FINAL REPORT FOR NWCSC_FUNDED PROJECTS

Moving from Awareness to Action: Advancing Climate Change Vulnerability Assessments and Adaptation Planning for Idaho and Montana National Forests

1. ADMINISTRATIVE

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2. PUBLIC SUMMARY

Public land managers face the daunting task of incorporating climate change vulnerability assessments into their land use planning. The task is especially challenging for federal agencies such as the US Forest Service (FS) that must tackle planning at multiple scales, with tight regulatory oversight, insufficient funding, and strong public engagement. This NWCSC project developed decision support tools to guide resource managers through the process of including future climate projections, climate change vulnerability assessments, and adaptation response strategies and tactics into ongoing and existing planning efforts such as FS forest plan revisions and individual project plans. The tools were developed and tested through direct engagement with resource managers. The tools guide participants through a step-wise process that provides a structured framework to help managers (1) integrate climate projections with other local information relevant to selecting management actions, (2) justify those choices, (3) incorporate those choices into management documents, and (4) communicate those choices to the public. Two user engagement groups populated the framework and tools for use in two different applications: FS R1 recreation managers planning at the project level and FS R1 recreation forest plan revision teams for the Custer-Gallatin and Nez Perce-Clearwater National Forests. Although much of the content such as future climate projections, vulnerability assessments, and adaptation response strategies and tactics was identical for both groups, how that information was processed and used was different between the two groups. The process of developing the tools demonstrated the importance of striking a balance between decision support tools that are too prescriptive to address a range of situations[1] versus too general to

[1] "Situation" generally refers to different recreation opportunities, such as winter motorized recreation, summer non-motorized recreation (e.g., hiking, backpacking), white-water rafting, etc.

truly provide guidance. The success of these tools has led to a continuation of this project beyond the initial NWCSC funded period. Development of tool content specific to the non-forested vegetation resource area is on-going.

3. TECHNICAL SUMMARY

Our goal was to develop decision support tools to address the resource management challenge of responding to future conditions imposed by climate change and implementing decisions at a range of spatial scales. Climate change is the most pressing ecological challenge of our time, yet resource managers struggle to incorporate it into management decisions. Projected changes are likely to result in cascading impacts to species, habitats, and physical processes, and will exacerbate current resource challenges such as conflict over water resources, effects of invasive species, and meeting expectations for resource harvest. Resource managers and planners are addressing this challenge by revising current plans and practices with increased attention on potential climate impacts to natural resources, communities and social/economic values to better attain long-term goals. In the U.S. Forest Service (FS), addressing climate change has included developing vulnerability assessments and adaptation strategies that draw attention to potential effects and responses to climate change across broad geographic areas. In an effort to be comprehensive at a broad spatial scale, these assessments tend to present a wide range of generally stated effects and options that may or may not be applicable everywhere. Meanwhile, most management decisions and actions are undertaken regarding particular locations, such as at individual forests and project sites. These decisions must be based on local knowledge of conditions and feasible actions.

The decision support structure and tools (henceforth framework and tools) designed under this NWCSC funded project provide a process-based approach for incorporating what we know about coming consequences of climate change with other locally-derived information to answer the resource- and decision-specific questions that are relevant to managers. The framework and tools were designed to facilitate the need managers have to put individual decisions into a larger context in order to help evaluate and prioritize actions according to the spatial pattern of climate change intensity and the potential consequences to the resource as a whole, that follow from a suite of individual decisions or site-specific actions.

The framework and tools were developed through direct, continuous engagement with resource managers. We at first experimented with several decision support tool structures and climate-derived variables, testing these with managers to arrive at a framework and tools that struck a balance between being too prescriptive to address a range of situations versus too general to truly provide guidance. The result of our experiments demonstrated that a structured workshop where participants engage with a “critical questions” method, followed by a filtering matrix method, were the most effective tools. We also found that the composition of the group was highly determinative, with coproduction of effective solutions best achieved when the group included individuals with skill and expertise in each of the following:

- Technical expertise with the focal resource area,
- Region-wide understanding of institutionally specific planning mechanisms,
- Knowledge and familiarity with corporate geospatial holding,

- Knowledge of and access to local geospatial data, and
- Long-term experiential knowledge of existing conditions and memory of prior institutional responses to extreme weather and environmental conditions.

We identified climate-derived variables that are more pertinent to resource-specific decisions than simple summaries of annual changes in temperature and precipitation, and were able to incorporate climate model uncertainty into the decision process.

This NWCSC funded project shows how assessments of climate change risk and potential adaptation strategies developed over large geographic areas can be focused to address specific areas and decisions. Our tools help managers justify why one management approach was chosen over another, thereby enabling legal compliance and facilitating public outreach. This is a contribution to social and geographic sciences, but perhaps more importantly, it is a contribution to expedite consideration of climate change into decisions made by resource management agencies.

4. PURPOSE AND OBJECTIVES

The project's original overarching goal was to conduct a climate change vulnerability assessment over large landscapes and develop associated adaptation strategies for key resources in forested areas of north-central Idaho and western Montana national forests (within FS Region 1). However, subsequent to NWCSC's selection of this proposal another project surfaced, with several of the same regional objectives. Rather than implement two different approaches to regional vulnerability assessment, a collaborative work plan was developed whereby the alternative project (aka Northern Rockies Adaptation Partnership or NRAP) would conduct a region-wide vulnerability assessment and produce an adaptation planning document (i.e., General Technical Report) while the NWCSC products would focus on creating decision tools to help implement climate change adaptation strategies.

A revised project proposal was submitted to NWCSC in April 2014, with a new overarching goal of augmenting an existing, landscape-scale vulnerability assessment and adaptation strategy project for FS Region 1 (R1) by developing spatially explicit tools and guidance for applying vulnerability and adaptation information at multiple planning levels. Specific objectives included:

1. Identify how vulnerabilities and resiliencies of priority terrestrial and aquatic ecosystems, individual species, and ecosystem services vary spatially in their response to climate change and non-climate change stressors to help prioritize conservation areas and activities.
2. Identify and prioritize implementable management responses to climate change based on spatial analysis. Describe how effectiveness of and trade-offs among potential management actions vary spatially.
3. Develop an implementation guide describing how to integrate climate vulnerability and adaptation strategies into specific planning and management operation levels (e.g., NEPA, forest plan revision) using case studies from R1 forests as examples.

Since project inception, we have also added two more objectives:

4. Participate in the NRAP regional assessment of vulnerabilities, resiliencies, and potential adaptation strategies for terrestrial and aquatic ecosystems, target species, and ecosystem services regarding climate change and non-climate change stressors.
5. Develop decision support tools that provide guidance to managers for incorporating climate change impacts and vulnerability information in planning documents as well as improve understanding of what adaptation strategies may be most appropriate for a given scenario.

Objective 4 was added to address the goal of incorporating the vulnerability and adaptation information and insights from the NRAP process as well as improve their integration into land management decisions. The purpose of objective 5 was to create a more holistic set of tools – site-specific yet sensitive to the regional context – a need expressed by partners and identified as missing in current forest planning and management processes.

Figure 1 maps out the linkages between NRAP and this project for one specific planning exercise: a forest plan revision planning team working to incorporate knowledge about potential climate change effects on winter recreation opportunities into forest plan revision stages and documents. Region-wide science-based background information developed through the NRAP process (blue box) generally informs three of five forest plan revision components. The spatial tools and decision support framework provided by this project (green box) effectively down-scale the region-wide information to be useful in actually crafting the forest plan, environmental impact statements, and monitoring plans.

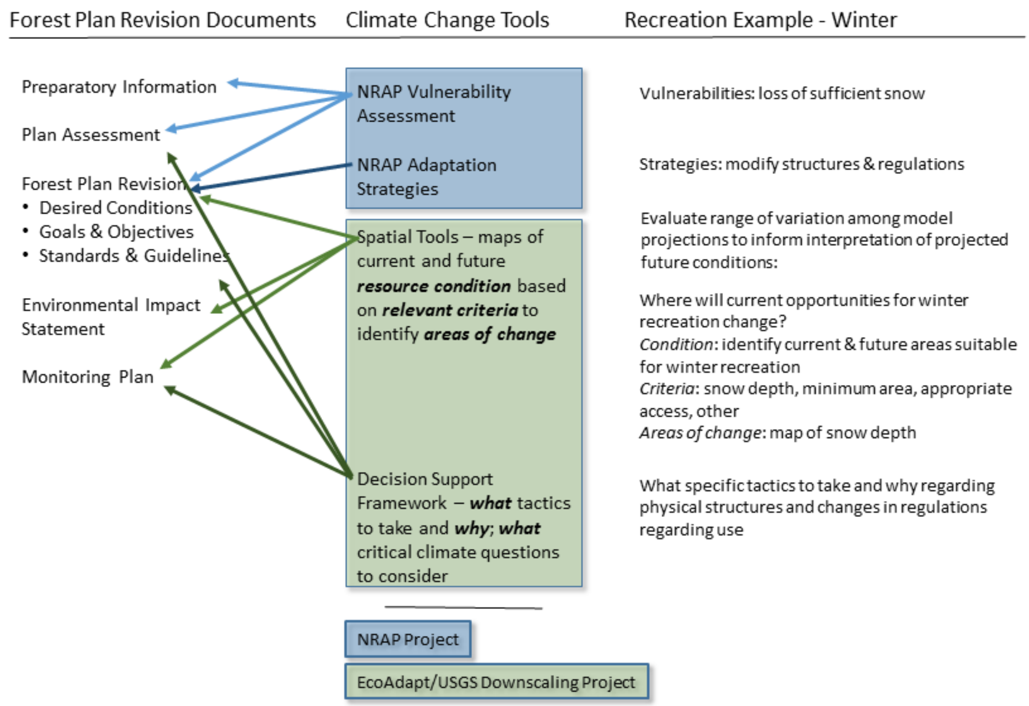

Figure 1. Relationship among NRAP products, our products, and forest plan revision documents. Brief examples of product outputs regarding winter recreation are given.

5. ORGANIZATION AND APPROACH

Our methods reflect the revised project proposal from April 2014.

1. *Regional Vulnerability Assessment and Adaptation Strategies (Objective 4)*. Attended NRAP regional workshops to engage with workshop participants, assess adaptation strategy development methodology, improve understanding of implementation issues, and begin using findings in our project before release of interim and final NRAP products.
2. *Stakeholder Engagement – Part Ia (Objective 5).* Met with regional and forest unit partners to discuss desired outcomes from our project and lessons learned from previous attempts to develop spatially explicit management tools. Meetings conducted in-person at regional office in Missoula, MT.
3. *Stakeholder Engagement – Part Ib (Objectives 1, 5).* Met with regional and forest unit partners to review the results of NRAP and discuss ways in which to downscale results from the region-wide assessment to sub-regional, forest-level, or resource-specific information. Selected priority resources on which to focus the spatial analysis and began identifying specific resource management questions related to climate change. Began identifying key

climate and non-climate datasets for spatial analysis. Integrated NRAP regional climate vulnerabilities and adaptation strategies for FS R1 into forest unit decision-making processes such as forest plan revision and program-level plans. Discussed approach for using multiple future climate scenarios. In addition to exploring spatial analysis tools with stakeholders, created multiple site-specific decision support tools such as decision trees and prioritization matrices and experimented with them by presenting them to stakeholders for feedback and selection. All meetings conducted via conference call or online using WebEx.

