U.S. Department of the Interior
U.S. Geological Survey

NW CSC
Northwest Climate Science Center

NORTHWEST CLIMATE SCIENCE CENTER
SCIENCE AGENDA FOR 2018-23

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ABBREVIATIONS

ACCCNRS	Advisory Committee on Climate Change and Natural Resource Science
CSC	Climate Science Center
DOI	Department of the Interior
NCCWSC	National Climate Change and Wildlife Science Center
NW CSC	Northwest Climate Science Center
SAC	Stakeholder Advisory Committee
SAP	Science Advisory Panel
USGS	U.S. Geological Survey

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SCIENCE AGENDA FOR 2018-23

EXECUTIVE SUMMARY

The Department of the Interior Northwest Climate Science Center (NW CSC) was established to help safeguard the natural and cultural resources of Idaho, Oregon, Washington, and surrounding river basins by providing managers and decision makers with accessible science on climate change impacts and adaptation actions. The NW CSC Science Agenda for 2018–23 builds upon an extensive research portfolio funded by the NW CSC from 2011 to 2017 and charts the overall science direction and research opportunities for the NW CSC over the next 5 years. The Science Agenda is based on seven guiding principles that strongly influenced its development and will steer its implementation, including allowing resource management priorities to drive science opportunities and supporting coproduced actionable science. Through a deliberate and open dialogue that the NW CSC established between regional resource managers and scientists, we identified 6 management priorities (aquatic resources, at-risk species and habitat, invasive species and diseases, forest ecosystems, shrubland ecosystems, working lands and waters), 12 management goals, and 41 key science opportunities that will help guide the NW CSC's research funding decisions and other activities. The human dimensions of climate adaptation are also recognized under three goals that may provide alternative and useful ways to frame regional climate change and natural resource issues. Because the Science Agenda sets the expectations for how the NW CSC intends to meet the science information needs of resource managers, an evaluation component is embedded within and considered an integral way of assessing both the impacts of the NW CSC on the region and accountability to the NW CSC's regional stakeholders and Federal funding agency.

INTRODUCTION

Since the creation of the U.S. Department of the Interior (DOI) Northwest Climate Science Center (NW CSC) in 2010, residents of Idaho, Oregon, and Washington and in surrounding river basins have experienced record-setting high temperatures and low snowpack, severe and costly wildfire seasons, and extensive drought emergencies. The impacts of climate change are already being felt in the Northwest, and adaptation planning is occurring in every sector, from public health to emergency response to infrastructure management. Because resilient, safe, and economically prosperous conditions for people depend heavily on intact, functioning ecosystems, the need for climate change information and adaptation options is more important now than ever.

The NW CSC was established to help safeguard the natural and cultural resources of the Northwest (fig. 1) by providing managers and decisionmakers with timely and accessible science on climate change impacts and adaptation actions. The NW CSC is one of eight regional DOI Climate Science Centers (CSCs) across the country that are managed by the U.S. Geological Survey (USGS) National Climate Change and Wildlife Science Center. To capitalize on the diverse scientific expertise of each region, all CSCs are Federal-university partnerships composed of a host university, regional university consortium partners, and USGS staff and scientists. For 2018–23, the NW CSC is hosted by the University of Washington in conjunction with Boise State University, University of Montana, Washington State University, and Western Washington University.

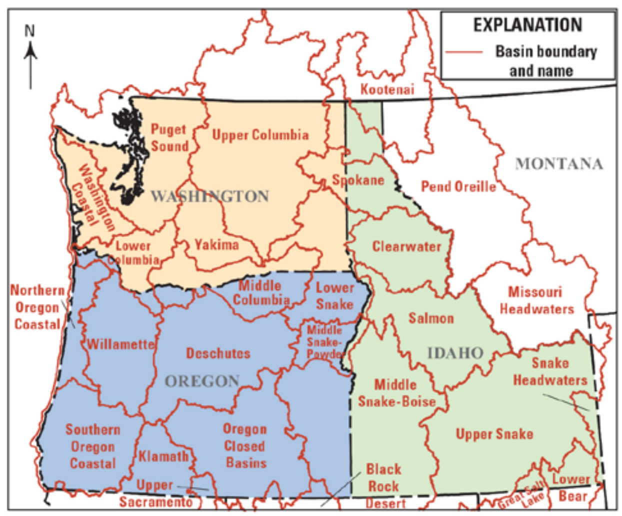

Figure 1. Map showing the geographic region and river basins served by the Northwest Climate Science Center.

The mission of the NW CSC is to deliver science to help fish, wildlife, water, land, and people adapt to a changing climate.

This Science Agenda builds upon an extensive research portfolio funded by the NW CSC from 2011 to 2017 and charts the overall science direction and opportunities for the NW CSC in 2018–23. It offers a common platform for the delivery of all other NW CSC services (e.g., education and training, communications, data management and delivery) and will guide the formulation of annual workplans. Most importantly, the Science Agenda will help determine climate adaptation science projects to be funded by the NW CSC over the next 5 years.

GUIDING PRINCIPLES OF THE NW CSC SCIENCE AGENDA FOR 2018–23

The NW CSC Science Agenda for 2018–23 is based on seven guiding principles that strongly influenced its development and will steer its implementation (sidebar). Each of these evolved from myriad conversations with resource managers, scientists, Tribal staff, funding partners, Landscape Conservation Cooperatives, and DOI and USGS leaders over the past 7 years. This Science Agenda differs from its predecessor (the 2010–17 Science Agenda) in that it (a) is based on resource management priorities rather than "science needs," (b) assesses the current state of knowledge on the topics included, and (c) has a built-in evaluation module to provide feedback on the agenda's implementation success at multiple levels. The guiding principles of the Science Agenda for 2018–23 are as follows:

1. **Let resource management priorities drive science opportunities.**
   The most efficient way to ensure that NW CSC-sponsored science is relevant to natural and cultural resource management priorities is to explicitly identify those priorities (based on input originating from stakeholders and traditional ecological knowledge [TEK]) and then derive science opportunities from them. Through deliberate processes with the NW CSC Stakeholder Advisory Committee (SAC) and Science Advisory Panel (SAP), we have identified six high-level management priorities, multiple management goals within each priority, and key science opportunities to address each goal.

2. **Focus on climate adaptation science and evaluating on-the-ground climate adaptation actions.**
   NW CSC stakeholders (natural and cultural resource managers) have expressed a need for innovative solutions to large-scale climate change challenges, help with developing vulnerability assessments and climate adaptation plans, and scientific evidence to support management decision making and on-the-ground adaptation actions. The key science opportunities identified in the Science Agenda are all geared towards meeting these climate adaptation needs.

3. **Support coproduced actionable science.**
   A central tenet of the Science Agenda is supporting actionable science (box 1) that is centered on adapting to future environmental conditions. As the multi-stakeholder Federal Advisory Committee on Climate Change and Natural Resource Science (ACCCNRS) defines it, actionable science "provides data, analyses, projections, or tools that can support decisions regarding the management of the risks and impacts of climate change. It is ideally coproduced by scientists and decision makers and creates rigorous and accessible products to meet the needs of stakeholders" (ACCCNRS, 2015). Supporting the coproduction of actionable science is one of the cornerstone services the NW CSC

GUIDING PRINCIPLES OF THE SCIENCE AGENDA

Let resource management priorities drive science opportunities

Focus on climate adaptation science

Support co-produced actionable science

Emphasize synthesis and interpretation

Capitalize on partnerships and leveraging

Encourage innovation

Maintain flexibility

has provided and will continue to provide to the natural and cultural resource management communities. This service is intended and designed to occur at both the individual project level and the regional program level.

4. **Emphasize synthesis and interpretation of existing information and data.**
   Conversations with NW CSC stakeholders have yielded numerous requests for synthesis products that summarize and interpret existing information and data. Providing these products will be one of our primary goals and a basis of evaluation for successful implementation of the Science Agenda. Synthesis products also represent a cost- and time-efficient way to disseminate scientific information during challenging Federal budget years. Synthesis and interpretation of existing data are ongoing processes—as we learn more we need to revisit past interpretations to see if they change on the basis of new information.

BOX 1. SUPPORTING ACTIONABLE SCIENCE

Key components of actionable science that the NW CSC supports include:

1. Conducting scientific research (based on Western science or Traditional Ecological Knowledge) that is directly related to our stakeholders' stated resource management priorities;
2. Developing projects that are policy and practice relevant, not policy prescriptive;
3. Encouraging scientists and managers to work together through the life of the project, from the proposal stage through final product development; and
4. Ensuring that scientific products and tools developed through funded projects are understandable and accessible to end users.

5. **Capitalize on partnerships and leveraging opportunities.**
   The NW CSC is fortunate to work with many Tribal, Federal, and State partners who are focused on climate change issues and (or) natural and cultural resource conservation at varying scales in the Northwest. We will continue to identify areas where our overlapping goals, unique constituencies and expertise, and funding situations give rise to partnership and leveraging opportunities.

6. **Encourage innovation.**
   While many current climate adaptation actions are modifications of existing actions repackaged to meet climate change challenges, there is need for innovative actions and initiatives in many areas of resource conservation. In implementing this Science Agenda, we will encourage our resource manager and scientist project teams to propose and test innovative solutions to climate adaptation challenges.

7. **Maintain flexibility.**
   The NW CSC recognizes that there are significant variables and constraints that may affect or influence implementation of science activities at any given time. Primary among these are concerns over resources administered by the DOI and its bureaus, evolving regional priorities expressed by our stakeholders and other partners based on emerging climate change-related issues and threats previously not foreseen, annual congressional budget allocations and guidance, staff capacity, and tactical investments. Consequently, the Science Agenda has been developed to be flexible enough to respond effectively to these conditions while identifying the key science opportunities to address management priorities.

