From:	Grizzle, Betty
To:	Guinotte, John
Cc:	Stephen Torbit
Subject:	Re: IDFG comments
Date:	Tuesday, December 19, 2017 4:42:27 PM
Attachments:	Petersen et al 2017 USRT Climate Change Vulnerability Assessment.pdf Rupp et al 2017.pdf

---

See attached (they were used/cited in the SSA). As I said, these are related to other regional modeling efforts.

On Tue, Dec 19, 2017 at 3:36 PM, Guinotte, John <john_guinotte@fws.gov> wrote:

> Hi Betty, Do you have these two papers or the citations? 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, Dec 19, 2017 at 3:37 PM, Stephen Torbit <Stephen_Torbit@fws.gov> wrote:
>
>> I don't have the two references cited here do you??
>>
>> Stephen C. Torbit
>>
>> Assistant Regional Director
>>
>> Science Applications
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>> U.S. Fish and Wildlife Service
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>> 134 Union Blvd.
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>> Lakewood, Colorado 80228
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>> 303-236-4602 – Office
>>
>> 720-626-7504 – Cell
>>
>> **From:** Grizzle, Betty [mailto:betty_grizzle@fws.gov]
>> **Sent:** Tuesday, December 19, 2017 2:33 PM
>> **To:** John Guinotte; Stephen Torbit
>> **Subject:** IDFG comments

Comments re to CC and modeling from Idaho Fish and Game (some relate to discussion of other models):

Table 3, Wolverine Den Site Melt-out Dates

Page 34

The MODIS data from which this table is derived is currently available through 2016. Why was this limited to only include melt-out dates from 2002–2008?

Page 70, paragraph 2; Page 71, paragraph 2

The Department suggests further discussion on the spatial resolution of the global climate models and resulting estimates provided by Rupp et al. (2017) and Petersen et al. (2017). For both of these projects, knowledge of the spatial resolution of the data is significant in correctly interpreting the results.

Page 74, paragraph 2

Again, the resolution of global climate models used in the analysis should be noted and taken into consideration in interpretation.

--

Betty J. Grizzle, D.Env.

Fish and Wildlife Biologist

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--

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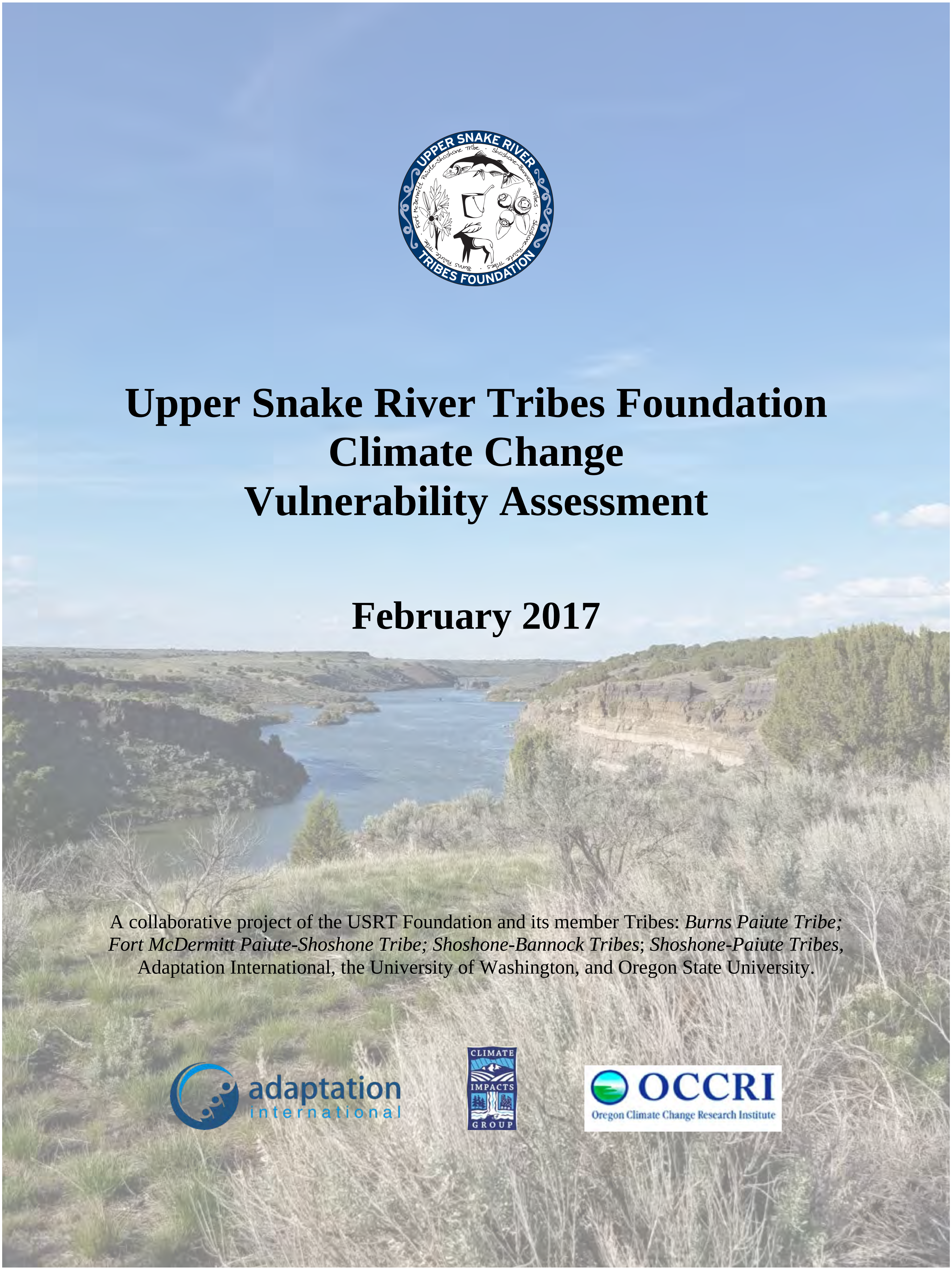


Upper Snake River Tribes Foundation Climate Change Vulnerability Assessment

February 2017

A collaborative project of the USRT Foundation and its member Tribes: *Burns Paiute Tribe; Fort McDermitt Paiute-Shoshone Tribe; Shoshone-Bannock Tribes*; *Shoshone-Paiute Tribes*, Adaptation International, the University of Washington, and Oregon State University.

The Upper Snake River Tribes (USRT) Foundation would like to acknowledge and thank the U.S. Department of the Interior, Bureau of Indian Affairs, for their generous funding contributions to this project.

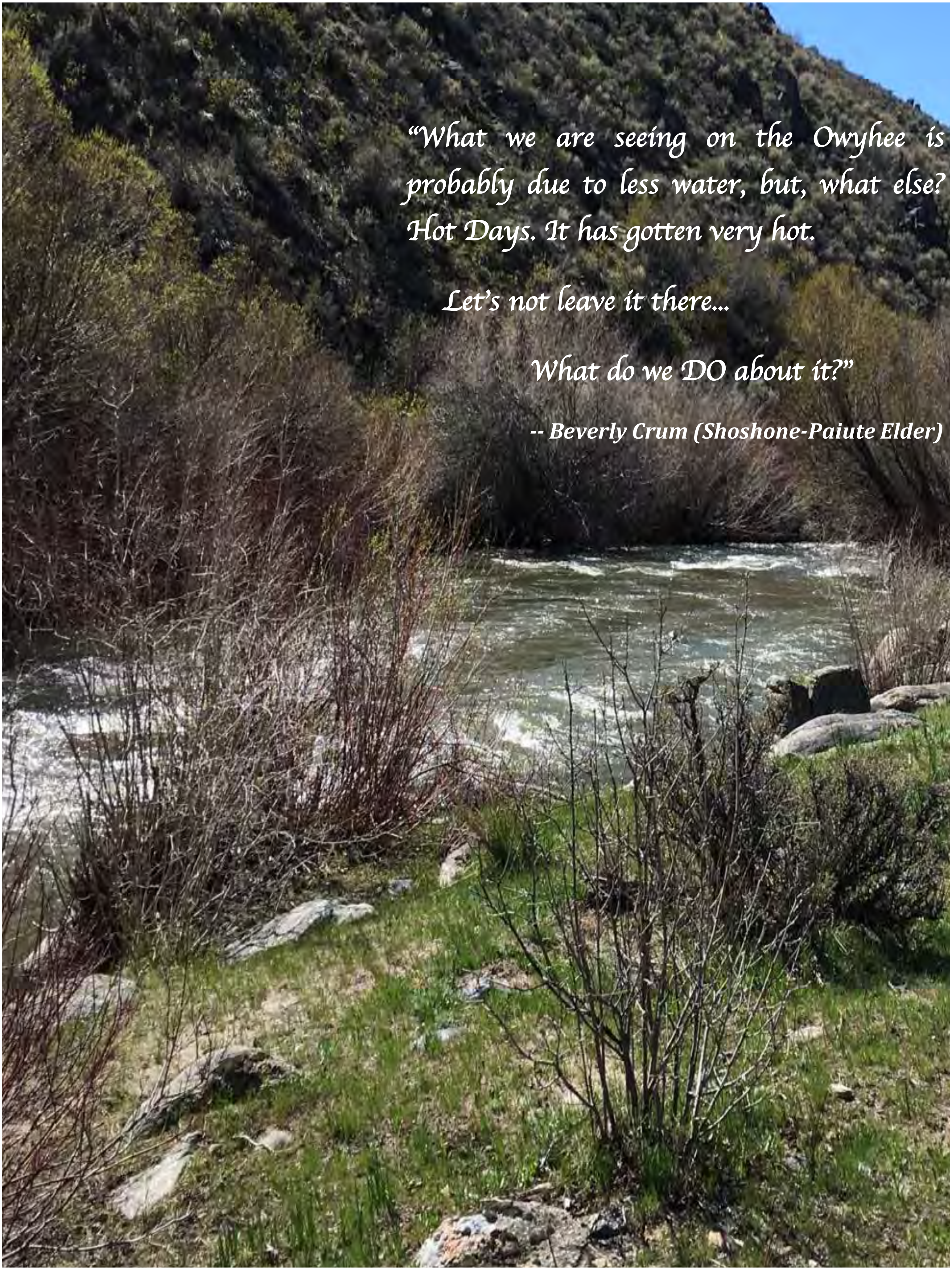
The USRT Foundation would like to acknowledge and thank the Environmental Protection Agency (EPA), Regions 9 and 10, for providing funding through the Indian General Assistance Program to assist in the completion of this report. A further thank you goes to USRT's EPA project officers Gilbert Pasqua (Region 9) and Jim Zokan (Region 10).

The USRT Foundation and the member tribes would also like to express gratitude to Alexis Malcomb, USRT office manager, and Jennifer Martinez, USRT administrator, for their dedicated work behind the scenes to administer this grant effectively, efficiently, and on schedule. Thank you, Alexis and Jennifer!

Cover Photo: Upper Snake River at Massacre Rocks. Scott Hauser. 2016

Third Page Photo: The Owyhee River on the Shoshone-Paiute Tribes of the Duck Valley Reservation. Sascha Petersen. 2016

Recommended Citation: Petersen, S., Bell, J., Hauser, S., Morgan, H., Krosby, M., Rudd, D., Sharp, D., Dello, K., and Whitley Binder, L., 2017. Upper Snake River Climate Change Vulnerability Assessment. Upper Snake River Tribes Foundation and Member Tribes. Available: http://www.uppersnakerivertribes.org/climate/



"What we are seeing on the Owyhee is probably due to less water, but, what else? Hot Days. It has gotten very hot.

Let's not leave it there...

What do we DO about it?"

-- Beverly Crum (Shoshone-Paiute Elder)

THANK YOU to the tribes involved in this project. They graciously hosted workshops and shared knowledge throughout the project.

Burns Paiute Tribe	**Fort McDermitt Paiute-Shoshone Tribe**	**Shoshone-Bannock Tribes of the Fort Hall Reservation**	**Shoshone-Paiute Tribes of the Duck Valley Reservation**

Special thanks to the members of our project Core Team who identified Shared Concerns across the Upper Snake River Watershed, reviewed climate projections, and offered their expertise on local climate vulnerabilities.

Core Team	Organization	Core Team	Organization
Scott Hauser	Upper Snake River Tribes Foundation	Billy Bell	Fort McDermitt Paiute-Shoshone
Bob Austin	Upper Snake River Tribes Foundation	Dan Stone	Shoshone-Bannock
Alexis Malcomb	Upper Snake River Tribes Foundation	Wayne Crue	Shoshone-Bannock
Erica Maltz	Burns Paiute	Travis Stone	Shoshone-Bannock
Jason Fenton	Burns Paiute	Ted Howard	Shoshone-Paiute
Jason Kesling	Burns Paiute	Buster Gibson	Shoshone-Paiute
Charlotte Rodrique	Burns Paiute	Carol Perugini	Shoshone-Paiute
Bradley Crutcher	Fort McDermitt Paiute-Shoshone	Jinwon Seo	Shoshone-Paiute
Duane Masters Sr.	Fort McDermitt Paiute-Shoshone	Heather Lawrence	Shoshone-Paiute
Justina Paradise	Fort McDermitt Paiute-Shoshone	Chris Cleveland	Shoshone-Paiute

Project Team	Organization	Project Team	Organization
Sascha Petersen	Adaptation International	Lara Whitley Binder	UW’s Climate Impacts Group
Jake Bell	Adaptation International	Meade Krosby	UW’s Climate Impacts Group
Ellu Nasser	Adaptation International	Harriet Morgan	UW’s Climate Impacts Group
Kim Rodgers	Adaptation International	Kathie Dello	Oregon Climate Change Research Institute
Michelle Fox	Adaptation International	Darrin Sharp	Oregon Climate Change Research Institute
Molly Ellsworth	Adaptation International	David Rupp	Oregon Climate Change Research Institute

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I. Executive Summary

The Upper Snake River Watershed has been home to humans for more than 10,000 years. Many of their ancestors still reside on the landscape and are members of the Burns Paiute Tribe, Fort McDermitt Paiute-Shoshone Tribe, Shoshone-Bannock Tribes of the Fort Hall Reservation, and Shoshone-Paiute Tribes of the Duck Valley Reservation. Together, these four member tribes comprise the Upper Snake River Tribes (USRT) Foundation.[1]

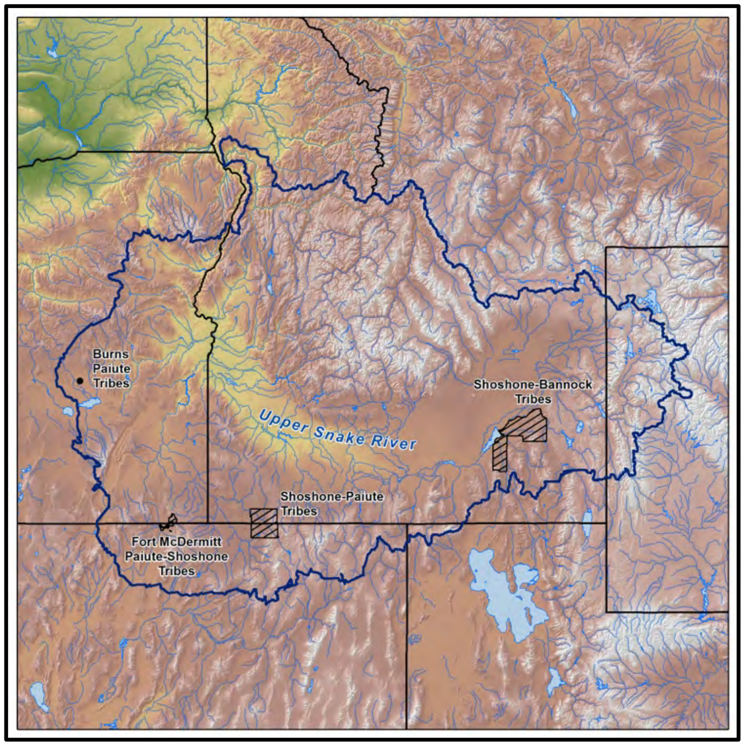


Figure 1: The Upper Snake River Watershed project area for this assessment, an area of more than 97,000 square miles.

The climate around the Upper Snake River is changing. USRT member tribes have already noticed shifts in species and habitats driven by increasing temperatures and changing precipitation patterns. Such changes in temperature and precipitation have resulted in drying sagebrush steppe habitat, extended wildfire seasons, less winter precipitation falling as snow, earlier spring run-off, low summer river flows, higher water temperatures, reduced flow from springs/seeps, proliferation of invasive weeds, and the decreasing productivity of rangelands. The project area is shown in Figure 1.

A. Collaborative Process

This collaborative vulnerability assessment expressly considered the species, habitats, and resources that are important and valuable to USRT member tribes. Climate change impacts on these resources have the potential to affect tribal members' culture, spirituality, and lifeways.

The collaboration involved the direct and ongoing participation of USRT staff and the leadership, staff, and membership of the four member tribes. Combining the best available localized climate projections with traditional knowledge, tribal priorities, and local observations was central to the success of this assessment (Figure 2).

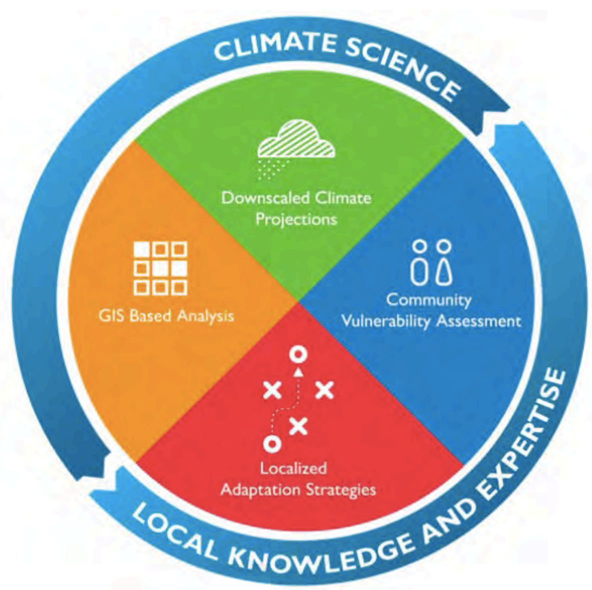


Figure 2: The collaborative process used in this project combined the best available climate science with local and traditional knowledge.

This vulnerability assessment included four steps:

1. *Analyzing downscaled temperature and precipitation projections for the project area;*
2. *Site visits to USRT member tribes' reservations to identify Shared Concerns;*
3. *Use of the NatureServe Climate Change Vulnerability Index (CCVI)*[2] *and other methods to determine relative vulnerability rankings; and*
4. *A collaborative vulnerability assessment workshop in Boise with USRT member tribes' staff and leadership.*

B. Downscaled Climate Projections

This assessment used the project area as a starting point for developing localized climate projections. With guidance from the Core Team, the Project Team identified three subdomains within the project area with somewhat distinct elevations, climates, and ecosystems. The Oregon Climate Change Research Institute (OCCRI) developed downscaled climate projections from the Multivariate Adaptive Constructed Analogs (MACA)[3] project for the full project area as well as the three subdomains. To focus the range of climate changes projections for the region, the Project Team selected two climate change scenarios: a lower warming scenario Representative Concentration Pathway (RCP) 4.5, an aspirational but still achievable future where global agreements and policies work to dramatically reduce greenhouse gas emissions; and a higher warming scenario, RCP 8.5, where global greenhouse gas emissions continue to increase at their present rate for the next several decades, often colloquially referred to as "business-as-usual". Details on these projections are available in Section III of the main report.

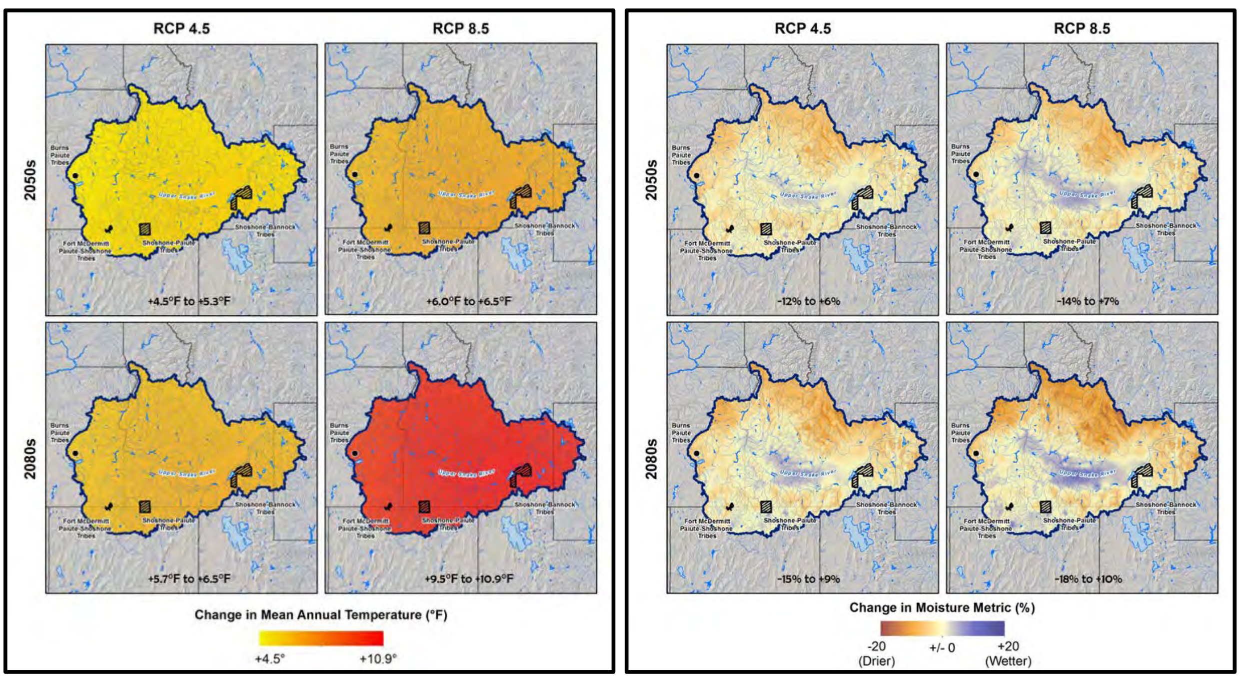


Figure 3: Projections of average annual temperature change (left) and changes to an average annual Hamon moisture metric (right) across the full project domain. For both figures, projections are provided for two different time periods (2050s upper row, and 2080s lower row) and two different climate scenarios (RCP 4.5 "less warming" - first column of both panels, and RCP 8.5 "more warming" – second column of both panels).

The downscaled climate projections provide information on potential future temperature, precipitation, and evapotranspiration on seasonal and annual time-frames. This information was analyzed by the Core Team, tribal leaders, and tribal members during site visits and the collaborative workshop. They were also utilized in the CCVI vulnerability ranking tool.

Oftentimes *annual* climate change projections do not tell the complete story of shifting climate variables within the seasons and how species, habitats, and ecosystems will be differentially affected. Seasonal projections can help tell that story. Below are the seasonal climate change projections for the “South” subdomain, which broadly covers the Upper Snake River Plains and most of the USRT member tribes’ reservations (Figure 4).

Seasonal Climate Change Projections for the South Subdomain of the Upper Snake River Watershed in the 2050s

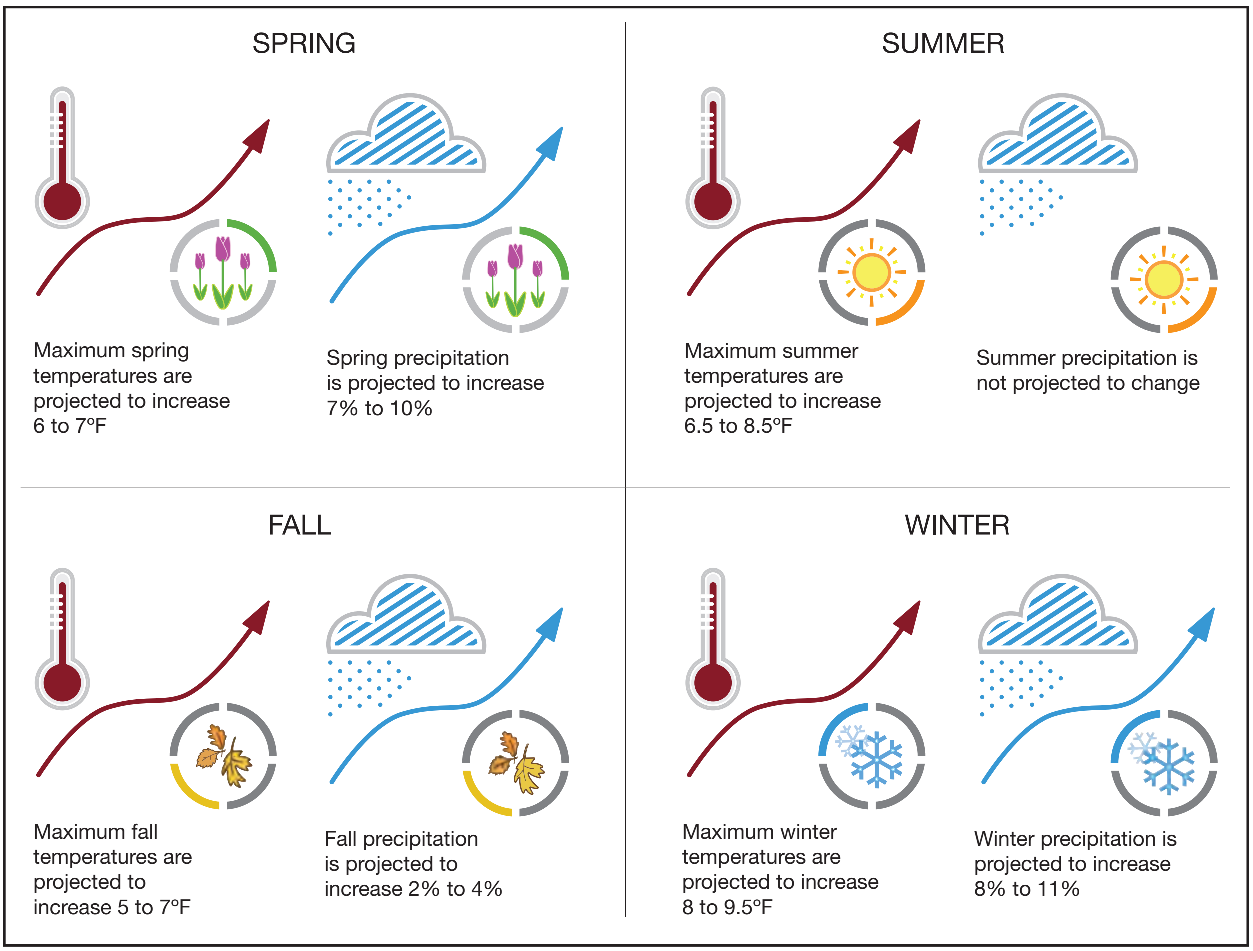


Figure 4: Seasonal temperature and precipitation projections for the 2050s (2040-2069) in the South subdomain of the Upper Snake River Watershed. Temperature increases and percent precipitation change are relative to modeled historical averages from 1950-2005. The range of values represent the average of the lower climate scenario model projections (RCP 4.5) and the average of the higher climate scenario model projections (RCP 8.5) across all models.

C. Site Visits and Shared Concerns

The project was led by a Core Team composed of leadership and staff from USRT’s four member tribes and USRT (see Section IV for more details on the Core Team and the project process). The

Core Team attended and helped organize site visits to each of the four tribes' reservations in April 2016. During these site visits, the tribes identified many species, habitats, and resources they had seen affected by changing climate conditions or they were concerned about being affected by future climate change. Concerns that were documented by two or more tribes are considered Shared Concerns. Due to time and budget constraints, the complete list of Shared Concerns was not assessed during this project. While not comprehensive, the set of 28 Shared Concerns assessed for climate change vulnerability in this project provided a balanced cross-section of the species, habitats, and resource issues important to the USRT member tribes (Table 1).

Table 1: Shared Concerns identified by the USRT member tribes and assessed over the course of this project. Those assessed quantitatively using the CCVI are indicated with an "X." All other concerns were assessed qualitatively.

Plant Species	**Assessed with CCVI Tool**
Antelope Bitterbrush	
Big Sagebrush	X
Black Cottonwood	X
Camas Root	
Common Chokecherry	X
Geyer's Willow	X
Meadow Hay	
Noxious Weed: Medusahead	
Noxious Weed: Whitetop	
Quaking Aspen	X
Redosier Dogwood (Red Willow)	X

Animal Species	**Assessed with CCVI Tool**
Beaver	X
Black-tailed Jackrabbit	X
Bull Trout	X
Cattle	
Chinook Salmon	X
Columbia Spotted Frog	X
Elk	X
Golden Eagle	X
Mule Deer	X
Redband Trout	X
Steelhead	X

Habitats	**Assessed with CCVI Tool**
Sagebrush Steppe	
Riparian	
Wet-meadow	
Springs and Seeps	

Resource Issues	**Assessed with CCVI Tool**
Asthma	
Wildfire	

D. Climate Change Vulnerability Index (CCVI)

NatureServe's CCVI tool was used to analyze the climate change vulnerability of species identified as Shared Concerns. The CCVI tool utilizes data inputs that include: projections of changes in air temperature and moisture availability, species range data, and species-specific life history characteristics. These data are used to calculate a species' relative vulnerability ranking using 23 distinct factors that affect the species' climate change exposure[i], sensitivity, and adaptive capacity.

[i] The CCVI tool defines these terms as follows. *CCVI Exposure*: Projected climate change (shifts in temperature and moisture) across the range of the species within the assessment area. *CCVI Sensitivity*: The extent to which a species will respond to shifts in climate. *CCVI Adaptive capacity*: The ability of the species to withstand environmental changes.

Based on these calculations, species are assigned one of four climate change vulnerability rankings.

(1) **Extremely Vulnerable**: Species abundance and/or range extent within the project area is extremely likely to substantially decrease or disappear.

(2) **Highly Vulnerable**: Species abundance and/or range extent within the project area is likely to decrease significantly.

(3) **Moderately Vulnerable**: Species abundance and/or range extent within the project area is likely to decrease.

(4) **Less Vulnerable**: Available evidence does not suggest that species abundance and/or range extent within the project area will change substantially, though there may be changes elsewhere across the species' full range.

The CCVI tool was used to generate draft *quantitative* vulnerability rankings for the 16 plant and animal species that had sufficient range and life history data to use the tool. The remaining 12 Shared Concerns were given draft *qualitative* vulnerability rankings based on available research and local knowledge, and in some cases sensitivity information from the CCVI.

E. Collaborative Workshop and Final Results

An essential step in this project process was the collaborative vulnerability assessment workshop held July 28, 2016 in Boise, Idaho. Two members of the Project Team and ten members of the Core Team, representing USRT and each of the four USRT member tribes, gathered for this one-day workshop. The focus of the workshop was to incorporate local and traditional knowledge into the draft vulnerability assessment results for each of the Shared Concerns.

This collaborative review was accomplished using a combination of large group discussions and small group breakout sessions during which the Core Team members reviewed, evaluated, and commented on the *quantitative* and *qualitative* results of the CCVI assessment process for each of the Shared Concerns. Local knowledge was extremely valuable in modifying these results to account for local variance in factors of exposure, sensitivity, and adaptive capacity, such as: local changes in the landscape, observed interactions between species, and species' existing response to extreme weather, climate change, and changes in habitat. Ultimately, incorporation of this information led to an adjustment of 19 individual factors affecting vulnerability and the re-ranking of one species' relative vulnerability ranking.

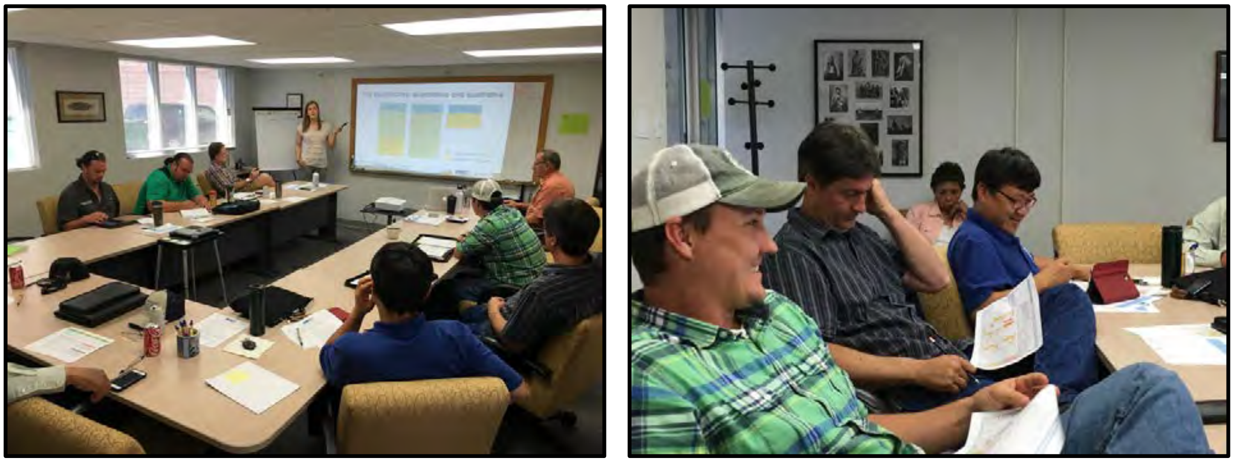


Figure 5: Photos from the Collaborative Vulnerability Assessment Workshop. Photo credit: Sascha Petersen.

Following review and update by the Core Team at the vulnerability assessment workshop, Table 2 presents the final vulnerability rankings for the Shared Concerns species assessed *quantitatively* in this assessment.

Table 2: Overall vulnerability rankings for the 16 quantitatively assessed species of Shared Concern for the 2050s. Column titles reflect the climate change scenario with less warming (RCP 4.5) and more warming (RCP 8.5). Labels are the overall vulnerability ranking: EV = Extremely Vulnerable; HV = Highly Vulnerable; MV = Moderately Vulnerable, and LV = Less Vulnerable.

Species	2050s RCP4.5	2050s RCP8.5
Bull Trout	EV	EV
Chinook Salmon	EV	EV
Redband Trout	EV	EV
Steelhead	EV	EV
Columbia Spotted Frog	HV	EV
Big Sagebrush	MV	HV
Black-tailed Jackrabbit	MV	HV
Elk	MV	HV
Mule Deer	LV	MV
Black Cottonwood	LV	MV
Quaking Aspen	LV	MV
Golden Eagle	LV	LV
American Beaver	LV	LV
Common Chokecherry	LV	LV
Geyer's Willow	LV	LV
Redosier Dogwood	LV	LV

F. Next Steps

Planning for and adapting to climate change is a process and not the outcome of a single project. This assessment is the first in a series of three steps USRT and its member tribes plan to undertake over the next several years as part of a comprehensive climate change effort, including:

- Climate Change Vulnerability Assessment – *Completed in early 2017;*
- Adaptation Plan – *To be completed in 2017-18;* and
- Implementing Adaptation Actions and Monitoring – *Dependent on future funding.*

Strengthened collaboration between the four tribes and assessment of their Shared Concerns under regional climate change was, perhaps, the most important outcome of this assessment. The collaborative results of this assessment help establish a common foundation for future adaptation efforts among and between the USRT member tribes. The species-specific vulnerability information in this report can assist in the development of truly localized adaptation strategies and actions that minimize the negative effects of climate change and take advantage of emerging opportunities. Continued collaboration and action to address these vulnerabilities and prepare for the future will help ensure that the tribes who have lived and subsisted in the Upper Snake River Watershed for thousands of years will continue to thrive for generations to come.

II. Introduction

The Upper Snake River Watershed has been home to Indian tribes for more than 10,000 years. Many of their ancestors still reside on the landscape and are members of the Burns Paiute Tribe, Fort McDermitt Paiute-Shoshone Tribe, Shoshone-Bannock Tribes of the Fort Hall Reservation, and Shoshone-Paiute Tribes of the Duck Valley Reservation; the four member tribes of USRT.[4]

Maintaining a cultural tradition on a landscape over the course of more than 10,000 years is fundamentally an exercise in effective adaptation. In the Upper Snake River Watershed, this time-period included: a transition out of an ice age; mass emergence and migration of plants and animals; and the collision of societies, materials and goods, and disease from the opposite side of the world. USRT member tribes now face the environmental, societal, and cultural effects of human-driven global climate change and will look both to their proven cultural strengths and the adoption of innovative techniques to continue to successfully adapt and thrive on the landscape.

The climate around the Upper Snake River is changing. Tribal members have already noticed changes in precipitation patterns, increasing temperatures, and shifts in species and habitats. Such changes have manifested themselves in impacts such as drying sagebrush steppe habitat, extended wildfire seasons, less winter precipitation falling as snow, earlier spring run-off, low summer streamflows, high water temperatures, reduced flow from springs/seeps, proliferation of invasive weeds, and diminishing productivity of rangelands.

Figure 6: Photos from Site Visits to USRT Member Tribes' Reservations. Clockwise from top left: Shoshone-Paiute, Shoshone-Bannock, Burns Paiute, and Fort McDermitt Paiute Shoshone. Photo credits: Sascha Petersen and Scott Hauser.

To better understand these changes, USRT and its four member tribes collaborated with Adaptation International, the University of Washington's Climate Impacts Group, and the Oregon Climate Change Research Institute, to complete a climate change vulnerability assessment. This assessment is the first in a series of three steps USRT plans to undertake over the next several years as part of a comprehensive climate change response that includes:

- Conducting a Climate Change Vulnerability Assessment – *Completed in 2017;*
- Developing a Climate Change Adaptation Plan – *To be completed in 2017-18;* and
- Implementing Adaptation Actions and Monitoring – *Dependent on future funding.*

The information gathered during this vulnerability assessment will provide the foundation for developing adaptation strategies and actions that assist USRT member tribes in successfully minimizing the negative effects of climate change, while also taking advantage of any positive opportunities that may arise. Participation by tribal leadership, membership, and staff in conference calls, webinars, meetings, and site visits were key to the success of the vulnerability assessment and will continue to be invaluable in future efforts to prepare for and respond to climate change.

This collaborative assessment expressly considered the species, habitats, and resources that are important and valuable to USRT member tribes. Climate change impacts on these resources have the potential to affect tribal members' culture, spirituality, and lifeways. Tribal governments and other tribal entities will likely realize cost savings by integrating the results of this climate change vulnerability assessment into their existing wildlife management, community development, and/or other long-range plans.

A. Background on USRT and Member Tribes

Recognizing the four USRT member tribes' historical use of the landscape, which extends beyond the boundaries of their current reservations, this climate change vulnerability assessment applies to the complete Upper Snake River Watershed, an area of 97,060 square miles (~ 62,118,234 acres) shown within the blue polygon in Figure 7. The tribes maintain and utilize rights to resources, cultural properties, and practices that occur in this area, which include but are not limited to hunting, fishing, gathering, and subsistence uses.

Upper Snake River Tribes Foundation

The USRT Foundation is a 501(c)(3) non-profit corporation, composed of four Indian tribes that currently live in the Upper Snake River Watershed in Idaho, Nevada, and Oregon: Burns Paiute Tribe, Fort McDermitt Paiute-Shoshone Tribe, Shoshone-Bannock Tribes of the Fort Hall Reservation, and Shoshone-Paiute Tribes of the Duck Valley Reservation. In 2007, the USRT Charter was adopted pursuant to the Motherhood Document of 1998. USRT's primary goals are to facilitate tribal unity to protect and nurture all compacting tribes' rights, languages, cultures, and traditions in addressing issues related to the Snake River Basin. USRT priorities include the sustained availability of fish and wildlife, land, water, and air, cultural resources, and the federal trust responsibility.

The four member tribes have common vested interests in protecting rights reserved through the United States Constitution, federal treaties, federal unratified treaties, executive orders, inherent rights, and aboriginal title to the land, which has never been extinguished by USRT member tribes. USRT works to ensure the protection, enhancement, and preservation of the tribes' rights, resources, cultural properties, and practices. These rights include but are not limited to hunting, fishing, gathering, and subsistence uses.

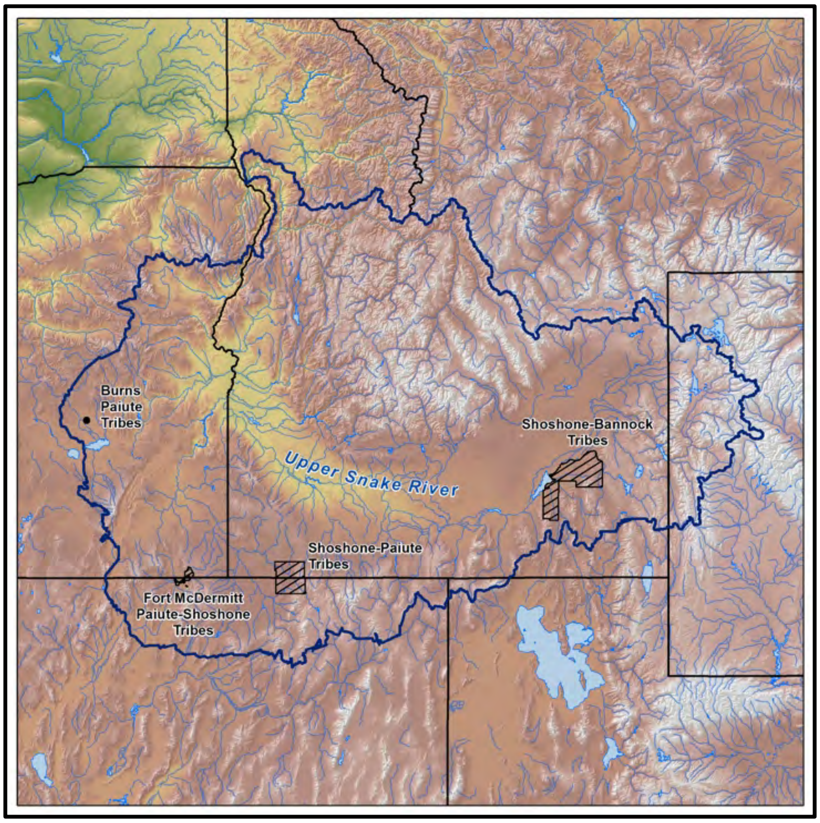


Figure 7: Upper Snake River Watershed study area (dark blue boundary), along with the four USRT member tribes' reservations and locations (black dots and shaded areas).

Several years ago, the USRT Commission recognized that the effects of climate change could impact the goals of the USRT Charter. Since 2012, USRT has been working to: identify climate impacts that affect USRT's member tribes, attend climate change trainings and workshops, and seek funding to complete work on climate change planning. In 2015, USRT received funding from the Bureau of Indian Affairs and Environmental Protection Agency (Regions 9 and 10) to conduct a climate change vulnerability assessment for the Upper Snake River Watershed.

Burns Paiute Tribe

The Burns Paiute Reservation is composed of 760 acres north of Burns, Oregon, in the arid region of the Great Basin,[5] with a total of 966 acres held in trust by the Tribe. There are approximately 412 people who hold membership with the Burns-Paiute Tribe.[6] They consist primarily of descendants of the Wadatika (Wada Root eaters) Band of Northern Paiute Indians, along with surviving peoples of six other eastern Oregon Northern Paiute bands.[7]

The Tribe's aboriginal territory and traditional use areas include portions of the Cascade Mountains, the Columbia River, the western Great Basin, and the High Plains/Plateau of western Idaho. Major campsites were historically along lakes, streams, and rivers, where water sources as well as food could be harvested. The Paiutes used willow, tule plant, and sagebrush to make baskets, sandals, fishing nets, and traps. The resources found within this ancestral territory were visited seasonally and sustained the Wadatika, providing for their material, spiritual, and medicinal needs.[8] The natural resources of the Upper Snake River Watershed continue to sustain the dietary, cultural, spiritual, and economic needs of the Burns Paiute Tribe.