4. *Spatial Analysis and Mapping (Objectives 1, 2)*. Analyzed spatial and other data, either publically available or provided by FS staff, as well as climate projections to create maps of current and future resource condition to identify areas of change. Tailored this information to be relevant to and easily incorporated into forest plan revision documents.

5. *Decision Tools (Objectives 3, 5)*. Developed resource area-specific lists of 'critical questions' and other non-map-based decision support tools to help resource managers evaluate mapped and other information to determine the most effective adaptation strategies and tactics regarding climate change; critical questions are modeled after the Climate Project Screening Tool[2]. Created vulnerability-adaptation tables, which link adaptation tactics with the specific climate vulnerabilities whose impacts they can help to reduce or address based on information from the scientific literature and/or expert opinion. Decision support tools were initially developed with a small group of managers in an iterative fashion. Tools underwent further revision after introduction to a broader group of managers in step 6.

6. *Stakeholder Engagement – Part II (Objectives 1, 2, 3, 5).* Following the creation of both map-based and non-map-based decision support tools, met with FS managers and other stakeholders to explore the results and discuss how and where products are best used to inform management decisions. We also used the climate-informed maps to demonstrate where specific strategies and tactics could be applied on the landscape; for example, changes in location of winter motorized recreation opportunities on the Nez Perce-Clearwater National Forests. Engagements were conducted in-person.

7. *Implementation Guide (Objective 3)*. Provide "how to" guidance on application and integration of vulnerability and adaptation information into forest planning as well as other regional conservation efforts using the recreation resource as an example. Elements included:
    a. Guidance and examples for spatial analysis of current conditions and projected changes for natural resources, with specific linkages to adaptation strategies and what may be most appropriately implemented where.
    b. Decision support framework to help managers consider important climate-related questions for priority resources (e.g., recreation) and focus in on the most relevant adaptation options for a given situation or scenario.

[2] Morelli, T.L., S. Yeh, N.M. Smith, M.B. Hennessy and C.I. Millar, 2012, Climate project screening tool: An aid for climate change adaptation, USDA Forest Service, Pacific Southwest Research Station, Research Paper PSW-RP-263.

c. Tables linking vulnerabilities with adaptation strategies to help managers identify what adaptation strategies to implement and why (i.e., what vulnerabilities do they help to reduce or address).
d. A table demonstrating ways in which to better integrate climate and non-climate stressors, including synergistic impacts, in decision-making and decision justification (i.e., NEPA).

While we originally planned to provide implementation guidance as a handbook, it became clear that the groups we were working with needed higher levels of interactivity than could be provided with a handbook. We deemed it a more effective approach to cogenerate content that populated the tools with resource-specific information through in-person meetings. Groups of resource managers who are actively engaged in forest plan revisions were enthusiastic about the new tools and synergistically adapted them to their specific location(s). We also included representatives from the regional office who brought a broader spatial perspective as well as experience gained from working on other forest plans. We also found it essential to have in attendance a strong advocate for our tools who had a clear vision for how planning for climate change could help individual forests.

6. PROJECT RESULTS

Four types of decision-support tools were created to support the application and integration of vulnerability and adaptation information into different management operation levels. Results for each of these tools are described below.

A. Climate-informed maps

Monthly downscaled output (temperature and precipitation) from 33 of the 5th Climate Model Intercomparison Program (CMIP5) derived by Thrasher et al. (2013)[3] for the representative concentration pathway of 4.5 and 8.5 watts/m^2 and snow water equivalent, runoff, soil water storage, and evaporative deficit from water balance models driven by these data developed by Alder and Hostetler (2013)[4] formed the core of future environmental parameter projections for the NWCSC project. These data are at an 800 m grid resolution for the conterminous U.S., which provides both adequate resolution to differentiate topographically relevant differences and a standardized dataset that can be used for all FS units in R1. A relatively high spatial resolution was necessary to address differences that were being encountered across sites where on-the-ground decisions were being made; this made other available climate projections such as those used for the region-wide vulnerability assessment less attractive.

[3] Thrasher, B., J. Xiong, W. Wang, F. Melton, A. Michaelis, and R. Nemani. 2013. New downscaled climate projections suitable for resource management in the U.S. Eos, Transactions American Geophysical Union, 94: 321-323, doi:10.1002/2013EO370002.
[4] Alder, J. R. and S. W. Hostetler. 2013. USGS National Climate Change Viewer. US Geological Survey http://www.usgs.gov/climate_landuse/clu_rd/nccv.asp doi:10.5066/F7W9575T.

We followed the approach of Snover et al. (2013)[5] of choosing models and specific climate variables that best inform the adaptation options of the focal resource (e.g., winter recreation). Models were selected to represent the widest range of future climate projections (warmest-coolest, driest-wettest), the lowest seasonal bias as derived by Zhu Liu et al. (2014)[6], and the shortest and longest seasonal precipitation cycles (Figure 2) among others. Table 1 depicts the logic linking the focal resource with management relevant questions and the climate variable and models.

Table 1. An example of climate models selected to address management questions for winter-based recreation. Climate models included: Model for Interdisciplinary Research on Climate Earth System Model (MIROC-ESM), Geophysical Fluid Dynamics Laboratory Earth System Model 2 M (GFDL-ESM2M), and historic climate data from PRISM (PRISM Climate Group)[7].

Resource Focus	***Management question***	***Spatial Data to Support Inquiry***	***CMIP5 Models***
Winter-based recreation	What is the extent of snow-free areas by month throughout the forest?	Feb, Mar, and Apr snow water equivalent (SWE)	MIROC-ESM (Extreme loss of SWE) GFDL-ESM2M (best replication of seasonal change across the landscape for the FS units of interest)
	Where will timing of recreation opportunities shift?	Difference maps of historical (PRISM) versus projections of Feb, Mar, and Apr SWE	
	Where will current opportunities for winter recreation be lost? Where will new opportunities possibly arise?	Overlays of above SWE difference maps with FS recreation point data	

[5] Snover, A.K., N.J. Mantua, J.S. Littell, M.A. Alexander, M.M. McClure, and J. Nye. 2013. Choosing and Using Climate-Change Scenarios for Ecological-Impact Assessments and Conservation Decisions. Conservation Biology, 27(6): 1147-1157.

[6] Zhu Liu, A. M., T.J. Phillips, and A. Agha Kouchak. 2014. Seasonal and regional biases in CMIP5 precipitation simulations. Clim Res, 60: 35-50.

[7] PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu.

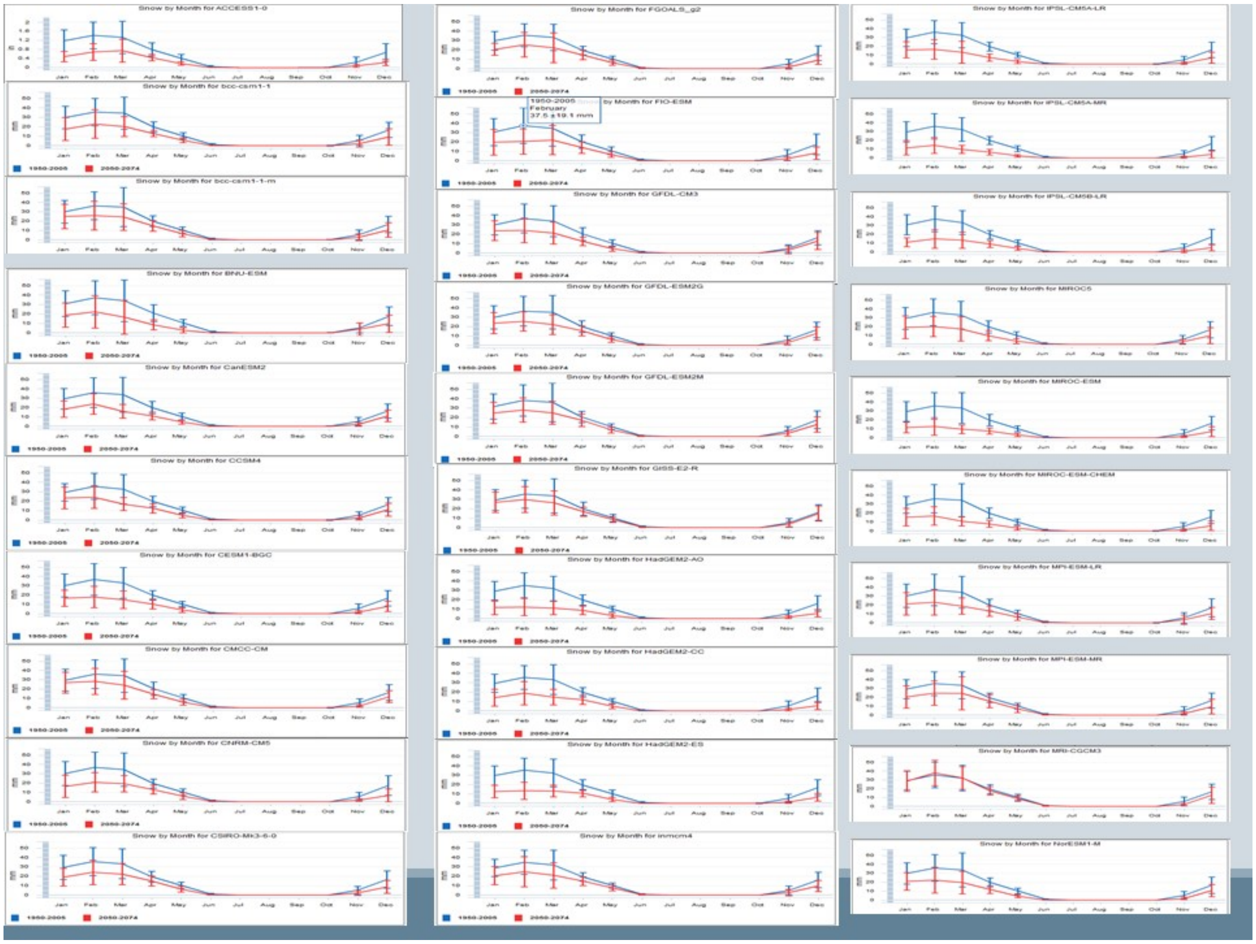

Figure 2. Graphs of 33 model outputs of monthly SWE (months on x- axis, SWE on y-axis, blue line is historical SWE, red line is SWE climate model output). Compiled from the USGS National Climate Change Viewer (https://www2.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp).