CLIMATE CHANGE IN THE NORTHWEST

The Northwest is well known for its diverse landscapes: rocky shorelines meet wet, temperate rainforests, and snow-packed volcanic mountains descend into the dry sagebrush steppe. Ample snowmelt and rainfall fill salmon- and trout-laden streams and large hydroelectricity-producing rivers. East of the Cascade Range, native bunchgrasses sustain large herds of mule deer, pronghorn, and cattle, while sagebrush provides cover to sage grouse and pygmy rabbits. Growers use the region's rich soils to produce apples, wheat, wine grapes, dairy products, grass seed, Christmas trees, potatoes, and onions, while Tribal members harvest salmon, elk, camas roots, berries, and other traditional First Foods. Climate change threatens all of these iconic Northwest features, species, crops, and ultimately, human livelihoods as rising temperatures and changes in precipitation patterns combine to create novel environmental conditions across the region.

Temperature and Precipitation

In the 21st century, average annual temperature in the Northwest is projected to increase by approximately 1.7 degrees Celsius (°C) to 5.7 °C (3 degrees Fahrenheit [°F] to 10 °F) by 2070–99 (compared to 1970–99), with the largest increases occurring in summer (Mote and others, 2014). Annual average precipitation projections vary across climate models, but most agree that summer precipitation will decrease substantially (up to 30 percent by the end of the century) (Mote and others, 2014). These projected Northwest climate conditions are expected to result in dramatic changes to the region's water supplies, as well as to the frequency and severity of wildfires, droughts, floods, and pest and pathogen outbreaks, all of which could have severe ramifications for human health, agricultural production, power generation, and recreation.

Changes in Water Supply and Quality

Increasing temperatures and changing precipitation patterns will pose serious challenges to Northwest water supplies. Reductions in winter snow accumulation and melting glaciers combined with changes in the timing of snowmelt and groundwater recharge and discharge rates will have myriad consequences for ecosystems, fish, wildlife, and human communities throughout the region. For example, fish species that spend all or part of their lives in rivers, including salmon, steelhead, and trout, will experience decreased summer flows, increased flooding and winter flows, increased sediment in streams, and warmer stream temperatures. Projections suggest that one-third of the current suitable habitat for coldwater fish in the Northwest will be too warm for them to tolerate by 2100 (Karl and others, 2009).

Increased Wildfire Frequency and Severity

Increased wildfire frequency and area burned are cited by many Federal, State, and Tribal agencies as one of their highest concerns under future climate scenarios. As air temperatures increase and summer soil moisture levels decrease, the probability of widespread, catastrophic wildfires continues to rise. Whereas wildfire is a natural part of many robust, functioning forest, shrub, and grassland ecosystems, atypical "mega-fires" can disrupt multiple industries (e.g., farming, logging, recreation), threaten property and human lives, destroy important habitat areas, increase soil erosion and sediment load into streams, and lead to serious public health and safety concerns. The 2015 fire season in Oregon and Washington, for example, concerned an area of 686,796 hectares (1.7 million acres) burned and about $609 million in fire suppression costs (Northwest Interagency Coordination Center, 2016).

Increased Frequency and Intensity of Extreme Events

Changes in the frequency and intensity of droughts, floods, and heat waves, are redefining the climate and weather patterns in the Northwest. Increasing temperatures, diminishing snowpack, and reduced summer soil moisture are expected to increase the frequency and severity of droughts across the western United States (Andreadis and Lettenmeier, 2006; Folger and Cody, 2015). The Northwest has already experienced these conditions: during August 2015, 100 percent of land area in Oregon and Washington and 48 percent of land area in Idaho were in severe or extreme drought status. These conditions affected over 12 million people in the region and cost Washington farmers approximately $700 million in economic damages (McLain and others, 2017). In forested areas, severe droughts can heighten the susceptibility of trees to attack by mountain pine beetles and increase the probability of stand-replacing wildfires. Alternatively, flood risks are expected to increase as more precipitation falls as rain rather than snow during winter months and as snowpacks melt quickly during warmer spring months. Reservoirs in Idaho, for example, have been stressed in 2017 by a combination of heavy snowpack followed by rapid snowmelt.

Sea Level Rise and Coastal Communities

The effects of sea level rise, erosion, inundation, threats to infrastructure and habitat, and increasing ocean acidification collectively pose a major threat to the region. Global sea levels are projected to rise an additional 0.3–1.2 meters (about 1–4 feet) from current levels by 2100; however, parts of Washington and Oregon may experience slower sea level rise than the global average because of tectonic uplift along the coastline (Mote and others, 2014). Coastal wetlands in the Northwest support a wealth of ecosystem services, including providing habitat for fish and wildlife and protection from floods. The tidal marshes, mudflats, and shallow bays of coastal estuaries link marine, freshwater, and terrestrial habitats and provide economic and recreational benefits to local communities, including commercial, Tribal, and recreational shellfish harvest. For Washington and Oregon, many tidal marshes will be resilient to sea level rise over the next 50–70 years, but some studies indicate that sea level rise will eventually outpace marsh growth and drown most high- and mid-marsh habitats by 2110 (Thorne and others, 2015).

Increased Spread and Damage from Invasive Species, Pests, and Pathogens

The spread of nonnative plants and animals causes extensive environmental damage in the Northwest, with consequences to commerce, agriculture, energy generation, tourism, and other industries. Warmer air and water temperatures will allow many weeds, pests, and pathogens to expand their ranges and increase the probability of surviving through the winter. In aquatic systems, for example, the spread of exotic zebra and quagga mussels (*Dreissena polymorpha* and *D. bugensis*, respectively) poses serious threats to hydropower facilities and other submerged infrastructure. For the Columbia River Basin, Warziniack and others (2011) estimated that economic losses from mussel invasion could reach $64 million annually.

Tribes

Native American Tribes will be some of the hardest hit communities in the Northwest. Because their economies and culture are so closely connected with the natural resources on their reservations, ceded lands, usual and accustomed areas, and Ancestral Territories, changes to the availability of those resources can have significant economic and cultural consequences leading to potential impacts on Tribal health, cultural survival, and treaty-protected rights.

Human Health

The potential impacts of climate change on human health are numerous: projected longer, more intense heat waves will challenge public health agencies, while air pollution from increased ground-level ozone and wildfire smoke will likely worsen respiratory and cardiovascular illnesses. Water quality that is compromised by both drought and increased water temperatures could lead to conditions that give way to harmful algal blooms and waterborne diseases.

Economic Impacts

Many sectors of the Northwest economy will be impacted by climate change. Agriculture may be altered by changes in growing season lengths, increased pest and pathogen pressure, severe droughts, and extreme heat. In Oregon, for example, extreme heat is projected to reduce beef production, leading to estimated losses of $7 million and $11 million in 2020 and 2040, respectively (Niemi and others, 2009). It is also important to note that, contingent on water supplies, climate change could be beneficial for crops that require warmer temperatures and longer growing seasons.

Northwest rivers generate 32 percent of the Nation’s hydropower (Kao and others, 2014); therefore, significant decreases in streamflows could reduce hydroelectric supply and lead to economic losses in the region. Extreme decreases in hydropower production may occur in summer months at the same time that increased demand for cooling is needed. In the Columbia River system, summer hydropower production is projected to decrease by approximately 17–21 percent by 2080 (Hamlet and others, 2010).

Warmer temperatures and earlier snowmelt have already impacted Oregon’s outdoor recreation industry, which is worth nearly $13 billion and directly employs 141,000 people. By 2040, losses to snow-based recreation industries like skiing could reach $124 million, while losses to the coldwater fishing industry could surpass $260 million (Deehr, 2016).

KEY SCIENCE OPPORTUNITIES FOR THE NW CSC BASED ON RESOURCE MANAGEMENT PRIORITIES

Given the multiple climate-related challenges facing Northwest communities, Tribes, and resource managers, it is crucial that the NW CSC focus its efforts on addressing the highest resource management priorities and providing climate adaptation science for the next 5 years. We found that the most effective way to identify these priorities was to facilitate an open dialogue between regional resource managers and scientists; facilitating this coproduction process is a primary function of the NW CSC and a bedrock principle in the architecture of the Science Agenda. We developed a participatory process (app. 1) with the SAC (app. 2) and the SAP to identify the management priorities, management goals, and key science opportunities described below. SAP members then assessed the state of knowledge for each key science opportunity (app. 3) according to the categories in box 2.

MANAGEMENT PRIORITIES IDENTIFIED IN THE SCIENCE AGENDA

Aquatic resources

At-risk species and habitats

Invasive species and diseases

Forest ecosystems

Shrubland ecosystems

Working lands and waters

Box 2. Assessing the State of Knowledge of Key Science Opportunities

NW CSC Stakeholder Advisory Committee (SAC) members communicated their resource management priorities and “desired outcomes” to the NW CSC; these were used by NW CSC staff to derive key science opportunities. The NW CSC Science Advisory Panel (SAP) then assessed the state of knowledge on each key science opportunity using the following categories:

Category 1: Knowledge and tools already exist, but need to be publicized

Category 2: Knowledge exists, but requires synthesis, assessment, interpretation, or tool development in order to be accessible to management

Category 3: NW CSC can develop relevant knowledge to address a particular management priority or desired outcome in 2018-23

Category 4: NW CSC may not be able to develop relevant knowledge in 2018-23, but could set the stage for developing that knowledge in the subsequent five years (2023-2028)

Management Priority 1: Aquatic Resources

Climate change is already bringing significant changes to aquatic resources, as rising air temperatures and altered precipitation patterns are leading to water shortages and water temperatures that can be lethal to fish. When the intensity of precipitation increases, so does the sediment loading and nonpoint nutrient pollution, both of which impact water quality and aquatic resources. Managing aquatic resources also includes understanding groundwater changes in relation to climate and land use, balancing the management of streamflow for power production with the needs of instream flows and salmonid habitats, and incorporating climate change information into hatchery design and the siting of fish passages and barriers.

