other Field Offices within the North American Wolverine's range) is drafting 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~~ projected future conditions for the species. The SSA report will be used to ~~comply with a court order and~~ inform a decision (to ~~later~~ be published in the *Federal Register*) to classify the North American wolverine as threatened, endangered or "not warranted" under the Act. Public inquiries may be directed to the agency contact listed below.

Importance of the "dissemination". The SSA report will disseminate likely "influential scientific information" and provide the scientific foundation to inform any subsequent listing determination and/or recovery plan under the Act.

About the Peer Review Process:

Timing of the review: The peer review will take place between October and December 2017.

Commented [BJG1]: This is currently October into November, 30 days.

Type of review: The Service is contracting the solicitation and coordination of the independent scientific review. The purpose of seeking independent peer review is to ensure that the best biological and scientific data are being used in the SSA, as well as to ensure that reviews by recognized experts are incorporated into the SSA. Peer reviewers ~~were~~ are asked to consider, but not limit their responses, to the following questions and provide any other relevant comments, criticisms, or ideas:

Available Data

1. Please identify any oversights or omissions of data or information, and their relevance to the assessment. Are there other~~s~~ sources of information or studies that were not included that are relevant to assessing the current and future threats to North American wolverine ~~viability of this~~

~~species~~ and not repetitive of other information or studies already included? What are they and~~are~~ 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 ~~Have the authors been~~ 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 viability~~ 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 ~~given the data~~ and the analyses conducted been clearly identified and has the degree of uncertainty been appropriately characterized? If not, please identify any specifics concerns.

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

About public participation: If the SSA report is used to support a classification determination, the public will then have the opportunity to comment on that proposed rule or finding when it is published. The Service will not be providing public comments to the peer reviewers before they conduct their review. The public is invited to submit comments on this peer review plan by sending emails to the agency contact listed below. The Service will summarize in the final decision document, and make publicly available, copies of each individual independent peer review letter.

Number of reviewers: The Service will use up to five (5) individual independent subject matter expert peer reviewers.

Necessary expertise. The Service requests that the contractor seeks peer reviewers with expertise in the following topics of scientific investigation including:

1. Each reviewer must have a Ph.D. or an Masters~~.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:

Commented [BJG2]: See comments in the SOW related to this sentence and in #2.

Commented [BJG3]: See comment in SOW. Up to 5?

Commented [BJG4]: Should we say Masters? Some of these are M.Sc.

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

b. Expert knowledge of wildlife biology, wildlife management, demographic management of mammals (especially meso carnivores), genetics, population modeling, ~~, small~~ population management and conservation, and/or scientific literature on wolverines or other musteli~~e~~ds;

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 ~~small~~ meta populations;

e. Experience as a peer reviewer for scientific publications;

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

Scope of the review. Peer reviewers will be advised that they should not provide advice on policy, including a decision-maker's tolerances for risk and uncertainty.

Selection of peer reviewers. The contractor will be responsible for assigning an experienced, senior and well-qualified manager to lead this review and for the selection of at least 3 and up to 5 well-qualified, independent reviewers.

Commented [BJG5]: Up to 5?

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 personally, or~~ 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, ~~none of the reviewers~~ individuals who served as peer reviewers for previous proposed rules or who were ~~should have served as~~ 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.

Each reviewer will submit a conflict of interest disclosure that will be posted along with the peer review plan on the Service's Science Excellence website (https://www.fws.gov/science) and made publicly available.

Agency contact: Justin Shoemaker, Classification and Recovery Biologist, 309-757-5800 ext. 214 or email: justin_shoemaker@fws.gov

From: Guinotte, John
To: Grizzle, Betty; Stephen Torbit
Subject: Re: Draft of section so far
Date: Wednesday, September 13, 2017 8:18:28 AM
Attachments: table2-1b_jmg.xlsx

Hi Betty, This looks like a good start to me. I'm cc'ing Steve as he was starting to write this section yesterday. Attached is most recent table 2-1 on differences between noaa and mckelvey. The future scenarios column captures the differences in model output. Best, John

On Tue, Sep 12, 2017 at 5:14 PM, Grizzle, Betty <betty_grizzle@fws.gov> wrote:

> John - Here is what I prepared so far. Would appreciate your quick review.
>
> Northern and Southern Rocky Mountains–Glacier and Rocky Mountain National Parks
>
> The Service requested and provided funding support for a fine-scale assessment of snow extent and depth in order to assess the effects of climate to snow persistence in two regions of the western United States (Ray *et al*. 2017, entire). The primary objective of this study was to improve upon the scientific understanding of the current extent of spring snow retention as well as the future temporal and spatial extent of snow retention under a changing climate (Ray *et al*. 2017, p. 9). In sum, this involved the following (Ray *et al*. 2017, p. 10):
>
> - Use of fine-scale models to analyze the topographic effects of snow, including the effects of slope and aspect (compass direction that slope faces)
> - Use of a range of plausible future climate change scenarios
> - Analysis of extremes and year-to-year variability by selecting representative wet, dry, and near normal years (using observed conditions) and then estimating projected changes under several future climate scenarios
> - Assessment of changes in snow persistence by elevation
>
> The study was designed so as to intentionally build on the previous assessment of snow cover persistence in the western United States presented in McKelvey *et al*. (2011). However, given the time, funding, and computational constraints needed for developing a fine-scale assessment, the study discussed here was limited to two regions (approximately 1,500 to 3,000 km^2 each) in the northern and southern Rocky Mountains (see Appendix G for maps). The two study areas were selected as they encompass the latitude and elevational range of wolverines within the contiguous United States. Glacier National Park is representative of a high latitude and relatively low elevation area that is currently occupied by wolverines, while the Rocky Mountain National Park region represents a lower latitude and high elevation area, and which is within the wolverine's historical range and, more recently, where a wolverine was documented as occupying from 2009 to at least 2012.

We provide here a brief summary of the methods used in this study for both study areas. 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 in order to provide context relative to trends and year-to-year variability (Section 3 of report). Next, snow cover extent and variability were analyzed from satellite remote sensing (MODIS) data from 2000 to 2016 in order to calculate a snow disappearance date for each year at each pixel (Section 4). 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), and elevation dependence for wet, near-normal, and dry years (with median of all years used as reference). Future snow pack projections were then conducted using the Distributed Hydrology Soil Vegetation Model (DHSVM), which was run for the historic period 1998-2013, and then validated against SNOTEL observing stations. Five scenarios for the future were selected from CMIP5 global climate model projections based on the RCP 4.5 (moderate) and RCP 8.5 (high) emissions scenarios. These projections were then downscaled using the "delta method" (as was done in McKelvey et al. 2011). Analyses were presented for "light snow cover" (SWE > 5 mm) and "significant" snow (SWE > 0.5 m) for April 15, May 1, and May 15 for previously defined representative years.

Although the methods used in this study have similarities with those presented in McKelvey et al. (2011), there are several key differences. These are presented in Table 7 below.

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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

Spatial Resolution
Geographic Area
Topography
Validation
Future Scenario Method
Future Scenarios (GCMs)
Time-related Results
Snow Detection and Measurements
# of years of MODIS data used
Snow Model used
Snowcover dates analyzed

NOAA / CU study (2017)
250m x 250m = 0.0625 km2
RMNP and GNP, 300m below treeline and above
slope, aspect, shading were used
SNOTEL (ground stations) and MODIS (satellite data)
Delta Method used to project 2000-2013 conditions out to yr 2055
cnrm, canesm, miroc, giss, fio, hadgem2 (RMNP only)
long-term means and interannual variability (i.e. wet, near normal and dry years)
Snow or no snow (1.25 cm threshold), snow depth (0.5m threshold "significant snow"), and SWE
17 (2000-2016)
DHSVM (Univ of Washington)
April 15, May 1, and May 15

Copeland et al (2010) and McKelvey et al (2011)
~5km x 7km = 37 km2
Western U.S, except California and Great Basin
slope and aspect were not used
None
Delta Method (yr 2045, 2085, 2070-2099)
Ensemble of 10 GCMs, pcm1, and miroc 3.2
changes in long-term mean snowpack only
Snow or no snow (13 cm threshold)
7 (2000-2006)
VIC (Univ of Washington)
May 1, May 15, May 29