Fort McDermitt Paiute-Shoshone Tribe

The Fort McDermitt Paiute-Shoshone Tribe's Reservation spans the Nevada–Oregon border, in Humboldt County, Nevada, and Malheur County, Oregon, near the Quinn River, which runs through the Tribe's Nevada lands, east to west. The reservation includes 16,354 acres in Nevada and 19,000 acres in Oregon. There are 1,016 enrolled members of the Fort McDermitt Paiute-Shoshone Tribe.[9] The valley of the Quinn River was the location of a winter campsite utilized by nomadic Northern Paiutes and a few Western Shoshone peoples, when it was occupied by the cavalry for a military fort in the 1860's and eventually closed in the 1890's.

The Paiute in this area became known as the "Northern Paiute" and are related culturally and linguistically to the Shoshone, Bannock, and other tribes of the region. They had traditional seasonal territory ranging from the southwest into Nevada, Oregon, and southwestern Idaho. Paiute bands in the Great Basin typically ate roots, seeds, fish, small mammals, birds, waterfowl, and some larger animals like antelope, deer, and mountain sheep. The natural resources of the Upper Snake River Watershed continue to sustain the dietary, cultural, spiritual, and economic needs of the Fort McDermitt Paiute-Shoshone Tribe.

Shoshone-Bannock Tribes of the Fort Hall Reservation

The Fort Hall Reservation is in the eastern Snake River Plain of southeastern Idaho, north and west of the town of Pocatello. Initially the Reservation was 1.8 million acres, an amount that was reduced to 1.2 million acres in 1872, the result of a survey error. The Reservation was further reduced to its present size (546,500 acres) through subsequent legislation and the allotment process. [10] There are more than 5,800 people who hold membership with the Shoshone-Bannock Tribes.[11] When the Northern Paiutes left the Nevada and Utah regions for southern Idaho in the 1600s, they began to travel with the Shoshones in pursuit of buffalo. They became known as the Bannocks.

The Tribes generally subsisted as hunters and gatherers, traveling during the spring and summer seasons, collecting foods for use during the winter months. They hunted wild game, fished the region's abundant and bountiful streams and rivers (primarily for salmon), and collected native plants and roots such as the camas bulb. The natural resources of the Upper Snake River Watershed continue to sustain the dietary, cultural, spiritual, and economic needs of the Shoshone-Bannock Tribes of the Fort Hall Reservation.

The Snake and Blackfoot rivers and the American Falls Reservoir border the Reservation on the north and northwest. In addition to vast populations of fish, there are moose, deer, wild horses, and buffalo in the area. The ecosystem faces ongoing environmental challenges, such as loss of vegetation, erosion of stream banks, warmer water temperatures, and siltation in spawning gravels brought on by unrestricted grazing and rapid flooding.

Shoshone-Paiute Tribes of the Duck Valley Reservation

Descendants of the Western Shoshone and the Northern Paiute occupy the Duck Valley Reservation on the border of southwestern Idaho and northeastern Nevada along the East Fork of the Owyhee River.[12] The reservation is 289,819 acres, including 22,231 acres of wetlands. There are approximately 2,200 people who hold membership with the Shoshone-Paiute Tribes.[13] The Tribes once traveled seasonally through the land which is now the tristate area of Idaho, Nevada, and Oregon and beyond. The Reservation was established in 1886 for the Western Shoshone and was later expanded in 1910 for the Northern Paiute through respective executive orders.

The Tribes' lifestyle was well adapted to the desert environment in which they lived. Each band or tribe generally centered on a lake or wetland, which supplied fish and waterfowl for subsistence. Surrounding areas provided salmon, steelhead, rabbits, pronghorns, pinyon nuts, grass seeds, and roots as important parts of their diet. The natural resources of the Upper Snake River Watershed continue to sustain the dietary, cultural, spiritual, and economic needs of the Shoshone-Paiute Tribes of the Duck Valley Reservation.

B. USRT Project Scope and Objectives

As the USRT member tribes' diverse experiences within the same shared region illustrate, the Upper Snake River Watershed encompasses a complex and unique range of ecosystems, plants, and animals. The large geographic scope of the project provided the bounds of the localized climate change projections (Section III). The diversity of natural resources throughout the region is reflected in the range of Shared Concerns identified by the USRT member tribes in this project (see Section IV, Table 5).

USRT identified the following seven objectives for completing a climate change vulnerability assessment for the Upper Snake River Watershed and USRT's member tribes' reservations.

- Identify the audience for the climate change vulnerability assessment.
- Engage tribal leadership, staff, and membership during development of the vulnerability assessment.
- Identify species, habitats, and waterbodies most vulnerable to climate change.
- Integrate Traditional Ecological Knowledge to inform climate change planning and ensure its relevance.
- Complete a climate change vulnerability assessment to position USRT effectively for future adaptation planning and implementation.
- Increase ability to achieve future conservation and subsistence goals and objectives in the face of added impacts and complexities of climate change, alongside other stressors.
- Incorporate adaptive management planning into all USRT member tribes' fish and wildlife, natural resources, and other relevant land management plans to better reflect future changing conditions and resource requirements.

III. Climate Change in the Upper Snake River Watershed

Climate is the long-term average of weather over a given area; whereas *weather* is what is happening in the atmosphere at a given place and time. For example: in Boise, the temperature and amount of rain on a given day is the *weather*, while the average precipitation in December (typically over a 30-year span) is the *climate*. Climate can be calculated across different spatial scales: globally, regionally, and locally. Each scale is useful for understanding a component of the climate system. For this assessment, the climate analysis starts at the global scale, but quickly downscales to the Upper Snake River Watershed, as it is most relevant to the USRT member tribes' climate change preparedness work.

A. Changing Climate Conditions

Global average annual temperature has increased about 1.5˚ Fahrenheit from 1880 to 2012, as calculated using a combination of observations and measurements based on thermometers, satellites, and other means. This may seem like a small increase, but globally, this change is beyond the range of natural variability or annual and decadal changes that occur under the influence of climate events such as the El Niño Southern Oscillation.[14] More than half of the warming observed from 1951-2010 is attributed to human activities,[15] such as the burning of fossil fuels, which release heat-trapping greenhouse gasses (e.g. carbon dioxide, CO_2) into the Earth's atmosphere. This increase in temperature has caused many environmental changes that have been measured around the world (Figure 8).[16]

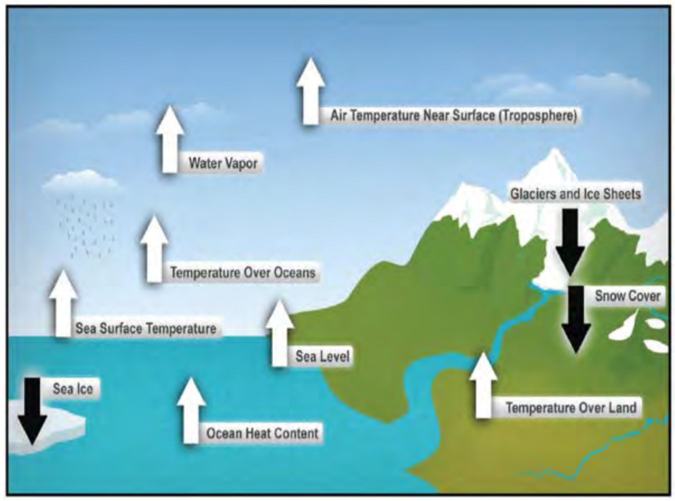


Figure 8: Some of the global indicators showing that the Earth's climate is warming. White arrows indicate increasing trends while black arrows indicate decreasing trends.[16]

The USRT member tribes have been documenting changes on the land for many centuries. Direct observations and measurements of temperature and precipitation around the region can be used to help understand these changes over the last 100 years. Figure 9 show changes in temperature across the inland Pacific Northwest during the period 1895-2014.[17] Annual temperature has increased at

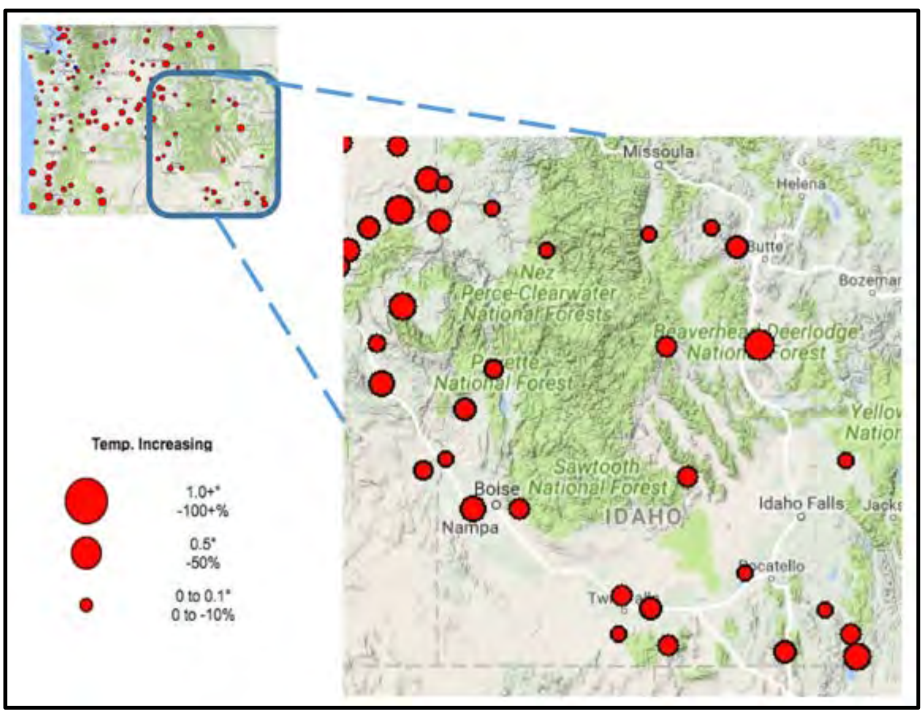


Figure 9: Past change in temperature at long-term climate station locations in the Pacific Northwest from 1895-2014.[17]

all stations across the domain, though by different amounts. Averaged over the entire Pacific Northwest, temperature has increased about 1.3˚ Fahrenheit[18] over that time.

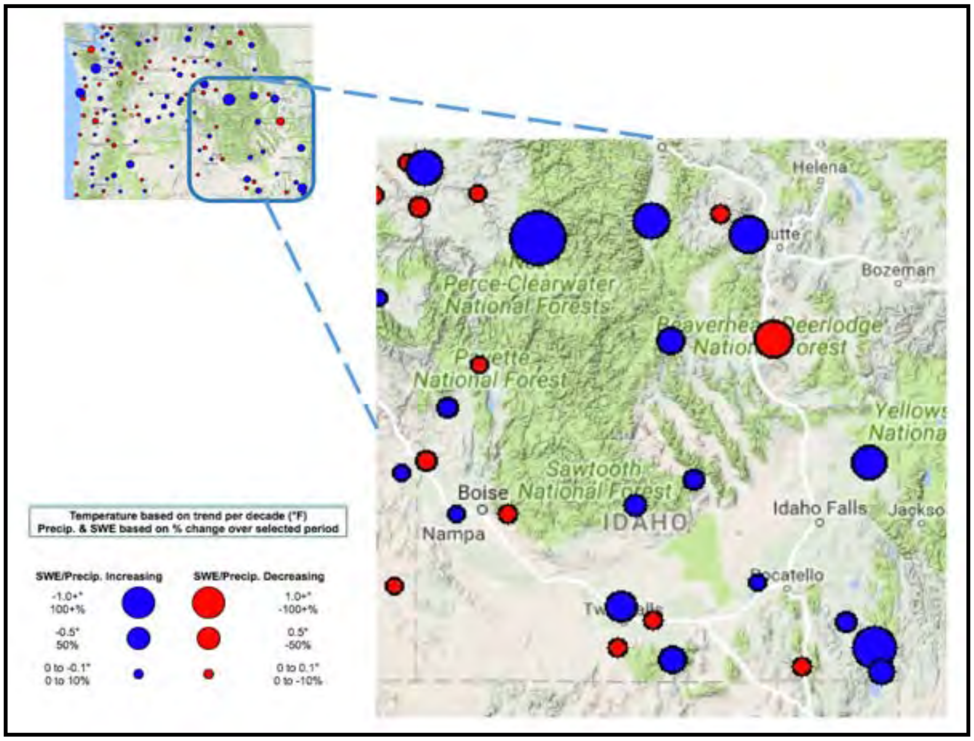


Figure 10: Past change in precipitation at long-term climate stations in the Pacific Northwest from 1895-2014.[19]

Changes in precipitation have been much more variable. Some stations in the Pacific Northwest have shown an increase in annual precipitation, others a decrease over the same 1895-2014 time period.[19] Averaged over the area, there is not much of a trend in the change in annual precipitation over that time.[20] Seasonal trends in precipitation are explored in the detailed analysis of climate projections completed for this project (Section III.D.).

B. Climate Projections

Climate projections refer to the output from global and regional-scale climate models and should not be considered "forecasts" but instead attempts to answer a "what if?" question. These projections are simulations of *what* the climate might be like *if* society follows a particular trajectory of greenhouse gas emissions. The amount of greenhouse gasses the global society ultimately emits will be determined by factors like: global population growth, changes in global economic activity, and preferred energy sources (e.g., the balance of fossil fuels vs. clean energy technologies).

The latest generation of global climate models uses a set of future scenarios called Representative Concentration Pathways (RCP). Each RCP scenario represents a trajectory of atmospheric concentrations of greenhouse gases to, and beyond, the end of the 21st century, and provides a flexible way of defining a set of climate futures that make a variety of socio-economic assumptions.[21] This report focuses on two of the scenarios, RCP 4.5 and RCP 8.5. RCP 4.5 represents a future where global agreements and policies work to dramatically reduce greenhouse gas emissions. In RCP 4.5, greenhouse gas emissions peak in the 2040s, then decline. The socio-economic assumptions of RCP 4.5 are largely aspirational, but still achievable with significant global action in the next decade. RCP 8.5 assumes continued dominance of fossil fuel energy sources, where global greenhouse gas emissions continue to increase at their present rate for the next several decades. RCP 8.5 is often colloquially referred to as the "business-as-usual" scenario. RCP 4.5 and 8.5 scenarios provide a range of possible future global and regional temperatures and precipitation trends, with more significant changes projected in the RCP 8.5 scenario.

While it is useful to understand global climate change projections, it is the regional and local projections that are most important for assessing the potential impacts to the habitats, plants, and animal species and other resources important to the USRT member tribes. To develop regional projections of a future climate, scientists downscale global climate model outputs using a series of statistical and/or dynamical (modeled) processes. This assessment presents the future regional projections of climate using a downscaled dataset called the Multivariate Adaptive Constructed Analogs (MACA).[22]

C. Study Area and Data

The Project Team selected the large boundary for the project (shown in blue in Figure 11) based on watershed boundaries that encompass the four USRT member tribes. The 97,060 square miles (62,118,234 acres) included in the assessment covers large sections of southern Idaho and eastern Oregon, and small portions of northern Nevada, northern Utah, and western Wyoming.

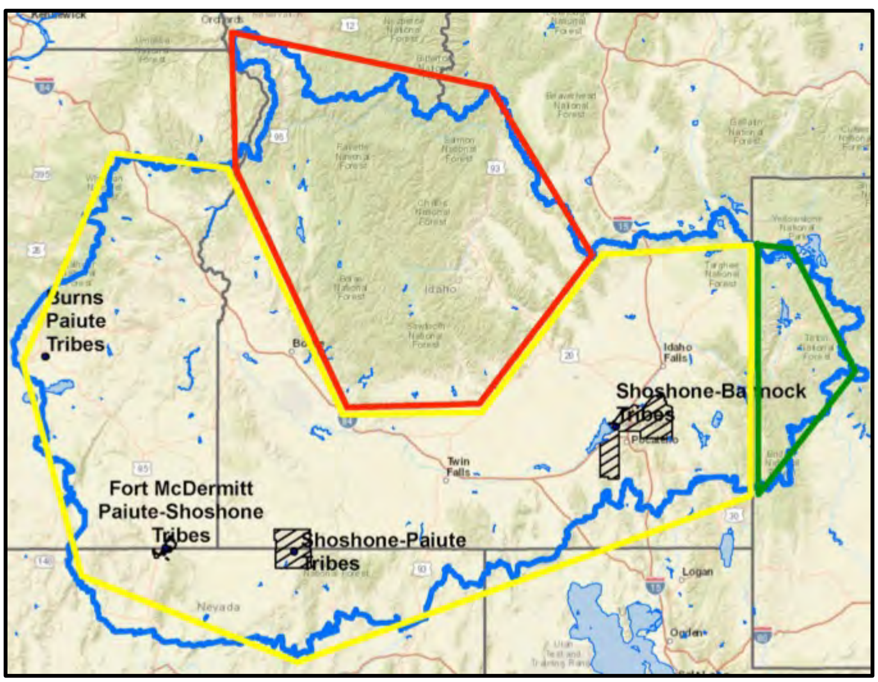


Figure 11: Study area (blue polygon – 97,060 square miles) and subdomains (red - North, yellow - South, and green –East, polygons) used for climate analysis.

This larger domain was divided into three smaller subdomains, each with somewhat distinct elevations, climates, and ecosystems. These subdomains are hereby referred to as the North (shown outlined in red), South (outlined in yellow), and East (outlined in green) (Figure 11). Downscaled climate projections from the region are from 20 global climate models (GCMs) run with two emissions scenarios (RCPs 4.5 and 8.5). These outputs were used to calculate potential future changes in temperature and precipitation. Since climate is considered the long-term (>30-year) average of weather for a specific location, it is important that changes be compared between multi-decadal periods. These projections were analyzed in reference to a baseline period (1950-2005) for three future time periods: the 2030s (which represents the years 2020-2049), the 2050s (which represents the years 2040-2069), and the 2080s (which represents the years 2070-2099). While most of the figures in the next section focus on either the 2050s or the 2080s, the full set of projections for each domain and each time-period are available in Appendix A.

D. Future Change in the Upper Snake River Watershed

Temperature

Across the entire project area and the three subdomains, average annual temperatures are projected to increase in both future climate scenarios and across all time periods. RCP 4.5 (left column in Figure 12) shows a smaller magnitude of warming in both mid-century (2050s - first row Figure 12) and late century (2080s - second row Figure 12) than RCP 8.5 (right column Figure 12). Mid-century annual average temperature under RCP 8.5 (6.0-6.5°F) is projected to be similar to end of the century warming under RCP 4.5 (5.7-6.5°F). Figure 12 displays the average value of the 20 models. Figures in Appendix A show the individual model outputs and the complete range of future projections by RCP in each subdomain.

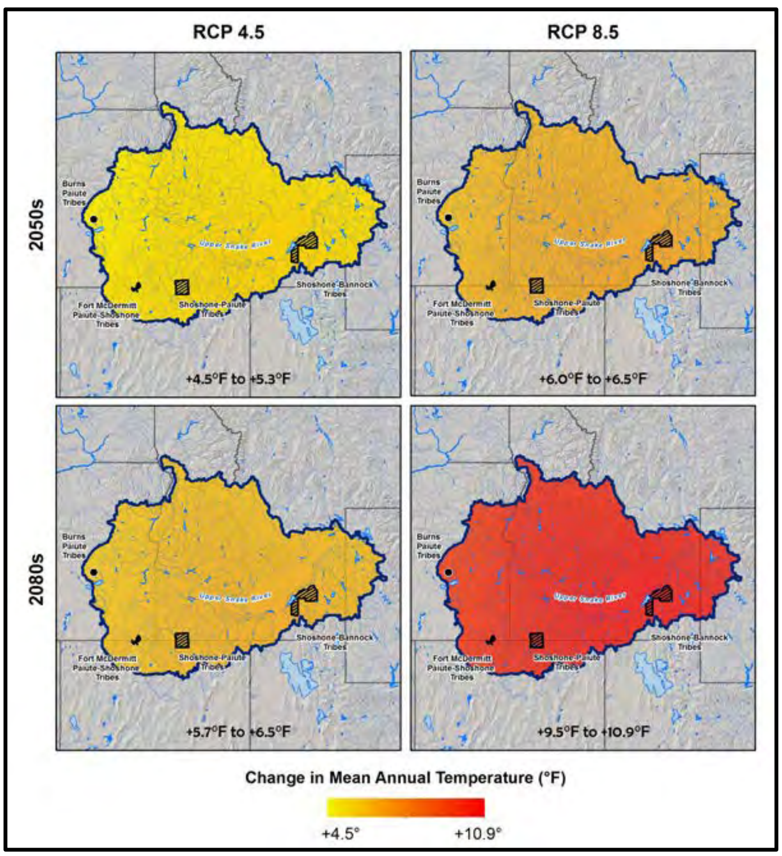


Figure 12: Future projected change in temperature through 21st century in the full project domain.

Presented in another way, Figure 13 shows the projected annual temperature in the South subdomain over time. The light lines are the individual model results and illustrate how temperature varies year to year. The dark lines are the average of all 20 models and more closely represent the general climate trend. Modeled historical temperatures for the subdomain are shown in gray and projected future temperatures are shown in yellow (RCP 4.5) and in red (RCP 8.5).

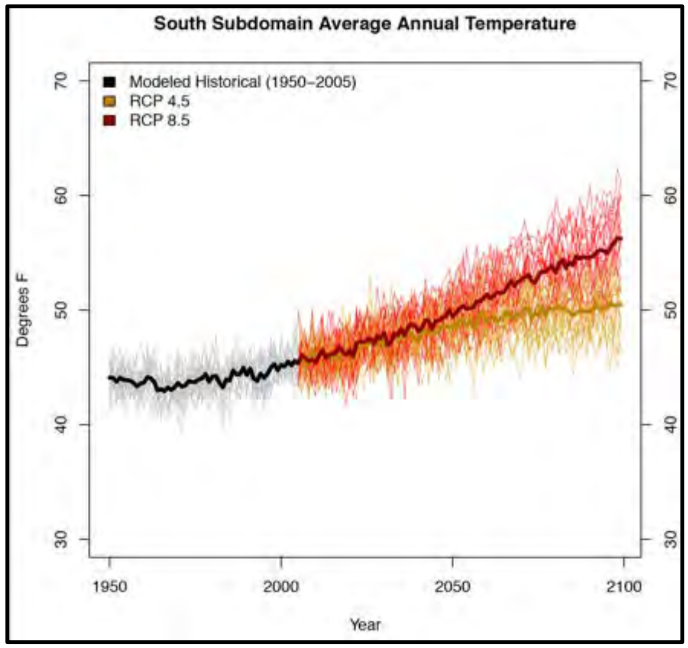
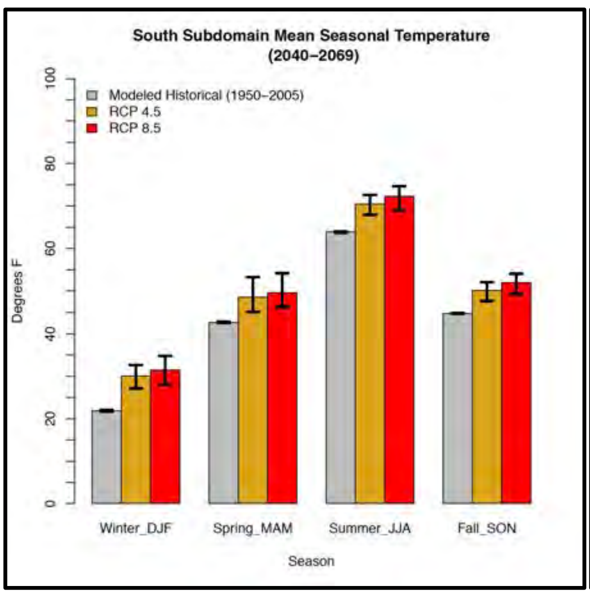


Figure 13: Average annual temperature projections for the South domain. Modeled historical past shown in gray. Future projections shown in Yellow (RCP 4.5) and Red (RCP 8.5), where light colored lines are the individual model results and the dark lines are the average of all 20 climate models.

Seasonal temperature projections are generally more relevant for species-level vulnerability assessment purposes. Much like annual temperature, each season is projected to be warmer in the future. RCP 4.5 shows slightly less warming in all seasons than the RCP 8.5 scenario. Winter and summer are projected to warm the most significantly from historical conditions in all domains. The largest increase in temperature is in the South subdomain, which includes the lower elevation and historically warmer areas in the region.



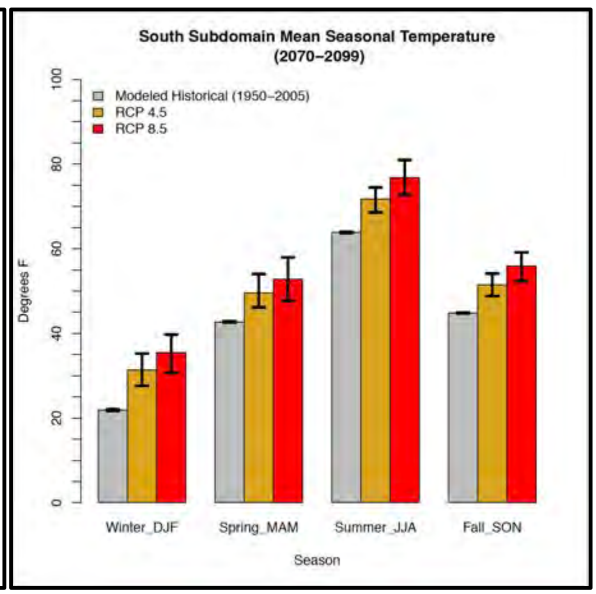


Figure 14: Seasonal average temperature projections for the South subdomain for two time periods analyzed. The modeled historical past for the subdomain is shown in gray and the two RCP scenarios are shown in the different colors (yellow is RCP 4.5 and red is RCP 8.5). Projections are displayed for time periods, 2040-2069 and 2070-2099. Bar heights show the mean from 20 climate models and the vertical lines show the range of all 20 climate models.

Precipitation

Average annual precipitation is not projected to change much in either RCP 4.5 or RCP 8.5 through the 21st century. Figure 15 shows the projected average annual precipitation in the South subdomain over time. The lighter lines are the individual model results and the darker lines are the average of all 20 models. Modeled historical precipitation for the subdomain is shown in gray and projected future precipitation is shown in light blue (RCP 4.5) and dark blue (RCP 8.5). The mean of both scenarios (bolded blue lines) shows only a slight increase over time, and this increase is much smaller than the year-to-year variability shown by the individual models.

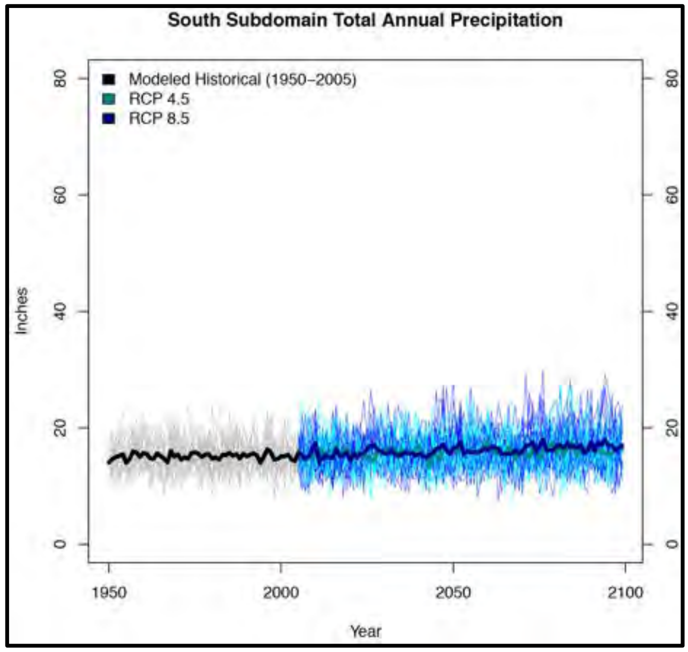


Figure 15: Average annual precipitation projections for the South subdomain. Modeled historical past shown in gray. Future projections shown in light blue (RCP 4.5) and dark blue (RCP 8.5), where light colored lines are the individual model results and the dark lines are the average of all 20 climate models.

Seasonal changes in precipitation may be the most useful projections for planning purposes. Winter and spring are projected to get wetter in all three subdomains, with the largest increase in the higher elevation North and East subdomains. There is little projected precipitation change for summer and fall seasons, for both time periods under both scenarios and across all subdomains, apart from possibly slightly drier summers in the North (see Figure 16).

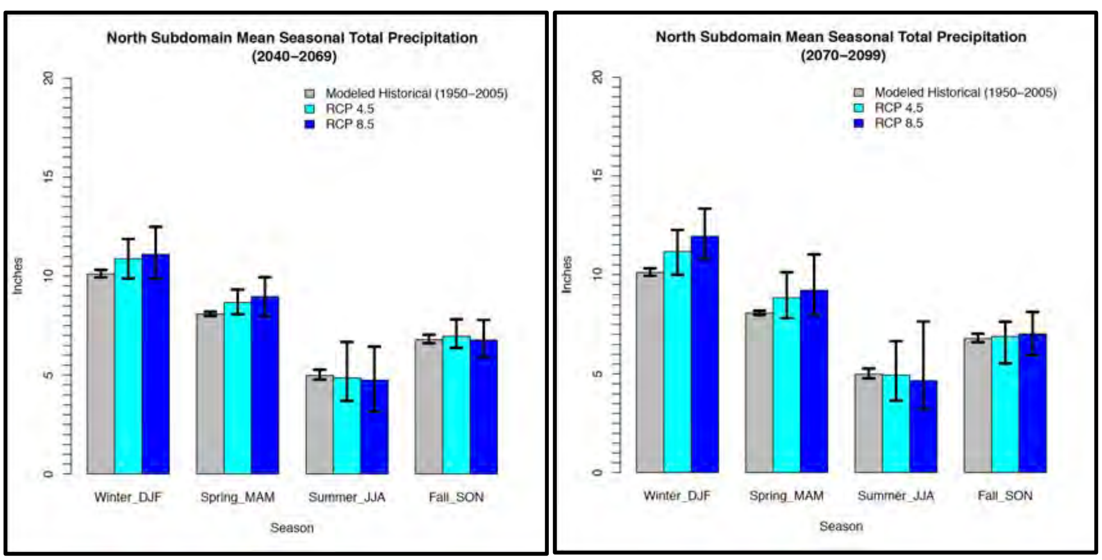


Figure 16: Seasonal precipitation projections for the North subdomain for two of the time-periods analyzed. Trends in these results are similar for the other subdomains. The modeled historical past for the subdomain is shown in gray and the two RCP scenarios are shown in the different colors (light blue is RCP 4.5 and dark blue is RCP 8.5). Projections are displayed for time periods 2040-2069 and 2070-2099. Bar heights show the mean from 20 climate models and the vertical lines show the range of all 20 climate models.

Changes to Hydrology

Climate change is expected to have important impacts on water availability and seasonal streamflows in the Snake River system because of warmer temperatures and declining snowpack. These changes will have direct and indirect effects on USRT member tribes by affecting the amount of water available in the region for: summer irrigation, instream flows for aquatic species, public water supply, hydropower production, and recreation.

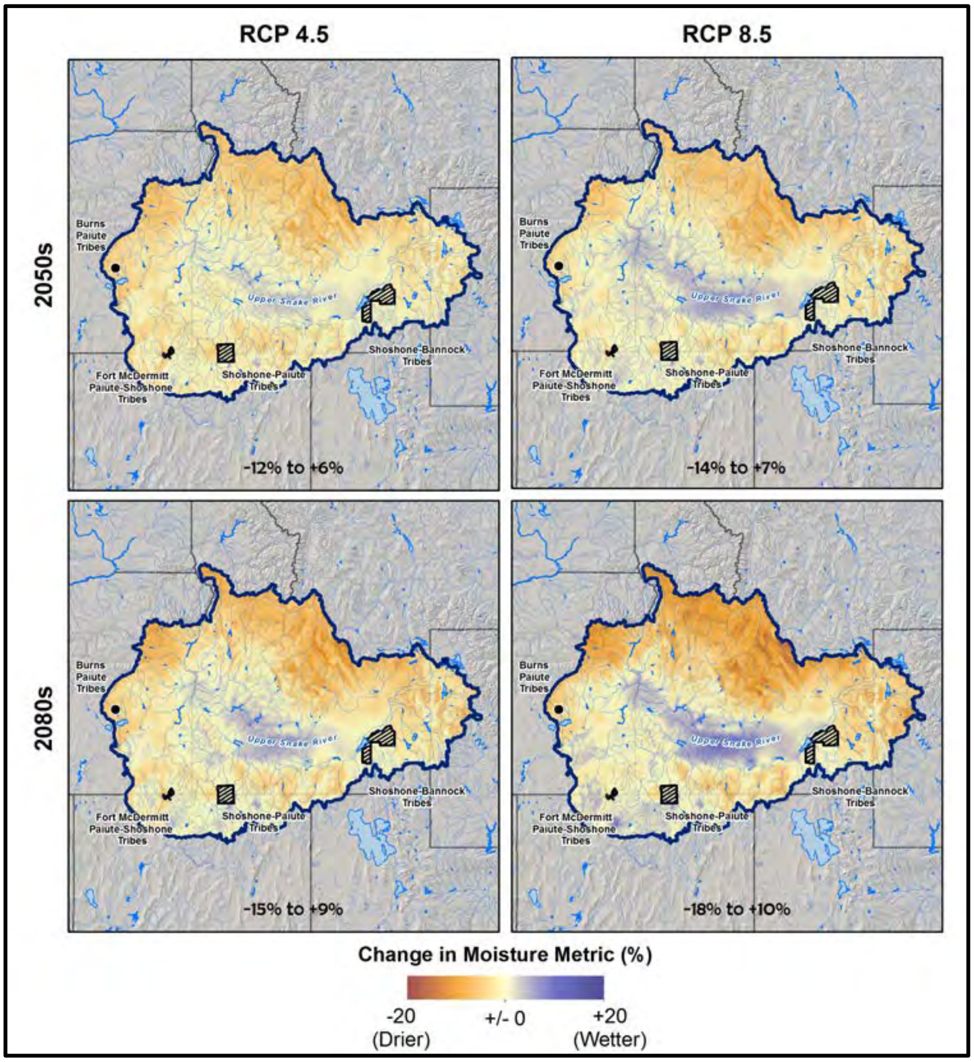


Figure 17: Percentage change in the Hamon moisture metric (a consideration of evaporation and evapotranspiration). Change is shown by time-period (rows 2050s & 2080s) and climate scenarios (columns - RCP 4.5 left & RCP 8.5 right).

Even with precipitation patterns staying relatively consistent, the warmer temperatures are likely to increase evaporation and evapotranspiration, which will decrease moisture availability and dry soils. However, this impact is not consistent across the region, as the more mountainous regions are projected to have less overall moisture available, while the Upper Snake River Plain is projected to have an overall increase in moisture availability.

Declining Snowpack

A major factor shaping how climate change affects streamflow in the Snake River Watershed is changes in snowpack. Snowpack provides a key form of water storage in the Pacific Northwest and, as winter temperatures increase, more winter precipitation will fall as rain rather than snow. This will lead to lower snow accumulation and more instantaneous runoff into rivers and streams. Warmer spring temperatures also result in earlier spring snowmelt.

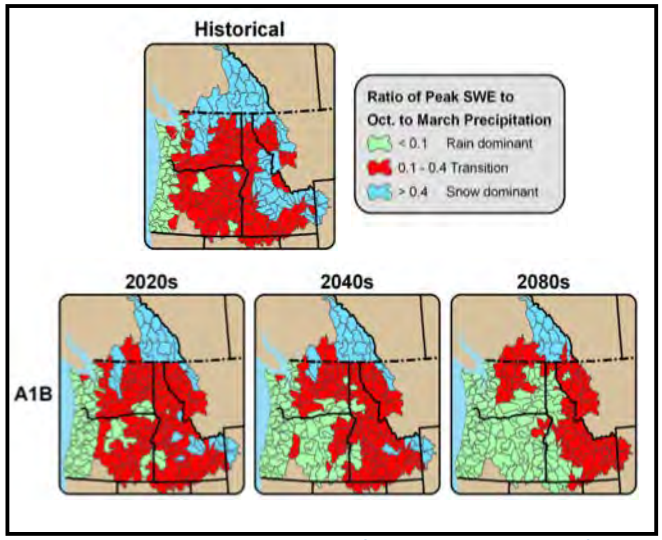


Figure 18: Historical and projected future watershed classification (rain-dominant = green, mixed rain/snow = red, snow-dominant = blue) for 10-digit Hydrologic Unit Code watersheds for a moderate warming scenario (the A1B scenario; bottom maps) for three future time periods.[23]

Watershed sensitivity to changes in winter temperature and snowpack will vary by basin-type. Snowpack losses are projected to be most acute in mid-elevation rain/snow mix watersheds where average winter temperatures are currently close to freezing. In these watersheds, even a small amount of warming can push average winter temperatures above freezing for longer periods of the winter. Snowpack in high elevation snow-dominant watersheds will also be affected, particularly after midcentury, as winter warming becomes more pronounced.[23,24] By the 2080s, the Snake River Watershed is projected to lose its snow-dominant watersheds and shift to more rain/snow mix and rain-dominant watersheds[ii] (Figure 18).

Table 3 shows the projected loss in April 1st snowpack for three locations in the Upper Snake River Watershed. These changes are consistent with overall changes in Columbia River Basin snowpack. Relative to the long-term average for 1916 to 2006, April 1st snowpack in the Columbia River Basin is projected to decline −29% for the 30-year period spanning 2030-2059 (i.e. 2040s) and −52% for the for the period spanning 2070-2099 (i.e. 2080s) for a moderate (A1B) greenhouse gas emissions scenario.[25] Scenario A1B assumes a more balanced energy portfolio than RCP 8.5, with greenhouse gas emissions leveling off by the middle of the 21st century.[26] In terms of greenhouse gas concentrations in the atmosphere, A1B closely tracks RCP 8.5 until about 2040; near that time the two scenarios diverge with A1B falling roughly halfway between RCP 8.5 and RCP 4.5 by the end of the 21st century.

Table 3: Projected changes in April 1st snowpack for three streamflow locations in the Upper Snake River region. Projected changes are for two time periods (2040s, 2080s) and a moderate warming scenario (the A1B scenario) relative to the long-term average 1916-2006.[27]

Monitoring Location	2040s (2030-2059)	2080s (2070-2099)
Salmon River at White Bird	- 35%	- 64%
Snake River at Brownlee Dam	- 37%	- 61%
Owyhee River below Owyhee Dam	- 70%	- 88%

[ii] Rain-dominant watersheds are watersheds where winter temperatures typically remain above freezing, making rain the dominant form of winter precipitation. As a result, streamflow in rain-dominant watersheds is highest in fall and winter months relative to other parts of the year.

Changes in Streamflow Volume, Timing, and Temperature

The increase in winter rains and decrease in winter snow will affect the behavior of Pacific Northwest rivers in important ways, although the magnitude of those changes will vary by basin-type. In general, the temperature-driven shift to more rain in the cool season produces higher fall and winter streamflows, increasing the risk of winter flooding (Figure 19). Warmer spring and summer temperatures lead to earlier peak runoff, increased evapotranspiration, and lower late-summer streamflows, which can exacerbate existing problems with summer drought and summer stream temperatures.[28,29,30,31] Hydrographs, like those in Figure 19, show the combined monthly average total runoff and base flow over the entire basin, expressed as an average depth in inches. They help show the potential shift in the timing of peak and low streamflow conditions as temperatures warm and snowpack melts.

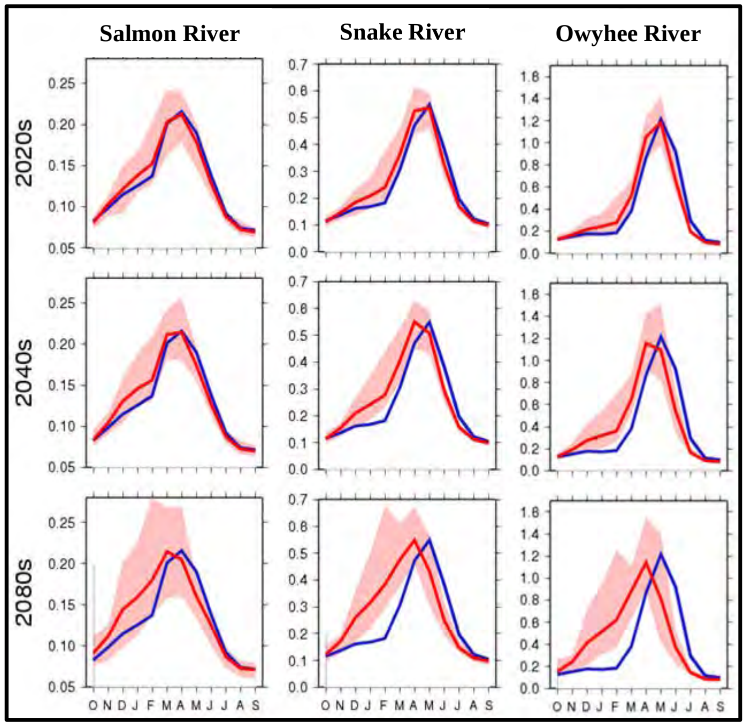


Figure 19: Projected naturalized changes in streamflow (shown in inches) for the Salmon River at White Park (left column), the Snake River at Brownlee Dam (center), and the Owyhee River below Owyhee Dam (right). Blue line shows the simulated historical values (1916-2006), light red bands show the range of all hybrid delta scenarios for the future time-period and emissions scenario (10 GCMs), and dark red lines show the ensemble average for the hybrid delta future projections. Results are shown for a moderate warming scenario, A1B.[26]

For the same moderate warming scenario shown in figure 19 (A1B), climate change is projected to increase maximum weekly mean stream temperatures across the Pacific Northwest by +1.8 to +7.2°F for the 2030–2069 period and +3.6 to +10.8°F by the 2070–2099 period (relative to 1970-1999).[32] Changes in stream temperature are projected to be the largest in the Snake and Willamette River basins relative to other areas of the Pacific Northwest.

Wildfire Risk

Changing fire risk under climate change holds potential for large-scale impacts to forests and grasslands in the western U.S. Multiple factors contribute to an overall increased risk of fire due to climate change. These factors include declining snowpack, more intense summer drought, reduced summer soil moisture, earlier onset of the growing season, and higher fuel loading; all of which have been found to be important drivers of increased fire activity in the Northern Rockies and across the western U.S.[33,34,35,36] Soil moisture deficits develop when the amount of water available in the soil is less than what is needed by plants for optimal growth (i.e., they become water-limited systems). Increases in summer soil moisture deficits (shown for June, July, and

August (JJA) – Figure 20) create more stressful conditions for forests and grasslands, leaving those areas more susceptible to fire as well as insect attacks and disease.