Management Goal 1.1: **Prepare for future reductions in natural water availability to minimize impacts to vegetation, fish, wildlife, and infrastructure**	
Key Science Opportunities	Knowledge Category
1.1.1. Identify drought impacts on groundwater recharge, discharge, and storage	2, 3, 4
1.1.2. Identify and evaluate methods to offset drought impacts to vegetation, fish and wildlife, infrastructure, and other water uses	2
1.1.3. Develop tools to forecast the timing, location, and magnitude of drought effects to develop operations scenarios for power production, flood control, and other water uses while mitigating impacts to migratory fish	2, 3

Management Goal 1.2: **Protect and enhance habitat for native salmon and trout, with particular focus on maintaining suitable stream temperatures**	
Key Science Opportunities	Knowledge Category
1.2.1. Identify current and future freshwater refugia to protect migrating and resident native fish populations from high temperatures and exceptionally high or low streamflows	3
1.2.2. Project future stream temperatures for major Northwest rivers, and their estuaries	3
1.2.3. Describe how aquatic plant and animal communities may change if environmental tolerances for water temperature, water chemistry, and streamflow are exceeded	4
1.2.4. Evaluate methods of controlling stream temperature and other water quality measures (e.g., how long does it take to realize the benefits of enhanced riparian habitat? How much can stream temperatures be influenced by riparian shade?)	2

Management Goal 1.3: **Manage native fish populations under changing climate conditions**	
Key Science Opportunities	Knowledge Category
1.3.1. Investigate how climate change (via drought, floods, and higher water temperatures) will affect native fish population characteristics	2, 3
1.3.2. Determine the effects of sea level rise on estuarine fish habitat	2, 3
1.3.3. Contribute to the evaluation of fish monitoring, trapping, and handling protocols to ensure that they are sufficiently protective under future climate conditions	2
1.3.4. Evaluate the effects of drought and stream temperature on fish husbandry programs	3
1.3.5. Contribute climate-related information relevant to the design and siting of fish passages and fish barriers	3

Management Priority 2: At-Risk Species and Habitats

"At-risk" species include federally listed threatened or endangered species, species of special or greatest conservation concern (as designated by State fish and wildlife departments), rare species, and species and habitats that are particularly sensitive to climate change and likely to become at-risk in the future.

Management Goal 2.1: **Manage habitat for at-risk fish and wildlife under changing climate conditions**	
Key Science Opportunities	Knowledge Category
2.1.1. Develop and evaluate options for managing and enhancing resilience of sensitive habitats (e.g., aspen stands, wetlands, sagebrush steppe) under altered precipitation, temperature, fire, and land use patterns	2
2.1.2. Assess potential impacts of drought and water management on wetlands, wetland-dependent species, and waterbirds	3
2.1.3. Identify cool-air refugia and fire refugia for at-risk species	3
2.1.4. Increase understanding of how changing climate conditions will affect the life histories of pollinators and the plants they pollinate	3
2.1.5. Work with partners to develop a climate monitoring program that focuses on climate parameters relevant to at-risk species and habitats	2

Management Goal 2.2: **Identify thresholds and trigger points for situations in which recovery goals, conservation planning, and management strategies for at-risk species and habitats need to be modified**	
Key Science Opportunities	Knowledge Category
2.2.1. Determine trigger points for management of at-risk species and habitats to inform managers when recovery goals and conservation plans need to be modified	3
2.2.2. Identify thresholds at which species or habitats may become at-risk as a result of climate change	2, 3

Management Priority 3: Invasive Species and Diseases

Many management agencies have devoted considerable resources to preventing the spread of invasive species and diseases or restoring invaded areas. However, there are serious concerns about how climate change will affect rates of spread and questions about which species may become ecologically and (or) economically damaging under future climate conditions.

Management Goal 3.1: **Update or develop strategies to manage the spread of invasive species and noxious weeds in sensitive habitats under projected climate conditions**	
Key Science Opportunities	Knowledge Category
3.1.1. Determine changes in the rate of spread of invasive species and noxious weeds in various terrestrial habitats	2
3.1.2. Determine changes in the rate of spread of invasive species and noxious weeds in various aquatic habitats	3, 4
3.1.3. Evaluate the efficacy of current invasive species and noxious weed management actions under projected climate conditions	3, 4
3.1.4. Engage economists, social scientists, ecologists, and policy specialists to evaluate the tradeoffs and benefits of various management strategies for addressing climate change impacts on the spread of invasive species, and determine which are most effective, affordable, socially-acceptable, and environmentally sustainable	3, 4

Management Goal 3.2: **Update or develop strategies to manage the spread of diseases under projected climate conditions**	
Key Science Opportunities	Knowledge Category
3.2.1. Determine potential climate change effects on disease severity, incidence, and spread in terrestrial habitats	3, 4
3.2.2. Determine potential climate change effects on disease severity, incidence, and spread in aquatic habitats	3, 4

Management Priority 4: Forest Ecosystems

Forest managers understand that climate change will directly and indirectly impact forest plant and animal species through a variety of mechanisms, including more frequent and severe disturbances (e.g., wildfires, droughts, pest outbreaks). What is unclear is how forests will respond to these disturbances: which species will thrive, and which will be extirpated? Managers also need information on future streamflows to determine optimal sizes and placements of culverts, as well as scientific evaluation of adaptive management practices for silviculture activities and to control the spread of tree diseases.

Management Goal 4.1: **Plan for wildfire responses and maintain resilient forests under changing fire regimes**	
Key Science Opportunities	Knowledge Category
4.1.1. Understand how climate change will affect forest fire regimes	2, 3, 4
4.1.2. Determine types of vegetation communities that are likely to become established following stand-replacing fires, and identify areas where substantial changes from historical forest vegetation conditions are likely to occur	3

Management Goal 4.2: **Develop forest management practices that will proactively address potential climate change impacts**	
Key Science Opportunities	Knowledge Category
4.2.1. Improve understanding of how groundwater and soil moisture are related to forest health and how those may be altered with climate change	2, 3, 4
4.2.2. Identify and evaluate adaptive management approaches for silviculture, such as planting more drought-tolerant species or ecotypes, to reduce mortality risks and growth losses within the harvest land base	2, 3
4.2.3. Determine optimal culvert placements and sizes to accommodate predicted changes in streamflows	2, 3

Management Goal 4.3: **Develop methods for controlling tree diseases, particularly Swiss needle cast, white pine blister rust, and sudden oak death**	
Key Science Opportunities	Knowledge Category
4.3.1. Identify and evaluate methods for controlling tree diseases that may spread because of climate change	2, 3
4.3.2. Evaluate the effectiveness of potential response measures under various climates, including planting disease-resistant seedlings, applying pheromone patches, exploring biological control agents, and supporting resilient forests in areas that have not yet been affected	2, 3

Management Priority 5: Shrubland Ecosystems

Arid and semiarid shrublands cover millions of acres of land in the Northwest and, through livestock grazing and farming, contribute billions of dollars to the regional economy. They also provide habitat for many iconic Northwest species, such as greater sage grouse, pronghorn, and elk. The biggest challenges that shrubland and rangeland managers face are invasive plant species, wildfire, and climate change, which is predicted to increase summer air temperatures and decrease soil moisture (Abatzoglou and Kolden 2011). These priorities are also recognized through parallel interagency efforts (e.g., Integrated Rangeland Fire Management Strategy Actionable Science Plan Team, 2016).

Management Goal 5.1: **Maintain and promote resilient shrublands under changing climate conditions**	
Key Science Opportunities	Knowledge Category
5.1.1. Identify thresholds and trigger points at which shrubland species or habitats may become at-risk as a result of climate change and other landscape stressors	2, 3
5.1.2. Evaluate how various grazing strategies can meet sage-grouse habitat requirements and provide forage for domestic livestock, wild horses, and burros under projected future climate conditions	2, 3
5.1.3. Evaluate methods for controlling invasive annual grasses given future climate conditions	2, 3
5.1.4. Provide climate change scenarios that can be used in 10-year grazing permit renewal decisions	3, 4

Management Priority 6: Working Lands and Waters

Climate change will impact infrastructure, agriculture, and private lands as changing precipitation patterns bring greater variability and uncertainty about water availability across the Northwest. More frequent, intense storms resulting in higher peak streamflows could damage roads and bridges and wash away fertile farm soils. Severe droughts will challenge the operations of farmers and growers and may have implications for approving new water rights. As a DOI entity, the NW CSC's mission is focused primarily on managing natural and cultural resources under changing climate conditions, but we recognize that climate change impacts to human communities and working lands can ultimately have negative impacts on species, habitats, and ecosystems.

Management Goal 6.1: **Ensure adequate resource distribution to maintain functioning lands and waters for humans as well as for plant and animal species and their habitats**	
Key Science Opportunities	Knowledge Category
6.1.1. Provide best possible predictions of future summer streamflows for consideration by water managers responsible for approving new water rights	2, 3, 4
6.1.2. Identify infrastructure, property, and aquatic habitats at greatest risk from changes in hydrologic flows, glacial outbursts, and more frequent and severe storm events	2, 3

Human Dimensions of Climate Adaptation

Determining how climate change impacts natural and cultural resources is valuable, but even our most successful efforts will have been for naught if people are not able or empowered to act on climate change information. Recognizing and explicitly incorporating human dimensions aspects of climate adaptation into the NW CSC's work are therefore key to ensuring that managers have the right tools to address their adaptation challenges. Here we identify three "Human Dimensions Goals" that may provide alternative and useful ways to frame regional climate change and natural resource issues. Because these goals map onto most, if not all, of the key science opportunities previously listed, and in order to retain flexibility in incorporating human dimensions elements into NW CSC-funded projects, we have intentionally not identified specific key science opportunities in this section.

Human Dimensions Goal 1: Determine the social acceptability of future ecosystem configurations that may occur under changing climate conditions, and management actions to address or adapt to these changes. For example, forest managers are interested in whether stand-replacing fires can be used to foster future resilience by facilitating transitions to new ecosystem structures better adapted to a warmer climate. However, the use of stand-replacing fires as a restoration tool has broad social, political, and economic implications. Social science research can help determine what treatments and conditions are socially acceptable to the public, assess variations in acceptability by diverse stakeholders, and establish strategies for engaging the public in dialogues about social acceptability of desired forest conditions.