Two webinars were held with our user group to describe the climate model selection process. We received feedback that, although the information was interesting, they were not in a position to spend time dealing with it and would strongly prefer just one future projection to work with. Conversely, the reaction to multiple climate model results during the workshops was very different. When multiple climate model derivatives were presented in an interactive Geographic Information System (GIS) format it initiated discussion about climate extremes experienced in past years, which led to a new conceptual approach to different model results. Extreme weather events are expected to increase in the future and the different climatological outcomes that were being represented by different models were seen as examples of future conditions that they could face.

The interactive GIS format worked because FS GIS staff helped to co-create derivatives from the compiled datasets during the workshop. For example, during one of the workshops it became clear that an important consideration was how to manage snowmobile trails during years when snow levels were very low (Figure 3). FS staff pulled up trail layers and recreational opportunity spectrum layers that showed where these activities were designated across the landscape. The snow water equivalent maps from various climate models did not adequately show where on the landscape snowmobiles could drive. Based on managers' expert knowledge of the depth of snow needed for snowmobiling (11-12 inches) we generated simplified maps (Figure 4) that spawned a lengthy discussion about alternative strategies for managing both snowmobile usage and hunting access, which is also influenced by snow depth.

An important consideration for managers is the potentially compounded uncertainty that is generated when creating derived climate variables. For example, the variable snow-water equivalent is subject to the combined uncertainty inherent in projects of both precipitation and temperature. Nevertheless, maps of critical variables do indicate the best available information regarding the spatial distribution of relative risk to future availability of recreation opportunities.

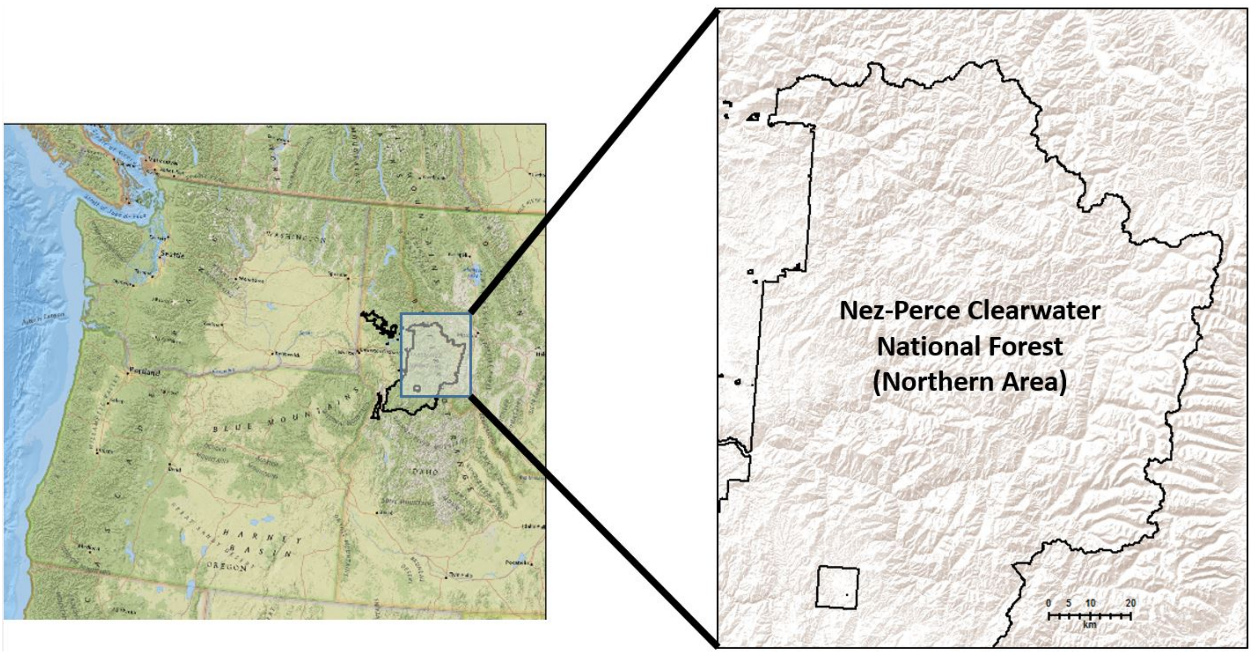

Figure 3. Location map for workshop discussion on options for snowmobile trails and for detailed maps in figure 4.

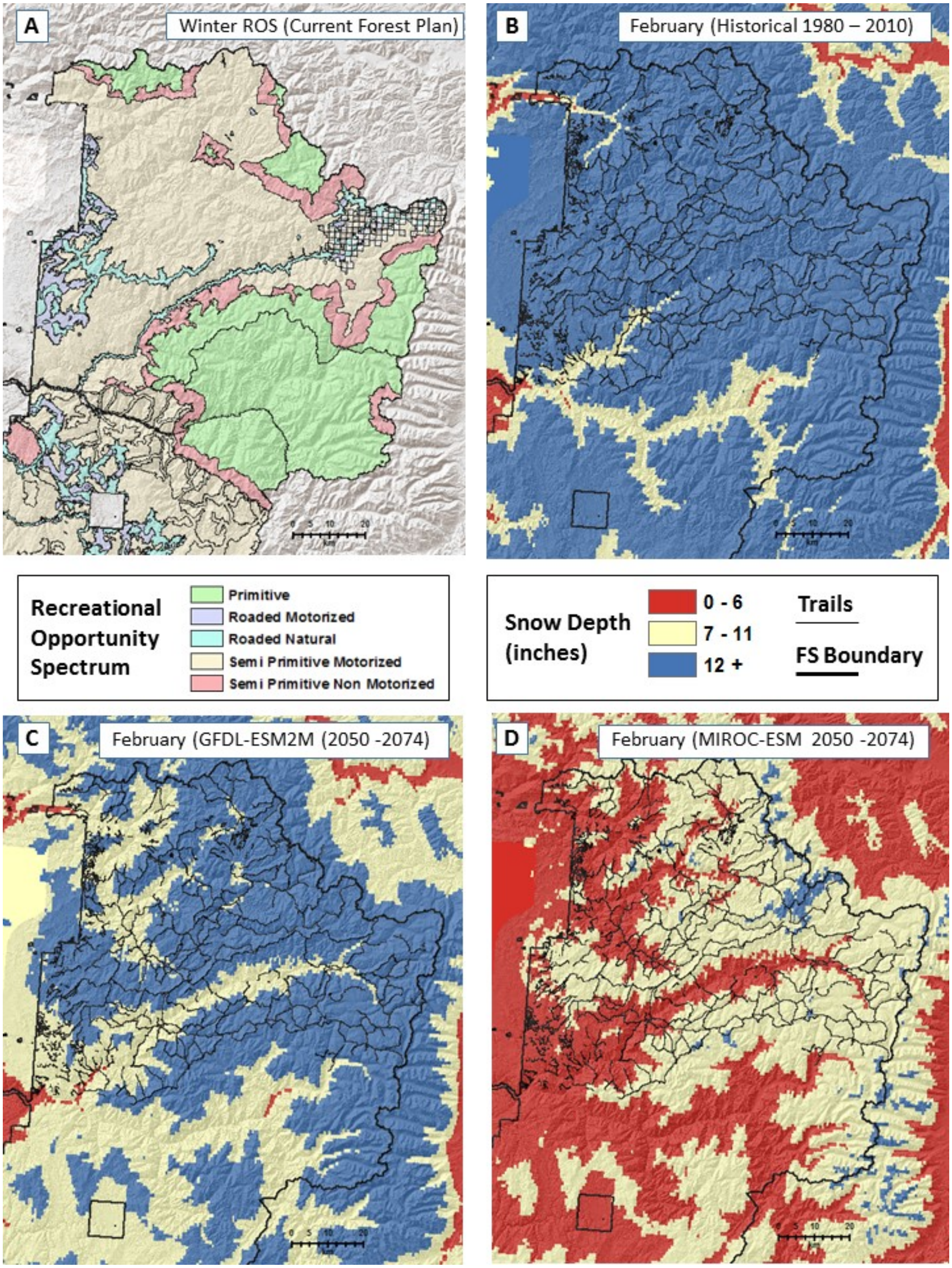

Figure 4. Maps that facilitate discussion of snowmobile management options. A) Winter recreational opportunity spectrum (ROS) maps showing semi-primitive motorized areas in yellow, B) depth of snow under current climatological condition, where most of the trails in the semi-primitive motorized area have adequate snow depth for snowmobiling, C) depth of snow under a 4.5 watts/m^2 increase under GFDL-ESM2M climate conditions, and D) under MIROC-ESM.

B. Decision support framework for recreation managers

Forest planning is conducted at multiple scales: region-wide, forest-specific, and project level. One of the needs we identified was for a conceptual structure that linked decision support tools to the types of planning that forest managers do. We created a decision support framework for recreation managers to help integrate climate considerations into management plans and projects. Specifically, the framework is intended to improve understanding of where (e.g., which planning document, *plan* vs. *project*) and when (i.e., based on a given climate, management, and resource condition situation or scenario) to apply adaptation strategies and tactics generated by the NRAP effort.

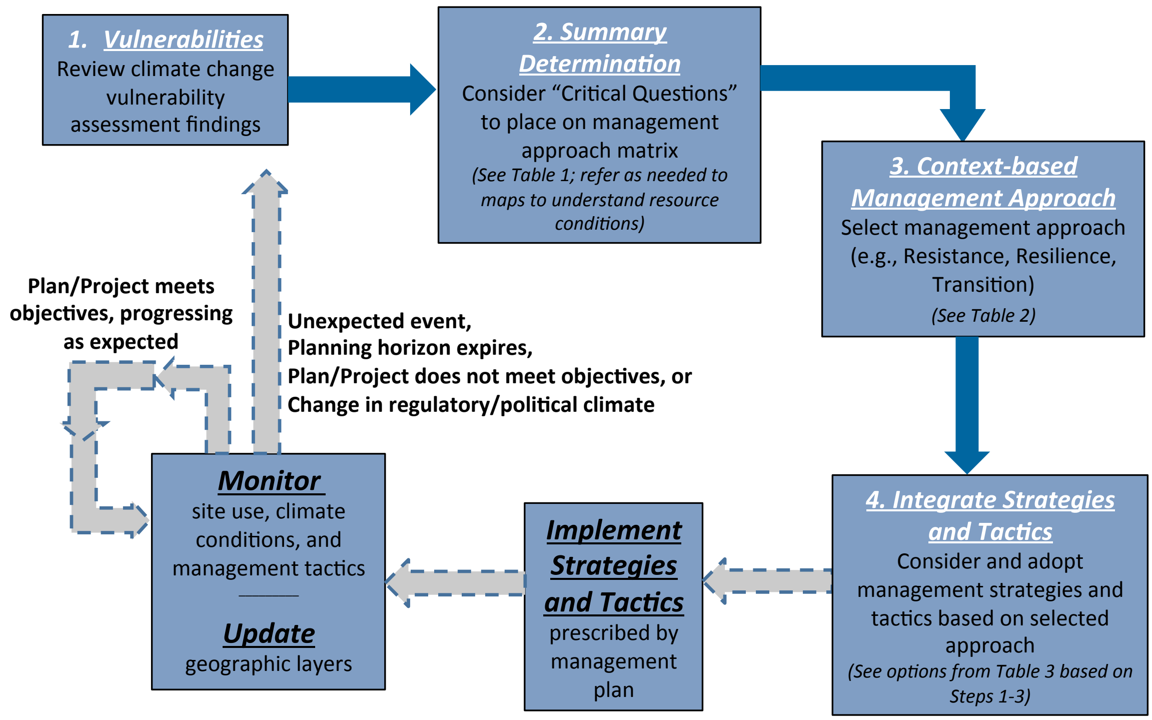

Figure 5. Conceptual model of management decision process, where Steps 1-4 represent a decision support framework that helps managers integrate climate considerations into plans, programs, and projects.