In addition to the factors noted above, fire risk in more arid, fuel-limited areas is governed by precipitation in the previous years. Abundant precipitation can lead to increased plant productivity and a higher fire risk in the year that follows.[37] This may have important implications for invasive species like cheatgrass, which has been found to be a significant factor in the size, duration, spread rate, and inter-annual variability of fires in Great Basin grasslands. Fires in areas with cheatgrass can be disproportionately more frequent, larger, and quicker to spread than in areas with other native vegetation types. Warmer and wetter winter and spring conditions in the northern Great Basin would favor cheatgrass growth, increasing the risk of fire in those areas.[38]

Figure 20: Projected change in total soil column moisture, in percent relative to historical (1916-2006), for the 2040s for a moderate warming scenario (A1B) using the Miroc 3.2 and PCM1 global climate models and the VIC hydrologic model.[32]

Climate change impacts on fire risk are frequently described in terms of changes in fire frequency, intensity (and severity), and area burned.[39]

- *Fire frequency* is the number of fires in an area over a certain time period and is affected by the amount of fuel in a given area (i.e. fuel load), how moist or dry the fuels are (i.e. the flammability of those fuels), and the presence of ignition sources such as lightning.[40] In the short-term, fire frequency is expected to increase due to warmer, longer, and drier fire seasons and high fuel loads in many forests.[41] Long-term changes in fire frequency are less certain. While there will likely continue to be soil moisture deficits (increasing fire risk), more frequent wildfires, over the next few decades, could reduce fuel loads in lower montane forests and decrease the fuel available for fires in the longer-term.[42] Increased water stress could also lower productivity, reducing fuel accumulation rates.[43] However, these scenarios are dependent on the balance between future fuel conditions, production, and fire suppression, all of which are uncertain.[44,45,46]

- *Fire intensity* is the amount of energy released by a fire (i.e. how hot it burns). Fire intensity is often discussed in correlation with *fire severity*, which refers to the overall effects of fire on vegetation (e.g. tree mortality), forest structure, and other issues such as human infrastructure. Factors contributing to fire severity and intensity include: the arrangement and availability of fuel loads; summer precipitation and temperature; short-term weather conditions before and during a fire; and topography.[47,48]

- *Fire area burned* refers to the total area burned by fire over a specific time-period (e.g. one year). Fire area burned is expected to increase in the western U.S. through at least mid-century (Figure 21).[49,50,51] In the Northwest, the median annual area burned under a moderate warming scenario is projected to increase from about 0.5 million acres historically (1916-2006) to 0.8 million acres in the 2020s, 1.1 million acres in the 2040s, and 2.0 million acres in the 2080s.[52] However, confidence in the projected changes in area burned after mid-century is lower, given the amount of fuel required to reach that level of area burned.[53,54] Shifts in vegetation over time in response to increasing moisture stress may also reduce the amount and connectivity of fuels.[55,56,57]

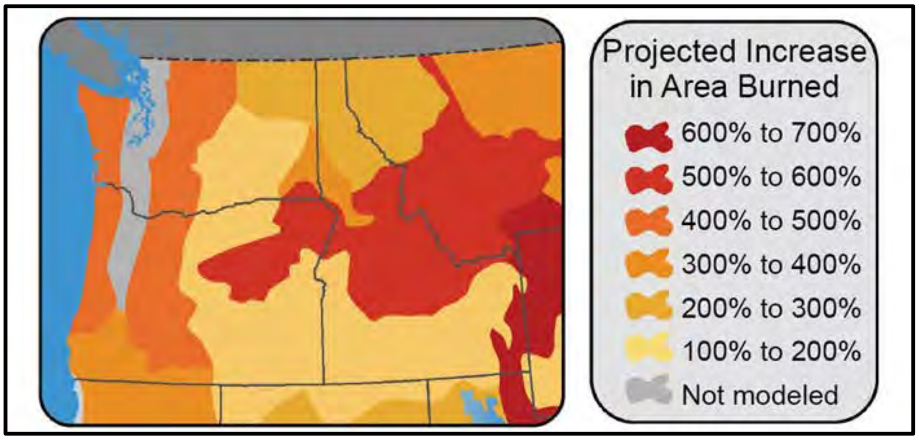


Figure 21: Projected increases in median annual area burned that would result from the regional temperature and precipitation changes associated with a 2.2° F global warming across areas that share broad climatic and vegetation characteristics. Local impacts will vary greatly within these broad areas with sensitivity of fuels to climate. Figure and caption (adapted).[59]

Another important component of future fire risk is the impact of climate change on forest insects and disease. Climate change is projected to change the frequency and location of insect and disease outbreaks, although changes will be species- and host-specific. Some insects and diseases may benefit from changing climate and host conditions, while other insects and diseases may become more limited.[58] These disturbance agents will affect tree mortality and habitat in the near-term, while also changing forest structure and composition over the longer-term.[59,60,61]

IV. Collaborative Project Process

This collaborative vulnerability assessment evaluated the climate-related vulnerability of species, habitats, and resources that are important and valuable to tribal members. This focus was achieved through direct and ongoing participation with USRT's leadership, staff, and membership. The sharing of traditional knowledge, local scientific observation, and tribal priorities is a crucial part of this assessment's relevance to the on-the-ground experiences of the USRT member tribes. Approximately 90 people affiliated with the USRT member tribes participated in this vulnerability assessment. This section describes the collaborative project processes used in this project.

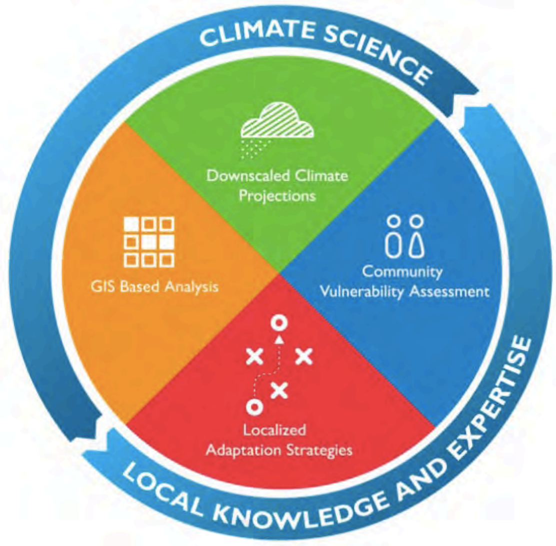


Figure 22: The collaborative process used in this project integrated downscaled climate projections with local knowledge and expertise.

A. Core Team

The first step in initiating the collaborative process with the four tribes was the creation of a Core Team with leadership and staff representatives from each tribe. This team met via webinar and phone throughout the course of the project. The Core Team also helped organize and attend site visits to the individual tribal reservations; review project materials; review the draft outputs of the Climate Change Vulnerability Assessment (CCVI); and attend a final vulnerability workshop on July 28, 2016 in Boise, Idaho. See Table 4 for a list of Core Team members.

Table 4: Core Team members of the USRT climate change vulnerability assessment.

Name	Organization	Name	Organization
Scott Hauser	Upper Snake River Tribes Foundation	Billy Bell	Fort McDermitt Paiute-Shoshone
Bob Austin	Upper Snake River Tribes Foundation	Dan Stone	Shoshone-Bannock
Alexis Malcomb	Upper Snake River Tribes Foundation	Wayne Crue	Shoshone-Bannock
Erica Maltz	Burns Paiute	Travis Stone	Shoshone-Bannock
Jason Fenton	Burns Paiute	Ted Howard	Shoshone-Paiute
Jason Kesling	Burns Paiute	Buster Gibson	Shoshone-Paiute
Charlotte Rodrique	Burns Paiute	Carol Perugini	Shoshone-Paiute
Bradley Crutcher	Fort McDermitt Paiute-Shoshone	Jinwon Seo	Shoshone-Paiute
Duane Masters Sr.	Fort McDermitt Paiute-Shoshone	Heather Lawrence	Shoshone-Paiute
Justina Paradise	Fort McDermitt Paiute-Shoshone	Chris Cleveland	Shoshone-Paiute

B. Site Visits and Identifying Shared Concerns

The four USRT member tribes reside in environments similar enough to have many common concerns related to the potential impacts of a changing climate on their valuable natural and cultural resources. Because USRT works to support all four of its member tribes, this project focused on evaluating the climate change vulnerability of "Shared Concerns". These Shared Concerns were identified through an extensive set of site-visits conducted by USRT staff, Adaptation International, and Oregon Climate Change Research Institute in April 2016. These site visits roughly followed a similar agenda (Figure 23).

The site visits offered an opportunity for the Project Team to introduce the assessment process and describe both climate science principles and localized climate change projections. Most importantly, the site visits provided space for a broad discussion of climate change concerns with tribal leadership, staff, and membership. The photos in Figure 24 illustrate the broad participation across the site visits. A summary of individual tribe's climate change concerns identified during each site visit can be found in Appendix B.

2:00pm-5:00pm **Meeting with tribal staff & council members**

- Brief Introductions
- Climate Change Vulnerability Assessment Overview
- Localized Climate Change Projections
- Discussion: Tribal Climate Change Concerns

5:30pm -7:00pm **Community Meeting** *(with Food)*

- Brief Introductions
- Climate Change Vulnerability Assessment Overview
- Localized Climate Change Projections
- Discussion: Tribal Climate Change Concerns

Figure 23: Burns Paiute site visit meeting agendas. Meeting agendas for site-visits were similar in structure.

Figure 24: Photos from the USRT member tribes Site Visits. Clockwise from top left in chronological order: Shoshone-Paiute, Fort McDermitt Paiute-Shoshone, Burns Paiute, and Shoshone Bannock tribes. Photo credits: Sascha Petersen and Scott Hauser.

Following the site visit with each of the four tribes, the Project Team synthesized notes and information gathered during the visits. ***The resulting list of climate change concerns included 46 animal species, plant species, habitats, and resource issues that were Shared Concerns.*** The information contained within this list was verified for accuracy by the Core Team via email and phone conversations.

Unfortunately, the available time and budget for this project did not allow for a detailed vulnerability assessment for all 46 Shared Concerns. A complete list of the 46 Shared Concerns is displayed in Table 5. Recognizing this, the Core Team, Project Team, and the University of Washington's Climate Impacts Group (CIG) worked together to select ***28 Shared Concerns*** (green highlight in Table 5) that were assessed during the remainder of this project. While this list is not comprehensive, it provides a representative cross-section of the species, habitats, and resource issues identified by the USRT member tribes during site visits. This selection of Shared Concerns was *not* a prioritization of any issue or resource, as all species, resources, and habitats identified by the member tribes are interconnected and important. ***USRT sees an urgent need to assess the climate change vulnerability for ALL Shared Concerns identified by USRT member tribes, perhaps under future funding and vulnerability assessment efforts.***

Table 5: Full Shared Concerns list from Site Visits April 18-21, 2016. Those species, habitats, and resource issues shown in green were included in this assessment process. Those issues assessed quantitatively with the CCVI tool are indicated with an "x", those unmarked were assessed qualitatively.

Plant Species	Assessed with CCVI Tool
Antelope Bitterbrush	
Big Sagebrush	X
Black Cottonwood	X
Camas Root	
Common Chokecherry	X
Geyer's Willow	X
Meadow Hay	
Noxious Weed: Medusahead	
Noxious Weed: Whitetop	
Quaking Aspen	X
Redosier Dogwood (red willow)	X
Booth Willow	
Burdock Root	
Coyote Willow	
Currants	
Mountain Sagebrush	
Noxious Weed: Canada Thistle	
Noxious Weed: Cheatgrass	
Peachleaf Willow	
Rubber Rabbitbrush	
Wyoming Sagebrush	

Animal Species	Assessed with CCVI Tool
Beaver	X
Black-tailed Jackrabbit	X
Bull Trout	X
Cattle	
Chinook Salmon	X
Columbia Spotted Frog	X
Elk	X
Golden Eagle	X
Mule Deer	X
Redband Trout	X
Steelhead	X
Cutthroat Trout	
Northern Leopard Frog	
Greater Sage-grouse	
White-tailed Jackrabbit	

Habitats	Assessed with CCVI Tool
Sagebrush Steppe	
Riparian	
Wet-meadow	
Springs/ Seeps	
Reservoirs	

Resource Issues	Assessed with CCVI Tool
Asthma	
Wildfire	
Juniper Encroachment	
Runoff	
Traditional Medicines	

Of the 28 Shared Concerns assessed in this project (green highlight in Table 5) 16 of the plant and animal species selected were assessed *quantitatively* using NatureServe's CCVI[62] tool, and an additional 12 Shared Concerns were assessed *qualitatively* (see Section IV for vulnerability assessment results). A graphic of this scoping process for Shared Concerns is illustrated in Figure 25.

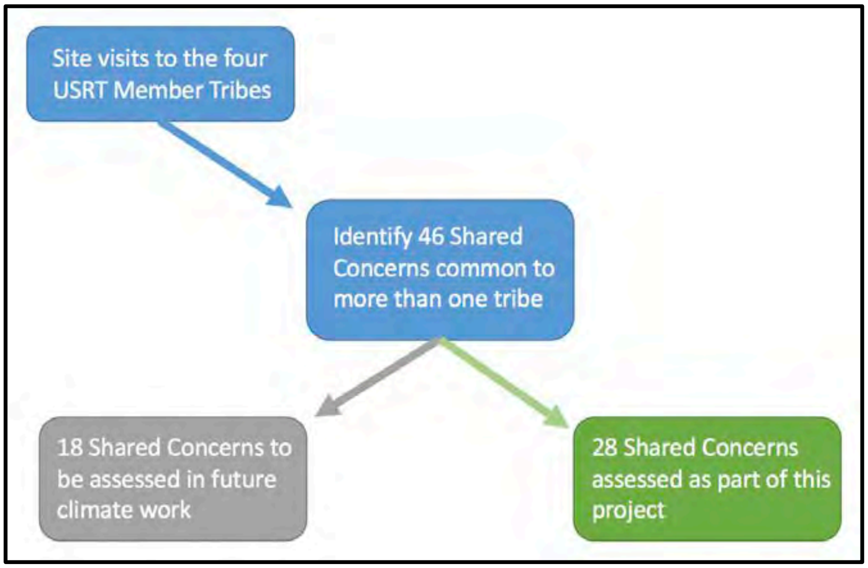


Figure 25: Scoping process for identifying and assessing Shared Concerns.

C. Climate Change Vulnerability Index (CCVI) Analysis

For the 16 Shared Concern species with readily available geographic range data, climate vulnerability was assessed *quantitatively* using NatureServe's CCVI. All four habitat types, the six species that lacked sufficient geographic range data, and the two resource issues were analyzed *qualitatively*.

NatureServe CCVI

The NatureServe CCVI Release 3.0[63] is a tool that estimates a species' relative vulnerability to climate change within a given assessment area. The CCVI uses projected changes in air temperature and moisture availability, species range data, and species-specific life history characteristics to calculate a species' direct and indirect climate exposure, sensitivity, and adaptive capacity[iii], ultimately generating a numerical sum quantifying a species' relative vulnerability. The CCVI tool has several benefits: it is publicly available, reproducible, and frequently used. These attributes will help to facilitate future updates to the vulnerability assessment as additional information becomes available. In addition, the results from this CCVI approach can be easily compared to results of other assessments also using the CCVI, such as the assessment currently being conducted by the Shoshone-Bannock Tribes. The CCVI tool also highlights species-specific sensitivities that contribute to vulnerability, offering detailed information to help guide future climate adaptation efforts.

Direct climate exposure was measured by calculating the percent of each species' range that is exposed to different levels of projected change in temperature and moisture. Indirect exposure to climate change, as well as species-specific sensitivities and adaptive capacity, were evaluated using a suite of 23 variables (Table 6).[iv] For more specific details on data sources and quantitative and qualitative assessment methods, please refer to Appendix C.

[iii] The CCVI tool defines these terms as follows. *CCVI Exposure*: Projected climate change (shifts in temperature and moisture) across the range of the species within the assessment area. *CCVI Sensitivity*: The extent to which a species will respond to shifts in climate. *CCVI Adaptive capacity*: The ability of the species to withstand environmental changes.

[iv] Though the CCVI includes 27 species- specific factors, we did not evaluate the four factors related to the "Documented response to climate change" due to lack of readily available data, leaving a total of 23 species-specific factors for the assessment.

Table 6: Factors used to evaluate species climate vulnerability in the CCVI analysis.

Factor	Description
Indirect Climate Exposure Factors	
Sea Level Rise	Effects of sea level rise on species habitat (not relevant for USRT species)
Natural Barriers	Geographic features of the landscape that may restrict a species from naturally dispersing to new areas
Anthropogenic Barriers	Features of anthropogenically altered landscapes (urban or agricultural areas, roads, dams, culverts) that may hinder dispersal for terrestrial and aquatic species
Climate Change Mitigation	Effects of land use changes resulting from human responses to climate change (seawall development, wind farm, biofuel production)
Species Sensitivity and Adaptive Capacity Factors	
Dispersal / Movement	Ability of species to disperse or migrate across the landscape to new locations as conditions change over time
Historical Thermal Niche	Exposure to temperature variation over the past 50 years
Physiological Thermal Niche	Dependence on cool or cold habitats within the assessment area
Historical Hydrological Niche	Exposure to precipitation variation over the past 50 years
Physiological Hydrological Niche	Dependence on a specific precipitation or hydrologic regime
Disturbance	Dependence on a specific disturbance regime likely to be impacted by climate change
Dependence on Ice / Snow	Dependence on ice, ice-edge, or snow-cover habitats
Restriction to Uncommon Geologic Features	Dependence on specific substrates, soils, or physical features such as caves, cliffs, or sand dunes
Habitat Creation	Dependence on another species to generate habitat
Dietary Versatility	Breadth of food types consumed; dietary specialists vs. generalists (animals only)
Pollinator Versatility	Number of pollinator species (plants only)
Propagule Dispersal	Dependence on other species for propagule dispersal
Sensitivity to Pathogens or Natural Enemies	Pathogens and natural enemies (e.g., predators, parasitoids, herbivores, and parasite vectors) that can increase or become more pathogenic due to climate change
Sensitivity to competition from native or non-native species	Species may suffer when competitors are favored by changing climates
Interspecific Interactions	Other interspecific interactions not including diet, pollination, and habitat creation
Genetic Variation	Measured genetic variation (high, medium, low)
Genetic Bottlenecks	Occurrence of bottlenecks in recent evolutionary history
Reproductive System	A plant's reproductive system may serve as a proxy for a species' genetic variation or capacity to adapt to novel climatic conditions (plants only)
Phenological Response	Phenological response to changing seasonal temperature and precipitation dynamics

Each factor listed in Table 6 was evaluated independently for each species and given a classification defined by NatureServe.[64] The five categories are: *1) Greatly Increases Vulnerability, 2) Increases Vulnerability,3) Somewhat Increases Vulnerability, 4) Neutral, and 5) Unknown*.

More than one categorical ranking can be selected to capture uncertainty or intermediate rankings regarding a species' sensitivity, adaptive capacity, or indirect climate exposure. In addition, not all sensitivity factors can receive the full range of categorical responses, as they do not all equally affect overall species vulnerability. For example, scores for "genetic variation" range only from *Neutral* to *Increase Vulnerability*.

Direct and indirect exposure to climate change and species-specific sensitivities are used to calculate an overall numerical vulnerability index score. This score is then converted to one of five possible vulnerability categories, based on threshold values. The four vulnerability ranking categories seen in this assessment are described below.[65]

- **Extremely Vulnerable**: Species abundance and/or range extent within the project area is extremely likely to substantially decrease or disappear.
- **Highly Vulnerable**: Species abundance and/or range extent within the project area is likely to decrease significantly.
- **Moderately Vulnerable**: Species abundance and/or range extent within the project area is likely to decrease.
- **Less Vulnerable**: Available evidence does not suggest that species abundance and/or range extent within the project area will change substantially, actual range boundaries may change.

These initial assessment findings were reviewed and revised during the Vulnerability Assessment Workshop using the expertise and local knowledge of USRT staff and the four member tribes. Two members of the Project Team and ten members of the Core Team representing USRT and each of the four USRT member tribes gathered in Boise for this one-day workshop. The focus of the workshop was on gathering and incorporating local and traditional knowledge into the draft vulnerability assessment results for each of the Shared Concerns.

Figure 26: Vulnerability assessment workshop in Boise on July 28th. Participants included leadership and staff from USRT and all four USRT member tribes. Photo credit: Sascha Petersen.

This collaborative review was accomplished using a combination of large group discussions and small group breakout sessions during which the Core Team members reviewed, evaluated, and commented on the *quantitative* and *qualitative* results of the CCVI assessment process for each of the species of Shared Concern. Local knowledge was extremely valuable in modifying the draft results to account for local variance in factors of exposure, sensitivity, and adaptive capacity, such as: local changes in the landscape, observed interactions between species, and species' existing response to extreme weather, climate change, and changes in habitat. Due to time constraints, not all the habitats and resource issues were addressed during the workshop. The Project Team conducted follow-up conference calls with select Core Team members to gather additional input on Shared Concerns including cattle, meadow hay, riparian habitat, sagebrush steppe habitat, springs and seeps, wet meadow habitat, and wildfire.

Following these meetings, CIG made modifications to the CCVI inputs as needed and re-ran the assessment for all species. Ultimately, incorporation of this information led to an adjustment of 19 individual factors affecting vulnerability and the re-ranking of one specie's relative vulnerability ranking.

This step in the overall process of the climate change vulnerability assessment was critically important for evaluating the relative vulnerability of plants, animals, and habitats of the Upper Snake River Watershed. Key staff members from all four USRT member tribes intensely reviewed the science-based CCVI metrics for each Shared Concern to incorporate traditional knowledge and local expertise. The workshop also strengthened connections between the four tribes and highlighted the shared challenges they face with changing climate conditions. These strengthened connections were perhaps the most important output of the workshop and helped establish a common foundation for future adaptation efforts.

V. Regional Vulnerability Assessment Results

A. Holistic Landscapes

This vulnerability assessment considers the ecosystems of the Upper Snake River Watershed through the perspective of individual habitats, plants, and animal species. Tribal elders who participated in this project emphasized the importance of a holistic vision of ecosystems. As they described, the assessment of any species requires that you consider both the habitats and species that depend on it. They described how it is inaccurate, and perhaps disrespectful, to suggest species lead their own existence apart from the whole. The elders explained how everything is connected within the Upper Snake River Watershed, and how this region is connected to the entire Earth. Planning for climate change is by its very nature an exercise in holistic thinking: warming temperatures and shifting precipitation patterns influence every living being on Earth, who in turn influence each other, and together have actions that further influence the global atmosphere.

Although this assessment discusses species and habitats individually, the information presented attempts to acknowledge and celebrate the true interconnection and holistic nature of the landscape and pay respect to the wisdom shared by the elders of the USRT member tribes.

B. The Environment is Medicine

"First: Water is life. The value of clean water cannot be overestimated."[66]
–Lindsey Manning, Shoshone-Paiute Tribe Chairman

The landscapes and ecosystems utilized by USRT member tribes provide nutritional sustenance, water for drinking and irrigation, materials for cultural practices, and a spiritual grounding for tribal members. During this assessment, water, plants, animals, and habitats were described by USRT member tribes as crucial components of community health and wellness. Any significant change to this landscape jeopardizes these valued connections between the tribes and the environment.

The climate change vulnerabilities described in this section raise very important questions about the future of nutrition, clean water, culture, and spirituality in the Upper Snake River Watershed. USRT was not able to fully explore these questions given the time and budget constraints of this project. During site visits, USRT member tribes identified **asthma** and **traditional medicines** as climate change Shared Concerns. Many of the described vulnerabilities of habitats, plants, and animals hold important implications for both asthma and traditional medicines. Some of these implications are summarized here, while many other issues will require attention in future climate change vulnerability assessments.

Traditional Medicines

In the Upper Snake River Watershed, climate change could influence conditions that are harmful to native plants and allow non-native invasive species to gain a foothold or expand in the region. While not directly assessed in this project, in many cases, the loss of native plants translates to the loss of traditional medicines, an important component of tribal culture, spirituality, and community health.

Asthma

Asthma is a non-curable chronic disease of the airways that affects the ability to breathe and can be controlled through medical management and avoidance of asthma triggers.[67] Some common asthma triggers related to climate include outdoor air pollution, pollen, mold, and smoke from wildfires or burning wood or grasses.[68] In the face of a changing climate, a central concern is that these conditions may become more common and cause additional respiratory impacts to tribal members with asthma.

Key climate change issues for asthma include:

- Increasing frequency or severity of wildfires (wildfire smoke can trigger or worsen asthma);
- Increasing summer temperatures and shifting precipitation patterns may increase drought conditions and related dust storms, which can trigger or worsen asthma; and
- Warming temperatures and shifting precipitation patterns may increase allergens that can trigger or worsen asthma.

Asthma has high health costs due to hospitalizations, missed work or school days, and in severe cases, loss of life. The Centers for Disease Control and Prevention estimates that nationally, asthma is the fourth leading cause of work absenteeism and diminished work productivity for adults.[69]

Wildfire and Air Pollution

The most damaging component of wildfire smoke is particulate matter. The tiny size of the particulates means they can move directly into the bloodstream, allowing the body to interact with complex chemicals adhered to the particulates.[70] Particulates under 2.5μm in aerodynamic diameter ($PM_{2.5}$) are especially toxic because they can penetrate deeply into lung tissue, with lasting effects from a single exposure.

The observations and projections in this report point to continued summer warming, continued summer drying of plants and soils, and an extended wildfire season. These changes would likely increase regional particulate matter and both exacerbate and create asthma health effects in the local population. Along with fine particulates, wildfire smoke also contains the precursors to ozone (O_3). During warm summer days, these precursors can create ground level O_3, which is known to worsen asthma and other lung conditions.[71] Even without wildfires, ground-level O_3 and particulate matter are expected to increase under climate change. O_3 formation increases with temperature, and the projected higher summer temperatures could cause modest increases in both particulate air pollution and ground-level O_3 in the Pacific Northwest.[72]

Dust Pollution

As with wildfire smoke, the most health-damaging components of dust are particles under 2.5μm in aerodynamic diameter and up to 10μm in diameter (PM_{10}). Increase in this type of air pollution in Idaho is associated with increased healthcare treatment for acute upper and lower respiratory illnesses.[73] The observations and projections in this report point to continued summer warming, continued summer drying of plants and soils, and potential increased risk of dust storms.

Allergens

For asthmatics, whose asthma attacks are triggered by exposure to allergens such as pollen and molds, climate-driven increases in temperatures and shifting seasons has been shown to increase pollen production, circulation, and dispersion.[74] Projected climate changes are expected to contribute to increasing levels of some airborne allergens, with associated increases in asthma episodes and other allergic illnesses.[75]

C. Climate Change Vulnerability of Habitats

Sagebrush Steppe Habitat

The sagebrush steppe habitat in many ways defines the Upper Snake River Watershed. The plants, animals, and springs of this landscape have been utilized by USRT member tribes for thousands of years and still provide important wildlife habitat and grazing areas for managed species.

Figure 27: Sagebrush Steppe Habitat. Photo credit: Matt Lavin

Existing Conditions & Observations by USRT Member Tribes[76]

Tribes have reported seeing large stands of dead and drying sagebrush, likely attributable to recent drought and a large-scale moth infestation in 2006. Sagebrush in this ecosystem is critically tied to snowpack. Seeds survive best when they drop before the first snowfall. The insulating snowpack helps keep them in contact with the soil, then as seeds migrate into the soil seed bank, snowmelt nurtures their development through the slow release of water over the spring season. In some areas, lower elevation sagebrush has been outcompeted by invasive cheatgrass and medusahead. These invasive species can sprout earlier and under snow, before the sagebrush comes out of dormancy, are more tolerant of drought, and can grow back more quickly after wildfire. The sagebrush steppe habitat is very sensitive to landscape-wide disturbance and, with recent changes to rangeland conditions and more frequent wildfires in the region, appears to be losing resiliency to these disturbances.

Conversion to Rangeland[77]

The sagebrush steppe ecosystem is the habitat most often converted to rangeland for cattle. There have been ongoing dry and drought conditions throughout the region for the past half-decade. With less water available, the native perennial grasses valuable to cattle can be out-competed by invasive annual grasses (e.g. cheatgrass, medusahead) and plants such as knapweed and thistle that thrive better in dry conditions. When the landscape gets too dry, the cattle must come in from the range earlier than expected and usually have put on less weight. Dry rangelands also have effects on nesting birds and waterfowl/shorebirds that use the grasses for habitat. In addition, cutting a grass field too early can decrease the browse available for deer. Even with a recent large snowpack at higher elevations, there did not seem to be much water available for native rangeland grasses.

Wildfire[78]

The wildfire season in the region historically occurred from July to September. The tribes have observed the wildfire season now extending from April to October on their reservations. Wildfire compounds the impacts of climate change and tribes have reported seeing large stands of dead and drying sagebrush, which increases overall fire risk for the ecosystem. It is common to see stand-replacing wildfire events in the sagebrush steppe, where almost all the vegetation is killed by the fire. Recent weather patterns have increased fuel loading with an early spring encouraging plant growth, and long, dry, hot summers turning this biomass into fuel. This ecosystem did evolve with wildfire; however, the system is currently faced with a shortened fire return interval and growing conditions that favor invasive plants. The ecosystem's historical mosaic of shrubs, forbs, and grasses has, in some areas, given way to dense stands of invasive grasses that burn hotter and create faster moving fires. This is especially true in the lower elevation sagebrush steppe. A fire return interval of 3-5 years is thought to be too frequent to allow successful recovery of the habitat and rangeland. At higher elevations, it can take 10-15 years for sagebrush steppe habitat to recover from a fire. Frequent wildfires increase the opportunity for erosion and sediment run-off into rivers as there are less plant roots to retain the soil. Best management practices generally aim to keep cattle off a landscape for two years following a fire.

Climate Change Vulnerability

Sagebrush steppe habitat estimated vulnerability: MODERATE.

This vulnerability ranking reflects the sagebrush steppe system's medium climate *sensitivity* and projected high *exposure* to temperature and precipitation changes in the Upper Snake River Watershed.

Key Sensitivities[79]:

- **Temperature change sensitivity** *(scored 3 out of 7)*

Sagebrush steppe is a widespread arid ecosystem in the western U.S. The distribution of sagebrush steppe is controlled by seasonal temperatures; it thrives in regions with cold winters and hot summers. Lying east of the Cascade Range, the Upper Snake River Watershed is buffered from the climatic influence of the Pacific Ocean and experiences significant seasonal temperature change with cold winters and hot summers.[80] While sagebrush steppe ecosystems in the region have adapted to warm, dry summers, projected increases in air temperatures[81] could further reduce soil moisture levels in the region through increases in evapotranspiration.[82]

- **Precipitation change sensitivity** *(scored 3 out of 7)*

Sagebrush steppe ecosystems receive most their annual precipitation during winter months. Some sagebrush steppe shrubs, such as the big sagebrush, have deep root systems which facilitate access to deep soil moisture provided by winter snow melt.[83] Their root system enables these species to survive through late-spring and summer when the availability of other water sources may be limited.[84] Despite the adaptations for some of the sagebrush species, the sagebrush steppe ecosystem is still susceptible to both summer and winter drought.[85]

- **Sensitivity to indirect factors** *(scored 5 out of 7)*

Sagebrush steppe ecosystems are sensitive to some of the indirect factors associated with climate change, specifically invasive species and shifts in fire regimes. Cheatgrass invasion has increased fire frequency in sagebrush steppe ecosystems because cheatgrass provides a continuous, highly flammable fuel source. This additional fuel source enables fires to cover larger areas and burn more frequently.[86] Decreasing fire return intervals reduce the likelihood of sagebrush establishment following a fire disturbance, which further facilitates the spread of cheatgrass. Sagebrush steppe ecosystems are also susceptible to invasion from juniper trees.[87] Early stages of juniper invasion can be reversed with fire treatment; however, the middle and late invasion stages are unlikely to be reversed with fire treatment. As the ecosystem transitions from shrub-dominant to one dominated by woody plants and trees (e.g., juniper), the overall likelihood of a shrub-dominated system declines.[88]

Riparian Habitat

Riparian areas are those terrestrial habitats found immediately alongside rivers and streams throughout the Upper Snake River Watershed. In this relatively dry landscape, riparian areas and their associated waterways provide essential water resources for plants and animals. Healthy riparian systems rely on an appropriate range of water temperature, volumes, and quality.


Figure 28: Riparian Habitat. Photo credit: Matthew Pintar.

Existing Conditions & Observations by USRT Member Tribes[89]

The presence of riparian plants, such as willows, is known to help shade streams and lower water temperatures, provide browse for animals, and support insect populations. Conversely, removal of this vegetation, for agricultural or housing development or due to wildfire, contributes to warmer stream temperatures. Small tributaries and springs that feed rivers can provide cold water input to streams and help moderate temperatures as well. Nearby groundwater withdrawals from agriculture can diminish the flow of these tributaries and groundwater into river systems and riparian habitat. Nutrient loads in river systems have increased in modern times due to agricultural run-off.

Reservoirs[90]

Many riparian habitats in the region are downstream from man-made reservoirs that store water for irrigation. These reservoir-types include stop water, irrigation, catchment basins, and run-off reservoirs. Consequently, many riparian habitats are affected by human-controlled releases from reservoirs. Water releases from reservoirs are generally scarce between October to April, so riparian habitats often depend on the availability of other water during this time. Reservoirs themselves are subject to higher nutrient loads from agricultural runoff, higher temperatures, and increasing plant and algae growth, which decreases water quality even before it is released downstream. Upstream of reservoirs, riparian habitats are subject to erosion as water storage backs up creeks, which saturates side soils. As the water is released, it drops quickly, sloughing the banks and bellying out bends. At low flow periods, these streams are consequently wider, more shallow, and therefore warmer.

Climate Change Vulnerability

Riparian habitat estimated vulnerability: MODERATE or HIGH.

This vulnerability ranking reflects this system's medium climate *sensitivity* and high projected *exposure* to temperature and precipitation changes in the Upper Snake River Watershed.

Key Sensitivities:[91]

- **Temperature change sensitivity** *(scored 5 out of 7)*

Riparian habitats in the assessment area are found along rivers and adjacent to bodies of water with relatively cool climates. Therefore, riparian habitats are moderately sensitive to shifts in temperature. Increasing temperatures could lower water levels, and in some instances, dry up small creeks or streams. In addition, changing precipitation regimes could dry groundwater springs or reduce the duration of their seasonal wetness. This could significantly change the species composition and structure of riparian habitats. If temperatures warm considerably, some of these systems could disappear completely.

- **Precipitation change sensitivity** *(scored 4 out of 7)*

Soil moisture, which is largely driven by regional precipitation and evapotranspiration regimes, is an important determinant of riparian species composition and structure. Hardwood tree species are typically an important component of riparian habitats, and these trees can be particularly sensitive to declines in water availability.

- **Sensitivity to indirect factors** *(scored 4 out of 7)*

Riparian habitats are particularly sensitive to shifts in streamflow and droughts. In general, the temperature-driven shift to more rain in the cool season produces higher fall and winter streamflows, increasing the risk of winter flooding. Additionally, increasing spring and summer temperatures will lead to earlier peak spring streamflow. This shift in peak runoff timing may lead to a reduction in riparian tree recruitment due to a mismatch between peak flow timing and seed release. Shifts in the timing and amount of summer stream flows will also affect water tables and soil moisture levels. Reductions in summer flows may negatively affect riparian plants with shallow root systems, including seedlings and juvenile trees.[92] Riparian habitats are also very sensitive to invasions from non-native species.

Wet-meadow Habitat

Figure 29: Wet-meadow Habitat. Photo Credit: Migiel Vieira.

Wet-meadow habitat broadly represents permanently saturated areas of the landscape, though meadow saturation can vary greatly in amount and in seasonal presence. Wet-meadows that are only flooded for half the year, or even a single month, can still hold value for habitat, groundwater recharge, and water purification.

Existing Conditions & Observations by USRT Member Tribes[93]

Higher elevation meadows are typically the result of precipitation patterns, while lower elevation meadows are the result of both precipitation and run-off from upstream landscapes. Wet-meadows are an important habitat for migratory birds in the Pacific Northwest flyway. That migration may be influenced by the condition of wet-meadows; for instance, if some wet meadows do not have adequate water or plant growth, birds may not stop and continue past those areas in search of other, more suitable stopovers. This, in turn, could increase the pressure on other wet meadows to support migratory birds. Most areas that are now used for agriculture in the region were once wet-meadow ecosystems. Intensive agricultural groundwater withdrawals (e.g. flood or pivot irrigation) have contributed to the drying out of some wet-meadow habitats.

Climate Change Vulnerability

Wet-meadow habitat estimated vulnerability: HIGH

This vulnerability ranking reflects the system's high climate *sensitivity* and high projected *exposure* to temperature and precipitation changes in the assessment area.

Key Sensitivities[94]:

- **Temperature change sensitivity** *(scored 5 out of 7)*

Wet-meadow habitat is generally found in high-elevation (3,200-9,800 feet) regions and is dominated by herbaceous species. Wet-meadow habitat is found on sites with extremely slow surface and sub-surface water flow.[95] Because soil moisture plays such a critical role in wet-meadow establishment and suitability, increasing temperatures could decrease soil moisture levels through increases in potential evapotranspiration, subsequently reducing the area of suitable wet-meadow habitat in the assessment area.[96]

- **Precipitation change sensitivity** *(scored 7 out of 7)*

Shorter snow duration in meadows due to earlier onset of spring snow melt could lead to increased growth and potentially a greater diversity of flora. However, projected declines in snowpack, resulting from a greater proportion of winter precipitation falling as rain rather than snow, will reduce summer soil moisture, a significant determinant of plant growth.

- **Sensitivity to indirect factors** *(scored 6 out of 7)*

Wet-meadows are typically more sensitive to the indirect effects of climate change because they are smaller and more fragmented than other habitat types. Increases in fire, flooding, disease, and shifts in wind will be magnified within wet-meadow habitats because the disturbance will affect a greater proportion of the total habitat area. Increasing distances between wet-meadows following major disturbances will affect species dispersal and seed regeneration.

Springs and Seeps Habitat

Springs and seeps refer to areas on the landscape where groundwater comes to the surface, creating an isolated wetland habitat before infiltrating back into the ground or continuing as a stream. Springs can be either cold or warm. On a dry landscape, these habitats can be the only water available for all surrounding plant and animal life.

Figure 30: Spring and Seep Habitat with impacts from Cattle. Photo credit: Sascha Petersen.

Existing Conditions & Observations by USRT Member Tribes[97]

Species diversity at a spring can be 100 to 500 times greater than surrounding areas. Tribal members use springs and seeps for drinking water and as important ceremonial sites. In general, USRT member tribes report reduced flows in many springs and seeps on their reservations. There have also been some reports of new springs emerging on reservations and decreased flows from springs known to only run during wet weather, likely directly tied to recent periods of drought. Like most bodies of water, a shallower spring with lower flow rates is subject to higher overall water temperatures and less dissolved oxygen than a larger spring with higher flow rates. Reduced flow and the loss of a spring altogether has been observed to concentrate wildlife species at other springs, creating a secondary impact on that habitat and increasing competition for water.

Historically, many springs and seeps have been used by ranchers to provide water for their cattle. This has had detrimental impacts on wildlife that use springs, as the cattle can cause erosion, soil compaction, and, in some cases, stop the water flow entirely. The tribes have undertaken both successful and unsuccessful efforts to protect these springs, while still providing water to cattle. It is not clear how wildfire may affect springs. The Shoshone-Paiute have replaced watering troughs at springs following wildfires and found some lower flow rates at those springs. Intensive agricultural withdrawal of groundwater has contributed to the drying out of certain springs. The extended agricultural growing season appears to be worsening this problem.

Climate Change Vulnerability

Springs and seeps habitat estimated vulnerability: N/A

Springs and seeps habitat was not given an overall vulnerability ranking in this project, as the available research does not provide enough data to make that determination.

Key Vulnerabilities:

- Decreasing snowpack and changes in the timing of seasonal spring run-off may result in decreasing inputs to the groundwater that ultimately supports springs and seeps.
- Increasing water temperatures in springs and seeps, associated with rising air temperatures, can have cascading ecological impacts to species and species diversity.
- More agricultural use of ground water could diminish spring/seep flow as the extended growing season increases demand for irrigation.

D. Vulnerability Assessment Results for Species

The final CCVI vulnerability rankings for 16 plant and animal species are provided in Table 7. These rankings are based on projected climate exposures for the region and the weighted sum of 23 distinct species-specific factors of sensitivity and adaptive capacity.

Table 7: Vulnerability rankings for the 16 plant and animal species assessed quantitatively using the CCVI. Results are shown by species (rows) and for the two different climate scenarios (RCP 4.5 and RCP 8.5) for two different time periods (2050s and the 2080s).

Common Name	Taxon	2050s RCP4.5	2050s RCP8.5	2080s RCP4.5	2080s RCP 8.5
Columbia Spotted Frog	Amphibian	HV	EV	EV	EV
Bull Trout	Fish	EV	EV	EV	EV
Chinook Salmon	Fish	EV	EV	EV	EV
Redband Trout	Fish	EV	EV	EV	EV
Steelhead	Fish	EV	EV	EV	EV
Golden Eagle	Bird	LV	LV	LV	LV
American Beaver	Mammal	LV	LV	LV	LV
Black-tailed Jackrabbit	Mammal	MV	HV	HV	HV
Elk	Mammal	MV	HV	HV	HV
Mule Deer	Mammal	LV	MV	MV	MV
Big Sagebrush	Plant	MV	HV	HV	HV
Black Cottonwood	Plant	LV	MV	MV	MV
Chokecherry	Plant	LV	LV	LV	LV
Geyer's Willow	Plant	LV	LV	LV	LV
Quaking Aspen	Plant	LV	MV	MV	MV
Redoier Dogwood	Plant	LV	LV	LV	LV

For a more comprehensive description of these vulnerability rankings, including detailed rankings of individual factors, please refer to Appendix C. For more information on projected climatic changes under each of the two climate scenarios (RCP 4.5 and RCP 8.5) for the two future time periods (2050s and 2080s) please refer to Section III. Species and habitats that were assessed qualitatively and *do not* have an overall vulnerability ranking are also discussed in this section but are not displayed in Table 7. In the following section, species-specific factors of sensitivity and adaptive capacity are described as "*Factors Affecting Vulnerability*". Species rankings for each of these factors reflects information from both the scientific literature and USRT member tribes.

E. Climate Change Vulnerability of Plants

This section provides further detail on some of the most important species-specific factors affecting climate change vulnerability for plants selected as Shared Concerns in this project. Species are listed alphabetically, and vulnerabilities are described quantitatively and qualitatively, as appropriate.

Antelope Bitterbrush (*Purshia tridentata*)

Existing Conditions & Observations by USRT Member Tribes[98]

USRT member tribes recognize antelope bitterbrush as important to big game and small mammals alike. The plant comes to maturity at approximately seven years and the seed crop (important for small mammals) is productive only once every seven years. During recent drought conditions (2012-2015), there was no viable seed crop. Antelope bitterbrush plants can recover from some fires, but must compete with invasive cheatgrass and take seven years to produce their first seeds.

Figure 31: Antelope Bitterbrush. Photo credit: Andrey Zharkikh.

Antelope Bitterbrush Vulnerability Rankings

Due to insufficient detailed information on the range of antelope bitterbrush within the project area, the species was assessed qualitatively and not given an overall vulnerability ranking in this project.