Human Dimensions Goal 2: Use traditional knowledge and (or) other social science research methods to identify how various sociocultural groups assign meanings and value to aquatic and terrestrial resources and understand how climate change impacts on water may affect people and communities in different ways. This goal would also consider how institutional flexibilities and constraints help or hinder management decisions and adaptation processes at various levels. This information will help resource managers communicate effectively with different sociocultural groups and find ways to talk about changes in water availability related to changing climate conditions in the Northwest.

Human Dimensions Goal 3: Incorporate models predicting human population growth, migration, distribution, and land use change into assessments of climate change impacts on aquatic and terrestrial ecosystems. These assessments will help better predict and plan for change across the region and also provide useful information for State and municipal agencies to manage the direction or intensity of human population growth through zoning and planning (e.g., urban growth areas).

DATA MANAGEMENT AND INFORMATION SHARING

A central function of the NW CSC is to share climate change-related information, data, and tools to support resource management decisions. The NW CSC follows the rigorous data management policies set out by our managing entity, the USGS National Climate Change and Wildlife Science Center, and utilizes USGS cyber infrastructure and repositories (e.g., ScienceBase, https://www.sciencebase.gov/catalog/; DEPTH, https://www.sciencebase.gov/depth/) to efficiently manage NW CSC-funded project data and products. The NW CSC also shares scientific information, data, decision-support tools, syntheses, and other products relevant to climate adaptation through our website (https://www.nwclimatescience.org/), story maps (http://uidaho.maps.arcgis.com/apps/MapSeries/index.html?appid=7f1b9dc9a184431b92575d5d3365e2f4), webinars, regional and national conferences, social media, press releases, and monthly email digests.

MEASURING ACHIEVEMENT

The Science Agenda expresses and sets the goals and expectations for how the NW CSC intends to meet the science information needs of resource managers and stakeholders in the region. Its centrality to the activities of the NW CSC makes it the ideal opportunity to embed an evaluation component designed to track and assess both the impacts of the NW CSC on the region and the ways in which the NW CSC demonstrates accountability to its regional stakeholders and Federal funding agency (USGS). The evaluation component of the Science Agenda will include three modules:

1. **Impact Evaluation**: How is the NW CSC making a difference to resource managers and other stakeholders in the region?
2. **Process Evaluation**: Is the Science Agenda being implemented in the ways agreed to by the SAC and NW CSC leadership (i.e., is the NW CSC being accountable to its stakeholders)?
3. **Project Evaluation**: Are projects funded by the NW CSC being undertaken and completed in ways that use funds effectively to achieve the best possible outcomes for scientists and resource managers (i.e., is the NW CSC being accountable to its funding agency)?

While related and complementary, these three modules are distinct in their objectives, metrics, and assessment tools. We engage in these diverse evaluation approaches to provide useful feedback to a variety of audiences including multiple organizational administrators, Congress, science producers, science users, partners, and staff.

Impact Evaluation

This evaluation component focuses on the ways in which NW CSC science services and products are informing resource management decisions. This component will consider a range of outcomes and impacts including the awareness, knowledge, opinions, and skills gained by the various communities that participate in the NW CSC science enterprise, as well as the direct contributions of NW CSC science to resource management plans, policies, or other formal decisions. While other activities that the NW CSC conducts and engages in (e.g., Climate Boot Camp, graduate fellow support, outreach and communications) contribute to the overall impact the NW CSC has in the region, these will not be explicitly evaluated through this module. We will, however, develop an evaluation module for those activities in the NW CSC Strategic Plan for 2018–23.

Overarching questions in the Impact Evaluation module include the following:

- Did NW CSC science services and products address specifically stated management priorities?
- Did the engagement between information producers and users occur early, often, and throughout the duration of the project?
- How are NW CSC-supported science products being used by resource managers and decision makers in the region? This includes specific instrumental uses of information and less-tangible conceptual uses.
- Who was impacted by the NW CSC's science activities?
- Do different modes of science delivery have different levels of impact?
- Was science product delivery appropriately timed to meet information use needs?
- Are there changes to resource condition that make them more resilient to climate change?

Sources of information: Project annual and final reports (see below), NW CSC core office records, surveys of participants in various NW CSC activities.

Process Evaluation

This module is intended to analyze whether the Science Agenda is being implemented as intended and according to its original design. In other words, we are interested in knowing the level of consistency between the Science Agenda as a planning document and the resulting scientific activities and products that define our portfolio. This evaluation approach allows for an analysis of strengths and weaknesses, identification of barriers or unexpected opportunities, and real-time examination of how the agenda could be better implemented. Overarching questions in this module will include the following:

- Were SAC members satisfied with their level of engagement and input into developing the Science Agenda?
- How have the key science opportunities identified in the Science Agenda been addressed in a given fiscal year? What is the range and type of scientific activities? Why have some key science opportunities not yet been addressed?
- Did other entities contribute to implementation of the Science Agenda?
- How did the NW CSC ensure coordination with other regional partners?
- Who were the recipients or coproducers of NW CSC science services and products (e.g., Federal, State, and Tribal resource management agencies)?

- What was the funding allocation per management priority (e.g., funds assigned to individual projects or project clusters)?

Sources of information: NW CSC core office records of activities, existing NW CSC core office regional inventory of projects, survey of SAC members, interviews with SAC members, postevent surveys.

Project Evaluation

Much of the Science Agenda is implemented through funding of individual projects, which are inextricably tied to the impacts the NW CSC has in the region. As a result, there will be significant overlap between the Impact Evaluation and the Project Evaluation modules. However, the Project Evaluation also includes questions of accountability for use of funds, which are required by the funding agency, the USGS. We will continue to track accountability information, but also integrate additional impacts questions into the reporting process. Overarching metrics in this module will include the following:

- Accountability information as required by the funder (USGS)
- Summary of project findings and any unexpected findings
- Outputs generated by the project and stakeholder satisfaction with that output (i.e., credibility and salience)
- Explanation of how and when the researchers collaborated with intended end users (e.g., were stakeholders satisfied with their level of engagement?)
- Was the project successful in producing and communicating information that was used by resource managers and (or) decision makers?

Sources of information: Annual and final project reports, surveys of resource management participants in each project, tracking of citations from project outputs.

Conducting the Evaluations

The Federal leadership team writes an annual workplan outlining how the agenda will be addressed each fiscal year. This workplan provides the best opportunity for reflection, course correction, or realignment of goals on an annual basis. Evaluation data collection will be timed to provide information to the NW CSC leadership prior to crafting these annual workplans. Data collection tools will be designed to integrate with existing and ongoing record keeping within the NW CSC. In some cases, additional questions may be added to existing forms (i.e., new questions on project final technical reports), or entirely new data collection tools may be used to collect critical pieces of information (i.e., surveys to stakeholder participants in research projects). The goal of each data collection tool will be to facilitate the collection of necessary information with as little additional workload for the NW CSC staff and our partners as possible.

IMPLEMENTATION

The partial or full implementation of this Science Agenda will depend largely on the annual Federal budget process, which reflects evolving priorities for Federal programs according to the Administration's Executive Branch and the corresponding Congressional appropriations bills enacted every fiscal year. In addition, we factor in considerations from national guidance provided by the USGS National Climate Change and Wildlife Science Center, opportunities generated with other CSCs, regional priorities expressed by SAC and other partners, and staff capacity. Considered together, these elements may turn parts of this Science Agenda into more accessible or unrealistic endeavors in any given year. The seven guiding principles of this Science Agenda help us steer its implementation despite shifting conditions and budgetary uncertainties.

Implementation of this Science Agenda will materialize through announcements of NW CSC funding opportunities open to researchers at CSC consortium institutions and USGS centers and offices. Discretionary opportunities for funding from and collaboration with the NW CSC may be available in the interim. The NW CSC also recognizes that our regional Federal, State, and Tribal partners are engaged in important research that also addresses our Science Agenda. To recognize and tally these external activities, ensure coordination, identify research gaps, and avoid duplication of efforts between agencies, the NW CSC has compiled a database of regional climate research projects funded since fiscal year 2011 (https://www.sciencebase.gov/depth/#/). This database, which currently consists of nearly 800 projects from 31 different agencies and organizations, showcases the significant progress that can be made by collectively addressing important climate science questions.

PARTNERS AND STAKEHOLDERS

Because the CSC network is a DOI construct, we work very closely with a number of DOI bureaus, including the Bureau of Indian Affairs, Bureau of Land Management, Bureau of Reclamation, National Park Service, and U.S. Fish and Wildlife Service. The NW CSC is also committed to working in conjunction with other Federal agencies, as well as State and local government agencies, universities and research institutes, Northwest Tribes and Tribal entities, and other conservation partnerships and nongovernmental organizations across the region. Management agency representatives help the NW CSC identify important management priorities, while academic, government, and Tribal scientists help us determine appropriate research directions to pursue. Together, we support projects that help the larger Northwest community respond to threats to our natural and cultural resources.

NW CSC Advisory Committees

The SAC of the NW CSC is composed of representatives from Federal, State, and Tribal resource management agencies in the Northwest region (app. 2). SAC members meet regularly to help identify natural and cultural resource management priorities to ensure that NW CSC-funded science is ultimately useful, relevant, and of value to the region. The SAC also provides crucial feedback on the effectiveness of the NW CSC's overall program.

The SAP of the NW CSC was created in 2016 to enhance the interaction between members of the NW CSC SAC and scientists engaged in climate change-related research. SAP members were drawn from Federal agencies, State departments, Tribes, and academic institutions in the Northwest, including the Nooksack Indian Tribe, Oregon Department of Fish and Wildlife, Oregon State University, University of Washington, USGS, and U.S. Forest Service. Their role is to identify strategic science opportunities that can help address management priorities identified by the SAC. Working closely with the SAC through a process described in appendix 1, the SAP helped identify the key science opportunities found in this Science Agenda and provided “state of knowledge” categories for each opportunity.