Figure 5 is an overview of the decision support framework visualized as a series of steps that managers take, starting with a review of the results of climate change vulnerability assessments and ending with monitoring the results of specific on-the-ground actions. Resources developed by this NWCSC project support steps two, three, and four. The review conducted in step one used the draft version of Halofsky et al. (2017)[8]. The Summary Determination conducted in step two is accomplished by working through the "critical questions" (see Table 2) to define and articulate the value, the current condition, and an understanding of future climatic suitability for the resource; in this case, the resource is a recreation opportunity. Completion of step two

[8] Halofsky, J.E., D.L. Peterson, S.K. Dante-Wood, L. Hoang, J.J. Ho, and L.A. Joyce, editors. 2017. Climate change vulnerability and adaptation in the Northern Rocky Mountains. Gen. Tech. Rep. RMRS-GTR-xxx. Fort Collins, CO: U.S. Dept. of Agriculture, Forest Service, Rocky Mountain Research Station. 881 p.

sets the stage for step three, which funnels step two results through a decision matrix of appropriate approaches: actions that resist change, such as protecting at all costs a ski area (Resistance); implementing habitat restoration to improve the capacity of a site to weather change (Resilience); allowing change to take its course (Transition); revisiting and revising underlying goals and priorities (Realignment); or proactively deciding to do nothing (No Action). Step four uses the matrix derived from step three to more easily select appropriate management actions (Strategies and Tactics). These four steps guide the managers through a thought process designed to hone in on workable solutions without being overwhelmed by the complexity of uncertainty. Managers then implement their selected strategies and tactics, monitor climate conditions and tactic effectiveness, and update geographic layers as needed.

A summary of the 4 steps of the decision support framework (details provided below):

1. Review climate change vulnerability assessment findings
2. Answer critical questions for three planning considerations: future climatic suitability, value, and current condition, and make summary determinations
3. Use management approach matrix to select the approach that best suits a given situation or scenario
4. Select corresponding adaptation strategies and tactics to integrate into management plans, programs, and projects

Step 1. Review climate change vulnerability assessment findings

Managers review the recreation climate change vulnerability assessment findings from the NRAP effort[2] to identify the key climate and non-climate factors that influence warm weather-, winter-, or water-based recreation opportunities. For example, key climate vulnerabilities include increased temperature; amount, timing, and type of precipitation; and reduced snowpack, while non-climate vulnerabilities include increased human populations and deferred or neglected maintenance. These key climate and non-climate vulnerabilities help guide what spatial information to assemble and map, and aid in answering the critical questions in Step 2.

Step 2. Answer critical questions for future climatic suitability, value, and current condition and make summary determinations

Recreation managers select a recreation opportunity of interest (e.g., winter motorized recreation) and answer the critical questions for each of the three planning considerations: future climatic suitability, value, and current condition of the recreation opportunity (Table 2). It may be necessary to redefine the items in the Summary Determination column to clarify their meaning relevant to individual recreation opportunities. Climate change projections and vulnerability assessments from the NRAP effort[2], along with climate-informed maps, can be used to help inform answers to critical questions. Based on responses to the critical questions, managers select the overall summary determination for each planning consideration.

Once summary determinations have been selected, managers move on to Step 3.

Table 2. Planning considerations and critical questions for recreation opportunities (e.g., winter motorized recreation).[9]

	Planning Consideration	Critical Questions	Summary Determination
Question A	What is the future climatic suitability of the recreation opportunity?	Use projected future climate scenarios and maps to help answer the following questions: • Will the timing of access for the opportunity likely shift in the future? • Are trailheads and other infrastructure strategically located to provide sufficient access to areas where the opportunity will likely be available in the future? • Will other nearby areas open up as possible sites/opportunities? • Will use likely become concentrated in particular areas or at particular times due to projected climate changes? • Is climate change likely to substantially alter the spatial distribution of animal habitat-related restrictions (e.g., bear, lynx)? (i.e., affecting a substantial portion of area; metric TBD) • Are climate-driven changes in disturbance regimes (e.g., fire, flooding, wind) likely to limit opportunity access (e.g., close trails or facilities)? (i.e., in a substantial portion of area; metric TBD) • Will demand for the opportunity likely be met in the future? *Winter-specific considerations* • Is snowpack projected to decline beyond a suitable level for different winter recreation activities (e.g., limit type or quality of activities)? *Water-specific considerations* • Is the amount or timing of streamflow projected to limit water-based recreation activities (i.e., type of activity, quality of activity)?	□ Climatically Suitable *(conditions likely to become or remain suitable to meet demand for the opportunity)* □ Climatically Marginal *(conditions may remain suitable in the short-term to meet demand for the opportunity)* □ Climatically Unsuitable *(conditions likely to become unsuitable to meet demand for the opportunity)*

[9] Projected climate trends include:
Winter: warmer temperatures, reduced snowpack, shifts in rain-snow transition to higher elevations, shorter winter season
Summer: warmer temperatures, longer season
Water: lower summer flow, earlier flows

Question B	What is the value of the recreation opportunity?	• Is the opportunity highly valued by the public?
		• Does the forest provide a unique recreational opportunity? (e.g., provided by no other forest unit, agency, or business in the area)
		• What is the fate of similar nearby opportunities?
		• Can the opportunity be made available (relocated) somewhere else? If so, how close?
		• Does the provision of the opportunity provide significant economic importance to local communities?
		• Is the value of the opportunity likely to persist?
		  ○ Near term (<5 years)
		  ○ Mid term (5-10 years)
		  ○ Long term (>10 years)
			□ High Value (*higher value; unique opportunity provided by the forest*)
			
			□ Moderate Value (*somewhat valued; opportunity may be provided elsewhere*)
			
			□ Low Value (*lower value; opportunity may be provided elsewhere*)

Question C	What is the current condition of the recreation opportunity?	• Are there sites that are currently climatically unsuitable or marginal (i.e., for providing the recreation opportunity)? • Are there sites within the recreation category that have degraded or marginal infrastructure (i.e., for providing the recreation opportunities)?	□ Good (*most sites currently provide recreational opportunity*) □ Marginal (*some sites are climatically marginal or have degraded infrastructure for providing the opportunity*) □ Poor (*some sites are climatically unsuitable and/or have degraded infrastructure for providing the opportunity*)

Box 1. Identifying the "Need for Change"

"Need for change" describes a strategic change to the current forest plan necessary to address conditions, trends, and risks to sustainability. As part of forest plan revisions, all forests are required to identify the "need for change" for different resources, which links resource conditions, trends, and risks with where and how the current plan needs to be changed in order to ensure long-term sustainability of resources. Identifying the "need for change" for resources provides the foundation for creating plan components of the revised forest plan.

Steps 1 and 2 in the decision support framework, as well as the climate-informed maps, provide important information to help develop need for change statements. Reviewing vulnerability assessment information for a given resource (Step 1) presents managers with a general overview of current resource condition as well as current and projected future trends and risks to the resource due to climate change. Answering critical questions (Step 2) and using climate-informed maps go beyond generalities to more directly consider the long-term sustainability of the resource (e.g., are climate conditions likely to become or remain suitable to meet demand for the recreation opportunity?) and provide critical support (e.g., high value, unique recreation opportunity provided by the forest) for articulating the need for change. For example, a current forest plan may limit the pace and scale of vegetation management activities in or near recreation and/or historic sites. Based on projected future trends in wildfire, it may be important to develop new management objectives that encourage vegetation management in these sites in order to avoid the loss of these resources during catastrophic fire events. Additional plan components could be considered that encourage local hiring in order to support socioeconomic sustainability.

Answering critical questions associated with Table 2, Question B summarizes why this resource is so important (i.e., its "value") while answering critical questions associated with Question A summarizes the risks to, and likely future trends for, long-term sustainability of the resource. Together, the answers to Questions A and B can provide the basis for a "need for change" statement.

Step 3. Use management matrix to select the approach that best suits a given situation or scenario

Using the summary determinations selected in Step 2 for the recreation opportunity of interest, managers locate the corresponding box in the management approach matrix (Table 3). Each box in the matrix is linked to one of 27 possible combinations of suggested management approaches that reflect the determinations for climate suitability, value, and current condition. Management approaches include resistance, resilience, transition, realignment, and no action (Box 2). Recreation managers select the approach that best suits their given situation or scenario, although they are encouraged to consider those approaches to implement in the near- or short-term (i.e., resistance, resilience) as well as those more suitable in the long-term (i.e., transition, realignment).

Box 2. Management Approaches (definitions)

Resistance: Prevents the effects of climate change from reaching and/or affecting a recreation category. *Near-term approach.*

Resilience: Buffers against climate change impacts by avoiding the effects of or recovering from changes. *Near- to mid-term approach.*

Transition: Intentionally accommodate change and adaptively respond to new conditions. *Long-term approach.*

Realignment: Revisit and revise underlying goals and priorities. *Long-term approach.*

No Action: Proactively decide to do nothing.

Note: These terms refer to the planning horizon, not necessarily the time when actions should be taken. For example, if 'transition' is the goal, it may require near-term actions to achieve the goal over the long-term.

Once the appropriate box in the matrix has been identified, along with the preferred approach, recreation managers move on to Step 4.

Table 3. Management approach matrix for recreation opportunities. Management approaches reflect the overall direction that could be taken in the near- or long-term. Based on summary determinations in Table 2, resource managers choose one of the boxes below thereby selecting the management approach that best suits their situation. Green boxes are those that have at least two of the following: (1) Good current condition, (2) High value, or (3) Suitable future climate conditions. Red boxes are those that have at least two of the following: (1) Poor current condition, (2) Low value, or (3) Unsuitable future climate conditions.