Factors Affecting Vulnerability

- **Dispersal/Movement *greatly increases vulnerability*.** Generally, antelope bitterbrush seed is dispersed 20-30 feet, by small mammals.[99] This limited seed dispersal distance restricts the plant's ability to repopulate areas burned by wildfire or move in response to changing temperature and precipitation patterns.
- **Dependence on Other Species for Propagule Dispersal *somewhat increases vulnerability*.** Small mammal caches of antelope bitterbrush seeds play an important role in the natural regeneration of the plant. Observations suggest that small mammals and ants can cache the entire crop of antelope bitterbrush seed.[100] This vulnerability ranking reflects how propagule dispersal for the antelope bitterbrush is almost completely dependent on a small number of species, who are also potentially vulnerable to the effects of climate change.
- **Sensitivity to Competition *somewhat increases vulnerability*.** Antelope bitterbrush competes with invasive grasses, specifically cheatgrass, for resources. Cheatgrass is expected to be more tolerant of future climatic conditions in the assessment area and this competitive advantage may decrease establishment of antelope bitterbrush seedlings within the assessment area.
- **Interspecific Interaction *somewhat increases vulnerability*.** Antelope bitterbrush has a mutualistic relationship with nitrogen-fixing bacteria from the genus *Frankia*.[101] This mutualism increases the vulnerability of the antelope bitterbrush, as there are no potential candidates for mutualism partners outside of *Frankia*. It is not known how *Frankia* may be affected by climate change.
- **Disturbance Regime *somewhat increases vulnerability*.** Antelope bitterbrush is very susceptible to wildfire. It is considered a weak sprouter and is often killed by fire. In some areas, antelope bitterbrush may sprout after low-severity fire.[102]

- **Physiological Thermal Niche has a *neutral effect on vulnerability*.** Antelope bitterbrush is not significantly affected by thermal characteristics of the environment in the assessment area.[103]
- **Physiological Hydrological Niche has a *neutral effect on vulnerability*.** Antelope bitterbrush is not dependent on a strongly seasonal hydrologic regime, specific wetland habitat, or localized moisture regime. Antelope bitterbrush survives on arid and rocky sites due to its long taproots.[104]

Big Sagebrush (*Artemisia tridentata*)

Figure 32: Big Sagebrush. Photo Credit: Andrey Zharkikh.

Existing Conditions & Observations by USRT Member Tribes[105]

Tribes have reported seeing large stands of dead and drying sagebrush, some of which is attributable to a large-scale moth infestation in 2006. In some areas, lower elevation sagebrush has been outcompeted by invasive cheatgrass and medusahead. These invasive species can sprout earlier and under snow before the sagebrush comes out of dormancy, are more tolerant of drought, and can grow back more quickly after wildfire. Sagebrush has critical recruitment timing in its relationship to snowpack. Seeds survive best when they fall before the first snow. The insulating snowpack then keeps them in contact with the soil and as seeds migrate into the soil, snowmelt then nurtures their development through the slow release of water over the spring season.

Big Sagebrush Vulnerability Rankings

Rankings above represent climate change vulnerability in the 2050s and 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled "More Warming" and the lower climate change scenario (RCP 4.5) is labeled "Less Warming". The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Dispersal/Movement** ***greatly increases vulnerability*****.** While big sagebrush is primarily wind dispersed, animal and water dispersal has also been documented. Around 90% of big sagebrush seeds are dispersed within 30 feet of the parent shrub. A few seeds can be carried more than 100 feet away from the parent plant.[106] This limited dispersal distance affects big sagebrush's ability to repopulate areas after a disturbance (e.g., wildfire) or to adjust its range in response to changing temperature and precipitation patterns.
- **Climate Change Mitigation** ***somewhat increases vulnerability*****.** Big Sagebrush grows in relatively flat and open sagebrush steppe habitat that could be suitable sites for installation of wind turbines and arrays of solar panels.
- **Disturbance Regime** ***somewhat increases vulnerability*****.** Wildfire kills big sagebrush when aboveground plant foliage is charred. Foliage exposed to temperatures exceeding 195°F for more than 30 seconds is also fatal for big sagebrush.[107,108,109] Seedlings can re-establish following a fire, but more frequent and intense fires are likely to reduce the overall success of re-establishment.

- **Sensitivity to Competition *somewhat increases vulnerability*.** Sagebrush habitat is susceptible to loss due to cheatgrass invasion.[110] Cheatgrass is expected to be more tolerant of future climate change conditions in the assessment area.
- **Physiological Thermal Niche has a *neutral effect on vulnerability*.** Big sagebrush distribution is not significantly affected by thermal characteristics of the environment.
- **Physiological Hydrological Niche has a *neutral effect on vulnerability*.** Big sagebrush is not dependent on a strongly seasonal hydrologic regime, specific wetland habitat, or localized moisture regime.

Black Cottonwood (*Populus balsamifera* subsp. *trichocarpa*)

Figure 33: Black Cottonwood Branch. Photo credit: Andrey Zharkikh.

Existing Conditions & Observations by USRT Member Tribes[111]

Tribes reported reduced cottonwood abundance and low age-class diversity on the reservations. They attributed this to the combined effects of man-made interventions controlling water flows and increasing grazing, agricultural use, and other development in riparian areas. Cottonwood depend on occasional flooding events to scour floodplains and facilitate seed dispersal and establishment of young trees. These natural flooding events have become rare, with man-made interventions in water use across the landscape. Flood control infrastructure, such as diking and rip-rap, covers habitat where cottonwoods would otherwise grow.

Black Cottonwood Vulnerability Rankings

2050s

2080s

Rankings above represent climate change vulnerability in the 2050s and the 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled "More Warming" and the lower climate change scenario (RCP 4.5) is labeled "Less Warming". The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Disturbance Regime *somewhat increases vulnerability*.** Water-based black cottonwood seed dispersal occurs after peak-flows in the spring. Therefore, abnormally high river flows may carry black cottonwood seeds for so long that they are no longer viable once they reach a site to establish.[112] Black cottonwood is tolerant of brief periods of flooding and some populations are more tolerant of recurrent and prolonged flooding.[113] The black cottonwood has a shallow root system, which makes the species susceptible to ice, snow, and wind damage.[114] Shifting precipitation patterns may affect the timing and strength of these disturbance events.
- **Physiological Hydrological Niche *somewhat increases vulnerability*.** In southern and eastern Idaho, black cottonwood will establish on recently formed gravel bars. However, without recurrent flooding and sediment deposition, the black cottonwood is likely to be outcompeted by other species.[115] Shifting precipitation patterns as a result of climate change may affect the timing and strength of these disturbance events.
- **Sensitivity to Pathogens or Natural Enemies *somewhat increases vulnerability*.** Young and fire-damaged black cottonwood stands are susceptible to *Cytospora* canker. Black cottonwood seedlings are also susceptible to wood-decaying fungi, which include *Polyporus delectans* and *Philota destruens.*[116] Climate change could potentially impact black cottonwood by amplifying the effects of these diseases and parasites. For example, hotter and drier conditions expected with climate change can stress tree species and increase susceptibility to infection.

- **Dispersal/Movement has a *neutral affect or may somewhat increase vulnerability*.**[v] Black cottonwood seeds are light and dispersed by both water and wind. Seeds typically disperse several hundred feet, but dispersal distances up to several miles have been documented.[117] These dispersal distances may help facilitate cottonwood migration as temperature and precipitation patterns change.
- **Physiological Thermal Niche has a *neutral effect on vulnerability*.** Black cottonwood grows in a wide variety of climates, including both coastal and arid areas.[118]

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[v] This factor is ranked as both *neutral* and *somewhat increases* as seeds can disperse several hundred feet (somewhat increase vulnerability) and, in some cases, travel farther than 0.6 miles (neutral affect).

Common Camas (*Camassia quamash*)

Existing Conditions & Observations by USRT Member Tribes[119]

Tribes report that diversion of water for agriculture and other development has reduced the extent of suitable habitat for camas. Common camas harvests have also reportedly shifted as much as two weeks earlier in the year.

Figure 34: Camas Root. Photo credit: Sarah Amoff.

Common Camas Vulnerability Rankings

Due to insufficient detailed information on the range of common camas within the project area, the species was assessed qualitatively and not given an overall vulnerability ranking in this project.

Factors Affecting Vulnerability

- **Dispersal/Movement *increases vulnerability*.** Common camas seeds form in dry capsules lacking an obvious mechanism for dispersal.[120] The seeds fall close to the parent plant. This dispersal method could limit the ability of common camas to migrate or repopulate areas as habitat conditions are altered with changing climate conditions.
- **Physiological Hydrological Niche *increases vulnerability*.** Common camas depends on seasonal moisture availability for growth. Common camas habitat is generally saturated in spring, drying out by summer.[121] Shifting precipitation patterns under climate change could alter this seasonal moisture availability.
- **Reproductive System *increases vulnerability*.** Common camas reproduces vegetatively by offset bulblets.[122] Genetic variation of plant species restricted to asexual reproduction (vegetative or apomictic) is assumed to be very low. Lack of genetic variation is expected to hinder species' ability to adapt to climate change.[123]
- **Disturbance Regime *somewhat increases vulnerability*.** Fire disturbance can top-kill common camas. It is expected that short-interval fires would reduce the extent of common camas populations as growth and flowering occur throughout spring and summer.[124]
- **Physiological Thermal Niche has a *neutral effect on vulnerability*.** Common camas distribution is not significantly affected by thermal characteristics of the environment in the assessment area.

Common Chokecherry (*Prunus virginiana*)

Figure 35: Common Chokecherries. Photo credit: John Rusk.

Existing Conditions & Observations by USRT Member Tribes[125]

Common chokecherries are an important traditional food of the USRT member tribes. Tribes report that common chokecherries have been blooming prematurely with recent changes in freeze/thaw cycles. This premature blooming has caused them to be exposed to additional freezing temperatures, which has reportedly impacted some of the berry crop.

Common Chokecherry Vulnerability Rankings

Rankings above represent climate change vulnerability in the 2050s and the 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled "More Warming" and the lower climate change scenario (RCP 4.5) is labeled "Less Warming". The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Physiological Hydrological Niche *somewhat increases vulnerability*.** Common chokecherries grow between low and mid-elevations in areas with above average soil moisture levels and adequate drainage.[126,127] Future precipitation patterns under climate change may fall outside common chokecherry's hydrological niche.
- **Sensitivity to Pathogens or Natural Enemies *somewhat increases vulnerability*.** Common chokecherry is susceptible to *Plowrightia stansburiana*, a fungus which causes cankers to develop on the plant stem. This fungus eventually kills infected stems.[128] It is currently unclear how this fungus will be affected by climate change. However, climate change can increase the common chokecherry's overall susceptibility to an infection by enhancing other environmental stressors.[129]
- **Dispersal/Movement has a *neutral effect on vulnerability*.** While most common chokecherry seeds are deposited in close vicinity to parent plants, fruit-eating birds and animals also disperse seeds longer distances. Bears, moose, coyotes, bighorn sheep, pronghorn, elk, deer, and many bird species consume the fleshy fruit, and subsequently disperse common chokecherry seeds.[130] This wide range of seed dispersal mechanisms and distances could help facilitate migration and repopulation of habitats under the shifting climate conditions.
- **Physiological Thermal Niche has a *neutral effect on vulnerability*.** Common chokecherry distribution is not significantly affected by thermal characteristics in the assessment area.
- **Disturbance Regime has a *neutral effect on vulnerability*.** Common chokecherry is well adapted to wildfire disturbance. While common chokecherry is susceptible to top-kill by fire, the species sprouts from remaining root crowns and rhizomes beneath the soil surface. Studies

have shown that common chokecherry sprouting success increases with heat, suggesting that fire's ability to break down the seed coat is an important adaptation.[131]

- **Dependence on Other Species to Generate Habitat has a *neutral effect on vulnerability*.** Common chokecherries do not require any uncommon/restricted habitats that are generated or maintained by other species. Common chokecherry frequently inhabits mixed-stands with tall shrubs. In southern and central Idaho, common chokecherry grows in several Rocky Mountain Douglas-fir habitat types, along with Pacific ponderosa pine, Rocky Mountain maple, quaking aspen, and other habitat types.[132] Common chokecherry's success as a habitat generalist may be helpful under shifting environmental conditions due to climate change.

Geyer’s Willow (*Salix geyeriana)*

Existing Conditions & Observations by USRT Member Tribes[133]

Figure 36: Geyer’s Willow Branches. Photo credit: Andrey Zharkikh.

Tribes have reported seeing willow die-offs on the reservations, likely tied to recent land use practices in riparian areas such as agriculture, grazing, and development. These die-offs may also be influenced by changes in temperature and cyanobacteria blooms. Willows are known to lower nearby water temperature and some of the tribes are actively restoring willows on their reservations. Geyer’s willow generally uses rhizomatous dispersal with some additional dispersal by wind and branch cuttings from beavers. Geyer’s willow is typically an upper elevation species.

Geyer’s Willow Vulnerability Rankings

Rankings above represent climate change vulnerability in the 2050s and the 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled “More Warming” and the lower climate change scenario (RCP 4.5) is labeled “Less Warming”. The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Physiological Hydrological Niche *somewhat increases vulnerability*.** Geyer's willow is found in wet meadows and marshes, adjacent to seeps and springs, and alongside the borders of slow moving streams and beaver ponds. It can also be found in wide, low-gradient valley bottoms.[134] Shifting precipitation patterns under climate change may alter water velocity and availability in these aquatic habitats.
- **Dependence on Other Species to Generate Habitat *has a neutral effect or somewhat increases vulnerability.*[vi]** Geyer’s willow habitat is often associated with abandoned and sediment-filled beaver ponds.[135] Species that are dependent on a few other species for habitat generation are more likely to be vulnerable to climate change.
- **Dispersal/Movement has a *neutral effect on vulnerability*.** Geyer’s willow is wind- and water-dispersed,[136] increasing its ability to migrate as climate change alters habitat conditions.
- **Physiological Thermal Niche has a *neutral effect on vulnerability*.** Geyer’s willow distribution is not significantly affected by thermal characteristics of the environment in the assessment area.

[vi] This factor is ranked as both *neutral* and *somewhat increase* because the Geyer’s willow is occasionally associated with beaver ponds (somewhat increase vulnerability) but also resides in other meadow and marsh habitats which are not generated by a specific species (neutral affect).

- **Disturbance Regime has a *neutral effect on vulnerability***. Geyer's willow sprout following a top-kill by wildfire. While fast, hot fires typically result in numerous sprouts per plant, longer, slower burning fires reduce the species ability to sprout, as these fires often burn down below the soil surface into the roots.[137]

Meadow Hay

Existing Conditions & Observations by USRT Member Tribes[138]

Meadow hay is one of the most important feed stocks grown by tribal members for cattle. Hay producers have recently witnessed an extended growing season, which requires an extended watering season. However, they have also had to face drought conditions. Disagreement between hay producers and water managers has emerged during these difficult environmental conditions.

Figure 37: Meadow Hay. Photo credit: Lanjew Farms.

Meadow Hay Vulnerability Rankings

Meadow hay did not receive an overall vulnerability ranking in this project as the CCVI tool is not designed for managed species. Its climate change vulnerability was therefore investigated qualitatively.

Factors Affecting Vulnerability

- Decreasing water supply reliability for irrigation
- Increasing pests and pathogens affecting crop timing, location, and productivity

Warmer temperatures due to climate change are already directly affecting agricultural production[139] and changing precipitation patterns could further exacerbate these issues. Indirect impacts, such as increases in pests and pathogens due to warmer temperatures, are also of concern, because they affect crop timing, location, and productivity.[140] These have troubling implications for the nutrition of agricultural feed. As the EPA states:

> *Increases in atmospheric CO_2 can increase the productivity of plants on which livestock feed. However, studies indicate that the quality of some of the forage found in pasturelands decreases with higher CO_2. As a result, cattle would need to eat more to get the same nutritional benefits.*[141]

In addition, with projected increases in summer temperature and precipitation declines, there may be fewer grasses on which to graze,[142] thereby increasing the need to grow meadow hay to support cattle ranching. Climate change models seem to suggest that dryland agriculture in hay fields without irrigation could decline,[143] while irrigated hay fields could benefit from warmer temperatures, especially after mid-century.[144] This assumes that there will be enough water available to continue irrigation.

Extreme events may pose the largest unknown risk to future crop productivity. The impact of extreme precipitation events, such as wildfires, and the associated post-event impacts of weed proliferation, insects, and diseases, could significantly increase losses in agricultural productivity.[145]

Noxious Weed: Medusahead (*Taeniatherum caput-medusae*)

Existing Conditions & Observations by USRT Member Tribes[146]

Tribes report that noxious weeds, such as medusahead, are continuing to spread across the landscape at the expense of native plants. Compared to native plants, these weeds can establish themselves more quickly after fires, during periods of drought, and following other extreme events. Medusahead is also capable of being transported by grazing cattle. In some lower elevation areas, sagebrush has been outcompeted by invasive cheatgrass and medusahead, as these species can sprout earlier and under snow before the sagebrush comes out of dormancy. Tribes currently use weed control techniques such as controlled chemical spraying and rangeland management (e.g., allowing cattle on the range to eat noxious weeds) to help limit the spread of these species.

Figure 38: Medusahead. Photo credit: Jason Hollinger.

Medusahead Vulnerability Rankings

Due to insufficient detailed information on the range of medusahead within the project area, the species was assessed qualitatively and not given an overall vulnerability ranking in this project.

Factors Affecting Vulnerability

- **Sensitivity to Competition *somewhat increases vulnerability*.** Medusahead and cheatgrass compete for habitat.[147] Medusahead may suffer, as cheatgrass is likely to respond more favorably to climate change.
- **Dispersal/Movement has a *neutral effect on vulnerability*.** Medusahead seed is wind-, water-, and animal-dispersed.[148] These various dispersal mechanisms increase the likelihood that the species will hold some adaptive capacity to shifting climate conditions.
- **Physiological Thermal Niche has a *neutral effect on vulnerability*.** Medusahead distribution is not significantly affected by thermal characteristics of the environment in the assessment area.[149]
- **Physiological Hydrological Niche has a *neutral effect on vulnerability*.** Medusahead has little dependence on a seasonal hydrologic regime or localized moisture regime that will be affected by climate change.[150]
- **Disturbance Regime has a *neutral effect on vulnerability*.** Medusahead inhabits disturbed sites with high soil-moisture levels.[151] Following a fire, medusahead often outcompetes native vegetation and establishes on the disturbed site.[152] Medusahead completes its lifecycle before the start of the normal wildfire season. Fires that burn quickly may not be hot enough to kill seeds buried beneath the soil surface.[153]
- **Pollinator Versatility has a *neutral effect on vulnerability*.** Medusahead is mainly self-fertile, with intermittent occurrences of wind cross-pollination.[154] Therefore, the species is not dependent on a small number of species for pollination.

- **Sensitivity to Pathogens or Natural Enemies has a *neutral effect on vulnerability***. In the foreseeable future, there is no indication that medusahead will be significantly affected by a pathogen or natural enemy that would benefit from the effects of climate change.
- **Phenological Response has a *neutral effect on vulnerability.*** Temperature is an important factor in controlling medusahead's leafing, flowering, and maturation period (i.e., phenology).[155] As temperatures increase, it is expected that medusahead phenology will shift productively with the longer growing season.

Noxious Weed: Whitetop *(Cardaria draba)*

Existing Conditions & Observations by USRT Member Tribes[156]

Tribes report noxious weeds, such as whitetop, continuing to spread across the landscape at the expense of native plants. Compared to native plants, these weeds can establish themselves more quickly after fires, during periods of drought, and following other extreme events. Whitetop is also capable of being transported by grazing cattle. Tribes use weed control techniques such as controlled chemical spraying and rangeland management (e.g., allowing cattle on the range to eat noxious weeds) to help limit the spread of these species.

Figure 39: Whitetop. Photo credit: Thayne Tuason.

Whitetop Vulnerability Rankings

Due to insufficient detailed information on the range of whitetop within the project area, the species was assessed qualitatively and not given an overall vulnerability ranking in this project.

Factors Affecting Vulnerability

- **Reproductive System *somewhat increases vulnerability*.** Vegetative reproduction is more important than sexual reproduction in the local spread of whitetop.[157] In plants, the genetic variation of species reliant on asexual forms of reproduction (vegetative or apomictic) is assumed to be very low. Lack of genetic variation is expected to hinder species' ability to adapt to rapid climate change.[123]
- **Dispersal/Movement has a *neutral effect on vulnerability*.** Seeds are distributed via wind, water, and attachment to vehicles and equipment.[158] This range of dispersal mechanisms increase the likelihood that the species will have some adaptive capacity to shifting climate conditions.
- **Physiological Thermal Niche has a *neutral effect on vulnerability*.** Whitetop distribution is not significantly affected by thermal characteristics of the environment in the project area. Whitetop is found in western North America rangelands and can exist in regions with heavy frosts and snowfall.[159]
- **Physiological Hydrological Niche has a *neutral effect on vulnerability*.** Whitetop has little dependence on a seasonal hydrologic regime, or localized moisture regime, that would be affected by climate change. Whitetop is well adapted to moist habitats and is not abundant in semiarid environments.[160]
- **Disturbance Regime has a *neutral effect on vulnerability***. Whitetop is an early successional species, inhabiting disturbed, open sites. Whitetop's extensive root system enables the species to sprout following severe fires, depending on site conditions. Whitetop may also establish by seed after a fire.
- **Sensitivity to Pathogens or Natural Enemies has a *neutral effect on vulnerability*.** In the foreseeable future, there is no indication that the species will be significantly affected by a pathogen or natural enemy that will benefit from the effects of climate change.

Quaking Aspen (*Populus tremuloides*)

Existing Conditions & Observations by USRT Member Tribes[161]

Quaking aspen thrive in specific post-glacial habitats, an ecological niche that is no longer emerging on reservations or across the Upper Snake River Watershed. Quaking aspen can respond successfully to wildfire.

Figure 40: Quaking Aspen. Photo credit: Famartin.

Quaking Aspen Vulnerability Rankings

2050s	MORE WARMING	MEDIUM VULNERABILITY
	LESS WARMING	LOW VULNERABILITY
2080s	MORE WARMING	MEDIUM VULNERABILITY
	LESS WARMING	MEDIUM VULNERABILITY

Rankings above represent climate change vulnerability in the 2050s and 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled "More Warming" and the lower climate change scenario (RCP 4.5) is labeled "Less Warming". The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Dispersal/Movement *somewhat increases vulnerability*.** The feathery seeds of quaking aspen are generally dispersed by wind and travel less than 3,000 feet, though in heavy winds they can travel several miles. Quaking aspen seeds also are water dispersed and can germinate while floating or submerged in water.[162] Climate change conditions may challenge the success of these dispersal mechanisms.
- **Physiological Thermal Niche *somewhat increases vulnerability*.** Quaking aspen are found in high elevation areas and northern latitudes that often include low seasonal temperatures and short growing seasons.[163] Projected increases in temperature and growing season length could negatively affect quaking aspen.
- **Sensitivity to Pathogens or Natural Enemies *somewhat increases vulnerability*.** Droughts may increase the susceptibility of quaking aspen to canker infections. Drier, warmer, climate conditions may favor invasion of gypsy moths –a known pest of quaking aspen – in the western United States.[164]
- **Physiological Hydrological Niche has a *neutral effect on vulnerability*.** Suitable climate conditions for quaking aspen vary widely across its range. However, quaking aspen is generally found in regions where annual precipitation is greater than evapotranspiration.[165] Because quaking aspen is not dependent on a narrowly defined hydrological regime that is vulnerable to loss or reduction with climate change, its physiological hydrological niche has a neutral effect on its vulnerability.

- **Disturbance Regime has a *neutral effect on vulnerability*.** Quaking aspen colonizes sites after fires and other disturbances. While moderate-severity fires do not damage quaking aspen roots, severe fires may damage or kill roots growing near the soil surface, preventing post-fire sprouting.[166]

Redosier Dogwood (*Cornus sericea*)

Existing Conditions & Observations by USRT Member Tribes[167]

Figure 41: Redosier Dogwood. Photo credit: Matt Lavin.

Redosier dogwood is an important cultural resource, utilized for cradle boards and baskets. Tribal members sometimes refer to Redosier dogwood as "red willow" and have reported seeing die-offs on the reservations that are likely tied to recent land-use practices in riparian areas (e.g., agriculture, grazing, and development). Redosier dogwood may also be affected by changes in temperature and cyanobacteria blooms. When growing near streams they are known to lower nearby water temperatures and some of the tribes are actively restoring plants in riparian corridors. Tribal members have reported noticing more brown dots on plants, which diminishes their suitability for baskets. Therefore, tribal members have had to travel farther to harvest suitable plants. Redosier dogwood generally uses rhizomous dispersal but is sometimes dispersed via branch cuttings from beavers and birds.

Redosier Dogwood Vulnerability Rankings

2050s

2080s

Rankings above represent climate change vulnerability in the 2050s and 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled "More Warming" and the lower climate change scenario (RCP 4.5) is labeled "Less Warming". The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Physiological Hydrological Niche *somewhat increases vulnerability*.** Redosier dogwood establishes in areas adjacent to lakes, ponds, streams, and wetlands. Redosier dogwood thrives along edges of nitrogen-rich wetlands, which are inundated during spring and dry out in summer. The redosier dogwood is unable to tolerate root saturation for extended periods of time, but can inhabit areas with fluctuating water tables.[168] Shifting precipitation patterns driven by climate change may disturb these hydrological conditions, somewhat increasing redosier dogwood's vulnerability to climate change.
- **Dispersal/Movement has a *neutral effect on vulnerability*.** Seeds are dispersed by several bird species from autumn through winter, including crows, vireos, redheaded woodpeckers and bluebirds.[169] These birds can transport the seeds over distances of 1 km (0.6 miles). These longer distance dispersal events increase the likelihood that the red willow has the capacity to adapt to shifting climatic conditions.
- **Physiological Thermal Niche has a *neutral effect on vulnerability*.** Redosier dogwood distribution is not significantly affected by thermal environmental characteristics in the assessment area.[170]

- **Disturbance Regime has a *neutral effect on vulnerability*.** Redosier dogwood is tolerant of flooding and scouring events[171], and is also relatively fire tolerant. Fires generally top-kill redosier dogwood shrubs, but mortality only occurs with severe fires where the upper soil layers are heated for extended periods of time.[172]

F. Climate Change Vulnerability of Animals

This section provides further detail on some of the most important species-specific factors affecting the climate change vulnerability for animal species selected as Shared Concerns for this project. Species are listed alphabetically, and vulnerabilities are described quantitatively and qualitatively, as appropriate.

American Beaver (*Castor Canadensis*)

Existing Conditions & Observations by USRT Member Tribes[173]

Tribes report beaver populations increasing across reservations, noting they were "trapped out" of many basins within their historic range. Beaver dam habitats depend on the presence of willows, aspen, and cottonwood. Beaver dams improve water quality and water storage on the landscape, creating new pools and wet-meadow habitats, which, in turn, protect streams from flash-flooding. However, these upstream effects can also increase drying of downstream wetland and wet-meadow habitats.

Figure 42: Beaver. Photo credit: Minette Layne.

American Beaver Vulnerability Rankings

2050s	MORE WARMING	LOW VULNERABILITY	Medium Vulnerability	High Vulnerability	Extreme Vulnerability
	LESS WARMING	LOW VULNERABILITY	Medium Vulnerability	High Vulnerability	Extreme Vulnerability
2080s	MORE WARMING	LOW VULNERABILITY	Medium Vulnerability	High Vulnerability	Extreme Vulnerability
	LESS WARMING	LOW VULNERABILITY	Medium Vulnerability	High Vulnerability	Extreme Vulnerability

Rankings above represent climate change vulnerability in the 2050s and 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled "More Warming" and the lower climate change scenario (RCP 4.5) is labeled "Less Warming". The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Anthropogenic Barriers *somewhat increases vulnerability*.** Roads can act as barriers to American beaver dispersal.[174] Railways, roads, and land clearing next to bodies of water may reduce habitat suitability for the American beaver.[175] These barriers may decrease the ability of the American beaver to migrate in response to changing climate conditions.
- **Physiological Hydrological Niche *somewhat increases vulnerability*.** American beavers avoid fast-flowing streams, lakes with strong waves,[176] and steams with significant stream-flow fluctuations.[177] Shifting precipitation regimes under climate change may alter hydrologic conditions in ways that negatively affect beaver habitat suitability.
- **Natural Barriers has a *neutral effect on vulnerability*.** American beavers are good dispersers[178] with a maximum annual dispersal distance between 15 and 30 miles.[179] It is unlikely that natural barriers will decrease the ability of the American beaver to migrate in response to changing climate conditions.

- **Dispersal/Movement has a *neutral effect on vulnerability*.** The species has a maximum annual dispersal distance of 15-30 miles.[180] Sub-adult American beavers (typically 2-3 years old) migrate an average of 5 to 10 miles from the family.[181,182] The beaver's excellent dispersal ability increases the likelihood that the species has the capacity to adapt to shifting climatic conditions.
- **Physiological Thermal Niche has a *neutral effect on vulnerability*.** American beaver distribution is not significantly affected by thermal characteristics of the environment in the project area. Beaver habitat is found in both warm, low-lying areas and cooler, high elevation areas.[183]
- **Disturbance Regime has a *neutral effect on vulnerability*.** Wildfire within riparian areas benefits American beaver populations as the species is adapted to the early stages of forest succession.[184]
- **Dependence on Other Species to Generate Habitat has a *neutral effect on vulnerability*.** The American beaver does not require any uncommon habitats that are generated or maintained by another species.[185]
- **Diet has a *neutral effect on vulnerability*.** American beavers consume a wide variety of woody vegetation, including aspen, willow, cottonwood, and birch. During summer months, the American beaver consumes aquatic plants, including pond lilies, duckweed, pondweed, and algae.[186] Species that can readily switch among different food types are less likely to be negatively affected by climate change.
- **Sensitivity to Pathogens or Natural Enemies has a *neutral effect on vulnerability*.** There is no indication that the American beaver will be significantly affected by a pathogen or natural enemy likely to benefit from the effects of climate change.
- **Sensitivity to Competition has a *neutral effect on vulnerability*.** The American beaver is not currently sensitive to competition from native or non-native species, and there is no indication that climate change will cause a species to become a competitor in the future.

Black-tailed Jackrabbit (*Lepus californicus)*

Existing Conditions & Observations by USRT Member Tribes[187]

The black-tailed jackrabbit is the rabbit species most utilized by USRT member tribes. Black-tailed jackrabbit can live in marshes or sagebrush steppe habitats and depend on sagebrush and greasewood plants. Tribes reported a decline in black-tailed rabbit species across the reservations, beyond the species' cyclical population trends. Black-tailed jackrabbit habitat has decreased due to energy and agricultural development and wildfire. Though isolated colonies remain within natural habitat, many populations have adapted to habitat loss by living in alfalfa fields.

Figure 43: Black-tailed Jackrabbit. Photo credit: Larry Smith.

Black-tailed Jackrabbit Vulnerability Rankings

2050s

2080s

Rankings above represent climate change vulnerability in the 2050s and the 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled "More Warming" and the lower climate change scenario (RCP 4.5) is labeled "Less Warming". The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Disturbance Regime *increases vulnerability*.** Smaller, intermittent wildfire in big sagebrush habitat can benefit black-tailed jackrabbit by increasing the prevalence of grasses and flowering plants, alongside shrub cover. However, recent large-scale fires have caused a decline in big sagebrush and an increase in cheatgrass encroachment,[188] negatively affecting black-tailed jackrabbit habitat.
- **Anthropogenic Barriers *somewhat increases vulnerability*.** Roads can act as barriers to dispersal and can be a source of mortality for the black-tailed jackrabbit.[189] This may limit the ability of black-tailed jackrabbit to migrate in response to changing climate conditions.
- **Climate Change Mitigation *somewhat increases vulnerability*.** Black-tailed jackrabbit habitat could be potential sites for solar array or wind farm development due to the open characteristics of the landscape. If those developments were to occur it, they would decrease habitat available for black-tailed jackrabbit.
- **Sensitivity to Pathogens or Natural Enemies *somewhat increases vulnerability*.** Climate change may potentially impact black-tailed jackrabbits by amplifying effects of parasites and disease (e.g., tularemia, bubonic plague, and Lyme disease).[190] Warming temperatures and subsequent shifts in seasonal patterns are expected to lead to earlier tick activity and

an expansion of suitable tick habitat, increasing the risk of black-tailed jackrabbit exposure to ticks.[191]

- **Dispersal/Movement has a *neutral effect on vulnerability*.** The black-tailed jackrabbit is an excellent disperser, and dispersal commonly extends several miles. In Idaho, the species was observed moving up to 28 miles over a 17-week period.[192] The black-tailed jackrabbit's excellent dispersal ability increases the likelihood that it will be able to move in response to shifting climatic conditions.
- **Physiological Thermal Niche has a *neutral effect on vulnerability*.** Black-tailed jackrabbit distribution is not significantly affected by thermal characteristics of the environment. Black-tailed jackrabbits are known to inhabit multiple habitat types with varying temperature regimes.[193]
- **Physiological Hydrological Niche has a *neutral effect on vulnerability*.** The black-tailed jackrabbit has little dependence on a strongly seasonal hydrologic regime or a specific wetland habitat that would be affected by climate change.
- **Diet has a *neutral effect on vulnerability*.** During summer, the black-tailed jackrabbit diet consists primarily of grasses, flowering plants, crops, and hay. During the winter, its diet consists primarily of buds, bark, and leaves of woody plants.[194] Species that can readily switch among different food types are less likely to be negatively affected by climate change than dietary specialists.
- **Sensitivity to Competition has a *neutral effect on vulnerability.*** The black-tailed jackrabbit is not currently sensitive to competition from native or non-native species, and there is no indication that climate change will cause a species to become a competitor in the future.

Bull Trout *(Salvelinus confluentus)*

Existing Conditions & Observations by USRT Member Tribes[195]

Portions of the Malheur River and other streams throughout the project area have already been observed to exceed suitable temperature limits for bull trout. Springs and groundwater inputs to streams are known to help moderate rising temperatures, but it is not known to what point they can offer protection from high temperatures. Man-made stream barriers have decreased interactions between bull trout populations, potentially isolating them genetically. Increasing sediment inputs (from erosion or wildfire) and nutrient run-off from agriculture have been observed in bull trout streams. Wildfires have been observed destroying riparian vegetation, which decreases river shading, and thereby increases river temperatures.

Figure 44: Bull Trout. Photo credit: USFWS Mountain-Prairie.

Bull Trout Vulnerability Rankings

Rankings above represent climate change vulnerability in the 2050s and 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled "More Warming" and the lower climate change scenario (RCP 4.5) is labeled "Less Warming". The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Physiological Thermal Niche** ***greatly increases vulnerability*****.** Bull trout require extremely cold water temperatures (45-50°F), with optimum temperatures for egg incubation ranging between 36°F and 39°F.[196] As stream temperatures continue to rise, the frequency with which these thresholds are exceeded, and the stream range over which they are exceeded, may increase.
- **Physiological Hydrological Niche** ***greatly increases vulnerability*****.** Bull trout spawning habitat consists of gravel riffles in small tributary streams and lake inlet streams, which are often in close proximity to springs. Bull trout inhabit deep, cold pools; fast-flowing streams; and large, cold lakes.[197] Shifting precipitation patterns under climate change could threaten the availability of these narrow hydrological conditions.
- **Anthropogenic Barriers** ***increases vulnerability*****.** Many streams and rivers within the project area have dams that prevent bull trout access to cooler habitat if their current habitat becomes too warm under climate change. There are eight dams on the mainstem of the Snake River, from below Shoshone Falls to Hells Canyon. These dams include Upper Salmon Falls Dam,

Lower Salmon Falls Dam, Bliss Dam, C.J. Strike Dam, Swan Falls Dam, Brownlee Dam, Oxbow Dam, and Hells Canyon Dam.[198]

- **Disturbance Regime *increases vulnerability*.** The survival of salmonid (i.e., salmon, trout, and char) eggs and embryos is strongly influenced by sediment deposition, water quality, and streambed scour and fill.[199] As air temperatures rise, watersheds are projected to become increasingly rain-dominant. This shift will increase the risk of winter flooding and increase sediment transport, which can negatively affect the survival of salmonid eggs.
- **Sensitivity to Pathogens or Natural Enemies *increases vulnerability*.** Warming stream temperatures may increase mortality caused by fish pathogens and diseases. *Vibrio* and *Ceratomyxa shasta* are two infections known to negatively affect salmonids and their effects could be exacerbated with warming stream temperatures.[200] Increasing water temperatures can stress salmonids, reducing their ability to mount an effective immune response to disease. Many important salmonid diseases become virulent when water temperatures reach or exceed 60-61°F.[201]
- **Sensitivity to Competition from Native or Non-Native Species *increases vulnerability*.** Warming stream temperatures will enable other trout species to inhabit rivers and stream reaches that were historically too cold for them. The bull trout’s competitive advantage as a cold-water specialist could thus decline, as warming temperatures allow competing species to disperse into its current range.[202]
- **Measured Genetic Variation *increases vulnerability*.** There is relatively little genetic variation within bull trout populations in the northwestern United States.[203] Species with low levels of genetic variation are expected to have difficulty adapting to climate change because the occurrence of new, beneficial mutations is not expected to keep up with the rate of climate change.[204]
- **Climate Change Mitigation *somewhat increases vulnerability*.** Future dam building is possible in the region. Dams act as barriers to bull trout movement into some portions of the Upper Snake River watershed.[205] Additional dam building could hinder bull trout’s ability to move into cooler streams as temperatures rise.
- **Dispersal/Movement has a *neutral effect on vulnerability*.** Migratory forms of bull trout hatch and develop in streams with fast currents before migrating downstream into slower, more productive rivers or lakes, which they inhabit before returning upstream to spawn.[206] One study of bull trout migrations in the mid-Columbia and Snake River Basin found that bull trout are excellent dispersers and can migrate 8-89 km (5-55 miles).[207] The bull trout’s excellent dispersal ability increases the likelihood that the species has the ability to adapt to shifting climate conditions.

Cattle

Existing Conditions & Observations by USRT Member Tribes[208]

Figure 45: Cattle. Photo credit: Pamela @Pamzpix

Tribes report that cattle are not gaining weight on rangeland like they have in the past. Cattle lose weight during drought events and are having difficulty finding nutritious foods on rangeland as native plant abundance decreases, while noxious weeds become more prevalent. Wildfires also diminish the availability of nutritious feed on the landscape. Drought conditions and the disappearance, or reduction, of water flows from some springs have forced cattle owners to use domestic water supplies for their cattle. Shifts in the timing of grass growth has also decreased the effectiveness of rangeland management, as the traditional synchronization of grass yield and cattle access is becoming less reliable. Cattle prefer wet-meadow areas of the landscape, but their presence there, without appropriate protections to sensitive habitats, can have negative repercussions on water quality and water availability that ultimately impact the cattle themselves. In many instances, ranchers are just barely turning a profit, making them highly sensitive to changes in their herd's health and weight.

Cattle Vulnerability Rankings

Cattle did not receive an overall vulnerability ranking in this project, as the CCVI tool is not designed for domesticated species. The climate change vulnerability of cattle was therefore investigated qualitatively.

Factors Affecting Vulnerability

Climate change effects on cattle and ranching include the decreasing reliability of water supplies, increasing risk of wildfire in rangelands, increasing heat stress on cattle, potential increases in disease and pathogens, and reduced quality of feed. Collectively, these impacts can have economic implications for USRT tribal members by increasing the time and resources required to access quality rangelands and reach finish weights. These changes could also decrease leasing revenue.

Impacts on Animal Physiology

Increasing summer temperatures, more extreme heat events, and the potential for increases in pathogens and parasites are climate change-related factors that directly influence cattle's physiological health. High temperatures (particularly heat events that occur in spring and early summer when cattle are less acclimated to heat)[209] can increase the risk of heat stress. Heat stress results in higher respiration rates, increasing body temperature, reduced food intake, and reduced performance.[210] Mortality can occur with more severe heat events, such as those that last three or more days.[211] Cattle at higher risk of heat stress include: newly arrived cattle that may have already been stressed by weaning, processing, or transportation; finished or nearly finished cattle, especially heifers; cattle that have been sick in the past and may have some preexisting lung damage; black or very dark-hided cattle; heavy bred cows that will calve sometime during the summer; older cows; and cattle which may be thin due to inadequate nutrition.[212]

Night-time cooling and access to shade, water, and active cooling (e.g., spray cooling) are important tools for limiting the effects of heat events on cattle. Warmer seasonal temperatures may also increase the survivability of pathogens and parasites by creating conditions more favorable to their reproduction, survival, and transmission. This includes diseases transmitted between livestock, as well as transmission of diseases between wild species and livestock. Climate change may facilitate these transmissions by altering wild animal distribution, movement, and feeding patterns.[213]

Impacts on Rangelands

In addition to direct impacts on cattle physiology, climate change will affect cattle and ranching practices through impacts on rangelands. These impacts include decreases in sagebrush steppe habitat utilized as rangeland across the Upper Snake River Watershed. Climate changes that directly affect rangeland include: a lengthening of the growing season, changes in plant productivity, shifts in rangeland species, reduced nutritional value of rangelands, the potential spread of invasive species, and increases in wildfire risk.

Projected changes in plant productivity and distribution vary with temperature, elevation, and carbon dioxide levels. Increasing temperatures, declining snowpack, and earlier snowmelt are expected to lead to earlier spring greening and lengthening of the growing season, particularly in cooler, higher elevation rangelands.[214] These changes may also allow for migration of rangeland plant communities to higher elevations.[215]

In contrast to cooler locations, productivity in warmer, lower elevation rangelands may decline. A key issue in these lower elevation rangelands is increasing summer drought stress, which is expected to reduce the reproductive viability of native perennials.[216] Over-grazing and increased fire frequency (whether due to climate change or fire management practices) can also affect productivity and lead to shifts in rangeland species.[217]

Some plant species (including some species of weeds) may benefit from higher levels of carbon dioxide in the atmosphere, which can stimulate plant productivity through increased efficiencies in photosynthesis and water use.[218] Plants that employ the C_3 photosynthetic pathway, including cheatgrass, are most likely to benefit from the higher atmospheric carbon dioxide concentrations. However, this benefit may be offset by rising temperatures and changes in precipitation patterns.[219] In more water-limited systems, warmer temperatures and drier conditions tend to favor C_4 species over C_3 species.[220]

Increasing atmospheric carbon dioxide and temperature have also been found to affect the nutritional quality of rangelands. Studies on shortgrass steppe species, and short- and tallgrass species in the Great Plains, found reduced forage quality (e.g., less protein and nitrogen) and decreased digestibility with higher temperature and higher atmospheric carbon dioxide concentrations.[221] Similar findings were reported for perennial forage grasses in the Northwest.[222]

Chinook Salmon (*Oncorhynchus tshawytscha*)

Existing Conditions & Observations by USRT Member Tribes[223]

Figure 46: Chinook Salmon. Photo credit: Andy Kohler.

Chinook salmon have been central to the culture and diet of the four USRT member tribes for thousands of years. They played an especially important part in the tribes' seasonal migration and subsistence diet. Unfortunately, these connections have been greatly diminished over the last century as eight dams on the Upper Snake River have prohibited Chinook salmon from reaching the USRT member tribes' traditional harvest areas. The Burns Paiute Tribe and Shoshone-Paiute Tribes have recently reinitiated ceremonial Chinook salmon fisheries on the upper Malheur River and East Fork Owyhee River by live-transporting Chinook salmon around the dams. Currently, the Fort McDermitt Paiute-Shoshone do not have access to Chinook salmon, while the Shoshone-Bannock Tribes can exercise their treaty right to harvest Chinook salmon. Climate change poses additional complex stressors to this already significantly impacted fishery.