Regional Academic Consortium

All regional CSCs are rooted in Federal-university partnerships; each CSC is hosted by a public university in conjunction with a multi-institution academic consortium. These partnerships ensure access to a broad range of scientific expertise, production of high-quality science, and sharing of funds, resources, and facilities. University involvement also allows CSCs to introduce students and early-career scientists to the innovative approach of coproducing actionable science, which helps guarantee that scientific products directly address real-world problems. For 2018–23, the NW CSC is hosted by the University of Washington in conjunction with Boise State University, University of Montana, Washington State University, and Western Washington University. This consortium has extensive experience and proven success in coproducing actionable science for decision makers; boasts a diverse set of experts and centers exploring challenges related to the physical, ecological, social, economic, and institutional dimensions of climate risk management; and is dedicated to building capacity within resource management agencies and among the next generation of researchers for addressing climate impacts.

USGS Science Centers

In the Northwest, there are seven USGS Science Centers and five Cooperative Research Units that house hundreds of scientists, technicians, and students working on various resource management issues. The NW CSC is able to draw on this tremendous expert pool to help identify science opportunities, conduct synthesis work, develop management-relevant tools, and carry out scientific research that addresses the management goals established in our Science Agenda.

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APPENDIX 1. PROCESS FOR DEVELOPING THE NW CSC SCIENCE AGENDA FOR 2018–23

IDENTIFICATION OF NATURAL AND CULTURAL RESOURCE MANAGEMENT PRIORITIES

In October 2014, Northwest Climate Science Center (NW CSC) Stakeholder Advisory Committee (SAC) members provided short presentations to articulate their agencies' top management priorities in relation to climate change. The NW CSC identified 10 themes from the information presented by SAC members (table 1–1). Recognizing that the NW CSC cannot address all of these topics in detail, we grouped these 10 themes into three tiers:

- Tier 1: Themes that provided the best opportunities for future NW CSC leadership
- Tier 2: Themes for which other agencies or organizations have a leadership role
- Tier 3: Themes for which the NW CSC has already done a substantial amount of work

Table 1. Top management priorities for addressing climate change identified by the Northwest Climate Science Center (NW CSC) Stakeholder Advisory Committee (SAC) in 2014.

Tier 1: Themes for NW CSC leadership
- Hydrologic regime shift impacts on salmonid habitat, agriculture, and infrastructure
- Ecological impacts of drought
- Identification of trigger points and ecosystem thresholds in relation to climate change
- Effects of climate change on invasive species, diseases, and pests

Tier 2: Substantial work has been conducted by other agencies/organizations
- Landscape and habitat connectivity
- Prioritization of areas for conservation or restoration
- Ocean acidification effects on shellfish

Tier 3: Themes where NW CSC has already funded substantial work
- Providing access to downscaled climate data
- Effects of sea level rise on estuaries
- Wildfire risk and adaptation actions

In October 2016, the NW CSC provided SAC members with a questionnaire to more clearly identify high-priority management activities and “desired outcomes” related to the Tier 1 themes. In addition, SAC members were asked for input regarding timeframes for which information was needed; geographic, economic, jurisdictional, and social scopes of information needed; and forms of information delivery that would provide the greatest benefit for managers (e.g., peer-reviewed studies, syntheses, web-based tools). On the basis of the results of this questionnaire, the NW CSC identified six broad **management priorities** that provided the framework for identifying the **management goals** and **key science opportunities** found in the Science Agenda.

Management priorities as presented by SAC members and categorized by NW CSC staff:

1. Managing aquatic resources
2. Managing at-risk species and habitats

3. Managing invasive species and diseases
4. Managing forest ecosystems
5. Managing shrubland ecosystems
6. Managing landscapes affected by human use/working lands and waters

Identification of Key Science Opportunities

After its establishment in November 2016, the NW CSC Science Advisory Panel (SAP) initiated their work on identification and assessment of key science opportunities for the NW CSC to pursue to most effectively address the six management priorities identified by SAC members. Although the 2016 questionnaire focused on Tier 1 topics, Tier 2 and 3 topics were not excluded from these six management priorities. Each management priority was reviewed by a subgroup of SAP members with expertise in that particular area. Through a series of conference calls, webinars, and meetings, the SAP subgroups worked closely with SAC members to resolve questions and ensure that they identified the science needed to address each management priority.

Because the "desired outcomes" offered by SAC members for each management priority were often highly specific and (or) overlapped with other desired outcomes, NW CSC staff consolidated these into **management goals** and derived the **key science opportunities** from those goals. SAP members then assessed the **current state of knowledge** (app. 3) for each key science opportunity by using the following five categories of knowledge:

1. Topics for which relevant knowledge and tools already exist, but need to be publicized
2. Topics for which relevant knowledge exists, but requires synthesis, assessment, interpretation, or tool development in order to be applicable to management
3. Areas where the NW CSC can develop relevant knowledge to address a particular management priority or desired outcome in 2018–23
4. Areas where the NW CSC may not be able to develop relevant knowledge in 2018–23, but could set the stage for developing that knowledge in the subsequent 5 years (2023–28)
5. Areas where developing relevant knowledge is not feasible within the scope or mission of the NW CSC [Note: this original category was later deemed unnecessary. Please see below.]

While a handful of management interests identified by the SAC could have initially led to science opportunities falling under category 5, the NW CSC decided to take a broad, inclusive approach and envision possible aspects of those opportunities that could benefit from our science and products. The SAC-SAP iterative process that we followed allowed us to add flexibility to the key science opportunities identified in this Science Agenda, thus providing a way to accommodate all of the priorities put forward by the SAC. Consequently, category 5 was later excluded from the range of available knowledge categories.

The state of knowledge assessment for each key science opportunity will help the NW CSC determine the appropriate level of activity and funding to meet management goals. For example, a key science opportunity that is rated "2" may require a synthesis report that can be completed by one researcher in 6 months with a relatively small amount of funding from the NW CSC, while a key science opportunity rated "4" may require a longer duration project with more managers and scientists involved and a larger amount of funding committed by the NW CSC and other partners.

APPENDIX 2. MEMBER AGENCIES OF THE NW CSC STAKEHOLDER ADVISORY COMMITTEE

State agencies
Idaho Department of Fish and Game
Montana Department of Natural Resources and Conservation
Oregon Department of Fish and Wildlife
Washington Department of Fish and Wildlife
Tribal entities
Affiliated Tribes of Northwest Indians (ATNI)
Columbia River Intertribal Fish Commission (CRITFC)
Cow Creek Band of Umpqua Tribe of Indians
Northwest Indian Fisheries Commission (NWIFC)
Suquamish Tribe
Tulalip Tribes
Federal agencies
Bonneville Power Administration (BPA)
Bureau of Indian Affairs (BIA)
Bureau of Land Management (BLM)
Bureau of Reclamation (Reclamation)
Federal Highway Administration (FHWA)
Great Basin Landscape Conservation Cooperative (GBLCC)
Great Northern Landscape Conservation Cooperative (GNLCC)
National Oceanic and Atmospheric Administration (NOAA)
National Park Service (NPS)
Natural Resources Conservation Service (NRCS)
North Pacific Landscape Conservation Cooperative (NPLCC)
U.S. Department of Agriculture Northwest Climate Hub
U.S. Environmental Protection Agency (EPA)
U.S. Fish and Wildlife Service (USFWS)
U.S. Forest Service Pacific Northwest Research Station
U.S. Geological Survey (USGS)

APPENDIX 3. BRIEF STATE OF KNOWLEDGE DESCRIPTIONS FOR KEY SCIENCE OPPORTUNITIES

MANAGEMENT PRIORITY 1: AQUATIC RESOURCES

Management Goal 1.1: Prepare for future reductions in natural water availability to minimize impacts to vegetation, fish, wildlife, and infrastructure

Summary of Current Knowledge

Various climate models and downscaled data exist for the Northwest and can be used to develop and enhance current watershed flow models (see the Northwest Climate Science Center [NW CSC] Integrated Scenarios of Northwest Climate, Hydrology, and Vegetation project [https://www.nwclimatescience.org/projects/integrated-scenarios-climate-hydrology-and-vegetation-northwest]). Locally specific projections of future streamflow at hundreds of locations in the Northwest under dozens of climate change scenarios are also available (e.g., Columbia River Climate Change Streamflow Dataset [http://hydro.washington.edu/CRCC/], PNW Fine Scale Hydroclimate Scenarios [https://cig.uw.edu/datasets/pnw-hydroclimate-scenarios-project-2860/], North Pacific Region Hydroclimate Scenarios [https://cig.uw.edu/datasets/north-pacific-region-hydroclimate-scenarios/]). The challenges in projecting streamflow timing and magnitude arise from the difficulty in representing episodic events (e.g., short-duration, extreme precipitation events) in climate models and from our limited understanding of smaller Northwest streams that run through remote or less-populated areas. The National Weather Service has developed a new attempt to model recent streamflow at more than 2 million points nationwide as a benchmark for monthly and yearly flooding predictions (http://water.noaa.gov/about/nwm).

The intent to manage flows with natural (e.g., vegetation, beavers, beaver surrogates) or anthropogenic (e.g., low head dams, retention structures, enhanced recharge) management solutions has been a focus of numerous restoration, remediation, and water management studies. Application of these measures will depend on the location and type of drought impacts that need to be mitigated as well as the timeline for implementation.

Where groundwater models exist, the forcing of the models can be adjusted on the basis of downscaled climate data. However, if models do not exist then it will take longer to put models together and in some cases collect sufficient calibration data to properly configure the models. Also, some groundwater systems are highly dependent on episodic precipitation events for recharge; these types of events are not well captured in downscaled climate data.