		CLIMATIC SUITABILITY		
CURRENT CONDITION	**VALUE**	**Suitable**	**Marginal**	**Unsuitable**
Good	High	No Action Resilience	Resistance Resilience Transition	Resistance Realignment
	Moderate	Resilience Transition	Resistance Resilience Transition	Resistance Realignment
	Low	No Action Transition	Transition Realignment	No Action Realignment
Marginal	High	Resilience	Resistance Resilience Transition	Resilience Realignment
	Moderate	Resilience	Resistance	Resilience

		Transition	Resilience Transition	Realignment
	Low	No Action	No Action	No Action
Poor	High	Resilience	Resilience Transition	Transition Realignment
	Moderate	Resilience	Resilience Transition	Transition Realignment
	Low	No Action	No Action	No Action

Step 4. Select corresponding adaptation strategies and tactics to integrate into management plans, programs, and/or projects

Once the management approach has been selected in Step 3, managers locate the corresponding adaptation strategies and tactics in Table 4. Aside from the "no action" management approach, all approaches have a suite of adaptation strategies and tactics from which to choose. Managers can select the appropriate strategies to be integrated into their *plans* and *programs*, and the appropriate tactics to be integrated into their on-the-ground *projects*. Table 4 below is an example of management approaches for "good" current condition.

Table 4. Management approaches for recreation opportunities with *good current condition*. Adaptation strategies and tactics are climate adaptation responses that make sense in terms of the selected management approach. Based on the management approach selected in Table 3, resource managers can integrate the associated adaptation strategies into their *plans* and *programs* and the adaptation tactics into their *projects*.

GOOD CURRENT CONDITION			
	CLIMATICALLY SUITABLE	**CLIMATICALLY MARGINAL**	**CLIMATICALLY UNSUITABLE**
HIGH VALUE	**No Action** **Resilience** *Adaptation Strategies* • Increase management flexibility to respond to changing access demands and use patterns • Minimize synergistic impacts of climate changes, recreation use, and other stressors *Adaptation Tactics* • Maintain and/or improve current recreation infrastructure to respond to changing use patterns/demand • Adjust capacity of recreation sites to accommodate changes in demand • Adjust infrastructure maintenance schedule as needed to accommodate changing conditions and/or demand issues • Prioritize post-disturbance treatments (e.g., relocation, armoring)	**Resistance** *Adaptation Strategies* • Manage recreation sites to mitigate risks to public safety and infrastructure and to continue to provide recreation opportunities for as long as possible *Adaptation Tactics* • Focus on activities that will remain feasible given projected changes, and take action to preserve those opportunities • Shift location of activities to maintain opportunities and/or to mitigate safety risks • Relocate at-risk infrastructure • Maintain to safety standards for as long as possible • Maintain and/or improve current recreation infrastructure at sites that will remain viable under future climate conditions **Resilience** *Adaptation Strategies* • Increase management flexibility to respond to changing access demands, use patterns, and resource availability • Minimize synergistic impacts of climate changes, recreation use, and other stressors *Adaptation Tactics*	**Resistance** *Adaptation Strategies* • Manage recreation sites to mitigate risks to public safety and infrastructure and to continue to provide recreation opportunities for as long as possible *Adaptation Tactics* • Focus on activities that will remain feasible given projected changes, and take action to preserve those opportunities • Maintain to safety standards for as long as possible • Identify nearby areas where similar activities might still be possible and consider feasibility of developing • Shift location of activities to maintain opportunities and/or to mitigate safety risks • Relocate at-risk infrastructure • Maintain and/or improve current recreation infrastructure at sites that will remain viable under future climate conditions **Realignment** *Adaptation Strategies* • Revisit and revise goals and priorities in

GOOD CURRENT CONDITION			
	CLIMATICALLY SUITABLE	CLIMATICALLY MARGINAL	CLIMATICALLY UNSUITABLE
		• Adjust infrastructure maintenance schedule as needed to accommodate changing conditions • Monitor recreation sites and set trigger points to determine when a site should be closed or access restricted • Modify existing infrastructure to better withstand future climate conditions • Educate the public about changing site conditions and/or safety issues • Prioritize post-disturbance treatments (e.g., relocation, armoring) **<u>Transition</u>** *Adaptation Strategies* • Increase management flexibility to respond to changing access demands, use patterns, and resource availability • Increase collaborations with partners and concessionaires to address changes in recreation opportunity supply and demand *Adaptation Tactics* • Develop new recreation sites designed for flexibility in use and/or resilient to climate impacts, or create new recreation opportunities at existing sites • Develop additional access restrictions, which may include changes to permitting processes, seasonal closures, or allowable uses • Invest strategically in infrastructure that will	order to provide sustainable recreation opportunities in response to changing supply and demand • Use research, monitoring, and assessment to increase knowledge of current conditions and projected changes *Tactics* • Create new recreation opportunities at existing sites • Develop additional access restrictions, which may include changes to permitting processes, seasonal closures, or allowable uses • Adjust the timing of actions (e.g. open/close dates, road or trail closures, food storage orders, special use permits) to accommodate changing conditions and/or demand issues • Conduct a cost-benefit analysis of maintaining the current opportunities over time in order to determine whether prioritized opportunities should change • Assess infrastructure vulnerability to climate change and natural hazards, and prioritize by seasonal use, viability, and required investment • Monitor climate variables critical to current and future use, and use monitoring results to determine whether to continue current opportunity and/or develop alternative opportunities

<table>
<tr><th colspan="4">GOOD CURRENT CONDITION</th></tr>
<tr><th></th><th>CLIMATICALLY SUITABLE</th><th>CLIMATICALLY MARGINAL</th><th>CLIMATICALLY UNSUITABLE</th></tr>
<tr><td></td><td></td><td>accommodate new access needs and/or changes in existing access
Adjust the timing of actions (e.g. open/close dates, road or trail closures, food storage orders, special use permits) to accommodate changing conditions and/or demand issues
Adopt new technology that may help disperse use, direct users, and provide information about changing conditions/climate impacts
Develop options for diversifying snow-based recreation (e.g., cat-skiing, helicopter skiing, higher-elevation runs)</td><td>Monitor snow dates, event dates, and snowpack depth using SNOTEL data and incorporate that data into decision-making processes
Limit expansion and/or pioneering of new recreation sites in riparian areas as demand for water-based recreation increases</td></tr>
<tr><td>MODERATE VALUE</td><td><u>Resilience</u>
Adaptation Strategies
Increase management flexibility to respond to changing access demands and use patterns
Minimize synergistic impacts of climate changes, recreation use, and other stressors
Adaptation Tactics
Maintain and/or improve current recreation infrastructure to respond to changing use patterns/demand
Adjust infrastructure maintenance schedule as needed to accommodate changing conditions and/or demand issues</td><td><u>Resistance</u>
Adaptation Strategies
Manage recreation sites to mitigate risks to public safety and infrastructure and to continue to provide recreation opportunities for as long as possible
Adaptation Tactics
Focus on activities that will remain feasible given projected changes, and take action to preserve those opportunities
Shift location of activities to maintain opportunities and/or to mitigate safety risks
Relocate at-risk infrastructure
Maintain to safety standards for as long as possible
Maintain and/or improve current recreation infrastructure at sites that will remain viable</td><td><u>Resistance</u>
Adaptation Strategies
Manage recreation sites to mitigate risks to public safety and infrastructure and to continue to provide recreation opportunities for as long as possible
Adaptation Tactics
Focus on activities that will remain feasible given projected changes, and take action to preserve those opportunities
Maintain to safety standards for as long as possible
Identify nearby areas where similar activities might still be possible and consider feasibility of developing
Shift location of activities to maintain opportunities and/or to mitigate safety</td></tr>
</table>

GOOD CURRENT CONDITION			
	CLIMATICALLY SUITABLE	**CLIMATICALLY MARGINAL**	**CLIMATICALLY UNSUITABLE**
	• Prioritize post-disturbance treatments (e.g., relocation, armoring) **<u>Transition</u>** *Adaptation Strategies* • Increase collaborations with partners and concessionaires to address changes in recreation opportunity supply and demand	under future climate conditions • Identify nearby areas where similar activities might still be possible and consider feasibility of developing **<u>Resilience</u>** *Adaptation Strategies* • Increase management flexibility to respond to changing access demands, use patterns, and resource availability • Minimize synergistic impacts of climate changes, recreation use, and other stressors *Adaptation Tactics* • Adjust infrastructure maintenance schedule as needed to accommodate changing conditions • Monitor recreation sites and set trigger points to determine when a site should be closed or access restricted • Modify existing infrastructure to better withstand future climate conditions • Educate the public about changing site conditions and/or safety issues **<u>Transition</u>** *Adaptation Strategies* • Increase management flexibility to respond to changing access demands, use patterns, and resource availability • Increase collaborations with partners and concessionaires to address changes in	risks **<u>Realignment</u>** *Adaptation Strategies* • Revisit and revise goals and priorities in order to provide sustainable recreation opportunities in response to changing supply and demand • Use research, monitoring, and assessment to increase knowledge of current conditions and projected changes *Adaptation Tactics* • Create new recreation opportunities at existing sites • Develop additional access restrictions, which may include changes to permitting processes, seasonal closures, or allowable uses • Adjust the timing of actions (e.g. open/close dates, road or trail closures, food storage orders, special use permits) to accommodate changing conditions and/or demand issues • Conduct a cost-benefit analysis of maintaining the current opportunities over time in order to determine whether prioritized opportunities should change • Assess infrastructure vulnerability to climate change and natural hazards, and prioritize by seasonal use, viability, and

<table>
<tr><th colspan="4">GOOD CURRENT CONDITION</th></tr>
<tr><th></th><th>CLIMATICALLY SUITABLE</th><th>CLIMATICALLY MARGINAL</th><th>CLIMATICALLY UNSUITABLE</th></tr>
<tr><td></td><td></td><td>recreation opportunity supply and demand
Adaptation Tactics
• Develop new recreation sites designed for flexibility in use and/or resilient to climate impacts, or create new recreation opportunities at existing sites
• Develop additional access restrictions, which may include changes to permitting processes, seasonal closures, or allowable uses
• Adjust the timing of actions (e.g. open/close dates, road or trail closures, food storage orders, special use permits) to accommodate changing conditions and/or demand issues
• Adopt new technology that may help disperse use, direct users, and provide information about changing conditions/climate impacts</td><td>required investment
• Monitor climate variables critical to current and future use, and use monitoring results to determine whether to continue current opportunity and/or develop alternative opportunities
• Monitor snow dates, event dates, and snowpack depth using SNOTEL data and incorporate that data into decision-making processes
• Limit expansion and/or pioneering of new recreation sites in riparian areas as demand for water-based recreation increases</td></tr>
<tr><td>LOW VALUE</td><td><u>No Action</u>