Chinook Salmon Vulnerability Rankings

2050s

2080s

Rankings above represent climate change vulnerability in the 2050s and 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled "More Warming" and the lower climate change scenario (RCP 4.5) is labeled "Less Warming". The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Physiological Thermal Niche** ***greatly increases vulnerability.*** Chinook salmon inhabit deep, cold pools prior to spawning.[224] Water temperatures exceeding 48-50°F may reduce survival of Chinook salmon embryos and alevins.[225] Additionally, migration delays and blockages can form when stream temperatures exceed 69.8°F and can contribute to reproductive failure.[226] As stream temperatures continue to rise, the frequency with which these thresholds are exceeded and total river miles affected may increase.
- **Physiological Hydrological Niche** ***greatly increases vulnerability.*** Large, deep, pools offer important holding habitat for Chinook salmon prior to spawning. While sufficient flows are required to ensure incubating embryos receive sufficient oxygenation, extreme low or high flows can destroy embryos and fry residing within the streambed.[227,228] Shifting precipitation patterns under climate change could threaten these sensitive hydrological conditions.

- **Anthropogenic Barriers *increases vulnerability*.** Many streams and rivers within the assessment area have dams that would prevent Chinook salmon access to more suitable, cooler habitat if the present habitat becomes too warm. There are eight dams on the mainstem Snake River from below Shoshone Falls to Hells Canyon include the Upper Salmon Falls Dam, Lower Salmon Falls Dam, Bliss Dam, C.J. Strike Dam, Swan Falls Dam, Brownlee Dam, Oxbow Dam, and Hells Canyon Dam.[229]
- **Sensitivity to Pathogens or Natural Enemies *increases vulnerability*.** Warming stream temperatures may increase mortality caused by fish pathogens and diseases. *Vibrio* and *Ceratomyxa shasta* are two infections known to negatively affect salmonids, and their effects could be exacerbated with warming stream temperatures.[230] Increasing water temperatures can stress salmonids, reducing their ability to mount an effective immune response to disease. Many important salmonid diseases become virulent when water temperatures reach or exceed 60-61°F.[231]
- **Climate Change Mitigation *somewhat increases vulnerability*.** Future dam building is possible in the region. Dams act as barriers to movement for Chinook salmon accessing stream reaches in the Upper Snake River and more dams could further limit their ability to move as habitat conditions change.[232]
- **Disturbance Regime *somewhat increases vulnerability*.** The survival of salmonid (i.e., salmon, trout, and char) eggs and embryos is strongly influenced by sediment deposition, shifts in water quality, and streambed scour and fill.[233] As air temperatures rise, watersheds are projected to become increasingly rain-dominant. This shift will increase the risk of winter flooding and sediment transport, which can negatively affect the survival of salmonid eggs.
- **Sensitivity to Competition from Native or Non-Native Species *somewhat increases vulnerability*.** Chinook salmon compete with resident brook trout, which feed on other fish species and are known to prey on young salmonids.[234] Climate change may alter this competitive interaction.
- **Measured Genetic Variation *somewhat increases vulnerability*.** Populations of Chinook salmon in the Snake River have low genetic variability compared to Chinook salmon populations in the Columbia River Basin.[235] Less genetic variability may somewhat restrict the ability of Chinook salmon to adapt to changing climate conditions.
- **Diet has a *neutral effect on vulnerability*.** In freshwater, juvenile Chinook salmon feed on terrestrial and aquatic insects. In salt water, Chinook salmon eat crustaceans and other bottom invertebrates. Adult Chinook salmon mostly prey on fish.[236] Species that can readily switch among different food types are less likely to be negatively affected by climate change than dietary specialists.
- **Dispersal/Movement has a *neutral effect on vulnerability*.** Chinook salmon are excellent dispersers, as they are anadromous and migrate several hundred miles to the stream in which they were spawned.[237] This dispersal ability may help facilitate successful response to changing climate conditions.
- **Phenological Response has a *neutral effect on vulnerability*.** No observed shift in Chinook salmon run timing has been recorded in the Snake River.[238]

Columbia Spotted Frog (*Rana luteiventris*)

Figure 47: Columbia Spotted Frog. Photo credit: USFS.

Existing Conditions & Observations by USRT Member Tribes[239]

USRT member tribes have reported an overall decrease in amphibian abundance. The Columbia spotted frog utilizes both low elevation and high elevation habitats. Its habitat can be affected (both positively and negatively) by the presence of American beavers in a watershed. Its habitat is also influenced by groundwater availability, which has been diminishing in some areas due to high groundwater withdrawals for agriculture. The Columbia spotted frog also uses springs and seeps as habitat and are sensitive to reductions in water flows in these habitats.

Columbia Spotted Frog Vulnerability Rankings

2050s	MORE WARMING	EXTREME VULNERABILITY
	LESS WARMING	HIGH VULNERABILITY
2080s	MORE WARMING	EXTREME VULNERABILITY
	LESS WARMING	EXTREME VULNERABILITY

Rankings above represent climate change vulnerability in the 2050s and 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled "More Warming" and the lower climate change scenario (RCP 4.5) is labeled "Less Warming". The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Physiological Hydrological Niche *increases vulnerability*.** The Columbia spotted frog inhabits shallow lakes, ponds, marshes, and small springs[240] during breeding and egg laying. Columbia spotted frogs typically inhabit permanent bodies of water, although some populations do inhabit seasonal pools. The Columbia spotted frog avoids dry uplands, except during migration to winter sites.[241] Shifting precipitation patterns under climate change may disturb or reduce the prevalence of these sensitive hydrological environments.
- **Sensitivity to Pathogens or Natural Enemies *increases vulnerability*.** Brook trout, cutthroat trout, and rainbow trout reduce the distribution and abundance of Columbia spotted frogs. Cutthroat trout prey on spotted frog tadpoles and juveniles, reducing the number of frogs that develop into adults.[242] Warming stream temperatures will enable trout species to inhabit rivers and streams that were previously too cold. In addition, climate change could potentially affect the Columbia spotted frog by amplifying the effects of diseases and parasites (e.g., chytrid fungus and trematodes).[243]
- **Measured Genetic Variation *increases vulnerability*.** Columbia spotted frog populations in Oregon are small and exhibit low levels of genetic variation. Small, isolated populations are vulnerable to reductions in genetic diversity and inbreeding. These limits to genetic diversity can increase the probability of local extinction with changing climate conditions.[244]

- **Natural Barriers *somewhat increases vulnerability*.** The Columbia spotted frog predominately inhabits areas with permanent water sources.[245] Therefore, stretches of land without wetlands, streams, ponds, or lakes can act as natural barriers to dispersal. Increasing temperatures and shifting precipitation patterns under climate change may alter the prevalence of these natural barriers within the assessment area.
- **Anthropogenic Barriers *somewhat increases vulnerability*.** Roads can act as barriers to dispersal and can be a source of mortality for the Columbia spotted frog.[246] These barriers may limit the Columbia spotted frog's ability to migrate in response to changing climate conditions.
- **Dispersal/Movement *somewhat increases vulnerability*.** The Columbia spotted frog has fairly limited dispersal abilities. In central Idaho, Columbia spotted frogs were documented dispersing up to 3,300 feet from breeding sites to reach summer habitats, though females typically remained within 1,600 feet of breeding sites.[247] These limitations to dispersal may impact the species' ability to migrate in response to changing climate conditions.
- **Physiological Thermal Niche has a *neutral effect on vulnerability***. Columbia spotted frog distribution is not significantly affected by thermal characteristics of the environment in the assessment area. The species inhabits both warmer low-lying areas and cooler higher elevation areas.[248]
- **Diet has a *neutral effect on vulnerability***. The Columbia spotted frog has a diverse diet composed of insects, mollusks, crustaceans, and arachnids. During the larval stage, the species consumes algae, organic debris, plant tissue, and small aquatic organisms.[249] Species that can readily switch among different food types are less likely to be negatively affected by climate change than dietary specialists.
- **Phenological Response has a *neutral effect on vulnerability*.** The timing of Columbia spotted frog egg deposition may be affected by water temperature, but other factors likely trigger movement of frogs to the egg-laying site.

Elk *(Cervus canadensis)*[250]

Existing Conditions & Observations by USRT Member Tribes[251]

Elk have reportedly migrated into some new areas on reservations, as they have been pushed out of other lands by cattle and development. They have a high capacity for migration and can traverse many rugged features of the landscape. Elk are "generalists," able to graze and browse on a diversity of plant foods.

Figure 48: Elk. Photo credit: Matt Knoth.

Elk Vulnerability Rankings

2050s

2080s

Rankings above represent climate change vulnerability in the 2050s and 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled "More Warming" and the lower climate change scenario (RCP 4.5) is labeled "Less Warming". The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Measured Genetic Variation *increases vulnerability*.** There is a lack of genetic variation within elk populations.[252] Less genetic variation may somewhat restrict the ability of elk to adapt to changing climate conditions.

- **Physiological Hydrological Niche *somewhat increases vulnerability*.** Elk seasonally inhabit riparian areas. In the western U.S., elk generally prefer habitats that are in close proximity (< 2,600 ft.) to surface water. Water availability may be especially important for elk during periods of forage desiccation, lactation, or heat stress. One study focused in south-central Washington, found that elk movements and home ranges decreased during summers with drought. Elk movements were centered near permanent water sources and along riparian zones with sufficient forage.[253] Shifting precipitation patterns under climate change could alter the suitability of these habitats.

- **Anthropogenic Barriers *somewhat increases vulnerability.*** Elk are sensitive to anthropogenic disturbance. Elk avoid roads and disturbances created by logging. Recurrent anthropogenic disturbance may reduce elk reproduction and the survival of offspring.[254] These barriers may restrict migration in response to changing climate conditions.

- **Sensitivity to Pathogens or Natural Enemies *somewhat increases vulnerability*.** Warming temperatures are expected to lead to earlier tick activity and an expansion of suitable tick habitat. Both changes may increase the risk of elk exposure to ticks.[255] While fire may reduce populations of parasites known to impact elk, this effect is likely to be short-term. Fire may reduce winter tick populations, however the long-term effect of fires on winter tick populations is unknown.[256]

- **Sensitivity to Competition *somewhat increases vulnerability*.** Elk and livestock diets overlap when forage availability is reduced. Therefore, the potential for competitive interactions is likely to be greatest on low-elevation winter ranges with adjacent foothills.
- **Natural Barriers has a *neutral effect on vulnerability*.** In the assessment area, elk have been observed traversing rugged mountain ridges.[257] It is unlikely that natural barriers will limit the ability of elk to shift its range in response to climate change.
- **Dispersal/Movement has a *neutral effect on vulnerability*.** Elk have excellent dispersal abilities. In mountainous regions, the species disperse between alpine meadows in summer and valleys in winter. On more level terrain, elk move between hillsides in the summer and open grasslands in the winter.[258] The elk's excellent dispersal ability increases the likelihood that the species will be able to move and keep pace with shifting climatic conditions.
- **Physiological Thermal Niche has a *neutral effect on vulnerability*.** Elk distribution is not significantly affected by thermal characteristics of the environment in the assessment area.
- **Disturbance Regime has a *neutral effect on vulnerability*.** Elk are associated with fire-dependent and fire-adapted plant species. Decreases in elk populations have been observed when fire frequency in these plant communities decrease.[259]
- **Ice/Snow Dependence has a *neutral effect on vulnerability*.** Deep snowpack can obstruct elk movement during winter and can bury forage. Because elk occasionally move from areas with deep snowpack to areas with less snow,[260] declining snowpack may be beneficial for the species by increasing their winter mobility.
- **Restriction to Uncommon Geological Features has a *neutral effect on vulnerability*.** Elk are habitat generalists, inhabiting grasslands, wetlands, shrublands, and forests.[261] Because elk are not tied to any specific geologic features they are more likely to be able to adapt to habitat loss from climate change, compared to species that are dependent on uncommon geologic features.
- **Diet has a *neutral effect on vulnerability*.** Elk have a diverse diet. Elk are grazers, but also eat flowering plants or mushrooms. They will also browse on willow, aspen, and oak in regions without grasses.[262] Species that can readily switch among different food types are less likely to be negatively affected by climate change than dietary specialists.

Golden Eagle (*Aquila chrysaetos*)

Figure 49: Golden Eagle. Photo credit: Peter G.W. Jones.

Existing Conditions & Observations by USRT Member Tribes[263]

Golden eagle feathers are an important part of ceremonial activities for the USRT member tribes. Tribal members have reported declines in golden eagle populations. No shifts in the timing of golden eagle nesting have been observed.

Golden Eagle Vulnerability Rankings

Rankings above represent climate change vulnerability in the 2050s and 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled “More Warming” and the lower climate change scenario (RCP 4.5) is labeled “Less Warming”. The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Climate Change Mitigation *somewhat increases vulnerability*.** Portions of the golden eagle’s range within the USRT project area include land with ‘good’ wind power classifications. Development of these areas would leave the golden eagle susceptible to injury or mortality from wind turbines.[264]

- **Sensitivity to Pathogens or Natural Enemies *somewhat increases vulnerability*.** While disease is not currently a major threat to golden eagle populations, West Nile virus is an emerging concern. Presently, in the western U.S., the golden eagle resides in semiarid landscapes with low mosquito (the vector for West Nile transmission) prevalence.[265] Shifting precipitation patterns under climate change could alter mosquito prevalence in the project area.

- **Dispersal/Movement has a *neutral effect on vulnerability*.** Golden eagles have excellent dispersal capabilities. For example, golden eagles from northern breeding areas (> 55°N) migrate more than 3,000 miles between breeding and wintering sites.[266] The golden eagle’s excellent dispersal ability increases the likelihood that the species will be able to move and keep pace with shifting climate conditions.

- **Physiological Thermal Niche has a *neutral effect on vulnerability*.** Golden eagle distribution is not significantly affected by thermal characteristics of the environment in the assessment area.[267]

- **Physiological Hydrological Niche has a *neutral effect on vulnerability*.** The golden eagle has little dependence on a strongly seasonal hydrologic regime or a specific wetland habitat that would be affected by climate change.

- **Diet has a *neutral effect on vulnerability*.** The golden eagle has a broad diet that consists primarily of small mammals (e.g., rabbits, hares, marmots, prairie dogs, and ground squirrels) and occasionally includes large insects, snakes, birds, juvenile ungulates, and carrion.[268,269] Species that can readily switch among different food types are less likely to be negatively affected by climate change than dietary specialists.
- **Sensitivity to Competition has a *neutral effect on vulnerability*.** The golden eagle is not currently sensitive to competition from native or non-native species and there is no indication that climate change will cause another species to become a competitor in the future.
- **Measured Genetic Variation has a *neutral effect on vulnerability*.** Genetic diversity of golden eagle populations is comparable with that of other large raptor populations.[270] Species with average to high levels of genetic variation are expected to be better able to adapt to changing climatic conditions.[271]

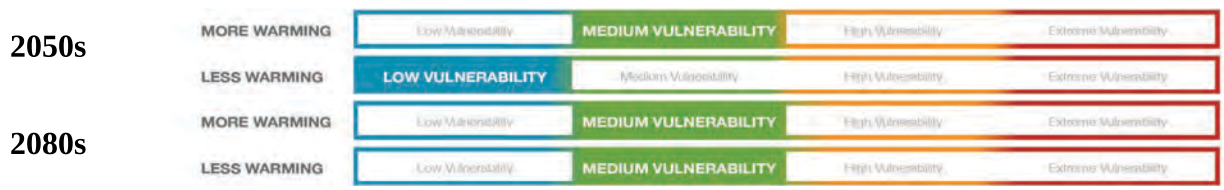
Mule Deer (*Odocoileus hemionus*)

Existing Conditions & Observations by USRT Member Tribes[272]

Tribes have noticed declines in mule deer populations. The mule deer historically browsed along alfalfa fields and may have been pushed out by development and water quality impacts from cattle. Constraints on traditional movement patterns are thought to increase opportunities for predators to access deer.

Figure 50: Mule Deer. Photo credit: Calla Hagle.

Mule Deer Vulnerability Rankings



Rankings above represent climate change vulnerability in the 2050s and 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled "More Warming" and the lower climate change scenario (RCP 4.5) is labeled "Less Warming". The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Physiological Hydrological Niche *somewhat increases vulnerability*.** Mule deer require water during extended heat events.[273] Extended dry periods and warm temperatures under climate change, especially in the summer months, may decrease overall water availability.

- **Anthropogenic Barriers *somewhat increases vulnerability*.** Fences are a major barrier to mule deer movement in the western U.S. When installed incorrectly, fences obstruct mule deer movement and may cause mortality. In addition to fences, urban, suburban, or rural housing developments can also obstruct mule deer movement.[274] These barriers to migration may limit the mule deer's ability to effectively move in response to changing climate conditions.

- **Sensitivity to Pathogens or Natural Enemies *somewhat increases vulnerability*.** There are many bacterial diseases and parasites that infect mule deer and may cause mortality. For example, bluetongue virus (BT) is transmitted to mule deer by biting gnats.[275] BT is typically most prevalent in deer populations during the summer months when hot and dry conditions are advantageous for the gnats. Increasing incidence of drought and warming temperatures may benefit gnat populations and increase the window of opportunity for outbreaks of BT in mule deer populations. [276]

- **Sensitivity to Competition *somewhat increases vulnerability*.** Mule deer habitat use may be indirectly affected by other wildlife species. Researchers concluded that mule deer habitat selection was largely explained by avoidance of areas inhabited by elk. Elk can eat a greater variety of forage than mule deer, giving elk a competitive advantage.

- **Physiological Thermal Niche has a *neutral effect on vulnerability*.** Mule deer distribution is not significantly affected by thermal characteristics of the environment in the assessment area.[277]
- **Dispersal/Movement has a *neutral effect on vulnerability*.** Mule deer have excellent dispersal abilities. Studies in Montana observed migration distances ranging 7-87 miles for males and 8-16 miles for females. Research suggests that longer mule deer migrations may be more common in patchy environments with greater distances between suitable habitat areas.[278] The mule deer's dispersal ability increases the likelihood that the species will be able to move and keep pace with shifting climate conditions.
- **Disturbance Regime has a *neutral effect on vulnerability*.** Mule deer are known to graze on early successional vegetation that re-colonizes after a disturbance event.[279] Mule deer are associated with fire-dependent and fire-adapted plant species and communities. Decreases in mule deer populations have been observed when fire frequency in these plant species and communities decrease.
- **Measured Genetic Variation has a *neutral effect on vulnerability*.** Studies of mule deer genetics have found high levels of genetic diversity throughout the species range.[280] Species with average to high levels of genetic variation are expected to be better able to adapt to changing climatic conditions.[281]

Redband Trout (*Oncorhynchus mykiss gairdnerii*)

Existing Conditions & Observations by USRT Member Tribes[282]

Figure 51: Redband Trout. Photo credit: Joel Santore.

Redband trout have habitat refugia on USRT member tribe's reservations. Tribes have reported low river levels in summer affecting their ability to fish trout, sometimes restricting fishing to the higher water levels in the spring season. Warmer stream temperatures following the removal of streamside vegetation by wildfire have also affected trout on reservations. Redband trout are fish-eaters and eat young salmonids.

Redband Trout Vulnerability Rankings

2050s

2080s

Rankings above represent climate change vulnerability in the 2050s and 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled "More Warming" and the lower climate change scenario (RCP 4.5) is labeled "Less Warming". The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Physiological Hydrological Niche *greatly increases vulnerability*.** During winter, redband trout inhabit cold, deep pools in mountain streams. During summer, redband trout inhabit low-gradient, medium-elevation stream reaches with pools, which are critical spawning habitat.[283] Redband trout also inhabit higher gradient channels with riffles or areas with boulder and cobbles. Shifting precipitation patterns under climate change could alter the suitability of these habitats for redband trout.
- **Anthropogenic Barriers *increases vulnerability*.** Many streams and rivers within the assessment area have dams that prevent redband trout access to more suitable, cooler habitat if their present habitat becomes too warm. Dams in the assessment area include Antelope Dam, Owyhee Dam, Bully Creek Dam, Malheur Dam, and Brownlee Dam. These barriers to migration may hamper the redband trout's ability to respond effectively to changing climate conditions.
- **Physiological Thermal Niche *increases vulnerability*.** While redband trout have often been considered more tolerant of warmer water temperatures than other salmonid species, recent research suggests that the thermal tolerances of redband trout populations in southeastern Oregon differ only slightly from other salmonids. It could therefore be concluded that the redband trout is not uniquely tolerant of warm water temperatures compared to other salmonids.[284] Thus, rising stream temperatures under climate change could negatively affect redband trout populations.[285]

- **Disturbance Regime *increases vulnerability*.** The survival of salmonid (i.e., salmon, trout, and char) eggs and embryos is strongly influenced by sediment deposition, water quality, and streambed scour and fill.[286] As air temperatures rise, watersheds are projected to become increasingly rain-dominant. This shift will increase the risk of winter flooding and sediment transport, which can negatively affect the survival of salmonid eggs.
- **Sensitivity to Pathogens or Natural Enemies *increases vulnerability.*** Warming stream temperatures may intensify mortality from fish pathogens. *Vibrio* and *Ceratomyxa shasta* are two infections known to negatively affect salmonids and these effects could be exacerbated with warming stream temperatures.[287] Increasing water temperatures can stress salmonids, reducing their ability to mount an effective immune response to disease. Many important salmonid diseases become virulent when water temperatures reach 60-61°F.[288]
- **Sensitivity to Competition from Native or Non-Native Species *somewhat increases vulnerability*.** Redband trout compete with resident brook trout, which are fish-eaters and known to eat young salmonids. It is estimated that there have been at least 35 non-native fish species introduced to the redband trout range within the Columbia River Basin.[289] Climate change may influence the success of redband trout as it competes for resources.
- **Climate Change Mitigation *somewhat increases vulnerability*.** Future dam building is possible in the region. Dams act as barriers to movement of redband trout to stream reaches in the Upper Snake River region and may limit their ability to migrate in response to warming water temperatures.[290]
- **Measured Genetic Variation has a *neutral effect on vulnerability*.** Substantial genetic divergence has been observed among the 17 native Columbia River redband trout populations.[291] Species with average to high levels of genetic variation are expected to be better able to adapt to changing climatic conditions.[292]

Steelhead (*Oncorhynchus mykiss*)

Figure 52: Steelhead. Photo credit: USFWS Mountain-Prairie.

Existing Conditions & Observations by USRT Member Tribes[293]

Three of the four USRT member tribes no longer have access to Steelhead on their reservations. Over the last century, eight dams on the Upper Snake River have limited the ability of steelhead to reach the USRT member tribes' traditional harvest areas. USRT tribes are actively working to help reintroduce steelhead into their historical habitat on reservations.

Steelhead Vulnerability Rankings

2050s

2080s

Rankings above represent climate change vulnerability in the 2050s and 2080s for two different climate change scenarios. The higher climate change scenario (RCP 8.5) is labeled "More Warming" and the lower climate change scenario (RCP 4.5) is labeled "Less Warming". The rankings reflect the assessment of local climate change projections and species-specific sensitivities and adaptive capacity from the CCVI analysis.

Factors Affecting Vulnerability

- **Physiological Thermal Niche *greatly increases vulnerability*.** Optimal water temperature for steelhead egg hatching is 50°F. Optimal growth for juvenile steelhead occurs between 57.2°F and 59°F. Water temperatures of 69.8°F lead to the formation of thermal migration barriers for steelhead in the Snake River. Daily maximum water temperatures above 66.2-68°F present lethal conditions for steelhead.[294] Warming water temperatures under climate change may increase the frequency with which these sensitive thermal limits are exceeded.

- **Physiological Hydrological Niche *greatly increases vulnerability*.** Steelhead inhabit cool, clear lakes and cold, fast-flowing streams. During winter, steelhead require deep pools in slow-moving streams.[295] Warming water temperatures under climate change may impact some of these sensitive hydrological requirements.

- **Disturbance Regime *increases vulnerability*.** The survival of salmonid (i.e., salmon, trout, and char) eggs and embryos is strongly influenced by sediment deposition, water quality, and streambed scour and fill.[296] As air temperatures rise, watersheds are projected to become increasingly rain-dominant. This shift will increase the risk of winter flooding and sediment transport, which can negatively affect the survival of salmonid eggs.

- **Sensitivity to Pathogens or Natural Enemies *increases vulnerability*.** Warming stream temperatures may increase salmonid mortality from fish pathogens. *Vibrio* and *Ceratomyxa shasta* are two infections known to negatively affect salmonids and these effects could be exacerbated with warming stream temperatures.[297] Increasing water temperatures can stress salmonids, reducing their ability to mount an effective immune response to disease. Many important salmonid diseases become virulent when water temperatures reach 60-61°F.[298]

- **Anthropogenic Barriers *increases vulnerability*.** Many streams and rivers within the project area have dams that would prevent steelhead from accessing more suitable, cooler habitat if their current habitat becomes too warm. There are eight dams on the mainstem Snake River from below Shoshone Falls to Hells Canyon include the Upper Salmon Falls Dam, Lower Salmon Falls Dam, Bliss Dam, C.J. Strike Dam, Swan Falls Dam, Brownlee Dam, Oxbow Dam, and Hells Canyon Dam.[299] These barriers to migration may hamper steelhead ability to respond effectively to changing climate conditions.
- **Climate Change Mitigation somewhat *increases vulnerability*.** Future dam building is possible in the region. Dams act as barriers to steelhead movement and may limit their ability to move in response to changing climate conditions.[300]
- **Sensitivity to Competition from Native or Non-Native Species somewhat *increases vulnerability*.** Resident brook trout, which are known to eat young salmonids, compete with steelhead.[301] Climate change may affect this competitive dynamic.
- **Measured Genetic Variation has a *neutral effect on vulnerability*.** Steelhead populations in the Upper Snake River exhibit relatively high genetic variation.[302] Species with average to high levels of genetic variation are expected to be better able to adapt to changing climatic conditions.[303]
- **Diet has a *neutral effect on vulnerability*.** Steelhead have a broad diet in both lakes and streams. In lakes, their diet mainly consists of bottom-dwelling invertebrates (e.g., aquatic insects, amphipods, worms, fish eggs) and plankton. In streams, steelhead consume drift organisms. In the ocean portion of their lifecycle, the steelhead diet includes fish and crustaceans.[304] Species that can readily switch among different food types are less likely to be negatively affected by climate change than dietary specialists.
- **Dispersal/Movement has a *neutral effect on vulnerability*.** Steelhead have excellent dispersal abilities. Anadromous forms can migrate hundreds of miles between spawning streams and non-spawning marine waters.[305] Steelhead's dispersal ability increases the likelihood that it has the ability to adapt to shifting climatic conditions.

VI. Conclusion

Changing climate conditions have already altered, and will continue to affect, the natural resources, landscapes, and people of the Upper Snake River Watershed. By taking the initiative to explicitly identify Shared Concerns and assess their climate change vulnerability, USRT's four member tribes have begun the process of climate change adaptation.

The results of this first phase of climate work by USRT's member tribes will create a foundation on which future phases can be built. The outputs of this project go beyond the relative vulnerability rankings presented in this report. ***The collaboration required throughout the project has strengthened the connections between the four tribes and enhanced understanding about the shared challenges they face under climate change.*** This is, perhaps, the most important outcome of this assessment. The specific vulnerability information in this assessment can be used in the development of customized adaptation strategies and actions that will ultimately assist USRT member tribes in minimizing the negative effects of climate change, take advantage of positive opportunities, and build climate resilience.

Plant and animal species, habitats, and natural resources are critically important to the tribes and have been an intrinsic part of their tribal culture for thousands of years. By proactively responding to climate change, USRT and its member tribes are working to ensure that these resources will be an integral part of their communities for generations to come.

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VIII. List of Appendices

Appendix A: Climate Modeling and Analysis

Data

The climate data was sourced from the Multivariate Adaptive and Constructed Analogs (MACA) datasets available at http://maca.northwestknowledge.net/. For this project, the monthly MACAv2-LIVNEH dataset was used (MACA version 2, using the gridded surface meteorological observational dataset, Livneh et al. 20131). This data set is at 6 km (1/16 degree) resolution, and follows the downscaled procedure in Abatzoglou and Brown (2012)2. The full domain covers the conterminous United States, but for this project was clipped to approximately 40.66-47.03N and 239.66-249.84E. Within this larger "super domain", three subdomains were defined for additional analysis (Figure A1).

The MACA dataset contains downscaled output from 20 global climate models: bcc-csm1-1-m, bcc-csm1-1, BNU-ESM, CanESM2, CCSM4, CNRM-CM5, CSIRO-Mk3-6-0, GFDL-ESM2G, GFDL-ESM2M, HadGEM2-CC365, HadGEM2-ES365, inmcm4, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, MIROC5, MIROC-ESM-CHEM, MIROC-ESM, MRI-CGCM3, NorESM1-M.

Processing

Two climate quantities were examined for this project: total precipitation and average temperature. Annual and seasonal averages were calculated for both precipitation and average temperature, where average temperature = (daily maximum temperature + daily minimum temperature) divided by two. Three subdomains were defined based on the unique topography and climatological zones: "North" (red polygon), "South" (yellow polygon), and "East" (green polygon). For each subdomain, an annual and seasonal precipitation total was calculated, as well as an annual and seasonal average temperature. Results were visualized via an annual time series and seasonal bar plots (Figures A2 – A13).

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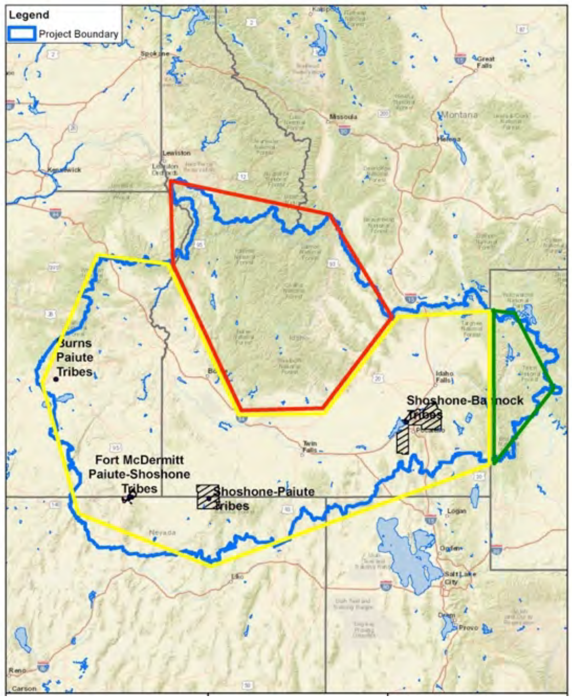

Figure A1. Map of the full project area (blue polygon) and the three subdomains (red, yellow, and green polygons) that were used to guide the climate analysis and create average projections for each subdomain.

Summary

The average annual temperature is projected to increase substantially, and similarly, across all three subdomains by the end of the 21st century. Under Representative Concentration Pathway (RCP) 8.5 emissions, the ensemble mean temperature increase is on the order of 11º Fahrenheit (F), while under the lower emissions RCP 4.5 scenario, the increase is about 5º Fahrenheit. Projections for total annual precipitation are less definitive. For the North and East domains (which have greater topographical variety), there is the suggestion of a small increase in total annual precipitation by the end of the century. The South domain exhibits even less of a trend in this respect. There is also less agreement between the model projections for precipitation vs. temperature. All models show an increase in temperature by the end of the century, across the board. In contrast, some models project an increase in total annual precipitation while others project a decrease.

Seasonally, for all domains, the average temperature is projected to increase under both emissions scenarios. The greatest increase in average seasonal temperature is projected for the winter (about 7-9º F for RCP 4.5 by the end of the century), with an increase of around 4-6º F for the other seasons (again for RCP 4.5). RCP 8.5 adds another 3-4º F to the RCP 4.5 projections by the end of the century.

Again, there is less agreement on seasonal precipitation trends. In general, for all domains by the end of the century, the winter and spring seasons are projected to be slightly wetter (more so in the North and East than in the South). Summer precipitation is projected to be flat to decreasing (but there is wide variability in these projections), and the fall trend is flat to slightly increasing.

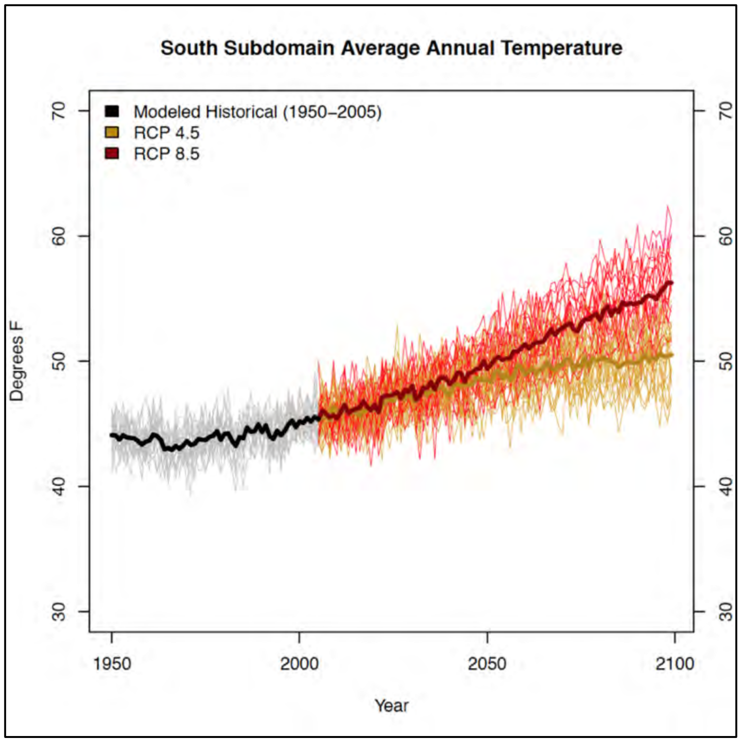

Figure A2. *Average annual temperature projections for the South Subdomain. The modeled historical past for the subdomain is shown in gray and the two RCP scenarios are shown in the different colors (yellow is RCP 4.5 and red is RCP 8.5). Each thin line shows the results of one climate model, while the heavy line is the mean of the 20 climate models.*

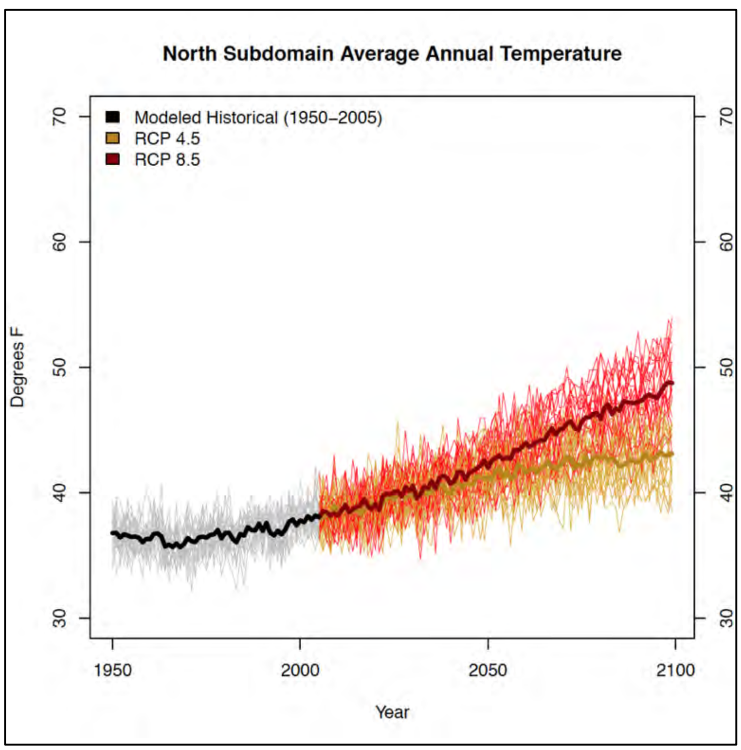

Figure A3. *Same as Figure A2, but for the North Subdomain.*

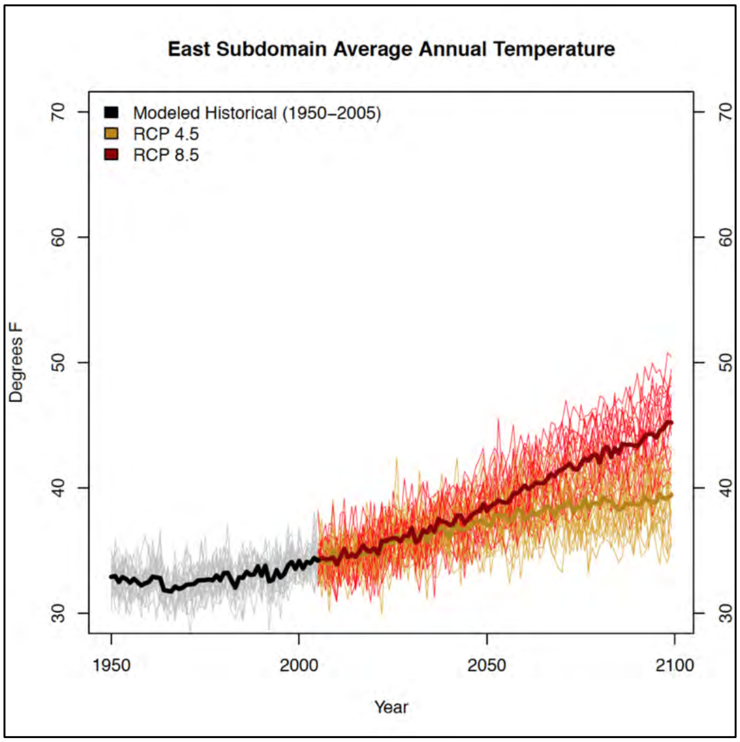

Figure A4. *Same as Figure A2, but for the East Subdomain.*

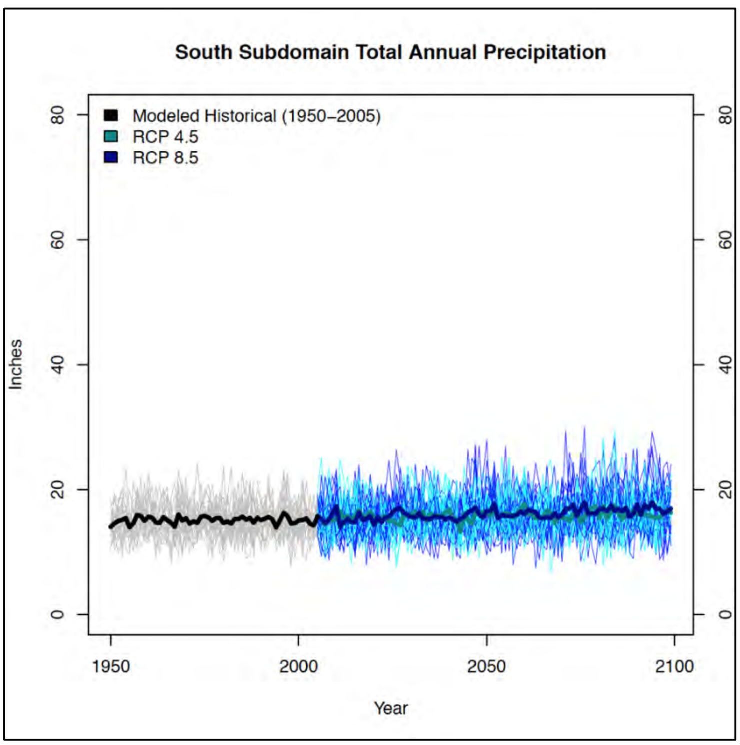

Figure A5. *Average annual precipitation projections for the South Subdomain. The modeled historical past for the subdomain is shown in gray and the two RCP scenarios are shown in the different colors (light blue is RCP 4.5 and dark blue is RCP 8.5). Each thin line shows the results of one climate model, while the heavy line is the mean of the 20 climate models.*

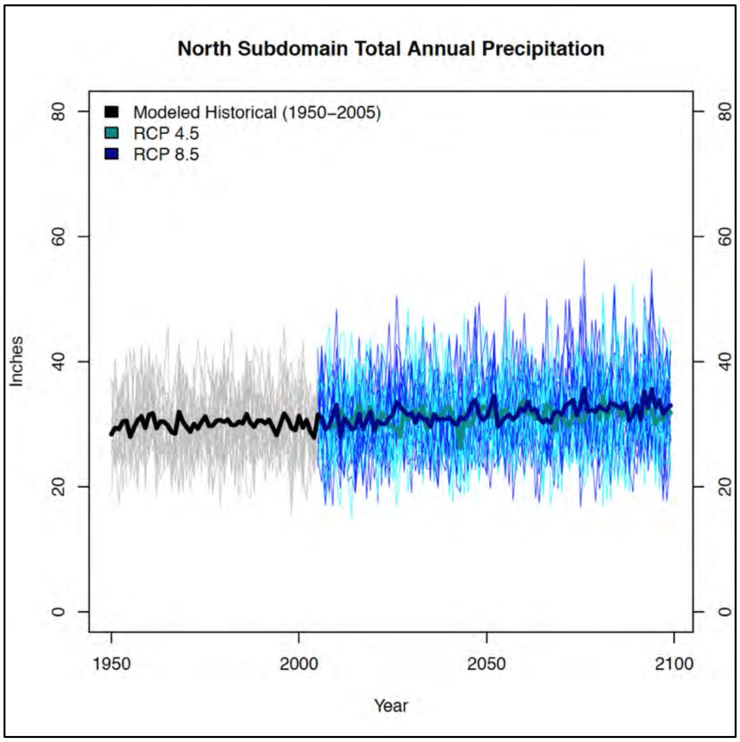

Figure A6. Same as Figure A5, but for the North Subdomain.

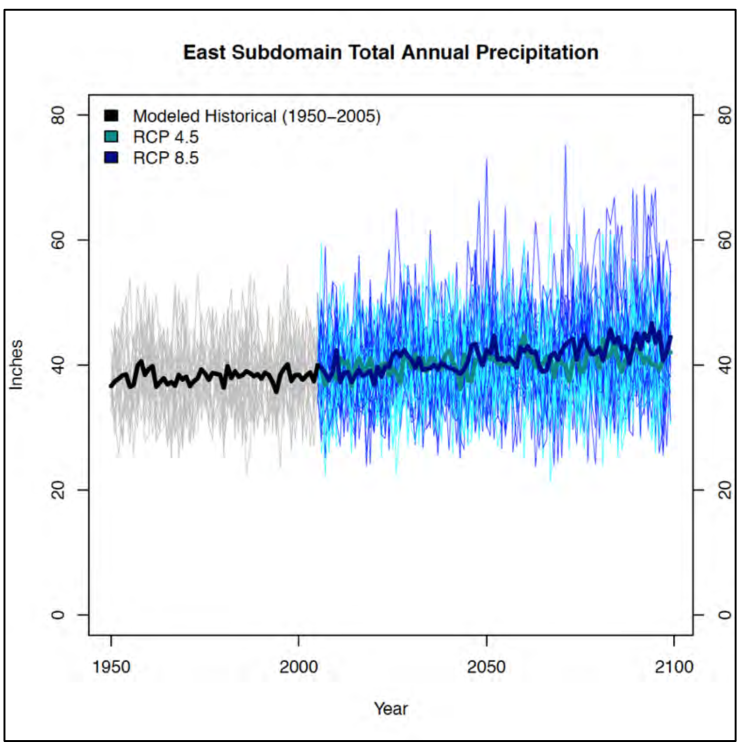

Figure A7. Same as Figure A5, but for the East Subdomain.