Management Goal 1.2: Protect and enhance habitat for native salmon and trout, with particular focus on maintaining suitable stream temperatures

Summary of Current Knowledge

Predictions of stream water temperatures have benefitted tremendously from both mechanistic (Wu and others, 2012) and statistical (Isaak and others, 2011; McNyset and others, 2015) stream temperature modeling tools. The physics of stream heat energy budgets and exchanges are well studied and well parameterized in many cases, even for large regulated rivers (van Vliet and others, 2012). The influence of shade on solar budgets to streams can be increasingly modeled at finer scales with tools that incorporate tree height from lidar and canopy density as a function of tree species. This capability allows credible estimates of the benefits of riparian enhancements or cumulative effects of shading

(Wawrzyniak and others, 2017) and comparisons to projected effects of climate change (Justice and others, 2017). Not all systems or stream temperature scenarios can currently be estimated satisfactorily, however; uncertainties associated with stream temperature predictions in response to management or climatic factors can be caused by uncertainty in important covariates in stream temperature models (Moore and others, 2005). Examples include uncertainty in streamflow and groundwater contributions due to spatial variability across climatic and hydrogeologic gradients (Burns and others, 2017). Advances in surface-water and groundwater flow modeling (discussed in Management Goal 1.1 in this appendix) will benefit linked temperature models.

Translating stream temperatures into effects on aquatic biota requires incorporation of temperature into the habitat requirements, biotic interactions, and life cycles of target species. For example, identification of coldwater refugia for migrating and resident salmon populations is achievable with current knowledge; we know where significant refugia exist and the patterns of how fish use these features (Goniea and others, 2006). What we currently lack is sufficient understanding of how coldwater features scale up to benefit fish at the population level. For instance, do costs of refuge use associated with increased susceptibility to angling or predation outweigh benefits (Keefer and others, 2009)? How closely must refuges be spaced along migratory pathways to counteract adversely high temperatures in the migratory corridor? What are the delayed and cumulative effects of thermal exposure along migratory routes (e.g., delayed mortality or reduced gonad viability) (Bowerman and others, 2016)? What other physical, chemical, or biological factors limit the true utility of refuges to benefit the fish using them? Linked physical, physiological, and population models will be necessary to adequately address these uncertainties.

Ecosystem thresholds for aquatic assemblages are notoriously difficult to predict a priori and, when crossed, can be very difficult to reverse in low-resiliency systems (Timpane-Padgham and others, 2017). Adaptive management that can detect and respond to ecological change within an effective timeframe will be essential for reducing risks associated with threshold shifts. Data on the extent of changes and causative factors are slowly emerging, but the extent is as yet unclear. Defining criteria for current (or desirable) ecological states and species assemblages a priori with user-group buy-in would be an important first step for implementing adaptive management in the face of ecological thresholds.

Water temperature changes due to climatic variability will be accompanied by other significant changes to the environment of native fishes, such as sea level rise and ocean acidification. Ranking and prioritizing management actions to deal with multiple fronts of this emerging crisis are extremely challenging. Decision-support tools that outline assumptions and current knowledge in a transparent manner will be needed to guide difficult choices and tradeoffs (Timpane-Padgham and others, 2017). For example, heightening or constructing seawalls to protect from coastal flooding may help maintain human infrastructure and some vulnerable habitats, but may reduce near-shore habitat quality for estuarine species (Zedler, 2017).

Management Goal 1.3: Manage native fish populations under changing climate conditions

Summary of Current Knowledge

Addressing the management of native fish under changing climate conditions will require (1) knowledge of current distributions of native fish populations, (2) knowledge of habitat requirements and climate sensitivity of native fish species and nonnative competitors, (3) knowledge of native fish species' adaptive capacities, (4) accurate downscaled climate projections, and (5) knowledge of barriers to fish movement. The preceding information could be used to build species distribution models, assess native fish species' vulnerability to future climates, and simulate the effects of different management strategies. Much of this information is available (Wenger and others, 2011; Isaak and others, 2015; Kovach and others, 2016), but requires synthesis and presentation in user-friendly formats for managers. Research is needed to determine the effects of climate and the interaction between native and nonnative trout.

There is likely sufficient knowledge regarding thermal stress and handling for salmonids to revise current handling protocols. Fine-scale management would require much improved real-time monitoring of river temperature and (or) predictive models. Research results suggest that there are differences in adaptive capacities relative to temperature within native fish populations and between populations (Eliason and others, 2011). Additional stock-specific research of thermal tolerance would be needed to manage at the population level.

Addressing drought would require (1) knowing future streamflow regimes (water availability) in target basins, (2) defining thermalscapes, and (3) developing low-flow hatchery rearing techniques. Future streamflow scenarios have been produced (see Management Goal 1.1 in this appendix). Thermal predictions are available, but they are of varying accuracy and could be improved. Recirculating or oxygen supplementation methods for hatcheries have been trialed, but these require refining and need to incorporate temperature control.

State and Federal agencies in the Northwest are already using existing climate change information for siting fish passages and removing fish barriers. Locally specific projections of runoff and streamflow under a range of climate change scenarios are available for a number of geographic domains at a variety of spatial scales (see Management Goal 1.1 in this appendix) and have been used by State and Federal agencies to inform culvert risk assessment and replacement planning (e.g., Strauch and others, 2015; Wilhere and others, 2016, 2017).

Addressing drought impacts and increased stream temperatures on native fish habitat and distributions requires knowing (1) future flow and temperature regimes, (2) the flow and temperature requirements and tolerances for target species, and (3) current fish distributions. Some information is available, but needs assimilation in species distribution models.

Some information is available regarding effects of sea level rise on estuarine fish habitat. The extent of sea level rise has been mapped in estuaries. There are at least two ongoing efforts to evaluate the effect on salmonid rearing habitat (https://coast.noaa.gov/digitalcoast/tools/slamm.html; Flitcroft and others, 2013).

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MANAGEMENT PRIORITY 2: AT-RISK SPECIES AND HABITATS

Management Goal 2.1: Manage habitat for at-risk fish and wildlife under changing climate conditions

Summary of Current Knowledge

Throughout the region, many State and Federal agencies, as well as nongovernmental organizations, have programs for listing and conservation of at-risk species and habitats. An example is the U.S. Forest Service's development of regional lists of "species of conservation concern" as part of the national forest planning program. Additionally there are resources compiling data on locations and status of taxa, such as the U.S. Geological Survey (USGS) Biodiversity Information Serving Our Nation (BISON) database (https://bison.usgs.gov/), the Integrated Taxonomic Information System (ITIS) database (https://www.itis.gov/), and the NatureServe (http://explorer.natureserve.org/) database. The International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species (http://www.iucnredlist.org/) also includes summary information on threats to populations. Overall, such resources can be used to provide baseline information on species' legal and ecological status, habitats, threats, distributions, and other factors.

Spatial datasets for levels of resilience to fire and resistance to invasive species across the Great Basin for sage-steppe ecosystem (Chambers and others, 2014) are available, and much of this work has been done for the sage grouse. However, available GIS layers and datasets for sage grouse are hard to find.

A valuable dataset available from The Nature Conservancy (and soon through a web application in development by the Conservation Biology Institute) is documented in a report by McRae and others (2016), who generated a suite of maps to document terrestrial resistance and regional connectivity in the Northwest. The datasets "identify broad, intact areas where movement of terrestrial organisms is largely unrestricted by human modifications to the landscape, as well as constricted areas where fragmentation has reduced movement options and further habitat loss could isolate remaining natural lands" (McRae and others, 2016, p. 4).

Work on Puget Sound prairies to maintain prairie conditions by using frequent fire, chemical, and mechanical removal of invasive species has been conducted, particularly by staff from The Nature Conservancy and now from the Center for Natural Lands Management. For oak woodlands in the Willamette Valley, there have been financial incentives for landowners to cut encroaching Douglas-fir and allow native oak woodlands to thrive again. Furthermore, a group of environmentally minded vineyard owners and forestland owners, the Willamette Partnership, is encouraging colleagues to include oak woodland restoration when developing vineyards or forest plantations in Oregon. The Oak Accord asks landowners to voluntarily agree to help slow the decline of oak habitats in the Willamette Valley by creating, restoring and protecting areas that currently have native oaks or have the potential to grow oak (http://willamettepartnership.org/oak-accord/).

Evaluation of effects of altered disturbance patterns has been conducted on fishers and martens (e.g., Spencer and others, 2011, 2015, models for the Sierras), as well as northern spotted owls. Researchers have looked at effects of a combination of natural (fire) and human (marijuana plantations and use of pesticides killing wildlife) disturbances. Beyond the Northwest, for wolverine, Canada lynx, snowshoe hare, and other species there is substantial information currently available on habitat requirements and climate impacts affecting habitat quality and longevity (Carroll, 2007; McKelvey and others, 2011; Tape and others, 2016).

There are also a lot of data on salmon in the region, but managing anadromous fish under changing climate conditions is a very complex problem (see Management Priority 1 in this appendix).

Regarding information on cool-air refugia and fire refugia, recent research has highlighted the value of floodplain and riparian areas as bird habitats in arid environments (e.g., Nimmo and others, 2016; Selwood and others, 2017). Harrison and Noss (2017) suggested that regions of high species endemism represent locations of relatively stable climate and that endemism hotspots could be recognized as climate refugia and serve as part of a conservation adaptation approach. Alpine (high-elevation) environments could also serve as biodiversity refugia in a changing climate (Gentili and others, 2015) at least temporarily. In general, identifying and conserving habitat refugia may serve as important temporary nodes in conservation networks designed to foster resilience to climate change (Garden and others, 2015). However, providing for species' range peripheries and establishing connectivity between nodes will also contribute to species' resilience to extreme weather events and climate shifts (Bateman and others, 2015). Aspects of fire refugia are covered under Management Goal 4.2.