<u>Transition</u>
Adaptation Strategies
• Increase collaborations with partners and concessionaires to address changes in recreation opportunity supply and demand</td><td><u>Transition</u>
Adaptation Strategies
• Increase management flexibility to respond to changing access demands, use patterns, and resource availability
• Increase collaborations with partners and concessionaires to address changes in recreation opportunity supply and demand
Adaptation Tactics
• Develop additional access restrictions, which may include changes to permitting processes, seasonal closures, or allowable</td><td><u>No Action</u>

<u>Realignment</u>
Adaptation Strategies
• Revisit and revise goals and priorities in response to changing supply and demand</td></tr>
</table>

GOOD CURRENT CONDITION			
	CLIMATICALLY SUITABLE	**CLIMATICALLY MARGINAL**	**CLIMATICALLY UNSUITABLE**
		uses • Adjust the timing of actions (e.g. open/close dates, road or trail closures, food storage orders, special use permits) to accommodate changing conditions and/or demand issues **Realignment** *Adaptation Strategies* • Revisit and revise goals and priorities in response to changing supply and demand	

C. Vulnerability-Adaptation tables

To help managers choose among the long list of potential actions in Table 4, we provide linkage between potential actions and the climate effects they are thought to reduce or address. To do this, we grouped adaptation strategies and tactics generated during the NRAP workshops on the basis of (1) enhancing resistance, promoting resilience, or facilitating transition, (2) research, monitoring, and/or assessment, or (3) planning and/or collaboration. Tactics were then classified as either likely or not likely to reduce and/or address the impacts of resource vulnerabilities, including climate and non-climate stressors and disturbance regimes. We classified tactics based on scientific literature review and expert opinion to develop a comprehensive summary of each tactic's likelihood of reducing or addressing climate and non-climate impacts. Our basic approach was to:

1. Classify a tactic as likely to reduce or address an impact
2. Classify a tactic as likely to increase general resilience of the resource,
3. Evaluate whether the tactic is recommended for implementation, and
4. Rank the quantity and quality of evidence supporting recommendation for implementation.

In some cases tactics were classified as *indirect*, indicating that they may not immediately reduce or address a given impact but perhaps could given time and/or an appropriate implementation response. In a number of cases the literature suggested mixed results depending on the context; in those cases, we evaluated recommendation for implementation as "mixed" or "limited" and included notes outlining caveats. Tactics evaluated as "likely" recommended for implementation were those for which no supporting scientific literature could be found, and were based on expert opinion. Strategies and tactics based on research, monitoring, and assessment and planning and collaboration were primarily classified as indirect (based on expert opinion).

Tables linking vulnerabilities with adaptation strategies and tactics were created for six resources: (1) Recreation, (2) Non-forested Vegetation, (3) Forested Vegetation, (4) Wildlife, (5) Hydrology, and (6) Fisheries. Recreation was the most challenging resource for which to find supporting literature. Wildlife was also challenging to evaluate as many of the adaptation tactics identified were not related to climate change (e.g., limit extensive grazing, hunting, and other disturbances) and primarily focused on habitat improvements. Strategies and tactics based on increasing collaboration with stakeholders and the public were most prevalent for resources with significant human influence including recreation, non-forested vegetation, wildlife, and hydrology. Strategies and tactics directed towards more research, monitoring, and assessment occurred principally in terrestrial and freshwater resources (i.e., non-forested and forested vegetation, hydrology) or those strategies related to habitat needs for resources (i.e., wildlife).

Table 5 is an example vulnerability-adaptation table for recreation; tables for other resources can be found in the appendix.

Table 5. Recreation vulnerability-adaptation table.

Key climate change vulnerabilities of recreation linked to specific adaptation strategies and tactics. Implementation of adaptation strategies and tactics may help to directly reduce and/or address the impacts of identified climate and nong climate stressors and disturbance regimes. Adaptation tactics focused on cultural and heritage resources, as well as those focused on research, monitoring, planning, and collaboration are included at the end of the table. Adaptation strategies and tactics listed in this table were identified by workshop participants, in the scientific literature, and in other similar efforts.

Key:

- ● Evidence-based
- ○ Expert opinion
- ✔ Recommended
- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors						Disturbances		Non-climate Stressors		Other	EVALUATION		Citations	Notes
		↑ Air temperature; ↑ Likelihood of extreme heat	Changes in precipitation (timing, amount, and type)	↑ Drought	↓ Low flows/water levels	↓ Snowpack; Earlier timing of snowmelt/runoff	↑ Water temperature	↑ High peak flows/flooding	Altered wildfire regimes	Pollution & poisons	↑ Water demand by downstream users	Tactic increases general resilience	Tactic recommended for implementation	Quantity/quality of evidence supporting recommendation		
Adaptation strategies and tactics that are based on enhancing resistance, promoting resilience, or facilitating transition																
Manage recreation sites to mitigate risks to public safety and infrastructure and to continue to provide recreation opportunities	Modify existing infrastructure to better withstand future climate conditions	●	●	○	○	○	●	●	○	●		○	✔	High	Bass & Baskaran 2003; Brattebo & Booth 2003; DeNardo et al. 2005; Stack et al. 2010	> Green roofs reduced summer cooling load and roof temperature, increased winter roof temperature, and decreased rate, volume, and timing of runoff (Bass & Baskaran 2003; DeNardo et al. 2005). > Vertical gardens reduced summer cooling load and surface temperature (Bass & Baskaran 2003). > Permeable pavement reduced runoff, and decreased levels of copper, zinc, and motor oil in infiltrated water (Brattebo & Booth 2003). > Upgraded culverts prevented damage from projected increases in precipitation, storm intensity, and high peak flows/flooding (Stack et al. 2010).
	Adjust infrastructure maintenance schedule as needed to accommodate changing climate conditions	○	●	○	○	○	○	●	○			○	✔	Moderate	Coe 2006; Stafford 2011	> Road sediment can be limited by reducing road-grading activity (Coe 2006; Stafford 2011), especially at elevations under 1,400 m (Coe 2006)
	Relocate at-risk infrastructure (i.e., move from lower elevations)		○					○	○			○	✔ *(Likely)*	None		
	Develop new recreation sites designed for flexibility in use, or create new recreation opportunities at existing sites	●	●	○	○	●	○	○	○	○	○	○	✔	Moderate	Balbi et al. 2007	> Investing in quality accommodations and indoor activities around ski areas maintained existing tourism and economic return under future climate conditions; investing in alternative snow-based activities ranked second, and was more effective than traditional improvements to ski facilities (Balbi et al. 2007)
	Prioritize post-disturbance treatments (e.g., relocation, armoring)		○					○	○			○	✔ *(Likely)*	None		
Increase management flexibility to respond to changing access demands and resource availability	Invest strategically in infrastructure that will accommodate new access needs and/or changes in existing access	●	●	○	○	●	○	○	○	○	○	○	✔	Moderate	Balbi et al. 2007	> Increasing free-ski/backcountry touring and investing in extended cross-country ski and other alternative snow-based activities maintains tourist volume and economic value better across the entire season than investment in traditional improvements to ski facilities (Balbi et al. 2007)
	Monitor recreation sites and set trigger points to determine when a site should be closed or access restricted	○	○	○	○	○	○	○	○	○	○	○	✔ *(Likely)*	None		
	Develop additional access restrictions, which may include changes to permitting processes, seasonal closures, or allowable uses	○	○	○	○	○	○	○	○	○	○	○	✔ *(Likely)*	None		
	Vary whitewater permit season to adapt to changes in peak flow and duration		○	○	○			○			○	○	✔ *(Likely)*	None		
	Educate the public about changing site conditions (e.g., snowpack, lake levels, streamflow)	○	○	○	○	○	○	○	○		○	○	✔ *(Likely)*	None		
Provide sustainable recreation opportunities in response to changing supply and demand	Adjust capacity of recreation sites (e.g., enlarge campgrounds, install fences or gates, collect additional fees)	○	○	○	○	○	○	○				●	✔	Low	Beunen et al. 2008	> Gateways at the entrance of a recreation site reduced traffic flow and associated impacts within the site (Beunen et al. 2008)
	Adjust the timing of actions (e.g. open/close dates, road or trail closures, food storage orders, special use permits) to accommodate changing climate conditions	○	○	○	○	○	○	○	○			○	✔ *(Likely)*	None		
	Focus on activities that will remain feasible given projected changes, and take action to preserve existing opportunities (e.g., invest in snow-making)	○	○	○	○	○	○	○	○			○	✔ *(Likely)*	None		
	Adopt new technology that may help disperse use, direct users, and provide information about the impacts of climate change	○	○	○	○	○	○	○	○			○	✔ *(Likely)*	None		
	Limit expansion and/or pioneering of new recreation sites in riparian areas as demand for water-based recreation areas increases (e.g., restrict access, revegetate impacted areas, increase signage)	○	○	○	○	○	○				○	○	✔ *(Likely)*	None		
Make the necessary transitions to address shorter winter recreation seasons and changing use patterns	Develop options for diversifying snow-based recreation (e.g., cat-skiing, helicopter skiing, higher-elevation runs)	●	●			●						○	✔	High	Balbi et al. 2007; Scott et al. 2006, 2008	> Increasing free-ski/backcountry touring and investing in extended cross-country ski and other alternative activities maintained ski area tourist volume and economic value under future climate conditions across the entire season better than traditional improvements (Balbi et al. 2007) > Incorporating diversified winter recreation options improved the viability of ski areas under future climate conditions (Scott et al. 2006, 2008)
	Increase safety education to make the public aware of the increased risk of avalanches and thin ice	●	●			●						●	✔	High	Burkeljca 2013; Espiner 1999; McCammon & Hägeli 2007	> Avalanche bulletins that balanced text with easy-to-understand graphics, included both numeric and descriptive elevation bands, and used graphics rather than the avalanche rose to communicate elevation and slope orientation were preferred and most understood by recreation users (Burkeljca 2013) > Pictorial signs increase user awareness of hazards and behavior compliant with management restrictions (Espiner 1999) > A checklist of obvious clues was the most effect decision aid under the widest variety of conditions (McCammon & Hägeli 2007)
	Maintain and/or improve current winter recreation infrastructure at sites that will remain viable under future climate conditions	●	●			●						○	✔	Moderate	Balbi et al. 2007	> Modeling determined the best strategy for maintaining tourist demand and economic returns based on ski area supply and demand under future climate conditions (Balbi et al. 2007)
	Shift location of winter activities to maintain opportunities and/or to mitigate safety risks (e.g., move ski trails)	○	○			○						○	✔ *(Likely)*	None		