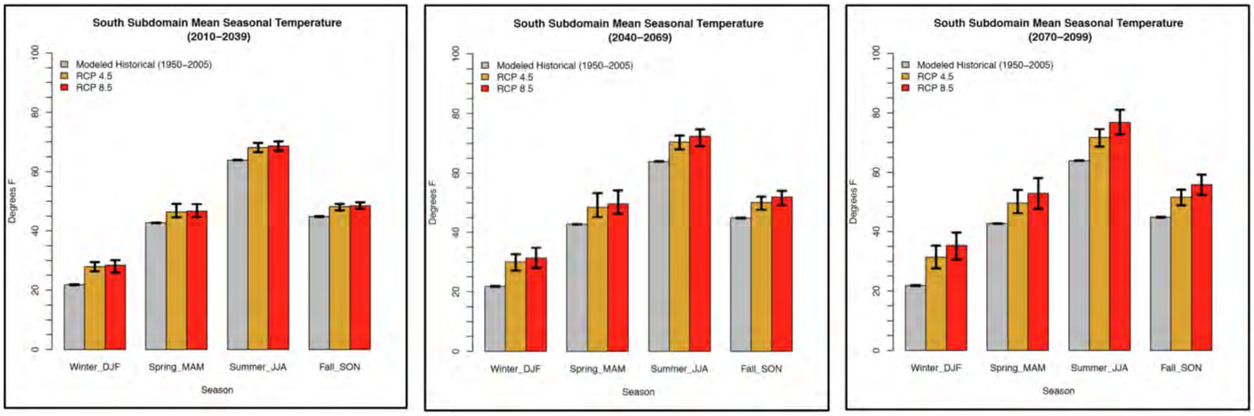

Figure A8. *Seasonal average temperature projections for the South Subdomain. The modeled historical past for the subdomain is shown in gray and the two RCP scenarios are shown in the different colors (yellow is RCP 4.5 and red is RCP 8.5). Projections are displayed for time periods 2010-2039, 2040-2069, and 2070-2099. Bars heights show the mean from 20 climate models and the vertical line show the range of all 20 climate models.*

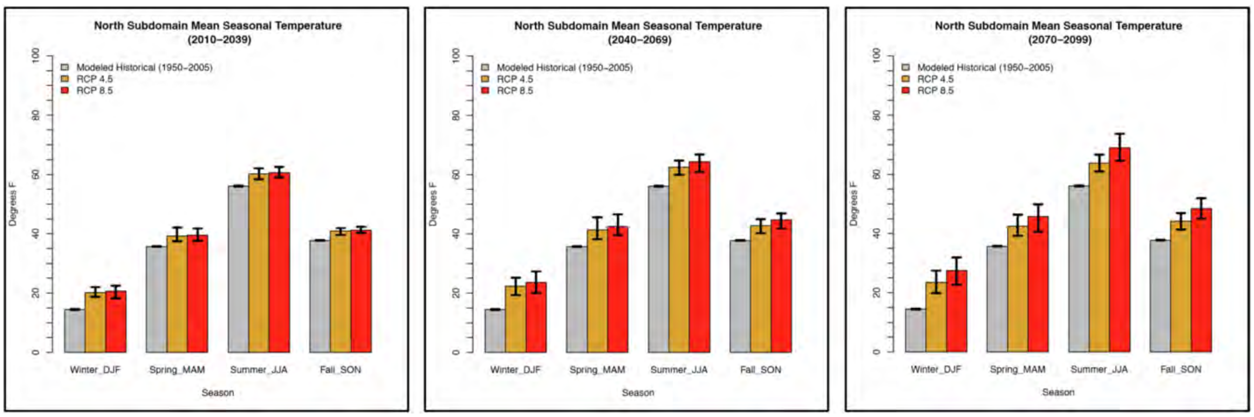

Figure A9. *Same as Figure A8, but for the North Subdomain.*

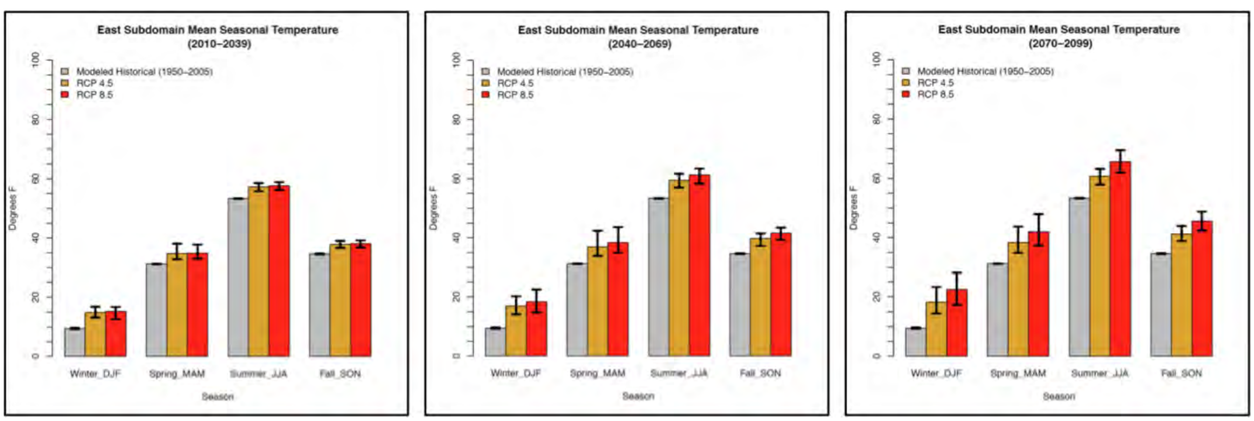

Figure A10. *Same as Figure A8, but for the East Subdomain.*

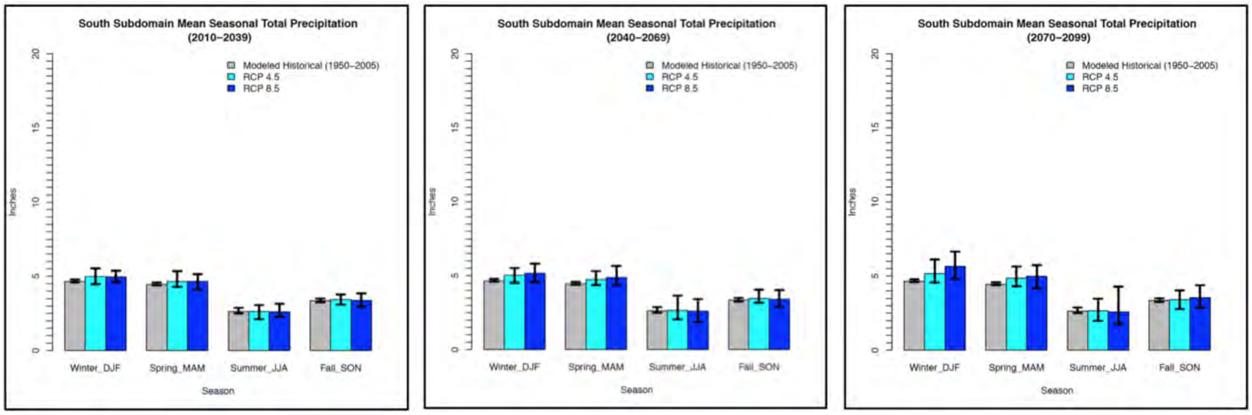

Figure A11. *Seasonal precipitation projections for the South Subdomain. The modeled historical past for the subdomain is shown in gray and the two RCP scenarios are shown in the different colors (light blue is RCP 4.5 and dark blue is RCP 8.5). Projections are displayed for time periods 2010-2039, 2040-2069, and 2070-2099. Bars heights show the mean from 20 climate models and the vertical line show the range of all 20 climate models.*

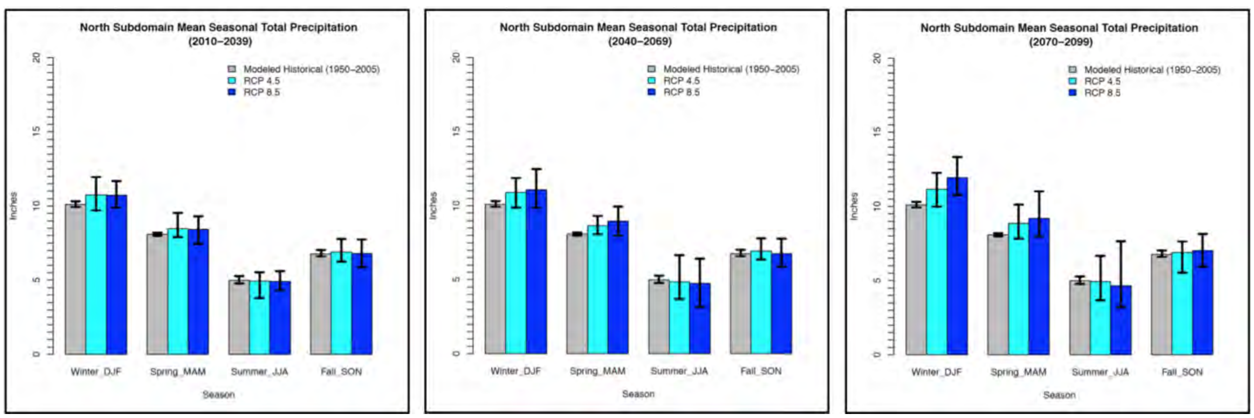

Figure A12. *Same as Figure A11, but for the North Subdomain.*

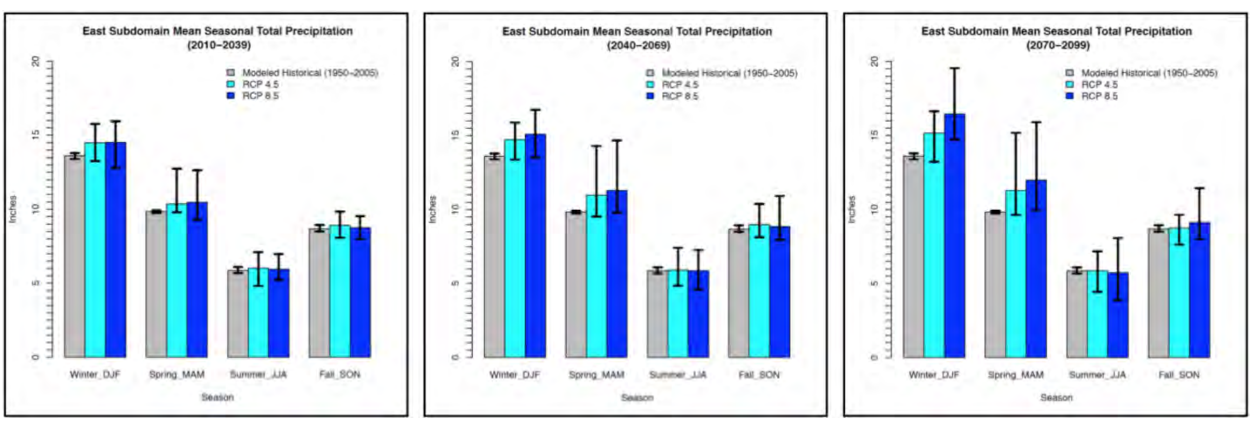

Figure A13*. Same as Figure A11, but for the East Subdomain.*

Appendix B: April 2016 Site Visit Notes

As described in Section IV of the vulnerability assessment, collaborative engagement with the four Upper Snake River Tribes (USRT) Foundation's member tribes throughout the project was crucial to the identification of relevant climate change Shared Concerns. This appendix presents notes taken at each of the four reservations during the project site visits in April 2016. This information was reviewed and used to scope the initial list of *46 Shared Concerns* that are presented in Section IV of the vulnerability assessment, which was later paired down to the *28 Shared Concerns* assessed in this project. Site visit notes are presented in chronological order.

Shoshone Paiute Tribe Site Visit Notes from Meetings Held April 18th, 2016	
Topic of Concern	Discussion
Dams	• Have significantly changed river flow in historical period • Have restricted fish passage • When flows are restricted (most of the year), river habitat with natural flow have become stagnant and experience higher temperatures • Reservoir dams are mostly "push-up" earthen dams, which flood a wetland. • 1932 Owyhee Dam blocked salmon, loss of salmon means loss of ocean nutrients to upland areas • Wildhorse reservoir dam built in 1937 by Bureau of Reclamation, 2nd larger dam built in 1959 by BIA and DOI. Wildhorse irrigates the valley and fills both Mountain View and Wildhorse reservoirs
Riparian habitat	• Agriculture influence and general development have decreased woody shade along banks • Nutrient loads to river have increased in modern times from agriculture run off • Cottonwood tree numbers down • Have seen willow die-offs (due to temp and cyanobacteria?), willows are present in two predominant sub-species, provide food and bank stability • Tributaries coming into systems help moderate stream temperature • Plants on bank provide shade, leaf litter, and insects • Pesticides have been sprayed along roadways
Industrial development	• Mining development continues, has been detrimental to fish
Reservoirs	• Reservoirs are quite shallow, subject to warming • Will need bigger or deeper reservoirs under climate change • Are seeing more biomass, low flows, high temperatures • Manage three reservoirs: Mountain View, Wildhorse, Lake Billy Shaw (fly fishing only) • Reservoirs are on average 6-7ft deep, however can also have places that are 20-30ft deep. • Plants on bank provide shade, leaf litter, and insects

Shoshone Paiute Tribe Site Visit Notes from Meetings Held April 18th, 2016	
Topic of Concern	Discussion
	• Reservoirs are fenced • Reservoirs have become enriched by nutrient loads. • Reservoirs typically don't release water until after June. • Fishing generates revenue for the Tribe
Fisheries	• Fisheries in reservoirs are affected by high temps and low dissolved oxygen • Native species: mostly manage redband trout, they have important habitat and refuges (stronghold) on reservation • Also have rainbow trout (introduced), a cold water species as an important sport fishery in reservoirs • Macroinvertebrate diversity is very important • Chinook: summer 2015 were re-introduced for the first time into the East Fork Owyhee River over a 7 mile stretch, working on gaining fish passage with USRT. • Chinook were reintroduced last year for the first time in 80+ years - trucked in and released into a section of the river. - Traditional fishing methods (spears) made with the instruction of the Sho-Ban and used by tribal members to collect the fish (125 total fish released). Quality of the river and habitat was important in ensuring the delivery/release of the fish. • Last year Chinook in East Fork Owyhee River saw 80° F water but they were surviving by staying dormant in cold pools from groundwater tributaries • Steelhead need to be reintroduced • Fish in reservoirs will go into hibernation mode at bottom to try and avoid hot surface temperatures, move up and down thermoclines • Have mountain trout up in mountains, still there in small numbers? • Tribe stocks reservoirs twice a year, so managing for maximum yield. • High biomass in reservoirs impacts fish respiration and spawning
Wet-meadow Habitat	• This habitat is predominant type in lowland areas, most land that is now agriculture started as this type before conversion • Beavers have increased storage of water, so other parts of streamside have dried up.
Wildfire	• High desert habitat is susceptible to fire • Risk of wildfire has increased • Whole stands of dead sagebrush provides fuel, dead from moths?
Temperatures	• In the 1970s wintertime temperatures would drop to - 35 for a week or so • The lack of a cold winter has meant less winter die offs of pests • Have experienced VERY HOT days, compared to hot days in historical period • Freezing temperatures are occurring more unexpectedly

Shoshone Paiute Tribe Site Visit Notes from Meetings Held April 18th, 2016	
Topic of Concern	Discussion
	• Historically third week in January was coldest of winter (approximately 20 below), then a chinook (warm, wet storm) would come in for spring.
Snowpack	• Hydrologists were reporting a 130% snowpack this year but may not be true (maybe more like 50% from the view of some tribal elders)… they are using a "historical" baseline only from 1980-2010 • It has been very dry in spring and dust storms have deposited on the snowpack and accelerated melting • Boise River snowpack has lost its "above average" mass very quickly this spring due to abnormally high nighttime temperatures • When precipitation falls as rain rather than snow it also increases water temperature, and keeps streams warmer than if snowpack is feeding stream.
Runoff	• Historically it was noted that creeks will regenerate in the fall and "wake up", is this because the plants quit "drinking" or other influence from temperature and barometric pressure? • In the future maybe there is a risk of seasonally losing runoff? • East Fork Owyhee River had higher temperatures and low flows last year • Tribe has interest in: Bruneau/Jarbridge/South Fork, East Fork Owyhee River
Traditional Medicines	• A decrease in "water baby" (type of plant) beds, due to mistreatment by people? Mistreatment by cattle? • No more poison ivy, this used to be medicine.
Springs	• Have done some spring head protections • Protected springs have solar powered troughs for cattle
Sagebrush habitats	• Have seen large stands of dead sagebrush • Sage grouse have been declining over western states but have somewhat stable populations on the reservation • Ant piles (red and red/black) seem to be dead • Mosquitoes seem to be getting to higher elevations
Traditional culture	• Traditional migration patterns were up into the mountains in summer and down to the lowlands and open water bodies in winter • Everything in the environment is connected in a circle • All things on earth are connected, water is the essence of life • Everything has a purpose, every habitat has its own importance. • Even on reservation have connection to global issues: ocean acidification, rainforest, polar bears, renewable energy.
Traditional Foods	• Have seen declines in deer, rabbit, and eagles • Diversity of water fowl has diminished • Other important species to tribe include: mule deer, ground hog, berries, roots, medicines, raspberry, strawberry, huckleberry • Not seeing bobcats anymore.

Shoshone Paiute Tribe Site Visit Notes from Meetings Held April 18th, 2016	
Topic of Concern	Discussion
Water Quality	• In periods of drought it is hard to meet drinking water quality standards • Have issues with high temperatures (no shade), sediment loads
Frogs	• Have seen reduction in frogs, used to hear them commonly
Precipitation	• Historically saw "six year" droughts (drought every six years), these have come closer together, some irrigation canals have dried up • Spring used to involve consistent rain for months, not something you see anymore
Plants	• Evergreen needles are turning brown • Little leafy plants are growing larger • Serviceberry in mountains is not producing anymore • Chokecherries seeing big worm "webs", they also have been blooming too early and freezing
Extreme Weather	• In 2006 had unusual tunnel cloud • Increases in thunderstorms occurring with snow • Used to have more blizzards • Historically had a lot of thunder and lightning
Groundhog	• Groundhogs are traditionally a preferred food, have been reduced. Maybe because of overharvest? • Saw die off in region recently from bubonic plague?
Additional Notes from phone discussion on 5.19	• Have seen willows over-run certain areas, cottonwood numbers down • BIA gives grant to diminish noxious weeds • Mosquitos seem to be aggressive on reservations, Tribe is working to eradicate mosquitos with some spraying • Ants seem to be doing well • Some have NOT seen large stands of dead sagebrush

Fort McDermitt Paiute-Shoshone Tribe Site Visit Notes from Meetings Held April 19th, 2016	
Topic of Concern	Discussion
Rivers	• There is a fork on the Quinn River 8 miles east, North Fork Quinn River had dried up from 1992-2011. • Irrigation dam on Quinn River washed out in the late 90s, need to rebuild • Water used to fill the Quinn River and could fish trout all summer, but now it may dry up by beginning of summer. Canal alongside road coming out of canyon used to flow all the time • Spring run-off is decreasing • "Wet weather" springs are no longer as common • Have seen more incidences of algae growth • Junipers are heavy water users • Have willows, roses along river. Lower river levels have meant these species are getting smaller • One stream coming from Oregon side-sacred streambed, riparian aid needed. Springs need to be protected from further damage.
Invasive Species	• Lots of noxious weeds present on reservation: common mullein, goathead, puncture vein, medusahead • Weeds have been growing more quickly: example, pink flowers. Weeds have been out competing natural grasses • Poisonous hemlock are present, thistles, knapweed, and curly docks
Fisheries	• Have rainbow trout, redband, some cutthroat on reservation • Used to have small fish with "suckers" that are not present anymore • Reservation does not have rainbow trout
Traditional foods	• Hunting has become more difficult • Recent fires have been destroying habitat • Deer have moved on to cleaner waters, cows have muddied many water sources • Deer used to browse along alfalfa fields. • Elk have arrived in area (nearby canyon), they didn't used to be present, have migrated in because of cattle lands and development • Gathering berries has become more difficult, chokecherries are having trouble with strange freeze/thaw cycles • Important traditional food species includes: groundhog, deer, rabbits, buckberries, chokecherries • Wild onions are no longer growing along streams, nor under sagebrush • Have seen decreases in small mammals and quails • Buckberries (somewhat unique to this reservation) have seen some drying and die off, use them for making pudding, historically you look at the bush during the dry season to know which plants will produce berries • Used to have red and orange currants along river, not anymore. • Have red and yellow willow along river • Have seen an increase in beavers • Wild garlic, yellow, and red berries, as well as roots

Fort McDermitt Paiute-Shoshone Tribe Site Visit Notes from Meetings Held April 19th, 2016	
Topic of Concern	Discussion
Dams/Irrigation	• Calvary built first dam on Quinn River in 1869, in 1996 there was a large snowstorm and on New Year's Day in 1997 had a large rain on snow event which washed out the dam. • New dam on Quinn River should be constructed to irrigate both sides of the valley, this would also help recharge aquifer • Agricultural wells draw down the aquifer • More wind seems to be increasing drying effect on plants and soils • Most fields were only given one irrigation all of last year • Snowpack dries up early due to wind
Snowpack	• Snowpack has diminished and is drying out • Snowpack used to be deep enough to bury a cabin, now it is only drifted by wind behind rocks • Past snowfall was in large amounts, now comes in 1 or 2 inches at a time • Used to be deep snow. Springtime floods used to come very high and close to the houses. • Porcupine has disappeared, maybe because of the diminished snowpack
Precipitation	• USDA maps (Las Vegas office) are saying reservation is "out" of the drought but Tribe does not believe that to be true • NOW get cold DRY air without moisture • Appears to be more wind and dust storms, overall drying
Sagebrush Habitat/ Rangeland	• Range by canyon spring has dried up and rye grass has disappeared, could we use rye grass for monitoring? • Wildflowers are not as big as they used to be • "Sunflowers" up on mountain are no longer present (likely arrowleaf balsamroot) • Barren areas are increasing • Sagebrush is drying out
Springs	• Saw a spring running up valley when it hasn't run before. • Overall springs have dried up • 17 identified springs on reservation • Most small and water muddied because of trampling from cattle. • Attempts to fence springs have failed due to vandalism by ranchers.
Traditional Medicine	• Some of the medicinal plants not as big as they used to be
Human Health	• Reservation sees issues with diabetes, mental health, substance abuse, asthma, high cancer rates - potentially related to mining nearby. • Clinic may see potential closure/reduction in services from reduced IHS funding • Humans are shorter in modern times, due to less nutritious foods? • Allergies have increased

Fort McDermitt Paiute-Shoshone Tribe Site Visit Notes from Meetings Held April 19th, 2016	
Topic of Concern	Discussion
Temperature	• Community has experienced extreme heat
Cattle	• Get skinny during drought • Not eating nutritious foods, since rangeland is suffering and noxious weeds are increasing • Some people are using domestic water for livestock • Tribal members grow meadow hay for cattle • Over grazing, education needed on restoration of grazing
Water Quality	• The municipal water is groundwater and not treated
Amphibians/ Reptiles	• Hornfrogs, snakes, lizards have decreased in numbers
Wildfires	• Wildfires have become more common
Traditional Culture	• Red willow is used for baskets. Tribal members have noticed more brown dots, which make bad baskets, have had to go farther for harvesting • Environmental Dept. needs to expand and take a more direct positive approach especially to the mentioned invasive and culturally sensitive species: sage-grouse, streams, springs, and riparian areas. • Archaeological/culture sites need protection in and around the reservation. Some of the common village sites that stand threatened by agricultural development are below the reservation; including sacred burial sites, identified and yet to be discovered on BLM, USFS-managed lands. • With the potential 19,000 plus additional acres for the Tribe, this is a big factor. Additional reservation lands 40-50 miles south also need to be monitored.
Agriculture	• Have seen extended growing seasons. However, season gets warm early, then slight cold, then real hot, then a very extended fall, and you need water for that entire period. • Many fields grow meadow hay for cattle
Wind	• White alkali dust blown in from the Black Rock Playa

Burns Paiute Tribe Site Visit Notes from Meetings Held April 20th, 2016	
Topic of Concern	Discussion
Human Health	• Concerns on reservation about allergies and mosquitos • Concerns about impact of influx of people moving to the region and settling on the relatively cheap land, puts more pressure on landscape • Allergies seem to be on the increase
Traditional Foods/ Medicines	• Wildfire often has a negative impact on these listed issues – email comment 5.4 • With bird migration, concerned about mismatch of arrival and availability of food • Important species include: Yupa?, Monkey Flower (around springs), Tuka (like bitter root), Juniper, Sagebrush (had a moth die off 2006) • Less mushrooms, which is an indicator of more dry soils • Important species include: camas fields, wild strawberries, elder berry, apple trees, chokecherries, currants, huckleberries, wada/seep weed (grows around fluctuating lake shoreline), bitterroot, antelope, ground squirrels, rabbits • Animals (like elk) have been acting strange, something is wrong with the environment • Have seen loss of some types of first foods: bitterroot decline with less snowpack; camas root shrinking in habitat and size from diversion of water • Berries are having difficulties • Small mammals seem to be on decrease (specifically ground hogs-yellow belly marmots, which are an important cultural resource) • Burdock roots seem to suffer from increased variability in freeze/thaw cycles • Seem to be less deer and elk around, have to go farther and farther for good hunting • For harvesting roots season has changed, shifted earlier • Development has constrained movement of deer, creates opportunity for more predation • Some feel they should eliminate take of big buck elks (5/6 point) to preserve genetics • Cattails used to be eaten • Drying of marshes has meant less duck eggs/goose eggs
Sagebrush Steppe	• Sagebrush had a moth die-off in 2006 • Tribe has recently acquired more property, trying to figure out how to balance agriculture/haying, ranching/grazing, wildlife, and overall water use. • Junipers are expanding their presence (Tribe has initiated some control cutting measures), junipers can drink up to 300 gal/day (Email correction sent 5.4: 100 gal/day) • Some tribal members feel only a portion of junipers should be cut

Burns Paiute Tribe Site Visit Notes from Meetings Held April 20th, 2016	
Topic of Concern	Discussion
	(perhaps every 3rd? like traditional harvesting…), there are reports that where they have been cut only hard packed dirt remains.
Springs	• Springs are life for water and plants • Over last 30 years, springs becoming more intermittent • Have done some spring head protections
Wildfire	• Recent fires have burned hot and dry, lots of fuel. • Fire season is typically July/August but shifting earlier and later in the season now. • Fire is often caused by lightning. • Fire is often followed by proliferation of non-native grasses (cheatgrass, medusahead) • Wetter weather in spring, encourages plant growth, followed by dry hot summers which turns the plant biomass to fuel • Most areas around reservation do not allow on the ground mechanized fire suppression (mostly fight from air)
Invasive Species	• Medusahead is present and expanding its range. • Increasing cheatgrass • Invasive brook trout and common carp do better with warmer water temperatures • Sage grouse suffer from the presence of these weeds • Invasive species can out-compete native plants in drought conditions
Traditional Culture	• Tribe has over 10,000 years of occupation in the region • Willows are used for cradleboards and baskets • Tules (type of grass) are used for crafts and duck decoys • Traditional practices are difficult to pass down since traditional resources are diminishing • Changes in water have impacted cultural sites, camas fields are most blaring example. • Cedar baskets are important to traditional culture • Native people take only what they need (e.g. only a 1/3 of ducks eggs are harvested at any one time, only take portion of berries). • Traditional movement included fishing down by the Malheur River, hunting in mountains (known as the "Seasonal Round")
Fisheries	• Have bull trout, which needs colder water, some streams already have unsuitable temperatures, spring inputs help cool water • Salmon: have Chinook (recently reintroduced group of 200) and steelhead • Concerned about high water temps • Malheur has been a focus for fish restoration but SOME climate science says it becomes unsuitable for fish habitat? (Email Comment sent 5.4: *They say it is so poor that resources "monies" shouldn't be invested in the region because it is a "nuked" area. They are not considering the riparian*

Burns Paiute Tribe Site Visit Notes from Meetings Held April 20th, 2016	
Topic of Concern	Discussion
	degradation and the site restoration potential.) • Had salmon die offs in the PNW last summer due to high temps
Water Availability	• Oregon Water Resources Department is calling a moratorium on new agricultural wells for a region in Harney Lake Basin and Silvies River Basin until they can complete a study with a 2020-ish deadline. Watershed. These restrictions have been for agriculture, NOT domestic use • Society has tried to turn the surrounding area (a natural desert) into an oasis • Have seen water shortage and poor water quality, more overall drying. • Reduced flows due to water management policies? • Sage grouse need dependent water sources, less water sources = more concentrated populations = more predation • Water levels are generally decreasing • Stock ponds are mostly push-up dams (Email comment sent 5.4: *Water availability in stock ponds really depends on how the snow melts. We can have a wet winter but if the snow comes off slow then we don't have water in the stock ponds. Conversely, we can have a dry winter and if the snow melts fast we could have full stock ponds. My thought is through time with more rain than snow the less likely hood stock ponds will fill.)*
Snowpack	• Have not been experiencing "real" winters recently • Historical winters were very cold. November through March used to have snowstorms
Runoff	• Good water flow in spring, by late July/August is usually drying up
Extreme Events	• There have been lots of wind storms • Have been worrying less about severe winter storms • Extreme weather has allowed noxious weeds to gain a foothold
Riparian Habitat	• Willows seem to be decreasing, there are not enough on the banks (Email comment sent 5.4: *Historic land management has caused that but restoration of those sites under climate change*) • Have red willow and other sub-species: Booth, Geyer's, coyote, red osier dogwood • Willows will lower water temperature, Tribe has a willow restoration effort underway
Temperatures	• Summers have become hotter, more difficult to enjoy
Amphibians	• Less amphibians around, bullfrogs have disappeared
Wet Meadow Habitat	• Marshes are drying, water diversion is contributor

Shoshone-Bannock Tribe Site Visit Notes from Meetings Held April 21st, 2016	
Topic of Concern	Discussion
Habitats	• For proper ecological function, precipitation and temperature patterns must align • In some cases habitat success is determined by extremes (e.g. consecutive days of heat event) • Would be helpful for tribal managers if the vulnerability assessment organizes issues by habitat type
Precip.	• Type of precipitation and extremes are most important issues facing ecosystems • Consecutive drought years (e.g. 3-4 years) could kill off sensitive species, may need to look at risk scenarios to evaluate • In summer rain events have seen whole seasonal rainfall come in a single event (3-4 inches in one day on Bannock Creek)
Snowpack	• Some projections suggest this area will stay transition, is this true? • Lost River goes subsurface currently, will this move from snow to transition? • The Ross Fork watershed is dependent on snowpack
Runoff	• Currently have perennial flow in rivers (don't hit base zero as USGS hydrologic shows). • Reservoir management (i.e. storage & release) has led to a widening of creeks. The storage backs up creeks which saturates side soils, then as the water is released it drops quickly, sloughing the banks and bellying out bends. This means that at low flows streams are wider, more shallow, and therefore warmer.
Temp	• Number of ice free days in the future will be important for wildlife managers • Have existing stream temperature issues in spring creek and clear creek
Fisheries	• Species composition type in streams may change • Tribe has treaty right to harvest salmon in northern, mountainous portion of Upper Snake • Northern, mountainous portion of upper Snake River has ESA Listed: Chinook, steelhead, sockeye, bull trout, sturgeon, lamprey (not ESA listed) • Cutthroat and rainbow trout are sensitive to water temperature, as water temperature goes up fish collect in spring fed areas to stay cool. This fish density can increase disease transmission
Wildlife	• Have beavers in rivers, they improve water quality and storage, able to keep rivers from becoming too "flashy", help set up wet meadows • Wildlife have seen habitat fragmentation and loss with highways and other development • Tribe helps set bag limits for migrating water fowl

Shoshone-Bannock Tribe Site Visit Notes from Meetings Held April 21st, 2016	
Topic of Concern	Discussion
Water Availability	• Tribe has some control over water supply while it is still upstream, need to better control distribution and efficiency • Need to know what the climate impact on groundwater may be • Tribes manage water resources of 581,031 Acre/FT, made up of: groundwater, surface water, lakes/reservoirs, streams originating on reservation • Municipal water use is sometimes restricted • Palisades and Blackfoot reservoirs have extended records available • If farmers begin to plant earlier than they need groundwater earlier, which further depletes runoff at seasonal low flow.
Shrub Steppe	• Experiences high stand-replacement events • Ecosystem has critical recruitment timing, seeds need to fall on insulating snowpack and then migrate to the soil and be nursed by remaining melting snowpack • System includes important species: sagebrush, bitterroot, sage grouse (which recently received a full EIS habitat conservation plan)
Riparian/ Wet-meadow	• System includes important species: chokecherries, currants, serviceberries • Cottonwoods need a scour event to establish themselves, cottonwood corridor on reservation may be lost without these scouring events. Yellow-billed cuckoo uses this corridor and is flagged for protection measures • System can access water through shallow expressions
Traditional Foods	• Important species includes: camas, aspen, elk, deer, ducks • Approximately 5 buffalo are harvested each year in Yellowstone, used for ceremonial purposes
Cedar/ Juniper/ Pinyon Pine	• Species have ceremonial use • Juniper uses a lot of water, will take over range land. Juniper might thrive under increasing precipitation scenario; they don't need snow to germinate. • Juniper is a wildfire risk: it sterilizes the soil, stands stack up as fuel. • Juniper does offer thermal cover to keep wildlife warm.
Springs	• Tribe has both warm and cold springs • "Bottoms" springs put out 1.7 million acre/feet a year • Fenced one spring last year • Springs are used for ceremonial purposes; many tribal members want to know if they are "safe" for these purposes
Water Quality	• Overall Pocatello has poor water quality, including "303" listings for: mercury, ethaline dibromide (from potato farmers fighting nematodes) • Algae growth is increasing, seeing it in American Falls Reservoir • Springs are used for ceremonial purposes, many tribal members want to know if they are "safe" for these purposes

Shoshone-Bannock Tribe Site Visit Notes from Meetings Held April 21st, 2016	
Topic of Concern	Discussion
Wildfire	• In the past, vegetation was dry for fire by June, now dry by May. • Post-fire, perennial invasive species take hold: cheatgrass, June grass
Agriculture	• Farmers have been starting one month earlier with their plantings and associated water use. What will this mean for water availability later in the summer? • Tribal Farms are made up by a patchwork of properties, tribe has: 3,000 - 5,000 acres -> alfalfa, potatoes (28% of Idaho production) • The Bureau of Reclamation makes sure agriculture is the priority for water use, NOT fish: 90,000 acres irrigated, 104,000 acres in production. • Tribe manages water supply for agriculture. Permits for groundwater are just getting started. • Agriculture and water use is usually active March 15th-Nov 15th. Have meters on large lines. Water use is connected with range use have: stock water, irrigation, spread water out for stock tanks. • Recently wheat farmers have been getting done with their crop by July 15th, in the past it was August or September
Cattle	• Tribe manages rangelands through range units - Cattle are rotated through different range units at different times of year. • Rangeland plant species are changing, cattle are not getting the right nutrients • Grass seasons are starting earlier and may no longer be matched up with management of range units - Seeing a mismatch between traditional dates for use of certain areas and the availability of grass on those sites. Sometimes the grass is maturing sooner and going to seed as the cattle are released into the area. • Ranching is part of tribal identity • The Tribe itself does not own cattle but tribal members do. Tribe owns approximately 300 buffalo.
Human Health	• There is a perception among tribal members that the entire landscape is contaminated.

Appendix C: Climate Change Vulnerability Index Analysis

Data Sources and Climate Scenarios

The Climate Change Vulnerability Index (CCVI) assessment requires historical temperature and precipitation data for the assessment area; projected temperature and moisture change; spatial data layers of target species ranges; and information on species life history characteristics (Table C1).

To assess as many species as possible, the project team relied heavily on existing databases of species characteristics and climate sensitivities, using the primary literature to supplement as needed. In addition, we incorporated local information provided by the Upper Snake River Tribes (USRT). The primary databases used in this assessment include: NatureServe Explorer, Fire Effects Information System, and the Climate Change Sensitivity Database. Detailed methods and data sources are described below (Table C1).

Table C1: *Primary Data types used in CCVI Analysis*

Data Type	Source
Temperature Projections	MACA (described in Appendix A)
Moisture Projections	MACA (described in Appendix A)
Historic Temperature	MACA (described in Appendix A)
Historic Moisture	MACA (described in Appendix A)
Sea Level Rise	Not Relevant for Study Area
Species Distributions	IUCN (http://www.iucnredlist.org/technical-documents/spatial-data); StreamNet (http://www.streamnet.org/data/interactive-maps-and-gis-data/); GECSC: Tree Species Distribution Map for North America (http://gec.cr.usgs.gov/data/little/)
Species Life History	NatureServe Explorer (http://explorer.natureserve.org/); Sensitivity Database (http://climatechangesensitivity.org/); The Birds of North America Online (http://bna.birds.cornell.edu/bna/species); USDA Forest Service (http://www.fs.fed.us/database/feis/plants/); AmphibiaWeb (http://amphibiaweb.org/search/index.html); Upper Snake River Tribe staff/member (*personal communication*)

CCVI scores were calculated for two time horizons: the 2050s (2040-2069) and the 2080s (2070-2099). We used MACA statistically downscaled climate data from CMIP 5[3] for projected temperature and moisture changes for both time horizons (relative to the historical 1961-1990 baseline average) across the USRT project area. We generated projections for each time horizon using two climate change scenarios from the IPCC Fifth Assessment: RCP 4.5 and RCP 8.5.**Error! Bookmark not defined.**,[4] The scenarios were developed by climate modeling centers for use in modeling global and regional climate impacts.

Using the climate model output, the project team calculated projected changes in moisture using a moisture metric—referred to here as the Hamon moisture metric (HMM)—which was calculated based on the Hamon potential evapotranspiration equation (Hamon 1961). The HMM quantifies the ratio between available water (based on precipitation) and evaporative demand (based on

[3](IPCC) Intergovernmental Panel on Climate Change. 2013. Working Group 1, Summary for Policymakers. Available at: http://www.climatechange2013.org/images/uploads/WGIAR5--SPM_Approved27Sep2013.pdf.

[4] Using a 20-model ensemble average.

temperature and number of daylight hours). HMM projections were generated for the 2050s (2040-2069) and the 2080s (2070-2099), under both RCP 4.5 and RCP 8.5.

Air temperature projections were classified using a continuous binning structure defined by NatureServe[5] (Young et al. 2015). The six temperature bins include:

(1) >6.0° F (3.3° C) warmer
(2) 5.6-6.0° F (3.1° C) warmer
(3) 5.1-5.5° F (2.8-3.1° C) warmer
(4) 4.5-5.0° F (2.5-2.7° C) warmer
(5) 3.9-4.4° F (2.2-2.4° C) warmer
(6) < 3.9° F (2.2° C) warmer

Moisture bins represent the predicted percent change in Hamon AET:PET moisture metric, 2040-2069 and 2080-2099 (based on RCP 4.5 and RCP 8.5). They express a percent change, with negative values indicating net drying. The six moisture bins include:

(1) < -11.9%
(2) -9.7% to -11.9%
(3) -7.4% to -9.6%
(4) -5.1 to -7.3%
(5) -2.8 to -5.0%
(6) > -2.8%

Each species is then evaluated based on specific life history characteristics and other factors that affect the species sensitivity to changing climate conditions or its ability to respond to those changes. The 23 factors are described in Table C2.

[5] Young, B.E, Byers, E., Gravuer, K., Hall, K., Hammerson, G., Redder, A., Cordeiro, J., and Szabo, K. 2011. Guidelines for Using the NatureServe Climate Change Vulnerability Index, version 2.1. Arlington, Va.: NatureServe.

Table C2. Factors used to evaluate species climate vulnerability in the CCVI analysis.

Factor	Description
Indirect Climate Exposure Factors	
Sea Level Rise	Effects of sea level rise on species habitat (not relevant for USRT species)
Natural Barriers	Geographical features of the landscape that may restrict a species from naturally dispersing to new areas
Anthropogenic Barriers	Features of anthropogenically altered landscapes (urban or agricultural areas, roads, dams, culverts) that may hinder dispersal for terrestrial and aquatic species
Climate Change Mitigation	Effects of land use changes resulting from human responses to climate change (seawall development, wind farm, biofuel production)
Species Sensitivity and Adaptive Capacity Factors	
Dispersal / Movement	Ability of species to disperse or migrate across the landscape to new locations as conditions change over time
Historical Thermal Niche	Exposure to temperature variation over the past 50 years
Physiological Thermal Niche	Dependence on cool or cold habitats within the assessment area
Historical Hydrological Niche	Exposure to precipitation variation over the past 50 years
Physiological Hydrological Niche	Dependence on a specific precipitation or hydrologic regime
Disturbance	Dependence on a specific disturbance regime likely to be impacted by climate change
Dependence on Ice / Snow	Dependence on ice, ice-edge, or snow-cover habitats
Restriction to Uncommon Geologic Features	Dependence on specific substrates, soils, or physical features such as caves, cliffs, or sand dunes
Habitat Creation	Dependence on another species to generate habitat
Dietary Versatility	(Animals Only) Breadth of food types consumed; dietary specialists vs. generalists
Pollinator Versatility	(Plants Only) Number of pollinator species
Propagule Dispersal	Dependence on other species for propagule dispersal
Sensitivity to Pathogens or Natural Enemies	Pathogens and natural enemies (e.g., predators, parasitoids, herbivores, and parasite vectors) that can increase or become more pathogenic due to climate change
Sensitivity to Competition from Native or Non-native Species	Species may suffer when competitors are favored by changing climates
Interspecific Interactions	Other interspecific interactions not including diet, pollination, and habitat creation
Genetic Variation	Measured genetic variation (high, medium, low)
Genetic Bottlenecks	Occurrence of bottlenecks in recent evolutionary history
Reproductive System (plants only)	A plant’s reproductive system may serve as a proxy for a species’ genetic variation or capacity to adapt to novel climatic conditions
Phenological Response	Phenological response to changing seasonal temperature and precipitation dynamics

The relationship of how these factors are used to determine the overall climate vulnerability of a specific species is show below. The products of exposure and sensitivities generate sub-scores, which are summed to generate a species' overall vulnerability score.