Regarding the impacts of drought and water management on wetland-dependent species and waterbirds, Mac Nally and others (2017) projected long-term declines in anurans (frogs and toads) under increasing aridity and warming in Australia. How such conditions (drought and water demand) might impact amphibians in the Inland Western United States is not well known but may follow similar patterns as the region undergoes increasing drought periods (Vose and others, 2016). The U.S. Forest Service Climate Change Resource Center provides some information on potential impacts of climate change on amphibians of the Northwest (Olson and Saenz, 2013). Additional amphibian work includes work at U.S Environmental Protection Agency, Western Ecology Division Lab in Corvallis and at U.S. Forest Service, Corvallis Forestry Research Lab, on salamanders and other species (see https://databasin.org/maps/3cf3cd550f26437ea02dd47c825ab383, https://databasin.org/articles/f9522813cd364a62afc57b2d4a2cb3a8, and https://databasin.org/datasets/0645c4572aa941cea81b76d09c81c2a9). Alpine wetlands are particularly vulnerable to climate change. Also important are freshwater and estuarine coastal wetlands along the Pacific Flyway (e.g., Iwamura and others, 2013; Veloz and others, 2013) and the potential impact of drought on ephemeral wetlands (e.g., Colloff and others, 2016, in Australia). Also of concern is sea level rise that affects coast wetland inundation (Oppenheimer and Alley, 2016) and changes to salinity gradients, coastal water temperatures, ocean acidification, and hypoxia (Kemp and others, 2009; Gaylord and others, 2015). Veloz and others (2013) highlighted the role of uncertainty in projecting effects of climate change on tidal marsh birds and thus that greater monitoring and modeling may be required to increase the reliability and robustness of projections (also see Jennings and Harris, 2017; Michalak and others, 2017).

With regard to managing and enhancing the resilience of sensitive habitats, Janowiak and others (2017) presented a database and climate risk metric for evaluating the potential response of forests to climate change. Brandt and others (2017) developed an ecosystem vulnerability assessment approach to guide climate adaptation programs. Massie and others (2016), as well as Sheehan and others (2015), concluded that, in the Northwest, climate change may cause increases in warm forest types and decreases of cool forest types within natural areas. Gray and others (2011) used a bioclimatic envelope model to evaluate the need and potential for assisted migration of aspen forests in western Canada. An issue of increasing concern is how climate change may provide ideal conditions for the introduction and spread of invasive species, compromising the conservation value and conditions of sensitive habitats for native species (Ohsawa and Jones, 2017). Much of this issue can be tied to the concept of refugia, discussed above. Additional issues include relocation of highways and other infrastructures from coastal estuaries because of sea level rise (Kulp and Strauss, 2017). In general, much work is addressing such issues; therefore, attention needs to be directed towards preventing duplication of efforts.

Management Goal 2.2: Identify thresholds and trigger points for situations in which recovery goals, conservation planning, and management strategies for at-risk species and habitats need to be modified

Addressing uncertainty is very important, as in a decision science framework to aid risk analysis and risk management. The type and level of uncertainty will differ among species and habitats, and thus the kind of information needed and the analyses and levels of precision that are possible will also differ. For example, there is much uncertainty as to how individual species' populations will respond to increasing frequency and intensity of extreme weather events and to rapid changes in temperature and precipitation regimes. There is uncertainty as to how ecologically flexible (evolutionarily adaptable) individual species may be to novel conditions and ecosystems created by rapid changes in climatic conditions in various geographic and topographic locations. And most importantly, there is great uncertainty in predicting thresholds or tipping points of climate change impacts on threats to at-risk species and habitats because the knowledge of what combinations of drivers cause those thresholds to be exceeded is mostly not known. Managers need tools to better understand and incorporate uncertainties into decisions and, in particular, to determine thresholds at which species recovery goals need to be modified under climate change.

Understanding when conservation or recovery goals would need to be instituted or modified to protect at-risk species and their habitats means being able to predict or rapidly respond to thresholds and tipping points (Lenton and Ciscar, 2013; Biggs and others, 2014; Pace and others, 2015). This is a known difficult problem, and some researchers such as Almpanidou and others (2016) have modeled species responses to climatic thresholds to project population responses. Such an approach could be used in the Pacific and Inland Northwest, where drivers of change are well known.

There is a need for a "clearinghouse" to consolidate information on physiological thresholds and levels of uncertainty in the data; Landscape Conservation Cooperatives (LCCs) have been working on this. The NW CSC has a niche to interact with partners, to synthesize the information for decision making, and to not replicate the work that has already been done on the subject. A decision framework that identifies thresholds and helps develop strategies to prepare for sudden shifts and that can be applied in a variety of contexts would be very useful.

Regarding pollinator response to climate change, little research has been conducted in the Northwest on the aptitude of pollinators such as butterflies and bees to shift behavioral phenologies; e.g., changing their timing and seasonality of egg-laying, emergence, flight, and pollination services. A few studies suggest that climate change, such as early onset of spring, can result in a mismatch in timing between pollinator occurrence and availability of plants for pollination (Kudo and Ida, 2013). Instead, most research has largely focused on providing connectivity of habitats to facilitate dispersal and movement in response to climate changes (e.g., Coristine and others, 2016).

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MANAGEMENT PRIORITY 3: INVASIVE SPECIES AND DISEASES

Management Goal 3.1: Update or develop strategies to manage the spread of invasive species and noxious weeds in sensitive habitats under projected climate conditions

Summary of Current Knowledge

Development of effective strategies to manage the spread of invasive species under changing climate conditions requires (1) knowledge of current distribution of invasive species, (2) knowledge of habitat requirements and climate sensitivity of invasive species, (3) knowledge of dispersal potential (e.g., migratory behavior), (4) accurate downscaled climate change projections, and (5) knowledge of barriers to movement. Information regarding these characteristics could be used to build species distribution models and assess the sensitivity to future climates. This management goal is also associated with the management of at-risk species and habitats, aquatic resources, shrublands, and forests.

Invasive *Bromus* spp. (brome) has been well studied. Bradley and others (2016) reviewed models of climate change responses of several problematic brome species from the Mojave Desert, Colorado Plateau, Great Basin, Intermountain West, and the Wyoming Plateaus. Modeled projections of change for other invasive plants are not as well developed, largely because there is less information for species such as *Taeniatherum caput-medusae* (medusahead) and *Ventenata dubia* (North Africa grass) on their soil, temperature, and moisture restrictions that regulate their spread and invasibility. However, these invasive plants continue to spread into new areas of the country annually. Models similar to those developed for annual bromes (Germino and others, 2016) could be developed for a selection of other high-priority invasive/noxious weeds. This would likely be a long-term (10 years or more) process, as invasions do not occur in a vacuum: they are affected by the impacts of climate change on native competitors and environmental drivers. These drivers may contribute (1) ecosystem resistance to species invasions or (2) ecosystem resilience to disturbances that are amplified under climate change (Brooks and others, 2016).

There are currently little data on distribution of invasive aquatic species. We lack information on the habitat requirements of aquatic invasive species, including climate-related variables. An initial attempt to compile this information could be accomplished through using professional opinion and (or) surveys. These could be improved over time by incorporating new techniques, such as collection and analysis of environmental DNA (eDNA), into monitoring programs. The dispersal potential of some aquatic invasive species can be learned on the basis of the species' native ranges.

Aquatic barrier data are largely available in State databases. Basic models for dispersal or spread in the Northwest could be attempted for the aquatic invasive species that are of highest management concern. To achieve the management goal, efforts should focus first on documenting current distribution of invasive species of most concern. Conceptual models should be developed to prioritize areas for survey and potential removal programs based on suitability of habitat for invasive species and the vulnerability of the native fauna to disturbance from nonnative invasive species.

Management Goal 3.2: Update or develop strategies to manage the spread of diseases under projected climate conditions

Summary of Current Knowledge

Addressing this topic will require (1) knowledge of current distribution of terrestrial and aquatic pathogens, (2) knowledge of pathogen life cycles (e.g., intermediate hosts, etc.), (3) knowledge of dispersal potential (e.g., passive, host migration), (4) knowledge of climate sensitivity of disease vector and intermediates, (5) accurate downscaled climate change projections, and (6) knowledge of the relation between climate measures and disease severity. Management Goal 3.2 is also related to other management priorities in the Science Agenda (managing at-risk species and habitats, managing aquatic resources, managing shrubland ecosystems, managing forest ecosystems).

Terrestrial systems.— A recent example of a disease discovered in the Northwest is white-nose syndrome (WNS) in bats, which is caused by a fungal pathogen. The North American Bat Monitoring Program (NABat) arose from the need to monitor bats and the impact of WNS on bats throughout the Nation (Loeb and others, 2015). Warmer temperature may be impacting the infection and spread of this disease. NABat has proposed a national protocol for monitoring bats and has experts who are focusing on questions relating to WNS. Addressing this management goal for WNS would require bat and WNS occurrence and distribution data, as well as understanding the climate sensitivity of bats and WNS. There is a need to implement NABat procedures in multiple States. Colony counts, WNS occurrence, and ancillary temperature data may improve information on the likelihood of WNS spread in the Northwest. Existing acoustic data could be used to develop occupancy models (or other models) to look at changing distributions based on climate and other variables.

Aquatic systems.— Oregon and likely all Northwest States have reasonably good data on current distribution of fish pathogens. For bacterial and viral pathogens, which have direct life cycles, the effects of temperature on pathogen growth and disease progression have been well studied. For parasites that have complex life cycles, the life cycles of the parasites causing the most significant diseases are documented, and intermediate hosts have largely been identified. Some research is needed to fill in data gaps. The dispersal mechanisms are largely known. The climate sensitivity of the pathogens and (or) vectors is known in some instances, but additional research is needed for others. Downscaled climate change projections are available from a variety of sources (see Management Goal 1.1 in this appendix). The relation between climate measures (e.g., water temperature, precipitation, discharge) and disease severity and (or) incidence has been investigated for only a few pathogens (e.g., *Ceratonova shasta* [Ray and others, 2015], infectious hematopoietic necrosis virus [Marcos-López and others, 2010]) and would require significant additional research to establish it more broadly.

Research efforts should focus first on understanding the relation between climate measures (e.g., water temperature, precipitation, discharge) and disease severity and (or) incidence for the key pathogens. Some key questions are as follows: Will increasing temperatures cause changes in pathogen virulence? Will changes in precipitation be more influential than temperature changes at host or pathogen range limits? Will the effects of other anthropogenic factors (e.g., dams, pollution) mask the predicted effects of climate change on disease? Can conceptual models be developed for aquatic pathogens for which there are limited data on the effects of climate-related parameters on life cycle stages? Additionally, an effort to compile fish pathogen distribution data across the Northwest should be considered.