Key:
- ● Evidence-based
- ○ Expert opinion
- ✔ Recommended
- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors: ↑ Air temperature; ↑ Likelihood of extreme heat	Climate Stressors: Changes in precipitation (timing, amount, and type)	Climate Stressors: ↑ Drought	Climate Stressors: ↓ Low flows/water levels	Climate Stressors: ↓ Snowpack; Earlier timing of snowmelt/runoff	Climate Stressors: ↑ Water temperature	Disturbances: ↑ High peak flows/flooding	Disturbances: Altered wildfire regimes	Non-climate Stressors: Pollution & poisons	Non-climate Stressors: ↑ Water demand by downstream users	Other: Tactic increases general resilience	EVALUATION: Tactic recommended for implementation	EVALUATION: Quantity/quality of evidence supporting recommendation	Citations	Notes
Protect recreation users from exposure to contaminated water and/or sediments	Cap/harden contaminated water areas	○	○	○	○	○		○		○	○	○	✔ (Likely)	None		*> This tactic could prevent user exposure to contaminants in areas where they have been heavily concentrated due to low water levels, and could also prevent movement of contaminants during flood events (expert opinion)*
	Provide alternative water-based recreation opportunities in areas with decreased risk of exposure	○	○	○	○	○		○		○	○	○	✔ (Likely)	None		*> This tactic could prevent user exposure in areas where contaminants have been concentrated due to low water levels or disturbed during flood events (expert opinion)*
	Provide transportation to safer and more developed water-based recreation sites in economically depressed communities	○	○	○	○	○		○		○	○	○	✔ (Likely)	None		*> This tactic could provide users access to safe recreation areas in situations where they otherwise would only have access to contaminated sites (expert opinion)*
Adaptation strategies and tactics for cultural/heritage sites																
Protect cultural and heritage sites and the use of cultural landscapes	Develop interpretation and education opportunities for the public in cultural and heritage sites that are most vulnerable to climate change	○	○	○	○	○	○	○	●			○	✔	Moderate	Brown et al. 2008	> Recreation users responded positively to educational and informational strategies at a post-fire wilderness site (Brown et al. 2008)
	Develop a vegetation plan to help mitigate natural hazards and promote resilience in cultural landscapes (e.g., encourage age/size class heterogeneity, manage invasive species, reestablish native vegetation)			○ *(indirect)*			○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			○	✔ (Likely)	None		
	Identify and prioritize cultural and heritage sites that are most vulnerable to climate change, and identify management approaches for these sites	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*			○	✔	Moderate	Dupont and Van Eetvelde 2013	> Vulnerability maps created in GIS based on impact and modeling studies identified the climate change impacts and areas that will be most affected for two heritage sites in Belgium (Dupont and Van Eetvelde 2013)
	Increase the use of surveys and monitoring at cultural and historic sites	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○	✔ (Likely)	None		
Adaptation strategies and tactics that are based on research, monitoring, and/or assessment																
Use research, monitoring, and assessment to increase knowledge of current conditions and projected changes	Assess infrastructure vulnerability to climate change and natural hazards, and prioritize by seasonal use, viability, and required investment	○ *(indirect)*	● *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	● *(indirect)*	○ *(indirect)*			○ *(indirect)*	✔	Moderate	Stack et al. 2010	*> While a large number of studies have demonstrated this tactic, few have evaluated whether it is effective* > Evaluate and prioritize culverts for replacement based on projected increases in precipitation, storm intensity, peak flows, and risk of damage to the natural and built environment (Stack et al. 2010)
	Assess changes in use patterns and identify expected shifts in supply and demand, demographics, and economic trends	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*		○ *(indirect)*	○ *(indirect)*	✔	High	Balbi et al. 2007; Peña et al. 2015; Richardson and Loomis 2004; Richardson et al. 2006	> Modeling successfully identified future changes in ski area supply and demand, economic returns, and use patterns under future climate conditions (Balbi et al. 2007) > Assessing recreation preferences using photo-questionnaires is an effective proxy for measuring demand (Peña et al. 2015) > A contingent visitor analysis can estimate changes in climate and resource variables on recreation demand (Richardson and Loomis 2004) > Visitor surveys provided information on visitor behavior, recreation benefits, and expected changes under future climate conditions (Richardson et al. 2006)
	Monitor climate variables critical to current and future site use	● *(indirect)*	● *(indirect)*	○ *(indirect)*	○ *(indirect)*	● *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			○ *(indirect)*	✔	Medium	Yu et al. 2009	> The MCIT methodology is a tourism climate index designed to monitor tourism season quality by taking into account both use and weather conditions (Yu et al. 2009)
	Use monitoring results to determine whether to maintain current site use, develop alternative opportunities, or abandon the site	● *(indirect)*	● *(indirect)*	○ *(indirect)*	○ *(indirect)*	● *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	✔	Medium	Yu et al. 2009	> The MCIT methodology is a tourism climate index designed to monitor tourism season quality by taking into account both use and weather conditions (Yu et al. 2009)
	Conduct a cost-benefit analysis of maintaining the current opportunities over time in order to determine whether prioritized opportunities should change	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	✔ (Likely)	None		
	Assess the viability of snow-based recreation sites (e.g., cross-country and downhill skiing) under future climate conditions	○ *(indirect)*	○ *(indirect)*			○ *(indirect)*					○ *(indirect)*	○ *(indirect)*	✔	High	Balbi et al. 2007; Yu et al. 2009	> Modeling helps to determine the best strategy for maintaining tourist demand and economic returns in and around traditional ski areas under future climate conditions (Balbi et al. 2007) > The MCIT methodology quantifies changes in tourism season length and quality (Yu et al. 2009)
	Monitor snow dates, event dates, and snowpack depth using SNOTEL data and incorporate that data into decision-making processes	● *(indirect)*	● *(indirect)*			● *(indirect)*						○ *(indirect)*	✔	Moderate	Yu et al. 2009	> The MCIT methodology is a tourism climate index designed to monitor tourism season quality by taking into account both use and weather conditions (Yu et al. 2009)
Adaptation strategies and tactics that are based on planning and/or collaboration																
Increase collaborations and incorporate climate change into planning processes	Evaluate and prioritize existing access by season to ensure consistency with changing Recreation Opportunity Spectrum settings	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*		○ *(indirect)*	○ *(indirect)*	✔ (Likely)	None		
	Develop management strategies to maintain or shift Recreation Opportunity Settings in areas likely to change under future climate conditions	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*			○ *(indirect)*	✔	Low	Yu et al. 2009	*> No studies were found that address Recreation Opportunity Settings, and many others demonstrate the tactic but don't evaluate whether it is effective* > The MCIT methodology quantifies the impact of climate change on specific tourism sectors and in specific locations (Yu et al. 2009)
	Coordinate with partners and concessionaires to identify possible impacts on recreation resulting from changes in supply and demand	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*		○ *(indirect)*	○ *(indirect)*	✔ (Likely)	None		
	Collaborate with local Chambers of Commerce and other businesses/organizations that entice visitors to the area to address changes in supply and demand	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*		● *(indirect)*	● *(indirect)*	✔	Medium	McAvoy et al. 1991	> A modified transactive planning process that includes both public managers and private businesses promotes cooperation and improves communication among the parties, and can be effectively integrated into the implementation phase of a traditional allocative planning model (McAvoy et al. 1991)
	Incorporate projected changes in concentrated winter use into forest management planning	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			○ *(indirect)*	✔ (Likely)	None		
	Determine whether changes in winter recreation have already been addressed within the Master Development Plan, and incorporate these considerations if necessary (e.g., add permitted uses, extend the season)	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			○ *(indirect)*	✔ (Likely)	None		

Key:

- ● Evidence-based
- ○ Expert opinion
- ✔ Recommended
- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors						Disturbances		Non-climate Stressors		Other	EVALUATION		Citations	Notes
		↑ Air temperature; ↑ Likelihood of extreme heat	Changes in precipitation (timing, amount, and type)	↑ Drought	↓ Low flows/water levels	↓ Snowpack; Earlier timing of snowmelt/runoff	↑ Water temperature	↑ High peak flows/flooding	Altered wildfire regimes	Pollution & poisons	↑ Water demand by downstream users	Tactic increases general resilience	Tactic recommended for implementation	Quantity/quality of evidence supporting recommendation		

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D. Incorporating climate change considerations into NEPA

We created a table of critical climate-related questions to consider in NEPA analysis for plans and projects (NEPA Critical Questions Table 6). This table highlights the primary elements in NEPA documents (e.g., Environmental Assessment or Environmental Impact Statement), identifies critical climate-related questions to consider for each element, and recommends information sources that can help answer critical questions. Recommended information sources focus primarily on the findings of the NRAP, as Table 6 is intended for resource managers of the same geographic region. As a complement to Table 6, we summarized a number of examples of demonstrating integration of climate vulnerability and adaptation information in NEPA analyses for plans and projects; these examples can be found in the appendix.

Generally, climate impacts and vulnerability assessment information can help resource managers articulate the *need* for a plan or project, while adaptation strategies and tactics can help address the *purpose* and *proposed action*. In particular, the vulnerability-adaptation tables that have been created through this project can be used to more explicitly address the *purpose*, demonstrate why the *proposed action* was selected over *alternatives*, and guides the creation of *monitoring* indicators.

Table 6. Critical climate-related questions to consider in plans and project-level NEPA analysis.[10]

	Description	NEPA Critical Climate-Related Questions	Information Sources

Purpose and Need	Articulate the purpose of the initiative/ project and why the action is needed	*Need:*
		• Will exposure to climate change likely result in impacts to the resource(s) of concern?
		    o What are the relevant projected climate changes for the project geographic area and/or resource(s) of concern?
		    o What are the direct effects of climate change on the resource(s)? Indirect effects?
		    o Could climate change exacerbate the impacts of or be exacerbated by other threats (e.g., land use conversion, invasive species, demand for water)? How?
		Purpose:
		• How will this initiative/project address the climate impacts or threats articulated by the project need?
		    o Consider what climate impacts or vulnerabilities may be minimized or avoided through implementation of this project
			Need:
			• Halofsky et al. (2017) – Chapter 3
			• Halofsky et al. (2017) – Vulnerability information in Chapters 4-7, 9-10
			• DataBasin[11]
			• USGS National Climate Change Viewer[12]
			
			Purpose:
			• Halofsky et al. (2017) – Adaptation strategies and tactics in Chapters 4-7, 9-10
			• Vulnerability-adaptation tables

Proposed Action and Alternatives	No Action	• How will climate change impact the ability of the No Action alternative to meet the Purpose and Need? • What climate vulnerabilities or threats may remain under the No Action alternative? o Answers to questions above under Purpose and Need can help highlight the ways in which climate impacts to the resource(s) of concern may fail to meet the Purpose and Need	• Halofsky et al. (2017) – Vulnerability information in Chapters 4-7, 9-10 • Vulnerability-adaptation tables