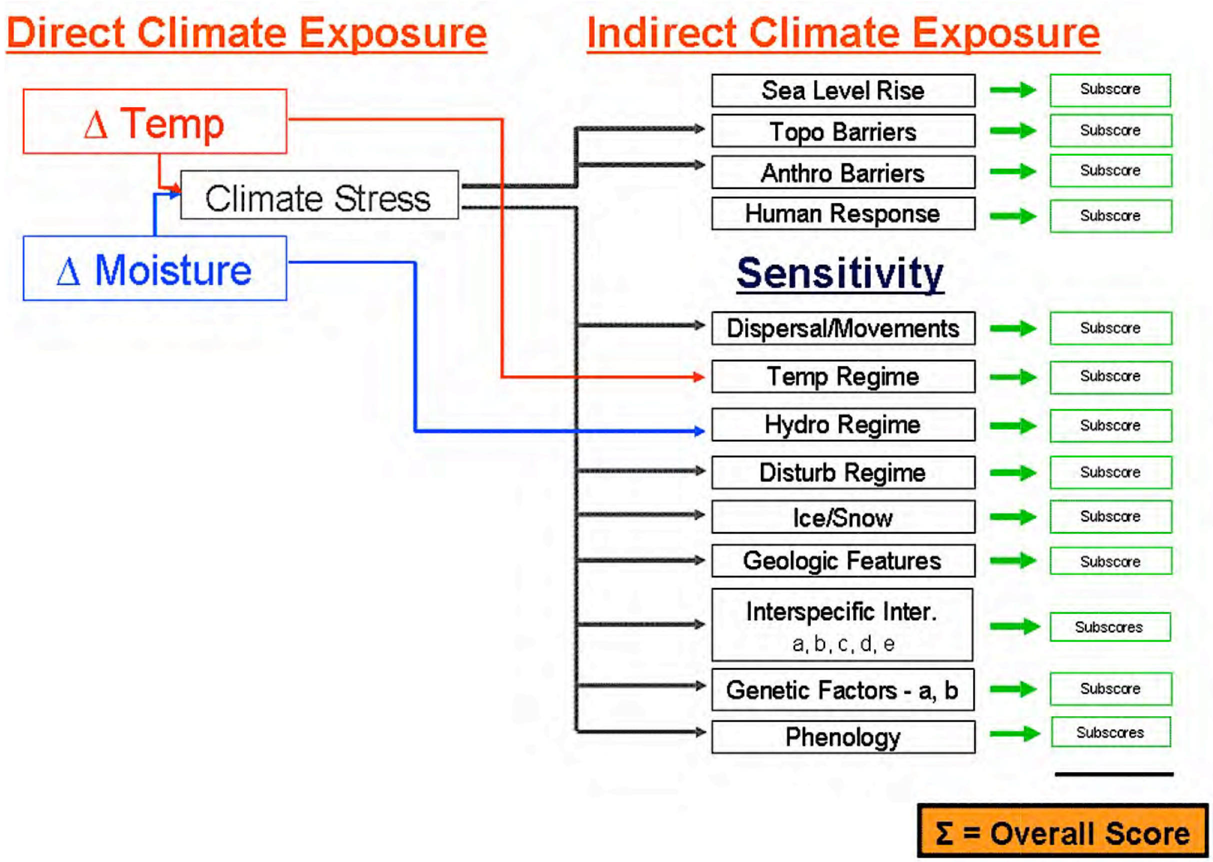

Figure C1: *Inputs to the NatureServe CCVI (from Young et al. 2011). The CCVI measures climate change vulnerability based on direct exposure to local climate change (e.g., changes in temperature and moisture), indirect climate exposure (e.g., anthropogenic barriers), and species sensitivity factors (e.g., dispersal capacity). The products of exposure and sensitivities generate sub-scores, which are summed to generate a species' overall vulnerability score.*

Quantitatively Assessed Species Results

Quantitatively (CCVI) Assessed Species

English Name	Group	Sea level	Natural barriers	Anthropogenic barriers	Climate change	Dispersal/Movement	Historical thermal niche	Physiol. thermal niche	Historical hydrol. niche	Physiol. hydrol. niche	Dependence on	Dependence on ice/snow	Physical habitat features	Other species for habitat	Dietary specificity	Pollinator specificity	Other species for	Pathogens/enemies	Competition	Other species interaction	Genetic variation	Genetic bottleneck	Reproductive system	Phenological response	Documented response	2050s; RCP4.5	2050s, RCP 8.5	2080s; RCP4.5	2080s, RCP 8.5
																										Index			
Columbia Spotted Frog	Amphibian	N	SI	SI	N	SI	N	N	N	Inc	U	N	N	N	N	N/A	N	Inc	N	N	Inc	N	U	N	U	HV	EV	EV	EV
Bull Trout	Fish	N	N	Inc	SI	N	N	GI	N	GI	Inc	N	N	N	N	N/A	N	Inc	Inc	N	Inc	N/A	N/A	U	U	EV	EV	EV	EV
Chinook Salmon	Fish	N	N	Inc	SI	N	N	GI	N	GI	Inc	N	N	N	N	N/A	N	Inc	SI	N	SI	N/A	N/A	Inc	U	EV	EV	EV	EV
Redband Trout	Fish	N	N	Inc	SI	N	N	Inc	N	GI	Inc	N	N	N	N	N/A	N	Inc	SI	N	N	N/A	N/A	U	U	EV	EV	EV	EV
Steelhead	Fish	N	N	Inc	SI	N	N	GI	N	GI	Inc	N	N	N	N	N/A	N	Inc	SI	N	N	N/A	N/A	U	U	EV	EV	EV	EV
Golden Eagle	Bird	N	N	N	SI	N	N	N	N	N	U	N	N	N	N	N/A	N	SI	N	N	N	N/A	N/A	N	U	LV	LV	LV	LV
American Beaver	Mammal	N	N	SI	N	N	N	N	N	SI	N	N	N	N	N	N/A	N	N	N	N	N	N/A	N/A	U	U	LV	LV	LV	LV
Black-tailed Jackrabbit	Mammal	N	N	SI	SI	N	N	N	N	N	Inc	N	N	N	N	N/A	N	SI	N	N	U	U	U	U	U	MV	HV	HV	HV
Elk	Mammal	N	N	SI	N	N	N	N	N	SI	N	N	N	N	N	N/A	N	SI	SI	N	Inc	N/A	N/A	U	U	MV	HV	HV	HV
Mule Deer	Mammal	N	N	SI	N	N	N	N	N	SI	N	N	N	N	N	N/A	N	SI	SI	N	N	N/A	N/A	N	U	LV	MV	MV	MV
Big Sagebrush	Plant	N	N	N	SI	GI	N	N	N	N	SI	N	N	N	N/A	N	N	U	SI	N	N	N/A	N/A	U	U	MV	HV	HV	HV
Black Cottonwood	Plant	N	N	N	N	SI-N	N	N	N	SI	SI	N	SI	N	N/A	N	N	SI	N	N	N	N/A	N/A	U	U	LV	MV	MV	MV
Common Chokecherry	Plant	N	N	N	N	N	N	N	N	SI	N	N	N	N	N/A	N	N	SI	N	N	U	N	N/A	U	U	LV	LV	LV	LV
Geyer's Willow	Plant	N	N	N	N	N	N	N	N	SI	N	N	N	SI-N	N/A	N	N	U	N	N	U	U	N	U	U	LV	LV	LV	LV
Quaking Aspen	Plant	N	N	N	N	SI	N	SI	N	N	N	N	N	N	N/A	N	N	SI	N	N	N	N/A	N/A	U	U	LV	MV	MV	MV
Redosier Dogwood	Plant	N	N	N	N	N	N	N	N	SI	N	N	N	N	N/A	N	N	U	U	N	U	U	N	U	U	LV	LV	LV	LV

Figure C2: *Detailed inputs (columns 3-26) for each species (rows). The inputs are determined based on how a particular factor (column) affects a species' climate exposure, sensitivity, and adaptive capacity. The detailed results are shown for two time periods (2050s and 2080s) and two climate scenarios (less warming [RCP 4.5] and more warming [RCP 8.5]) for each species, and color coded and labeled based on overall vulnerability ranking. The vulnerability rankings are: LV = Less Vulnerable; MV = Moderately Vulnerable; HV = Highly Vulnerable, and EV = Extremely Vulnerable.*

Qualitative Climate Change Vulnerability Assessment

Species **-** Four species could not be assessed quantitatively using the CCVI due to lack of species range data. The project team assessed these species' climate sensitivities within the project area using the CCVI sensitivity factors. The results of this assessment can be used to identify factors expected to increase these species' climate change vulnerabilities.

Habitats **-** The project team did not use the CCVI to assess the climate change vulnerability of habitats. Instead, the climate change vulnerability of habitats was estimated based on their climate change sensitivity and projected exposure to climate change within the Upper Snake River Watershed. Sensitivity values were taken from the Climate Change Sensitivity Database (climatechangesensitivity.org), a publicly available, online database that summarizes information from peer-reviewed literature and expert knowledge.

Climate Change Sensitivity rankings in the database were determined by habitat experts engaged through regional workshops and/or and independent assessment. This included approximately 300 experts with a diversity of backgrounds, expertise, and affiliations[6]; all held advanced graduate degrees in ecology, forestry, or biology. All species and habitat profiles were completed between 2009 and 2012.

Results

Here we provide a review of the analysis results for the 16 species analyzed using the CCVI, and the three habitat types evaluated qualitatively. Additional detail on the individual species is available in the main report, Section IV.

Key Findings for Sagebrush Steppe Habitat

Sagebrush steppe is a widespread arid ecosystem in the western U.S. The distribution of sagebrush steppe is controlled by seasonal temperatures; it is typically found in regions with cold winters and hot summers. Projected increases in temperature, and subsequent increases in potential evapotranspiration, could further reduce soil moisture levels within the ecosystem. Despite deep root systems which enable some sagebrush species to survive periods with reduced water availability in late-spring and summer months, this habitat is still susceptible to drought in summer and winter. In addition to being slightly sensitive to both temperature and precipitation, the sagebrush steppe ecosystem is also susceptible to invasion from cheatgrass and juniper trees, which is expected to increase across the western United States with climate change. In addition, this ecosystem is susceptible to an increasing fire interval, which reduces the likelihood of sagebrush establishment following disturbance. Fires in the western U.S. are expected to become more frequent and severe with climate change.

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[6] U.S. Forest Service, U.S. National Park Service, U.S. Fish and Wildlife Service, U.S. Bureau of Land Management, Washington Department of Natural Resources, Washington Department of Fish and Wildlife, Oregon Department of Fish and Wildlife, Idaho Department of Fish and Game, University of Washington, University of Idaho, Idaho Cooperative Fish and Wildlife Research Unit, Washington Natural Heritage Program, Canadian Forest Service, Parks Canada, The Nature Conservancy, National Wildlife Federation, and a number of Tribes and First Nations.

Key Findings for Riparian Habitat

Riparian zones within the USRT assessment area are found along rivers and adjacent to bodies of water with cooler climates. These riparian habitats are considered moderately sensitive to temperature changes because warming temperatures could lower water levels and dry out small creeks. Drying of these streams could affect the species composition and structure of these riparian habitats. Riparian habitats are also somewhat sensitive to precipitation. Soil moisture level is an important factor for species structure and composition in riparian communities. In addition to temperature and precipitation sensitivity, riparian habitats are also sensitive to disturbances such as flooding and competition from non-native species. Shifts in streamflow volume and timing will affect water tables and soil moisture levels within riparian habitats. In addition, riparian habitats are sensitive to invasions from non-native species.

Key Findings for Wet Meadow Habitat

Wet-meadow habitat is generally found in high-elevation (3,300-9,800 feet) regions and is dominated by herbaceous species. Wet meadow habitats are highly sensitive to both temperature and precipitation changes. Because soil moisture plays such a critical role in wet-meadow establishment and suitability, increasing temperatures could further decrease soil moisture levels through increases in potential evapotranspiration, subsequently reducing the area of suitable wet-meadow habitat in the project area. Projected declines in snowpack, resulting from a greater proportion of winter precipitation falling as rain rather than snow, will reduce summer soil moisture, a significant determinant of plant growth. In addition to sensitivity to temperature and precipitation changes, wet meadow habitats are also susceptible to the indirect effects of climate change including fire, flooding, and wind.

Appendix D: GIS Analysis

GIS Data Sources, Process, and Methods

This section summarizes the Geographic Information Systems (GIS) data sources, processes, and methods used to prepare data inputs for the Climate Change Vulnerability Index (CCVI) tool and to map climate change projections for the project area encompassing the Upper Snake River Tribes (USRT) member tribes. All GIS data and maps developed as part of this project have been provided to USRT for future reference and use.

Data Sources

The following GIS layers were obtained from USRT with the original source information provided. These layers were used to create the basemap of the climate projection figures.

- Hydrography, USGS National Hydrography Dataset (NHD), http://nhd.usgs.gov/
- Digital Elevation Model-250m (DEM)

Data Processing and Mapping

For this project, a standard horizontal datum, WGS 1984 (World Geodetic Survey 1984), was applied to all GIS layers in order to assure consistency and accuracy between multiple datasets. The NAD 1983 Albers projection was used for map design and area calculations. Map layout and design was created using ESRI ArcMap 10.3.3 software.

Project Boundary

The project boundary was created to include specific regions of concern based on input from USRT member tribes and USRT staff. The project boundary layer was used to clip the climate and species range GIS layers to create consistent inputs for the CCVI analysis by confining generated inputs to only the project area. This allowed the CCVI vulnerability rankings to be specific to the vulnerability of the species in this area.

Climate Maps

A total of eight climate projection maps were developed as part of this report to assess and display changes for both temperature and moisture. Projections for the 2050s and the 2080s time horizons were created for both Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 emissions scenarios, resulting in four total scenarios for each climate parameter.

Each temperature change raster was converted from degrees change Celsius to degrees change Fahrenheit, by multiplying the value of each raster cell by a conversion factor of 1.8. A common color scale based on the full range of temperature change values across all four scenarios was used to display changes. This approach was the best way to best illustrate both the degree of change for each scenario and the relative differences between each climate scenario and time horizon.

No further conversions were required for the moisture change raster. A color scale depicting a range of -20% to +20% change was used to display changes for all scenarios in order to show the degree and direction of change within and between RCP and time horizon scenarios.

Species Specific Layers for CCVI Analyses

To generate the inputs needed for individual species analysis using the CCVI tool, the climate layers needed to be reclassified and clipped to spatial range extent obtained for each species within the project area. First, species distribution maps were clipped to the overall project area. Next, the temperature and moisture projections were reclassified using the binning structures provided in Appendix C. Each of the binned climate projections were then re-clipped using each clipped species extent as the extraction mask, resulting in binned climate layers with the same spatial extent as the species distribution.

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Projections of 21st century climate of the Columbia River Basin

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Abstract Simulations from 35 global climate models (GCMs) in the Coupled Model Intercomparison Project Phase 5 provide projections of 21st century climate in the Columbia River Basin under scenarios of anthropogenic activity given by Representative Concentration Pathways (RCP4.5 and RCP8.5). The multi-model ensemble 30-year mean annual temperature increases by 2.8 °C (5.0 °C) by late 21st century under RCP4.5 (RCP8.5) over the 1979–1990 baseline, with 18% (24%) more warming in summer. By late 21st century, annual precipitation increases by 5% (8%), with an 8% (14%) winter increase and a 4% (10%) summer decrease, but because some models project changes of opposite sign, confidence in these sign changes is lower than those for temperature. Four questions about temperature and precipitation changes were addressed: (1) How and why do climate projections vary seasonally? (2) Is interannual variability in seasonal temperature and precipitation projected to change? (3) What explains the large inter-model spread in the projections? (4) Do projected changes in climate depend on model skill? Changes in precipitation and temperature vary seasonally as a result of changes in large-scale circulation and regional surface energy budget, respectively. Interannual temperature variability decreases slightly during the cool seasons and increases in summer, while interannual precipitation variability increases in all seasons. The magnitude of regional warming is linked to models' global climate sensitivity, whereas internal variability dominates the inter-model spread of precipitation changes. Lastly, GCMs that better reproduce historical climate tend to project greater warming and larger precipitation increases, though these results depend on the evaluation method.

Keywords CMIP5 · Projections · RCP4.5 · RCP8.5 · Columbia River Basin · Variability · Fidelity · Variance partition

1 Introduction

Anthropogenic climate change is expected to impact hydroelectric power generation, flood risk management, agricultural water supply, and ecosystems in the Columbia River Basin (CRB) of the northwestern United States (US) and British Columbia, Canada (Osborn 2012). Uncertainty in the magnitude of climate change clouds the future of these facets of the CRB, which are already under pressures as human populations grow, ecosystems degrade, infrastructure ages, and energy sources shift towards non-fossil fuels (Cosens 2010; McKinney et al. 2010).

Anticipated renegotiation of the Columbia River Treaty between the US and Canada motivates immediate recognition of climate change in policy and management (Osborn 2012). The Treaty, ratified in 1964, defines how hydropower operations are coordinated for electrical power generation and flood risk management. Barring new negotiations, beginning in 2024 the US will no longer manage floodwater storage in the Canadian reservoirs built pursuant

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to the Treaty and will have to rely on reservoirs within the country to manage flood risk.

Incorporating climate projections for the 21st century is a critical part of the process of modernizing the Treaty so that it promotes the sustainability of natural resources for all sovereign parties with interests in the basin. The precise trajectory of the regional climate is not known, but depends on anthropogenic activity (e.g., greenhouse gas (GHG) emissions and land use changes) and natural phenomena (e.g., volcanic emissions, solar irradiance, and the multi-scale "internal" variability of the complex earth system). To date, the primary source of climate projections is the Coupled Model Intercomparison Project (CMIP) of which CMIP5 is the latest completed phase (Taylor et al. 2012). CMIP5 generated hundreds of climate projections using over 35 global climate models (GCMs) and a number of experiments representing the effects of future anthropogenic activity under four scenarios known as Representative Concentration Pathways (RCPs).

While regional warming is a clear response to increased GHG concentrations, changes in precipitation may vary strongly regionally and seasonally in sign and magnitude due to thermodynamic and dynamic factors (e.g., Seager et al. 2010). In winter, precipitation is projected to increase north of roughly 35° N throughout North America (Maloney et al. 2014) and though CMIP5 GCM simulations differ notably among themselves in their dynamical responses to increased GHGs, a majority of models show a propensity for greater winter precipitation in the northwest US (e.g., Mote et al. 2013). Weather systems, such as atmospheric rivers, that historically bring substantial winter precipitation and cause the large majority of floods in West Coast states (Dettinger 2013), will carry more moisture, resulting in yet more precipitation (Gao et al. 2015; Payne and Magnusdottir 2015; Warner et al. 2015). Climate models also show evidence of a strengthening and southeastward extension of the Aleutian low in winter under enhanced GHG forcing (Seager et al. 2014b). The geostrophic response to this strengthening results in an increase in the strength of southerly flow toward the CRB (Seager et al. 2014b; Simpson et al. 2015) and slight decrease in the strength of the westerly flow (e.g., Luce et al. 2013). An intensification of the subtropical jet over the North Pacific south of the region is also projected (Neelin et al. 2013) coinciding with increased storm track activity off the west coast of the US (e.g., Chang 2013; Chang et al. 2015). With respect to precipitation, the zone of influence of the dynamical changes listed above appears to diminish rapidly away from the coast toward the continental interior where cyclonic activity is projected to decrease (Seager et al. 2014b; Chang et al. 2015; Simpson et al. 2015).

For summer, in contrast to those results for winter, CMIP5 simulations point to a decrease in precipitation over the northwest US (Maloney et al. 2014). Historically, regionally averaged seasonal rainfall is already lower in summer than in other seasons because of subsidence from the North Pacific subtropical high and northerly migration of the polar jet (Mock 1996). A northward expansion of the North Pacific subtropical high coincident with the drying over the northwest US is projected under enhanced GHG forcing (Seager et al. 2014b) coincident with a significant decrease in storm track activity across the CRB (Chang 2013).

A few studies have summarized CMIP5 climate projections specifically for the northwest US and CRB (Mote et al. 2013; Rana and Moradkhani 2015; Vano et al. 2015). Mote et al. (2013) report changes in mean annual and seasonal temperature and precipitation averaged over the Northwest US and show strong commonality between results of CMIP5 to CMIP3 experiments, though with greater overall warming in CMIP5 (see also Mote and Salathé (2010) for CMIP3 projections). Vano et al. (2015) give changes in mean annual temperature and precipitation covering several sub-regions of the CRB. Rana and Moradkhani (2015) provide changes in mean monthly-to-annual temperature and precipitation in the CRB from 10 (of over 35) CMIP5 GCMs. They also use bias-corrected and statistically downscaled GCM simulations; these steps may modify the patterns of change in ways that obscure the original GCM patterns (e.g., Ficklin et al. 2016).

While these studies provide statistical summaries of climate change in the CRB region they do not address (1) factors that contribute to seasonal differences, (2) whether interannual variability is projected to change, (3) factors that contribute to the large spread in projections across GCM simulations, and (4) whether the fidelity of simulations compared to historical conditions relates to the magnitude of projected change. This study addresses four knowledge gaps in regional climate projections for the CRB that are of practical interest for water resources, energy, and land management planning.

What drives the seasonal differences in the regional climate response? Seasonal difference in rates of regional climate change is a persistent feature in CMIP multi-model ensemble average projections (Mote and Salathé 2010; Mote et al. 2013). For example, a vast majority of models project accentuated warming during the summer across the region and declines in precipitation. We explore the extent to which changes in atmospheric circulation and fluxes in surface energy and water explain the seasonal variability in regional climate change.

Will the region's climate become more variable on a year-to-year basis? Though changes in climatic means have significant implications, changes in variability may compound or mitigate effects of changing means for climate impacts that historically occur in the tails of the distribution. Although aspects of changes in climate variability have been examined at globally at coarse spatial scales (Räisänen 2002), no known study has assessed changes in CRB climate variability on seasonal timescales. Here we examine changes in inter-annual variability of seasonally averaged temperature and precipitation, but do not examine changes in extremes that occur on much shorter time scales (e.g., daily) and have been reviewed elsewhere (e.g., Sillmann et al. 2013).

What causes the large spread in the distribution of regional climate projections? The inter-model and intra-model variability in projected changes in temperature and precipitation presents a challenge for assessing climate change impacts as some impacts in the region would be significantly different at the endpoints of the range in projections. This spread in CMIP5 GCM projections arises not only from multiple forcing scenarios (scenario uncertainty), but also from differences in sensitivity of the GCMs to the applied forcings (model uncertainty) and from the influence of initial conditions (internal variability) (e.g., Tebaldi and Knutti 2007; Hawkins and Sutton 2009). Like others, our objective is to partition the spread in projections for a given RCP into model uncertainty and internal variability. However, we take an additional step of apportioning a fraction of the variance in regional changes in temperature and precipitation to the changes in the global mean temperature, assuming that the change in the global mean temperature, averaged over a few decades, is closely linked to the transient climate response of a GCM.

Does regional GCM fidelity affect regional climate response? CMIP5 GCMs have known biases. In the western US they, on average, produce an annual climate that is too wet and slightly too cool and slightly overpredict the magnitude of the seasonal temperature cycle (Flato et al. 2013). Such biases may arise from errors in feedbacks strengths. For example, an exaggerated seasonal cycle may point to deficiencies in how land-surface atmosphere interactions are simulated, which in turn may affect how the regional surface energy balance, and thus the regional temperature, responds to increased GHG forcing (Christensen and Boberg 2012).

It has been suggested, therefore, that GCM fidelity (i.e., how well it performs against observations) be used as one basis for weighting regional climate projections (e.g., Giorgi and Mearns 2002; Brekke et al. 2008; Mote and Salathé 2010) or for selecting a subset of simulations for impacts studies (e.g., Pitman and Perkins 2008; Mote et al. 2011; Vano et al. 2015; Ahmadalipour et al. 2015), though not without some criticism (Christensen et al. 2010; Weigel et al. 2010). This suggestion assumes that better performing GCMs project changes in climate that differ from the entire multi-model ensemble. For the Northwest US and using CMIP3 GCMs, Mote and Salathé (2010) note that "reliability" weighting had little effect on the ensemble average change, though Christensen and Boberg (2012) found that CMIP5 GCMs with a warm bias over western Northern America tend to project more warming there. Using a more comprehensive set of evaluation approaches for assessing model fidelity with CMIP5 models (Rupp et al. 2013; Payne and Magnusdottir 2015; Ahmadalipour et al. 2015) we ask how much GCM fidelity alone statistically explains the variance in the magnitude of seasonal temperature and precipitation projections for the CRB.

2 Data and methods

2.1 Data and processing

Monthly outputs of variables were acquired from 35 CMIP5 GCMs (Table S1) for the historical, RCP4.5, and RCP8.5 experiments described by Meinshausen et al. (2011). In many cases, modeling groups provided more than one simulation per GCM—an ensemble. We acquired all ensemble members (up to 10) from each GCM that were available as of January 2015 for mean near-surface temperature (T) and precipitation (P). Besides T and P, the following diagnostic variables were acquired but for just the first ensemble member (denoted as "r1i1p1") from the historical and RCP8.5 experiments: downward and upward radiative shortwave flux at the surface (rsds and rsus, respectively), upward sensible heat flux at the surface (hfss), upward latent heat flux at the surface (hfls), and the zonal (ua) and meridional (va) wind at the 300-hPa level.

Model fields were regridded to a common grid with 1-degree latitude and longitude resolution through an inverse-distance-weighting algorithm. This resolution is similar to that of the finest resolution used by CMIP5 GCMs (Table S1). At the scale of the CRB, effects of smoothing arising from interpolation on projections from a single GCM are very minor relative to differences in projections among GCMs. Domain-wide values were calculated by averaging all pixels whose centers fell within CRB boundary upstream from Bonneville Dam (Fig. S1). We excluded the basin area downstream of Bonneville Dam for four reasons: (1) to avoid including grid cells that may be composed of both ocean and land, (2) the sea-land warming gradient that results in land cells along the coast warming less than cells in the interior (e.g., Rupp et al. 2016), (3) the CRB downstream of Bonneville is primarily fed by tributaries whose source waters lie in western slopes of the Cascade Range that are distinctly warmer and wetter than headwaters of the CRB, and (4) Bonneville Dam is the most downstream dam on the mainstem of the Columbia River, so how climate will change upstream of the dam is of practical interest for water resource considerations.

The mean and inter-annual variability for a given variable were computed as the average and standard deviation over a 30-year period (e.g., 1970–1999) for each calendar month and/or season. (We acknowledge that "variability" has facets that are not explicitly characterized by the second statistical moment, but we consider this a logical first step.) Change (Δ) was calculated as the difference in the "climate" of two 30-year periods. When estimating the standard deviation within a 30-year period, we wanted to exclude the effect of non-stationarity in the climatic mean (e.g., Räisänen 2002). To do so, we filtered out the long-term trend in each annual time series (1900–2099) of seasonal values using a Gaussian filter, acknowledging that we may be removing some low frequency (i.e., decadal-scale and longer) natural variability. The filter window had a standard deviation of 15 years. We tested the sensitivity to window size by increasing and decreasing it by a few years, but the effect on the end result was minor.

2.2 Partitioning the variance in projections

We partitioned the variance in the multi-model ensemble of temperature and precipitation projections into various components. Though this is sometimes referred to as "partitioning uncertainty" or "separating the sources of uncertainty" (Hawkins and Sutton 2009, 2011), we avoid such terminology because it evokes the somewhat philosophical matter of conflating uncertainty with the distribution of model projections.

We partitioned the variance into three components: (1) internal variability, (2) the regional response that tracks the transient response of global-mean temperature, (3) and the remainder. By treating RCP4.5 and RCP8.5 separately, we did not concern ourselves with the inter-scenario differences in projections. Internal variability is defined in this study as temporal variability that exists irrespective of anthropogenic forcing. The regional response that tracks the transient response of global-mean temperature, hereon referred to as the "global component", is calculated as the fraction of the variance of the multi-model ensemble of regional projections that is statistically explained by the projections of the globally averaged temperature. Finally, the third component is the fraction of variance that remains after accounting for the first two components. It can be thought of as being composed of those inter-model differences in sub-global responses to anthropogenic forcing that lead to inter-model differences in regional projections. For brevity, we call this the "regional component".

Various methods have been used to estimate internal variability. Hawkins and Sutton (2009, 2011), for example, fitted a fourth order polynomial to a time series of individual simulations and let the residuals from the regression represent internal variability. Long control simulations with forcings kept constant at pre-industrial (circa 1850) levels (see the "piControl" experiment in CMIP5) can also be used to estimate internal variability (e.g., Räisänen 2002). We used a third method, which estimates internal variability from the variance of the intra-GCM ensembles of projections. All these methods have their advantages and disadvantages. Our chosen method suffers from not having multiple simulations from all GCMs, but does not require additional data. The simplest method of the three—the fitting of a fourth order polynomial—involves the rather arbitrary and ad hoc decision to apply some particular function. Using control simulations requires the most data processing; moreover, the control runs do not include non-anthropogenic forcings that influence natural variability, such as volcanic eruptions and solar variability.

The intra-GCM ensemble variance in projections, s_{IV}^2, was estimated using GCMs with at least three ensembles members (12 GCMs for RCP4.5 and 10 GCMs for RCP8.5). The intra-GCM variance was calculated as

$$s_{IV}^2 = \frac{\sum_{j=1}^{n}\left[\sum_{i=1}^{m_j}(x_{i,j}-\bar{x}_j)^2\right]}{\sum_{j=1}^{n}(m_j-1)} \quad (1)$$

where x is the projected change (ΔT or ΔP), i indexes the ensemble member for jth GCM, m_j is the number of ensemble members for the jth GCM, n is the number of GCMs, and

$$\bar{x}_j = \frac{1}{m_j}\sum_{i=1}^{m_j} x_{i,j} \quad (2)$$

The intra-GCM (i.e., internal variability) fraction IV of the total variance is s_{IV}^2/s_{total}^2 where s_{total}^2 is the total variance across all simulations N (all ensemble members and all GCMs) and is given by

$$s_{total}^2 = \frac{\sum_{k=1}^{N}(x_k-\bar{x})^2}{N-1} \quad (3)$$

The global component of the variance was estimated using linear least squares regression, regressing regional ΔT and regional ΔP against global ΔT calculated over the same time period. All GCMs and all ensemble members were used. The coefficient of determination (R^2) of the regression became the global component fraction of the variance. Lastly, the regional component fraction of the variance was calculated as 1—R^2—IV. It is possible that R^2 and IV could sum to more than 1. In that case, both R^2 and IV were multiplied by 1/(R^2+IV) so that the two terms summed to 1 exactly.

2.3 Bearing of historical performance on projections

Rupp et al. (2013) examined the fidelity of CMIP5 historical simulations to observed 20th century climate using 18 performance metrics of monthly near-surface temperature and precipitation of the Northwest US and the surrounding area that included the northeast Pacific Ocean and a large portion of western North America. All but three of the GCMs in Table S1 (ACCESS1-0, ACCESS1-3, and NorESM1-ME) were evaluated in their study. We performed a linear regression of projected changes in seasonal temperature and precipitation to the ranked integer order of the models.

We examined the robustness of these results against two independent CMIP5 GCM evaluation studies. Payne and Magnusdottir (2015) evaluated 26 GCMs by examining fields of 250- and 850-hPa level winds and vertically integrated moisture flux over the northeast Pacific Ocean, along with the frequency of atmospheric rivers making landfall between 30° and 60° N along the west coast of North America. Ahmadalipour et al. (2015) evaluated 20 GCMs based on daily, monthly, and seasonal values of temperature and precipitation over the CRB.

To facilitate a comparison across three modeling studies that used different methods, datasets and GCMs, we categorized each GCM as falling in one of three categories, or grades, of relative performance from high to low: "A", "B", and "C". In the case of Rupp et al. (2013) we simply divided the ranked GCMs into terciles (about 11 GCMs per tercile). For Payne and Magnusdottir (2015), we relied on their conclusion that 9 of 26 GCMs were superior (A) and 7 were problematic (C); the rest we assigned a grade of B. Ahmadalipour et al. (2015) identified 10 of 20 GCMs as being in the top half. Of these 10, they found 5 scored well at all temporal scales: we categorized these 5 as A and the other 5 as B. The 10 GCMs in the bottom half were categorized as C.

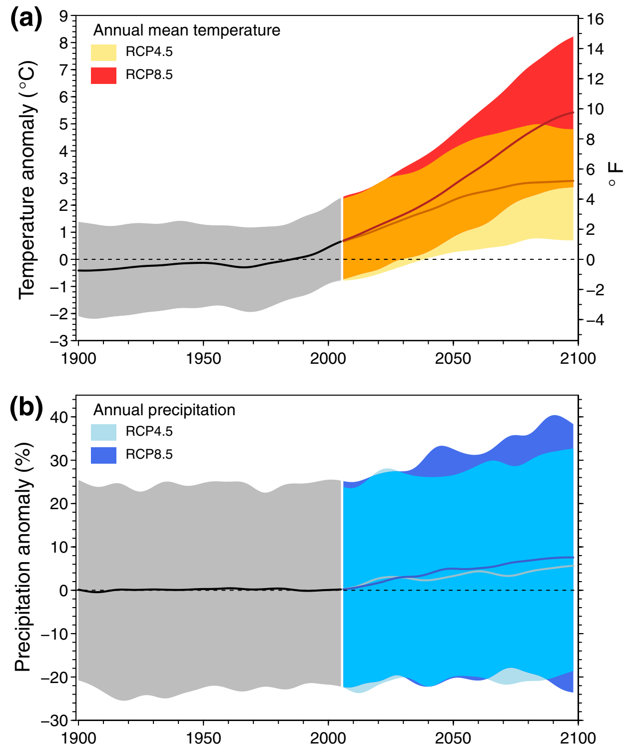

Fig. 1 Smoothed traces in simulated annual **a** temperature and **b** precipitation for the 20th and 21st centuries for the Columbia Basin above Bonneville Dam, relative to the 1970–1999 mean. The heavy smooth curve for each scenario is the CMIP5 multi-model ensemble mean (35 GCMs with one ensemble member only) calculated for each year and then smoothed (see text for details). The *top* and *bottom* bounds of the *shaded area* are minimum and maximum of the annual values, smoothed in the same manner as the mean values

3 Results and discussion

3.1 Projected changes in the climate of the Columbia Basin

3.1.1 Projected changes in annual and seasonal means

The 21st century trends in regional temperature are, without exception, towards a distinctly warmer climate for both RCP4.5 and RCP8.5 (Fig. 1). The multi-model ensemble mean annual temperature reaches 3.0 and 5.5 °C above the 1970–1999 baseline average by the end of the century under RCP4.5 and RCP8.5, respectively. RCP4.5 and RCP8.5 temperatures differ by 0.5 °C by 2050 and by 2.5 °C by 2099. Projections for precipitation are far less robust. Multi-model ensemble mean precipitation increases by up to 8% above baseline by the end of the century for RCP8.5; the increase is a little less for RCP4.5, but in both scenarios and all time periods, a significant minority of simulations project decreases in annual precipitation.

The shaded areas in Fig. 1 bound the minimum and maximum annual values from 35 simulations using the first ensemble member for each GCM and smoothing using a Gaussian filter with a 5-year standard deviation window. In a sense, the shaded areas provide a smoothed approximation of the range of likely temperature and precipitation anomalies in a given year. (Note: we say "approximation" because even though we have removed the biases in the mean by using anomalies, the GCMs are also biased in higher-order statistical moments and the biases vary across GCMs). The shaded areas broaden over time in both RCP4.5 and RCP8.5 because models vary in sensitivity to enhanced radiative forcing. Changes in variability with enhanced radiative forcing may also contribute to the spread. We discuss changes in variability at the end of this section (Sect. 3.1).

The color-shaded areas also provide an illustration of the magnitude of anthropogenically forced change relative to past annual variability shown in gray. In the case of

Table 1 Multi-model ensemble change (°C) in annual and seasonal temperature for the Columbia Basin above Bonneville Dam from the baseline period, 1970–1999, to each of three future periods

	2010–2039		2040–2069		2070–2099	
	Mean change	5, 95th percentile	Mean change	5, 95th percentile	Mean change	5, 95th percentile
RCP4.5						
Annual	1.3	0.6, 2.0	2.3	1.2, 3.4	2.8	1.3, 4.2
DJF	1.1	0.3, 2.0	2.2	1.0, 3.3	2.7	1.2, 4.1
MAM	1.2	0.4, 2.4	2.0	0.9, 3.6	2.5	1.1, 4.3
JJA	1.6	0.7, 2.5	2.7	1.4, 4.1	3.3	1.6, 5.1
SON	1.2	0.5, 1.8	2.2	1.0, 3.1	2.8	1.3, 4.0
RCP8.5						
Annual	1.4	0.9, 2.1	3.1	1.8, 4.4	5.0	2.9, 6.6
DJF	1.4	0.6, 2.4	2.9	1.6, 4.2	4.7	2.6, 6.1
MAM	1.3	0.6, 2.4	2.7	1.3, 4.2	4.2	2.4, 6.0
JJA	1.8	0.9, 2.8	3.8	2.2, 5.3	6.2	3.8, 8.5
SON	1.3	0.6, 2.0	3.1	1.7, 4.3	5.1	2.7, 6.8

Values are averaged over each 30-year period. All ensemble members per model are included

Table 2 Multi-model ensemble change (%) in annual and seasonal precipitation for the Columbia Basin above Bonneville Dam from the baseline period, 1970–1999, to each of three future periods

	2010–2039		2040–2069		2070–2099	
	Mean change	5, 95th percentile	Mean change	5, 95th percentile	Mean change	5, 95th percentile
RCP4.5						
Annual	1	−5, 6	3	−2, 9	5	−1, 13
DJF	3	−4, 13	5	−3, 15	8	−4, 20
MAM	3	−5, 11	6	−4, 14	7	−1, 17
JJA	−5	−21, 7	−5	−20, 10	−4	−19, 17
SON	1	−13, 12	3	−7, 14	4	−7, 17
RCP8.5						
Annual	2	−4, 8	4	−3, 13	8	0, 19
DJF	4	−7, 14	8	−3, 21	14	0, 31
MAM	3	−5, 11	7	−1, 21	11	0, 24
JJA	−5	−18, 6	−7	−28, 11	−10	−34, 19
SON	2	−10, 15	3	−9, 17	7	−8, 20

Values are averaged over each 30-year period. All ensemble members per model are included

temperature, the anthropogenically forced change is higher than annual variability, such that by 2050 it is very unlikely that the temperature in 2050, or any year thereafter this century, would be as low as the historical average, even accounting for natural variability. In contrast, the anthropogenically forced changes in precipitation are smaller than annual variability. Despite the increase in precipitation, years of anomalously low precipitation relative to the baseline would still be expected to occur with high frequency throughout the century.

Changes in annual and seasonal temperature and precipitation between the baseline period and three future 30-year periods are given in Tables 1 and 2, respectively. Provided are the multi-model ensemble mean and the 5th and 95th percentiles using all the available ensemble members. Seasons for these tables are defined as follows: December–February (DJF), March–May (MAM), June–August (JJA), and September–November (SON). We provided projections using these seasons to facilitate comparisons with other studies as these definitions are commonly used in climate change studies (e.g., Mote and Salathé 2010).

A look at multi-model ensemble mean projected changes in temperature by 2070–2099 for each calendar month (Fig. 2) reveals only four months—June through

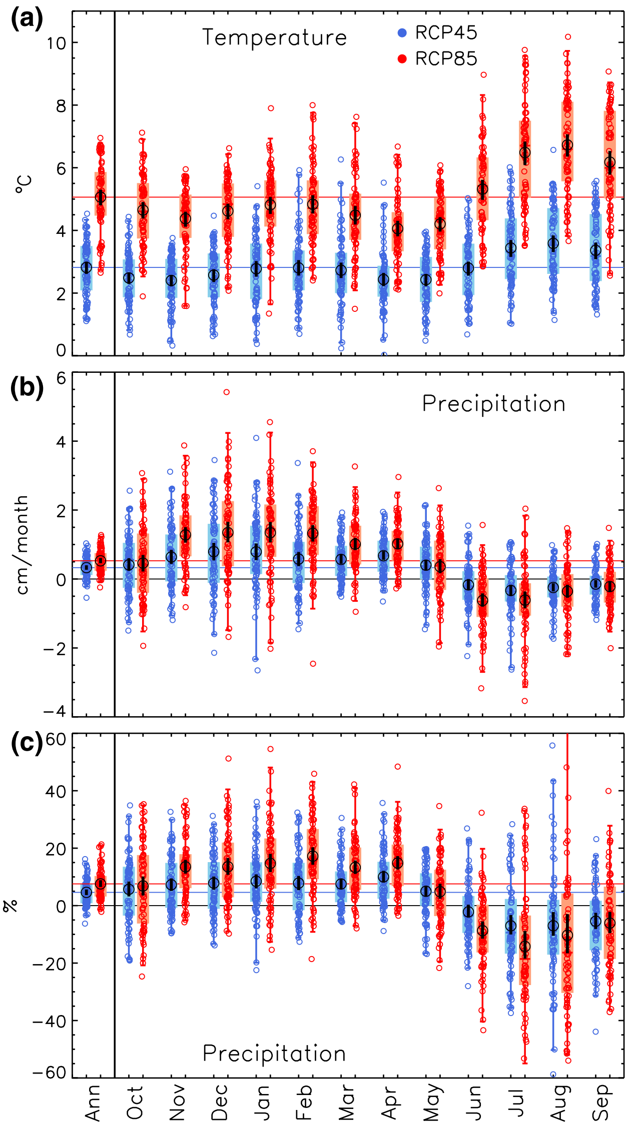

Fig. 2 Change in 30-year averages of monthly **a** temperature, **b** precipitation, and **c** precipitation as a relative difference, between 1970–1999 and 2070–2099, for the Columbia Basin above Bonneville Dam and for each scenario. *Open circles* show individual CMIP5 simulations (all available ensemble members) and the *box* and *whiskers* show inner quartiles and inner 95th percentiles, respectively. *Black circles* and *vertical black lines* show the mean of all simulations and the 95th percentile confidence limits on the mean, respectively. *Colored horizontal lines* show the annual mean

September—in which the mean monthly temperature changes exceed the annual change, and by up to an additional 1.7 °C (August; RCP8.5). Outside of these four summer months, December, January and February warm the most, while April and May warm the least; a difference in multi-model ensemble warming of +0.8 °C is seen between February and April under RCP8.5. We speculate that the snow-albedo feedback may be causing some of the difference between winter and spring temperature changes (e.g., Rupp et al. 2016), though an analysis of the spatio-temporal snow-albedo feedback across all CMIP5 GCMs is outside the scope of this study. Snow cover may be lost sooner in the calendar year (i.e., April and May) under GHG forcing, while there may simply be more snow cover to lose in midwinter than in April and May in the GCM simulations. However, caution should be taken when interpreting temperature changes effected by changes in snow cover in the region because the GCM's poorly resolve the mountains.

The four months (June–September) with the largest warming are also the only four months with projected decreases in precipitation. These also coincide with the driest four months of the year in observations when the mid-latitude storm track migrates north of the CRB and weakens and is replaced by subsidence associated with the North Pacific subtropical high (Mock 1996). We combine these four months into one season for the remainder of the analysis. Though we considered various ways of separating the year into multiple seasons, for simplicity we chose three seasons such that each season was composed of four consecutive months: October–January (ONDJ), February–May (FMAM), and June–September (JJAS). These divisions had the added benefit that ONDJ shares the same start date with the water year, typically defined in the western US as beginning October 1.

Seasonal projections of temperature and precipitation relative to baseline are shown in Fig. 3. Even as early as 2010–2039, for each season every one of the 150 simulated 30-year mean temperatures is above the baseline. The warm, dry summer season (JJAS) warms yet more than the cool, wet seasons with an additional 0.5 °C early in the century to 0.8 °C (RCP4.5) and up to 1.8 °C (RCP8.5) by the end of the century.