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MANAGEMENT PRIORITY 4: FOREST ECOSYSTEMS

Management Goal 4.1: Plan for wildfire responses and maintain resilient forests under changing fire regimes

Summary of Current Knowledge

There is a fair amount of research about how climate change is likely to affect fire regimes; however, much of this research is fairly broad in scale (e.g., encompassing several ecoregions) and (or) focused on similar systems in areas outside the Northwest. The Northwest has seen some of the largest fire years on record over the last 3–4 years, and an excellent opportunity exists to empirically test the effects of changing fire regimes on forest resilience. For example, since 2014, Washington has experienced records in burned area (2014), unprecedented fires in coastal temperate rainforests (2015), and short-interval reburns of forests with longer natural fire-return intervals. Many such areas have reburned for even longer periods, since around 2000. Relevant research from other regions could be used to design studies testing hypotheses about the effects of climate on fire size (Abatzoglou and Kolden, 2013; Westerling, 2016; McKenzie and Littell, 2017), frequency (Parks and others, 2012), and severity (Harvey and others, 2016b, c; Parks and others, 2016; Stevens-Rumann and others, 2016; Prichard and others, 2017), with particular focus on feedbacks between multiple fire events (e.g., reburns).

Evaluating prefire and postfire forest management options and strategies is an active area of research. The most important science questions that need to be addressed are as follows: How will a warming climate affect fire size, frequency, and severity across the Northwest, and how will results vary within the region? What management options (e.g., fuel treatments or postfire planting) can either mitigate or adapt to these changes?

Management Goal 4.2: Develop forest management practices that will proactively address potential climate change impacts

Summary of Current Knowledge

Regarding culvert placements, a fair amount of knowledge already exists. Locally specific projections of runoff and streamflow under a range of climate change scenarios are available for several geographic domains at a variety of spatial scales from a number of research groups (see Management Goal 1.1 in this appendix) and have been used by State and Federal agencies to inform culvert risk assessment and replacement planning (e.g., Strauch and others, 2015; Wilhere and others, 2016, 2017). For adaptive management approaches for silviculture, much work is being done within the U.S. Forest Service on the subject of forest restoration in the Northwest and elsewhere (see Janowiak and others, 2011, and other references cited below). Work is also available on the impact of drought on forests and grasslands, such as the national synthesis of Vose and others (2016). Much of this information can be summarized and synthesized into the themes of lessons learned and key uncertainties facing forest managers.

For climate change impacts to groundwater and soil moisture, studies are available from other regions of the United States (e.g., south Florida, Alaska) and other countries (e.g., The Netherlands) that could be useful to managers in the Northwest. The NW CSC has sponsored work on groundwater (Identifying Resilient Headwater Streams to Mitigate Impacts to Future Drought in the Northwest [https://www.nwclimatescience.org/projects/identifying-resilient-headwater-streams-mitigate-impacts-future-drought-northwest]) that is applicable to forested ecosystems. Lundquist and others (2016) demonstrated that, in the Northwest, opening overly dense forest canopies by creating forest gaps will generally lead to more snow accumulation and later snowmelt (up to 13 weeks later). They developed a decision tree model to help managers to act strategically to maximize snow retention (protecting forests in some areas while opening gaps in others; indicating areas where melt patterns differed), thereby providing more water later in the season for hydropower, agriculture, and fish flows.

Management Goal 4.3: Develop methods for controlling tree diseases, particularly Swiss needle cast, white pine blister rust, and sudden oak death

Summary of Current Knowledge

Some compendia are available on the known or projected impacts of climate change on tree stress and disease (see Heath and others, 2015). There is also some information about management strategies to combat white pine blister rust in five-needle pines throughout the Western United States (Schoettle and Sniezko, 2007; U.S. Forest Service, n.d.). The most important science questions that need to be addressed are as follows: How will a warming climate alter the potential for spread of introduced insects and pathogens, as well as change the nature of outbreak dynamics in native insects and pathogens? What management options (e.g., tree cutting or planting) can either mitigate or adapt to these changes?

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MANAGEMENT PRIORITY 5: SHRUBLAND ECOSYSTEMS

Management Goal 5.1: Maintain and promote resilient shrublands under changing climate conditions

Summary of Current Knowledge

Livestock grazing is the primary land use on arid and semiarid ecosystems in the Northwest, but land ownership of these same lands may vary depending on the ecoregion, with non-Federal ownership being greatest in Columbia Basin (70 percent) and Federal ownership dominating the other regions (62–77 percent; Knick, 2011). Therefore, grazing management to support sage grouse and other at-risk species in the light of projected climate changes within the region must evaluate management options for both Federal and non-Federal lands. On arid and semiarid lands, plant productivity and plant community structure and function are strongly regulated by soil water availability (Sala and others, 2012). Water is the most limiting resource in arid and semiarid ecosystems, but its impact on plants also depends on carbon dioxide availability and temperature (Smith and Nowak, 1990). Plants may be able to adjust to some of these changes within limits, but these responses will likely change among regions (Polley and others, 2017) and may be susceptible to lag effects (Sala and others, 2012).

The impacts of potential climate change scenarios on livestock grazing and subsequently on sage-grouse habitat will likely require models. As an example, SoilWat is a soil water availability model that was recently tested for climate change impacts on existing arid and semiarid grasslands, and it projects that many locations within the Columbia River Basin and Snake River Plains will become drier and less of the region will become moister (Schlaepfer and others, 2017). Much of this contraction of temperate drylands may also experience less deep-soil recharge of water. This reduction could have major impacts on at-risk species that are isolated with limited ability to emigrate. Landscape connectivity information is important for many species in addition to sage grouse. Although there are some landscape connectivity studies, the knowledge base is incomplete across the Great Basin for species other than sage grouse (Crist and others, 2017) or mule deer.

Invasive weedy plants, as with native plants, will likely adjust their distributions provided they have adequate mechanisms for dispersal and establishment. For example, *Bromus tectorum* (cheatgrass) is projected to migrate to higher elevation, whereas *B. rubens* (red brome) migrates northward with warming climates (Bradley and others, 2016). Management to control these invasive species in light of climate change requires information on the potential spread of the species (see section “Increased Spread and Damage From Invasive Species, Pests, and Pathogens” in report). Some herbicide control techniques work best when applied in conjunction with precipitation (Pyke and others, 2017) and may have their effectiveness change with changes in climate. Targeted grazing is a recently proposed method of using livestock to control palatable invasive grasses (Launchbaugh and Walker, 2006).

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MANAGEMENT PRIORITY 6: WORKING LANDS AND WATERS

Management Goal 6.1: Ensure adequate resource distribution to maintain functioning lands and waters for humans, as well as plant and animal species and their habitats

Summary of Current Knowledge

For simply quantifying the range of changes in flow for key periods (e.g., August), NW CSC has already supported the production of state-of-the-science streamflow scenarios for the future at more than 350 locations, including rivers mentioned by SAC members (see Management Goal 1.1 in this appendix). These data could be repackaged for specific locations of concern (knowledge category 2). More complicated and indepth would be the consideration of smaller stream reaches than are currently simulated by regional-scale hydrologic models that is, streams small enough to dry up. Approaches are being developed for specific locations where gage data exist, but could be broadened for the entire region (knowledge category 2). A wider consideration of both biophysical and human dimensions—for example, the possible interactions of irrigation demands, aquatic species declining toward a listing, stream temperature, State water rights, etc.—could be a challenging and exciting 5-year research project involving hydrologists, aquatic ecologists, legal experts, and economists (knowledge category 4). For example, a National Science Foundation-funded project very much along these lines was recently completed for the Willamette Basin. It included water rights, land use economics, reservoir management, and scenarios of population, climate, and vegetation change.

There are multiple tools and current research projects that are focused on peak flows, though streamflow calibration measurements are not homogenous across the Northwest. Watershed models that have peak flow components have been produced for multiple watersheds by Federal agencies and academic institutions. The USGS hosts Streamstats, which provides online peak flow data for every State in the Northwest for gaged and ungaged streams. Accurate peak flow data are some of the most requested data by USGS Federal and State partners. Unfortunately, Streamstats does not provide forecasted peak flow data. Moreover, nonstationarity mapping within the Northwest has indicated that multiple areas are showing changes in peak streamflows compared to prior decades (Clark, 2010). As mentioned in section “Management Priority 1: Aquatic Resources,” a source of uncertainty is the possible inability to predict episodic events that can drive peak flows, such as rain on snow events (knowledge category 3). These same models can provide runoff and other data to support erosion modeling within forests and on agricultural fields.

In low-flow years, which are becoming more common as the climate changes regional snow-driven hydrology, conflicts arise among instream uses (e.g., hydropower, recreation, flood control, fish flows) and between instream uses and diversions (e.g., irrigation). Each State’s application of Western U.S. water law (the Prior Appropriations Doctrine)(Benson, 2012) is somewhat different, especially in the implementation of mechanisms that provide flexibility in low-flow years. Therefore, assessing the implications of and potential responses to low-flow conditions requires attention to the variations in institutional context and response options across the region.

Forecasting and modeling peak flows for infrastructure design are typically conducted to avoid acute, catastrophic outcomes. Many models exist to facilitate risk planning, but are dependent on accurate representation of weather and climate patterns. Thus, a focus on providing and evaluating climate data, from global and regional climate models, especially for downscaled episodic events like convective storms or rain on snow events, would provide an important step forward. Modeling and forecasting low flow for optimizing irrigation or management of water rights are challenging compared to peak flows because of the number of processes that become important to the magnitude of streamflow in the channel as flow diminishes. Consequently, combinations of deterministic and stochastic models may be needed to provide large watershed (e.g., upper Snake River) representation of all of the processes, particularly where necessary data are unavailable at the scale needed, such as streambed permeability. Cost effective data collection techniques to capture these processes at watershed scales are needed, such as cataloging diversions and retention/detention, inexpensive low-flow monitoring devices, quantifying streambed infiltration, measuring return flows, and riparian demands.

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