Along with the seasonal differential in temperature projections there is a seasonal differential in the precipitation projections. Roughly three-quarters of the projections show a decrease in precipitation in summer (JJAS). In contrast, over 90% of the wet season (ONDJ and FMAM) projections show an increase by the latter part of the century. The causes of precipitation changes in the Pacific Northwest were reviewed in the Introduction, but we revisit a proximate reason why precipitation increases in winter but decreases in summer in CMIP5 simulations. In winter, anthropogenic GHG forcing induces a relative deepening of the Aleutian low and an extension to the southeast. Such a pressure change is accompanied by a stronger southwesterly component to the mean flow field off the coast of North America (north of Mexico) that advects moist air from lower latitudes of the North Pacific Ocean to the Pacific Northwest (Fig. 4a, b). In contrast, summer projections indicate northward expansion of the North Pacific subtropical high suggestive of increased subsidence over the Columbia Basin.

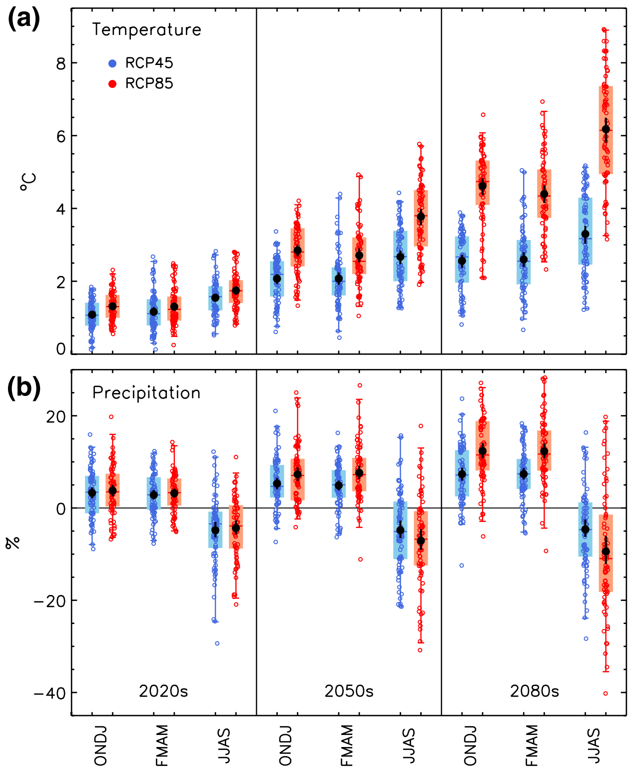

Fig. 3 Change in 30-year averages of seasonal **a** temperature and **b** precipitation between 1970–1999 and three future periods: 2010–2039 (2020s), 2040–2069 (2050s), and 2070–2099 (2080s), for the Columbia Basin above Bonneville Dam and for each scenario. *Symbols* are as in Fig. 2

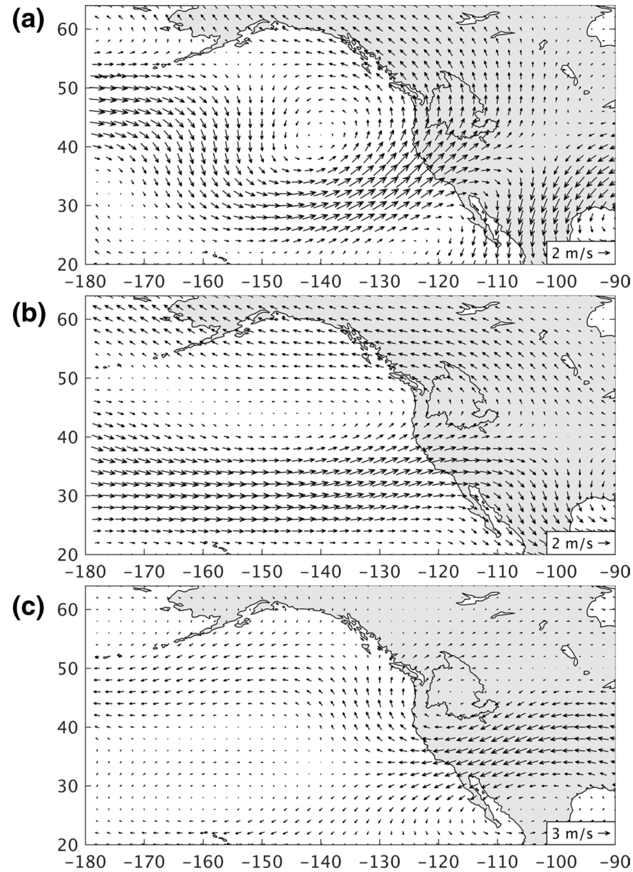

Fig. 4 Changes in mean 300-hPa winds for **a** October–January (ONDJ), **b** February–March (FMAM), and **c** June–September (JJAS). Changes are between 1970–1999 and 2070–2099 and for RCP8.5. The boundary of the Columbia River Basin above Bonneville Dam is shown

This association between enhanced rates of warming and decreased precipitation during summer suggests common mechanisms arising through changes in atmospheric circulation and land-surface feedbacks. The connection between interannual variability in summer temperature and precipitation in the region is facilitated through changes in cloud cover and soil moisture (e.g., Seager et al. 2014a; Yin et al. 2014). The poleward migration of the subtropical high and mid-latitude storm track under enhanced radiative forcing during the summer months result in an anomalous anticyclonic circulation across much of the CRB (Fig. 4c). Complementary to this anticyclonic circulation is a reduction in cloud cover and precipitation and increased shortwave radiation reaching the surface (Fig. 5a).

By contrast, downward shortwave radiation reaching the surface is projected to decrease in both ONDJ and FMAM. These seasonal differences in downward shortwave radiation reaching the surface are consistent with the seasonal warming differential. However, near-surface warming is affected by the change in net shortwave flux, which is projected to increase in all seasons and even more so in FMAM than in JJAS. This increase in FMAM net shortwave flux implies that, during the cool seasons, decreased surface albedo (via decreased snow cover) more than compensates for the increased cloud cover. We conclude, therefore, that seasonal differences in cloud cover changes do not directly explain the seasonal warming differential.

Seasonal differences in changes in surface latent and sensible heat flux may also contribute to projected differences in seasonal warming rates. Changes in surface latent heat flux are generally positive in all seasons (Fig. 5b) with the largest increases in FMAM and ONDJ, and nominal increases in JJAS. Increased evaporative cooling serves as a negative feedback to warming primarily during the cool season. Changes in surface sensible heat flux are positive and of similar magnitude in FMAM and JJAS, indicating a surface that is warming at a faster rate than the atmosphere. Upward sensible heat flux is essentially unchanged in ONDJ.

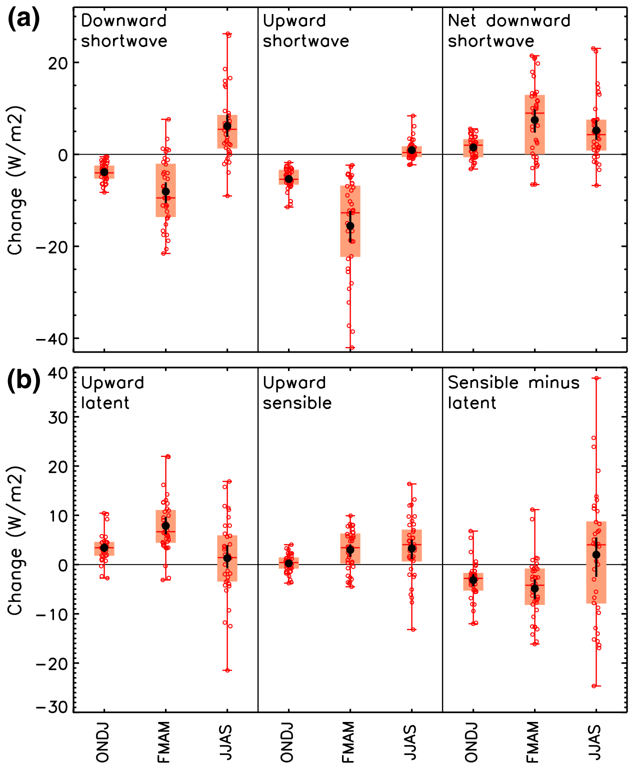

Fig. 5 Change in 30-year averages of seasonal **a** downward, upward, and net shortwave radiative flux and **b** upward latent heat flux, upward sensible heat flux, and sensible minus latent heat flux. Changes are between 1970–1999 and 2070–2099 for the Columbia River Basin above Bonneville Dam and for RCP8.5. *Symbols* are as in Fig. 2, except only the first ensemble member per model is shown

Subtracting the upward latent heat flux (a cooling effect) from the upward sensible heat flux (a warming effect) provides an index of the net vertical heat flux contribution to surface warming (Fig. 5b). During the cool seasons, this vertical heat flux contribution from the multi-model ensemble is negative (-3 and -5 W m^{-2} for ONDJ and FMAM, respectively, by the latter part of the century under RCP8.5) and statistically significant. In contrast, during JJAS this heat flux contribution is generally positive ($+2$ W m^{-2}), though not statistically significant.

We can make a first order approximation of the seasonal difference in the surface temperature change that would result in the seasonal difference in the change in vertical heat flux. Assuming the surface radiates like a blackbody, we can estimate the the change in temperature that would arise from a change in radiative flux ($\Delta\phi$) using the Stefan-Boltzmann relationship as:

$$\Delta T = \left(\frac{\Delta\phi}{\varepsilon\sigma} + T_0^4\right)^{1/4} - T_0 \qquad (4)$$

where T_0 is a reference surface temperature, $\sigma = 5.670373\text{E}{-8}$ W m^{-2} K^{-4}, and ε is the emissivity of Earth's surface, which is approximately 1 (e.g., Jin and Liang 2006). This assumption neglects additional feedbacks and other processes that would drive warming such as temperature advection. We also assume the differential long-wave radiative $\Delta\phi$ is solely tied to the differential vertical heat flux. As a result, we estimate a difference between FMAM and JJAS in their respective changes in temperature of 1.5 °C (using the multi-model historical ensemble average T_0 of 274.6 and 287.4 K for FMAM and JJAS, respectively). This value is consistent with the simulated seasonal differential in temperature change shown in Fig. 3a, suggesting that seasonal differences in warming arise primarily from seasonal difference in how changes in the energy budget are partitioned between latent and sensible heat fluxes. During summer, the projected decrease in precipitation leads to decreased soil moisture here and in much of the continental US (Dirmeyer et al. 2013), resulting in a smaller increase in latent heat flux than in the cool seasons when precipitation increases.

3.1.2 *Projected changes in seasonal interannual variability*

Variability in cool season (ONDJ and FMAM) temperature, quantified as the standard deviation of seasonal temperature (s_T), is somewhat reduced by late in the century in the multi-model ensemble (Fig. 6a). However, the reduction is only statistically significant by the late 21st century under RCP8.5, with a reduction in s_T of 8% in FMAM. Variability in JJAS temperature increases slightly, with the largest increase of 11% for the late 21st century under RCP85. In all seasons, the inter-model spread is large relative to the signal, with more than 25% of simulations showing changes of opposite sign to the multi-model ensemble change for both RCPs in all time periods.

This regional pattern of change in s_T is consistent with the general large-scale changes across the globe as shown in Holmes et al. (2016): winter s_T decreases at mid-latitudes and summer s_T increases, though model results diverge considerably in both seasons in the general area of the CRB. This seasonal difference in the simulated response of temperature variability to increased GHG forcing has persisted through generations of GCMs (Rind et al. 1989; Cao et al. 1992; Gregory and Mitchell 1995; Zwiers and Kharin 1998; Räisänen 2002). Previous studies point to decreased surface temperature gradients as a cause of decreased temperature variability in autumn and winter (see the review by Holmes et al. 2016). In winter, thermal gradients decrease by two mechanisms: (1) as ice and snow recede pole-ward meridional thermal gradients weaken and (2) the relatively

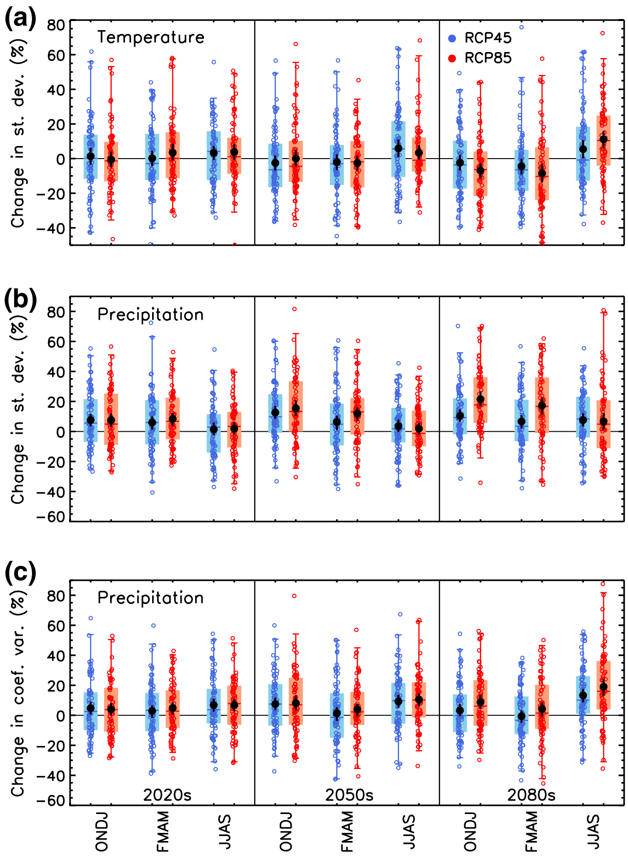

Fig. 6 Percent change in **a** standard deviation of seasonal temperature, **b** standard deviation of seasonal precipitation, and **c** coefficient of variation of seasonal precipitation between 1970–1999 and three future periods: 2010–2039 (2020s), 2040–2069 (2050s), and 2070–2099 (2080s) for the Columbia Basin above Bonneville Dam and for each scenario. Low-frequency variability was removed from each 30-year period prior to calculating the standard deviation (see text for details). *Symbols* are as in Fig. 2

cooler land surface warms faster than the relatively warmer ocean surface, reducing thermal gradients across coasts. Decreases in both gradients would be expected to decrease advection-driven temperature variability.

Increased summer temperature variability across mid-latitude landmasses under anthropogenic forcing has been linked to changes in the surface energy balance (Fischer and Schär 2009; Fischer et al. 2012; Seneviratne et al. 2006; Lenderink et al. 2007; Vidale et al. 2007). In climate projections of central Europe, precipitation decreases in summer, drying the soils, and leading to an enhanced Bowen ratio. The drying, in effect, strengthens that land–atmosphere temperature coupling and therefore increases temperature variability. The multi-model ensemble mean changes in summer s_T for the CRB are less than those projected for central Europe, perhaps because summers in the CRB are already relatively dry, so the small projected decreases in summer precipitation in the basin do not have much effect on changing the strength of the land–atmosphere temperature coupling.

Interannual variability in seasonal precipitation (s_P) is projected to increase in all seasons, with the largest increase (+22%) occurring in ONDJ under RCP8.5 by the late 21st century (Fig. 6b). Increases in s_P in JJAS are smallest, and are not statistically significant until late in the 21st century. With precipitation bounded below by zero, changes in s_P may simply be proportional to changes in mean P, as if the population were just scaled up by a constant factor. However, projected changes in s_P are proportionally larger than changes in mean P during the cool seasons. In summer, the changes in s_P are even of opposite sign to changes in mean P. For either winter or summer, the implication is that the increase in s_P has a significant component that is not simply explained by ΔP.

The coefficient of variation cv_P can help quantify how much of the change in s_P is due to a change in the mean and how much is due changes in the shape of the probability distribution not the result of simple scaling (Räisänen 2002):

$$\frac{\Delta s_P}{s_P} = \frac{\Delta \bar{P}}{\bar{P}} + \frac{\Delta cv_P}{cv_P}\left(1 + \frac{\Delta \bar{P}}{\bar{P}}\right) \tag{5}$$

where $\bar{P}$, s_P, and cv_P are the mean, standard deviation, and coefficient of variation, respectively of the baseline precipitation. The first term on the right side of Eq. (5) is the part of the relative change in s_P due solely to the change in mean precipitation and the second set of terms is associated with the change in the coefficient of variation. For the study area, changes in cv_P are positive in ONDJ and JJAS, while FMAM shows no statistically significant change (Fig. 6c). Changes are largest in JJAS: by the latter part of the century, cv_P increases by 13 and 20% for RCP4.5 and RCP8.5, respectively. In ONDJ, the corresponding increases are 3 and 9%.

3.2 Partitioning the variance in projections

The global component (i.e., the global temperature change) makes up the largest fraction of the variance of the multi-model ensemble of CRB temperature projections by mid- to late-21st century (Fig. 7), accounting for 69, 49, and 82% of the variance in ONDJ, FMAM, and JJAS, respectively, for the late century under RCP45 (see Fig. S2 for scatterplots of regional vs. global temperature changes). In other words, a substantial portion of the spread of regional temperature projections is due to the spread in global temperature

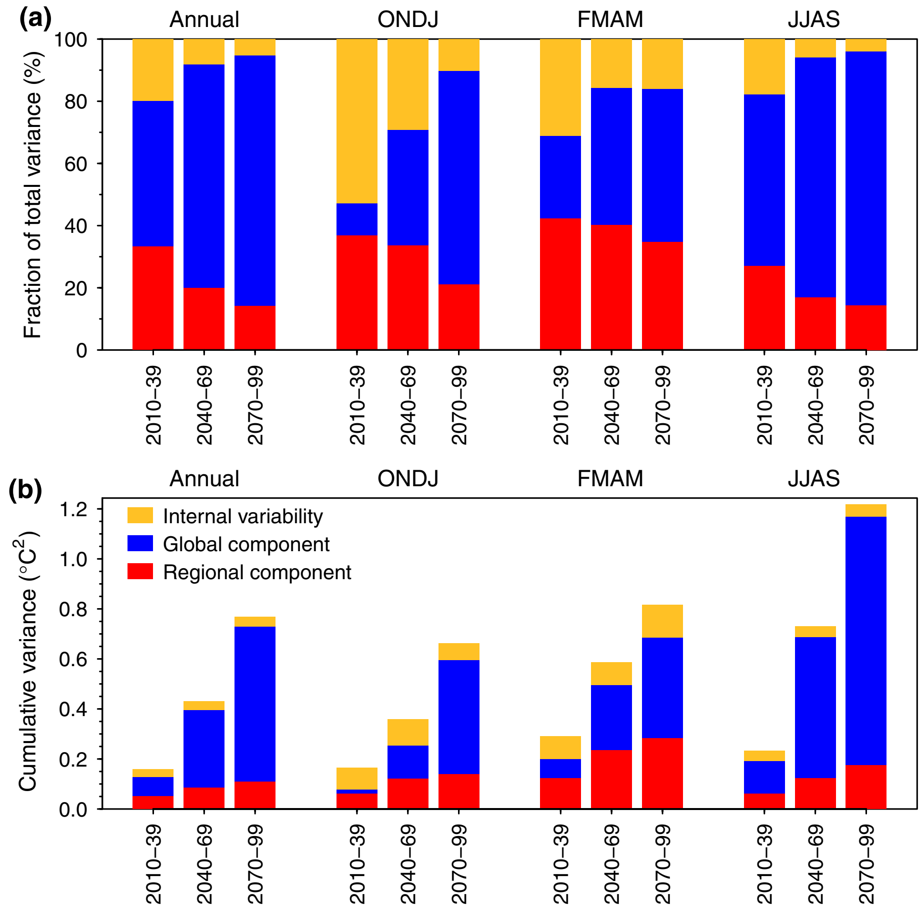

Fig. 7 Separation of variance in projected annual and seasonal temperature changes across the multi-model ensemble. Panel **a** shows the fraction of total variance from each of three components and panel **b** show the cumulative variance from the three components. Change is calculated as the difference in the 30-year average temperature between 1970–1999 and three future periods under RCP4.5: 2010–2039, 2040–2069, and 2070–2099. Regional temperature is averaged over the Columbia Basin above Bonneville Dam

projections across GCMs, with the effect strengthening at longer lead times. Internal variability is usually smaller than the global component, except in cool seasons in the early part of the 21st century (notably ONDJ, when it accounts for over 50% of the variance). This seasonal difference may reflect the fact that temperature is more variable in winter than summer. The regional component is larger in FMAM than in other seasons, which implies that regional aspects of the response to anthropogenic forcing separate GCMs more in late winter and spring than in summer.

The partitioning of variance for precipitation contrasts strongly with that for temperature (Fig. 8; see Fig. S4 for scatterplots of regional vs. global precipitation changes). The global component accounts for very little of the ensemble variance of the region's precipitation projections; only up to 5 and 4% of the variance for annual and ONDJ, respectively. The very small global component implies that the GCMs' transient global climate sensitivities offer little to no guide for what causes inter-model variability in CRB precipitation change. For early and mid-century, internal variability dominates, always accounting for at least 80% of the variance under RCP4.5 (see Fig S7 for RCP8.5), with the largest contributions during the cool season. By the latter part of the century, the regional component accounts for about half the variance during JJAS and roughly a quarter of the variance during the cool season.

3.3 Bearing of historical performance on projections

Overall, higher ranking GCMs from Rupp et al. (2013) project greater regional warming (ΔT) than lower ranking GCMs across annual and seasonal timescales under RCP8.5 (Fig. 9; results are similar for RCP4.5 and not shown). For example, the average change in temperature between the top and bottom halves of ranked GCMs is substantial, with the higher ranked models warming more than the bottom half by 0.7 °C (18%) FMAM and 1.4 °C (30%) in JJAS by late 21st century. Moreover, a significant negative linear trend exists for JJAS ΔT against ranked order. Two GCMs deviate conspicuously from this relationship and are marked in red: MIROC-ESM and MIROC-ESM-CHEM, which are among the three poorest performing

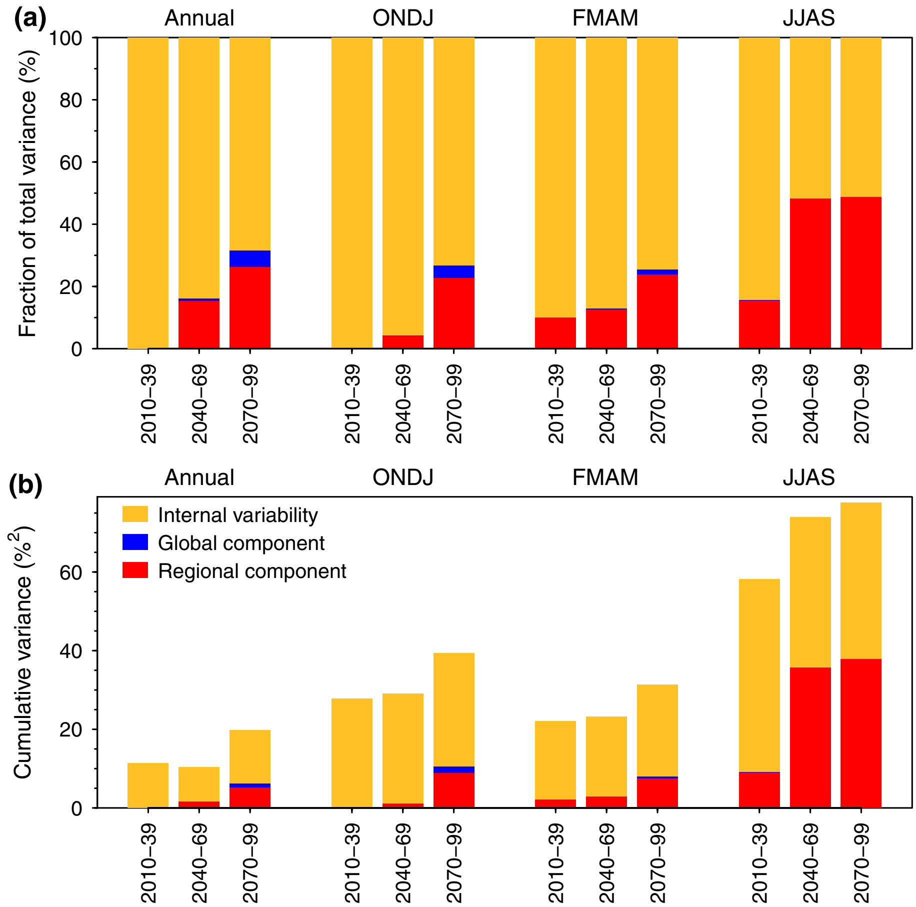

Fig. 8 Separation of variance in projected annual and seasonal precipitation changes across the multi-model ensemble. *Panel* **a** shows the fraction of total variance from each of three components and *panel* **b** show the cumulative variance from the three components. Change is calculated as the difference in the 30-year average temperature between 1970–1999 and three future periods under RCP4.5: 2010–2039, 2040–2069, and 2070–2099. Regional precipitation is averaged over the Columbia Basin above Bonneville Dam

models yet are among those that simulate the largest ΔT. If not for these two GCMs, the regression between ΔT and ranking would be statistically significant in all seasons, with ranking alone explaining at least one-third of the variance in ΔT in all seasons.

The average ΔP between the top and bottom halves of ranked GCMs is also noteworthy (Fig. 10), with the higher ranked models showing increases of 10 and 15% for annual and ONDJ, respectively, whereas the lower ranked models have increases of 5 and 9%, respectively. There is also a significant and negative linear relationship between GCM ranking and regional annual and ONDJ precipitation change. The GCM ranking explains 23 and 21% of the variance in relative annual and ONDJ ΔP, respectively. Relationships are not statistically significant in FMAM and JJAS for relative precipitation changes (though they are in JJAS for absolute changes; see Fig. S6).

The holistic nature of the evaluation done by Rupp et al. (2013) makes it difficult to identify the particular variables that may associate better performing models with more warming and more positive precipitation changes. Nonetheless, using these performance criteria to select a subset GCMs from which to generate climate scenarios for impacts analysis will engender a proclivity towards the warmer and wetter scenarios.

Finally, we compare the three evaluations of CMIP5 GCMs as summarized in Fig. 11. Comparing Rupp et al. (2013) with Payne and Magnusdottir (2015), we find much overlap: 63% of GCMs used in both studies share the same grade, 38% are one grade apart, and 0% are two grades apart. Rupp et al. (2013) and Ahmadalipour et al. (2015), in contrast, have dissimilar outcomes: a minority (35%) of GCMs used in both studies share the same grade, 40% are one grade apart, and 24% are two grades apart.

We concede that the method of allotting grades is not consistent across studies, by which we mean grades were not divided evenly into terciles in each study, nor were the identical sets of GCMs used in each study-to-study comparison. Still, it is clear that Rupp et al. (2013) and Ahmadalipour et al. (2015) arrived at different conclusions about CMIP5 model fidelity. For example, five of the "top ten" models identified by Ahmadalipour et al. (2015) make up of five the six lowest scoring models in Rupp et al. (2013).

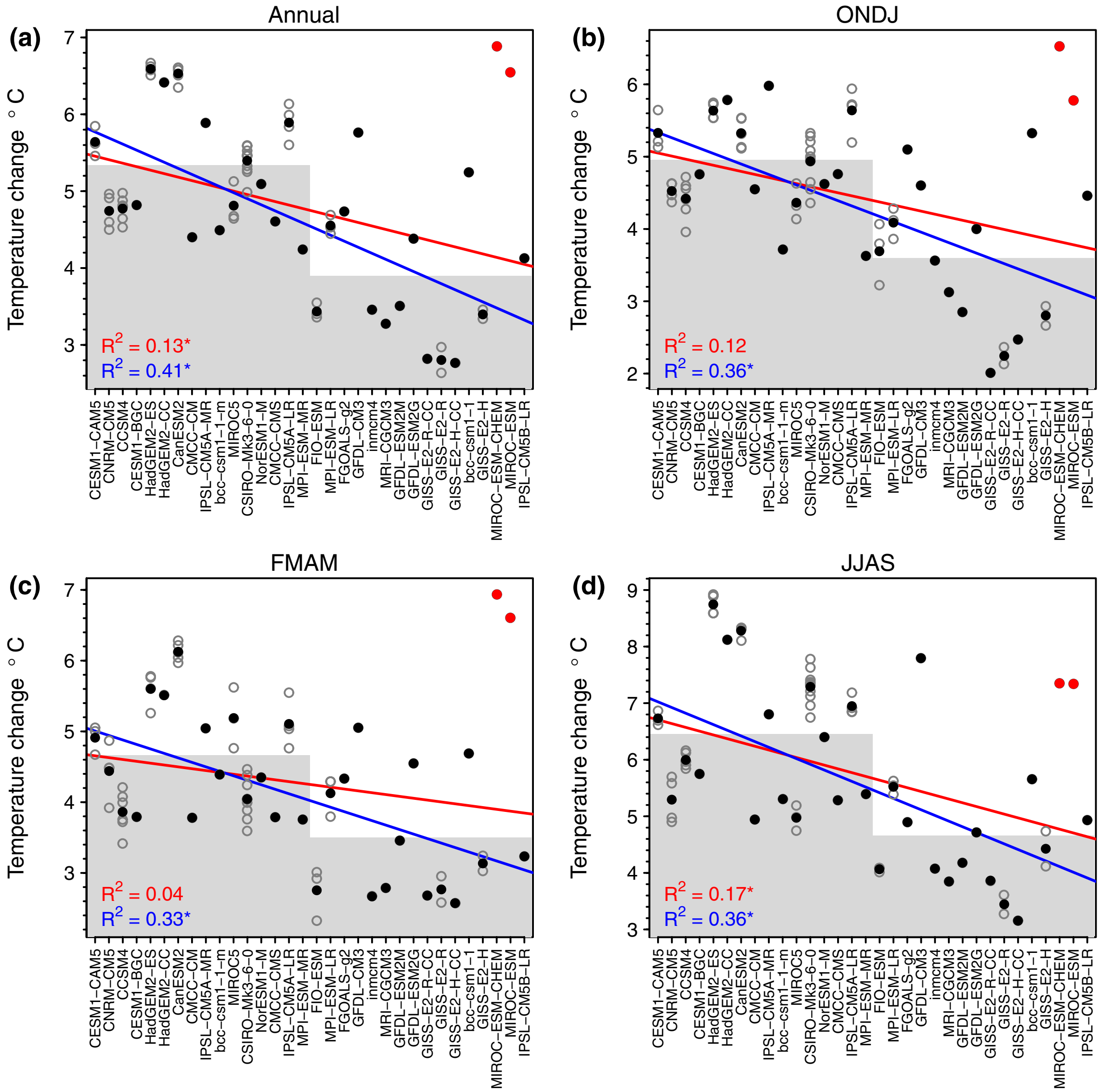

Fig. 9 Change in 30-year average of annual **a** and seasonal (**b**–**d**) temperature between 1970–1999 and 2070–2099 (RCP8.5) against the ranking (*left* is better) of models in Rupp et al. (2013). Temperature projections are for the Columbia Basin above Bonneville Dam under RCP8.5. *Solid circles* show the first ensemble member and lighter numbers show subsequent ensemble members. The best-fit linear regression and the associated R^2 with statistically significant relationships donated by an *asterisk*, before (*red*) and after (*blue*) removing MIROC-ESM and MIROC-ESM-CHEM (*blue*). The *two shaded bars* show the average temperature change for the top and bottom half of the GCMs

It is reasonable to conclude that the similarity between Rupp et al. (2013) and Payne and Magnusdottir (2015) lies in the clear physical connections between the variables analyzed in the two studies: lower and upper tropospheric winds and vertically integrated moisture flux over the northeast Pacific Ocean, along with frequency of atmospheric river landfall frequency, all impact the climate of the Northwest US. It is less clear why Ahmadalipour et al. (2015) differs so much from the other two studies. We do not know how much of this difference is due to particular statistical methods, choice of variables analyzed, and choice of reference datasets. It is interesting to note, however, that Rupp et al. (2013) used five metrics related to a model's sensitivity to either a change in anthropogenic forcing (20th century regional temperature trend) or solar forcing (the magnitudes of the seasonal cycle of temperature and precipitation and the mean winter and summer diurnal temperature range). Such sensitivities to solar forcing cycles can be indicators of the strength of some feedbacks that will also influence sensitivity to anthropogenic

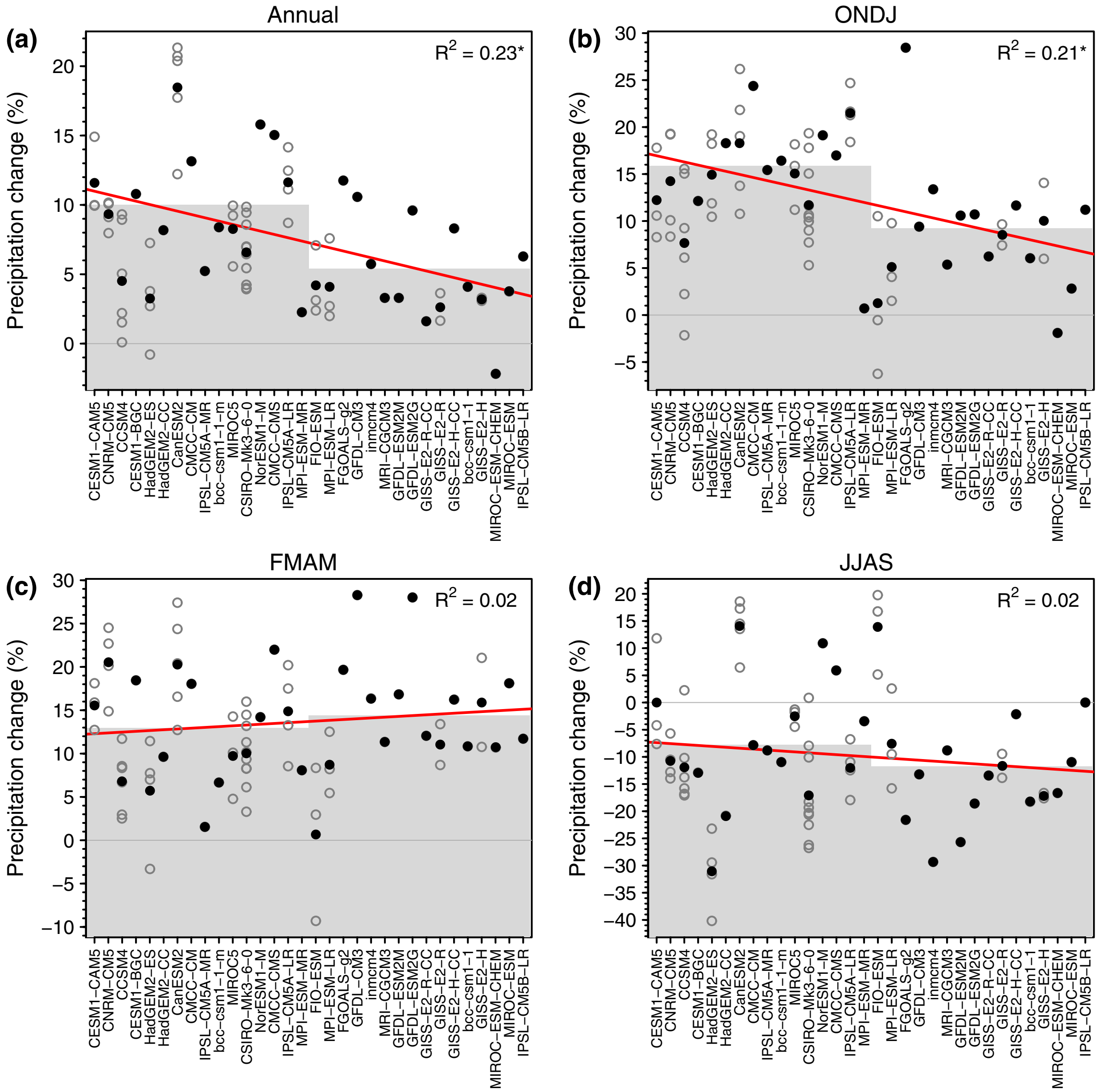

Fig. 10 Relative change in 30-year average of annual **a** and seasonal **b–d** precipitation between 1970–1999 and 2070–2099 (RCP8.5) against the ranking (*left* is better) of models in Rupp et al. (2013). Precipitation projections are for the Columbia Basin above Bonneville Dam under RCP8.5. *Solid circles* show the first ensemble member and *lighter numbers* show subsequent ensemble members. The *two shaded bars* show the average temperature change for the *top* and *bottom* half of the GCMs

forcing (e.g., Hall and Qu 2006). Ahmadalipour et al. (2015) did consider trends in temperature and precipitation, but only over the period 1970–2000, which is arguably too brief a period with which to assess the sensitivity of regional temperature to GHGs, and it certainly is too brief for precipitation (Abatzoglou et al. 2014).

Regardless of what causes the contrasting results between the two studies, the main point we make is that the relationships shown above between 21st century projections and GCM fidelity to observations—using fidelity as quantified by Rupp et al. (2013)—would not be the same using the evaluation of Ahmadalipour et al. (2015).

Model	Rupp et al. (2013)	Payne and Magnusdottir (2015)	Ahmadalipour et al. (2015)
ACCESS1-0	*	A	*
ACCESS1-3	*	A	*
CESM1-CAM5	1	*	*
CCSM4	2	A	A
CESM1-BGC	3	*	*
CNRM-CM5	4	A	C
HadGEM2-ES	5	*	C
HadGEM2-CC	6	A	C
CMCC-CM	7	B	*
EC-EARTH	8	A	*
CanESM2	9	A	A
IPSL-CM5A-MR	10	A	A
BCC-CSM1-1-M	11	B	C
MIROC5	12	B	B
NorESM1-M	13	B	C
CMCC-CMS	14	B	*
CSIRO-Mk3-6-0	15	C	C
IPSL-CM5A-LR	16	C	B
MPI-ESM-MR	17	*	*
FIO-ESM	18	*	*
BNU-ESM	19	B	C
MPI-ESM-LR	20	A	*
FGOALS-g2	21	C	*
GFDL-CM3	22	*	*
MRI-CGCM3	23	B	C
INMCM4	24	B	C
GISS-E2-R-CC	25	*	*
GISS-E2-R	26	*	*
GISS-E2-H-CC	27	*	*
GISS-E2-H	28	*	*
BCC-CSM1-1	29	C	B
GFDL-ESM2M	30	B	B
GFDL-ESM2G	31	B	A
MIROC-ESM-CHEM	32	C	C
MIROC-ESM	33	C	B
IPSL-CM5B-LR	34	C	B
NorESM1-ME	*	*	*

Fig. 11 Summarized results of three regional CMIP5 model evaluations: Rupp et al. (2013), Payne and Magnusdottir (2015), and Ahmadalipour et al. (2015). An *asterisk* denotes models not evaluated in a study. Models were assigned a relative performance category: high = A (*blue*), medium = B (*yellow*), and low = C (*red*) (see text for details). Models are ordered in the ranking given in Rupp et al. (2013), except for ACCESS1-0 and ACCESS1-3. NorESM1-ME was not evaluated in any of the three studies but is listed for completeness. Note: ACCESS1-0 and ACCESS1-3, which performed well in Payne and Magnusdottir (2015), use the atmospheric models in HadGEM2 and HadGEM3, respectively (Bi et al. 2013). Given HadGEM2-ES and HadGEM2-CC are among the high ranking GCMs in Rupp et al. (2013), we speculate that ACCESS1-0 and ACCESS1-3 would have placed in the top tercile by Rupp et al. (2013)

4 Summary and conclusions

Our updated assessment of 21st century changes to the climate in the CRB from CMIP5 confirms the broad outline of climate change from an earlier generation of climate models (e.g., Mote and Salathé 2010) but adds important aspects of the GCM projections over previous regional studies. Summer enhanced warming and drying is a robust feature of the CMIP5 model runs, and top-ranked models produce significantly higher temperature change and precipitation change than bottom-ranked models. Interannual variability in temperature and precipitation do not change much until late 21st century. Moreover, we have endeavored to connect the projected changes to physical mechanisms and have partitioned the variability in regional climate into three important sources.

Seasonal differences in projected temperature changes: Seasonal differences in warming result largely from land–atmosphere interactions that affect both temperature and precipitation. The additional warming during the summer months results from enhanced upper-level ridging across the region, which also results in decreased precipitation. The decrease in summer rainfall leads to reduced soil moisture and reduced latent heat flux. The compensating increase in sensible heat flux in response to the net increase in surface energy budget results in heating of the near-surface air. Compared with the earlier generation of climate model results, continued improvements in land-surface schemes should lead to greater realism and more physically robust projections.

Projected changes in climate variability: Interannual variability in seasonal temperature is projected to decrease slightly in the cool season and increase slightly in the warm season; however, the magnitudes of these changes are quite small even by the late 21st century. Reduced variability in regional winter temperatures is consistent with broader scale projections and likely tied to reduced meridional and land-sea temperature gradients during the cool season. Conversely, increased variability in summer temperatures arises because of land-surface atmosphere interactions. These findings contradict a common narrative that variability in climate, at least with respect to temperature, is already increasing.

Interannual variability in precipitation is projected to increase, especially in ONDJ. Increases in variability are proportionally greater than increases in mean precipitation. The results in general indicate more inter-annual variability in water delivery to the CRB that has relevance for water resource management. The implication is that the relative rate of increase in the upper quartiles of precipitation totals exceeds the relative rate of increase in the mean, consistent with the continental scale pattern of increases in extreme precipitation (Kharin et al. 2013) and, over the northwest US, increases in frequency of dry days (Polade et al. 2014).

Partitioning the variance in climate projections: The change in global mean temperature is the dominant factor behind the spread in regional warming projections by late 21st century. In other words, a model's projected global temperature change is a good index of its projected regional temperature change for the CRB. In the early 21st century, internal variability and the regional component of the inter-GCM temperature variance are comparable in magnitude and together explain the majority of the variance in the cool seasons. Conversely, internal variability explains nearly all of the inter-GCM variance in regional precipitation change in the early part of century. By the latter part of the century, inter-GCM differences explain about half of the variance in summer, less during other seasons. However, these inter-GCM differences are unrelated to differences in global mean temperature changes, implying that regional-scale processes that do not strongly impact the global temperature are at play.

Bearing of historical performance on projections: Regional historical performance, as quantified using one suite of metrics (Rupp et al. 2013), appears to be an indicator of the magnitude of projected changes in temperature. Using RCP8.5 and late-century changes as an example, the top-ranked half of CMIP5 GCMs warm by an additional 0.7 °C (FMAM) to 1.4 °C (JJAS) over the bottom half. Seasonal precipitation projections also show a relationship to GCM fidelity, though only in ONDJ; the top half of GCMs project 15% increase in precipitation, whereas the bottom half only 9% (also late century RCP8.5).

There is, then, the suggestion of a tendency for GCMs with greater fidelity to observations to have a higher sensitivity of temperature in the Columbia River Basin to global GHG concentrations. Moreover, the overall larger precipitation increases projected by the "better" performing models is consistent with the larger temperature changes also projected by the better performing models, via the Clausius-Clapeyron relationship of temperature to saturation vapor pressure. However, these results are dependent on the methods used for evaluating the GCMs, as illustrated by the strikingly different GCM rankings provided by Rupp et al. (2013) and (Ahmadalipour et al. 2015). To be able to confidently narrow the spread of regional climate sensitivity by considering GCM fidelity, more work is needed to design an evaluation methodology that uses observed/observable quantities that are indicators of the strength of feedbacks that determine a region's response to anthropogenic forcing.

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