[10] Table adapted from guidance in Delach, A., N. Matson, H. Murray, and C. Colegrove. 2013. Reasonably Foreseeable Futures: Climate Change Adaptation and the National Environmental Policy Act. Defenders of Wildlife Climate Change White Paper, 35 pp.
[11] For general climate change information; https://databasin.org/
[12] https://www2.usgs.gov/climate_landuse/clu_rd/nccv.asp

	Description	NEPA Critical Climate-Related Questions	Information Sources
	Alternatives and Proposed Action	• Does the alternative reduce the likelihood or severity of climate change impacts on the resource(s) of concern or the project itself? How? • Is the alternative itself vulnerable to climate change impacts? How? ○ For example, will culvert size be sufficient given projected future changes in high flow or peak flood events? • How will climate change impact the ability of the alternative to meet the Purpose and Need? Consider eliminating those alternatives that fail to meet the Purpose and Need due to projected future climate impacts.	• Vulnerability-adaptation tables • Halofsky et al. (2017) – Adaptation strategies and tactics in Chapters 4-7, 9-10 • Halofsky et al. (2017) – Vulnerability information in Chapters 4-7, 9-10

Affected Environment and Environmental Consequences	Compare the environmental effects of implementing the alternatives on various elements of the affected environment	• See questions above under Proposed Action and Alternatives
		• Also consider:
		  ○ What climate vulnerabilities or threats may remain under each alternative?
		  ○ Will the effects of climate change compound the impacts of a given alternative on the resource? How?
		  ○ Will climate change exacerbate the cumulative effects of other past, present, and reasonably foreseeable actions on the resource?
		  ○ Are there human responses to climate change that will themselves become cumulative effects (e.g., increased water withdrawals to meet agriculture demand during drought)?
		  ○ How do the various alternatives differ in their aggregate impacts when climate change is factored in?
			• Halofsky et al. (2017) – Vulnerability information in Chapters 4-7, 9-10
			• Vulnerability-adaptation tables

	Description	NEPA Critical Climate-Related Questions	Information Sources
Monitoring	Though not required, an important part of any plan is monitoring to ensure the effectiveness of management actions	• What indicators or metrics are currently measured that may provide information about climate changes and impacts? Describe the information they provide. • What indicators or metrics can be added to help detect climate changes or impacts relevant to the resource of concern? • What indicators or metrics can be added to help evaluate the effectiveness of management actions (e.g., adaptation tactics) on minimizing or avoiding climate impacts?	• Halofsky et al. (2017) – Chapters 4-7, 9-10 • Vulnerability-adaptation tables[13]

[13] Adaptation tactics supported by expert opinion may be especially important to monitor for effectiveness in minimizing vulnerabilities.

7. ANALYSIS & FINDINGS

1. *A new approach for downscaling region-wide vulnerability assessments and adaptation strategies and tactics.* Region-wide vulnerability and adaptation efforts provide a wealth of information for resource managers. However, it's often unclear exactly what vulnerability information is needed and what adaptation options may be most appropriate for a given situation or scenario. We created a decision support framework that leads resource managers through a step-wise process to help them identify when and where to apply adaptation strategies and tactics. While the tool presented here is populated with content specific to recreation managers, we are also populating the framework and tools with content for non-forested vegetation managers. The goal is to generate more examples demonstrating the robustness of this decision support framework by applying it to other resources. The framework and tool is also viable for different types of institutional management contexts as evidenced during a presentation of our tool at the Natural Areas Conference in October 2016. After the presentation a county planner expressed the desire to develop something similar to help them integrate adaptation options into their county adaptation plan. We have also received interest from planners at the Bureau of Land Management.

2. *Co-generation of decision support tools is an effective approach for ensuring products are useful and used by resource managers.* The tools created by this NWCSC project were developed through continuous engagement of and input from resource managers. This type of approach results in reduced time delay to incorporate feedback, increased agility to respond creatively to the needs as expressed through the feedback, and immediate usefulness of products while still in draft stage, and finally, higher potential for successful integration of the tools into management decision-making.

3. *A tool to evaluate science-based adaptation options*. A wealth of adaptation options were generated by the NRAP effort however, it can be challenging for managers to decide which adaptation tactics to actually implement. The vulnerability-adaptation tables created as part of this project provide one science-based tool that facilitates selection of adaptation tactics by managers; these tables can be used by managers to select tactics to implement based on those that reduce or address the most vulnerabilities, or select tactics that reduce or address the most *important* vulnerabilities. For example, increased temperature and reduced snowpack are the primary vulnerabilities for winter motorized recreation. Managers could use the vulnerability-adaptation tables in conjunction with the decision support framework to implement those actions that target impacts of increased temperature and reduced snowpack. Further, those adaptation tactics associated with evidence from the scientific literature provide a *best available science* justification for what to implement and why. The tables also serve as a useful tool for identifying tactics to monitor for effectiveness (i.e., those based on expert opinion), as more evidence is needed to demonstrate tactic effectiveness in reducing or addressing vulnerabilities. Recreation managers in FS R1 and beyond are already using these tables to support integration of vulnerability and adaptation information into plans and projects.

4. *Derivation of relevant climate parameters to meet management need.* Simply knowing the projected change in precipitation, even by month, is not as helpful for making management decisions compared with parameters derived from precipitation using ancillary information. For example, snow depth is more informative than snow water equivalent for assessing potential for snowmobile use, and both are better than precipitation.
5. *Top-down vs. bottom-up integration of climate information depends on the resource*. Managers of one resource tend to plan for and think about their resource differently than managers of another resource. Fisheries managers often approach resource planning from a bottom-up perspective; they can plan at a site level and scale up to create themes or trends for program or forest plans. For example, fisheries managers might take the following approach:
    - *Protect* sites likely to serve as cold-water refugia, with limited threats from non-native fish and connectivity to a larger stream network, and
    - *Relocate* native fish that currently occupy sites threatened by non-native fish and are likely to become too warm due to future climate changes.

   Conversely, recreation managers find it more challenging to plan at a site level and scale up; they generally implement a top-down approach (i.e., through program-level planning) to managing recreation resources.
6. *Recreation resource area is a critical sector for climate change planning.* The public provides more comments regarding recreation during the forest plan revision process than any other resource. Meanwhile, forest managers are least likely to consider the effects of climate when planning for future recreation needs. The topic of recreation resources is useful for educating forest managers and the public about projected climate changes and impacts.
7. *Finding a decision support tool that resonates with managers.* We found through experimenting with several support tool structures that virtually the same information and level of prescription can be presented in different ways but only one will find acceptance by managers.
8. *Resource management at multiple spatial and organizational scales is both a challenge and opportunity.* The challenge includes compiling and organizing information for resource priorities that are different for larger areas than at local scales and sites. The opportunities include being able to take larger areas into consideration when making decisions about rare local occurrences. For example, let's say managers are hesitant to apply a *transition* management approach to a resource because it is locally rare, yet protecting it at all costs would deplete resources and not be certain of success. If the resource were known to be more abundant in another forest unit, it would be defensible to apply a *transition* approach and allow extirpation of the local occurrence while simultaneously elevating the importance of that resource in its more suitable alternate location.

8. CONCLUSIONS & RECOMMENDATIONS

This NWCSC project relied extensively on co-generation of knowledge and products. The co-generation approach uses a different process than traditional research. Traditionally, information needs are identified, scientists accomplish the research, and the findings are reported. With co-generation, in addition to the traditional steps, additional steps must be take to ensure effective communication, translation across different perspectives, and a willingness to let the needs of the users take precedence. In the case of resource management, this often means including the need to communicate to a constituency that is front and center for some of the managers but absent from the table. The co-generation approach has multiple challenges, many of which have to do with how to most effectively work with partners. Our recommendations primarily address what we have learned about effectively working with resource managers. They include:

1. *Avoid generating prescriptive decision tools*. Managers were not supportive of prescriptive decision tools, particularly for project-level planning as they felt either (1) managers had a handle on how to integrate climate considerations at this level already, or (2) there were too many other factors that would need to be incorporated and current versions were likely too simplistic. For example, decision trees were found to be too prescriptive because they are based on choosing between dichotomous options when the situation may be more complicated for a specific project. Moreover, they tend to lead to a single answer rather than a range of options.
2. *Participatory mapping in the form of interactive GIS increases manager's familiarity with climate projections and improves development of useful derivative climate-based variables.* Mangers have expert knowledge about their sites and landscapes and have experienced or heard the stories of responding to extreme weather events such as droughts, fire, floods, or herbivory. Tapping into their expert knowledge while exploring maps that depict potential future climate conditions places the uncertainty inherent in climate projections into the familiar context of uncertain weather fluctuations - something most land managers deal with as part of the dynamics of a natural system. Flipping through different temperature or precipitation layers for different possible future climate conditions, superimposed on their familiar landscape, gives managers a level of visual familiarity that is grounded in their knowledge of the landscape. Underlying topographic processes such as temperature contours up a mountain slope or rain shadowed lessening of precipitation become more evident. Climate models become futures to consider rather than overwhelming outputs from incomprehensibly complex numeric outputs.
3. *Integrating climate information into different management operation levels continues to be challenging for resource managers*. Resource managers continue to be uncertain about where and how to integrate vulnerability and adaptation information into different management operation levels, and the level of detail to include in plans, programs, and projects. For example, many revised forest plan components include climate change generalities (e.g., "increase resilience to climate change") but no specific vulnerability information about a given resource or recommended adaptation strategies

and tactics (e.g., “rehabilitate X recreation sites based on climate change-related risk of more frequent flooding”). Many resource managers felt that climate change generalities were suitable for forest plans in order to avoid being too prescriptive, while specific vulnerability and adaptation information was more appropriate for program- and project-level planning.

4. *Frame tools around how managers make decisions for their resource*. To improve tool utility and uptake, it’s important to talk with and engage managers about how they make decisions for their resource. For example, fisheries managers consider habitat connectivity and threats from non-native fish when making decisions about what to do, whereas recreation managers think about value of a site or opportunity and pattern of use. Once these critical decision frames have been identified climate can be incorporated both as “critical questions” within each frame (e.g., how might climate change alter the threat of non-native fish on native fish?) and as its own decision frame (i.e., what is the future climatic suitability of the recreational site or opportunity?). In this way climate change is seamlessly merged into the thought process managers already go through to make decisions about their resource.
5. *Continuous engagement with resource managers is critical to project success and decision tool utility and uptake*. In-person meetings and workshops were particularly important for generating initial interest in the project, testing application of the decision tools, and creating climate-informed maps. Once we had generated support for and interest in the project, it became somewhat easier to schedule follow up meetings with resource managers via conference calls and webinars. This allowed us to continue engaging with managers throughout tool development and also ensured that we had good participation from resource managers during the final round of in-person workshops. The final in-person workshops provided an important opportunity for feedback on and on-the-fly revisions of the tools as well as encouraged immediate uptake of products. For example, one recreation manager planned to use some of our adaptation language in revising forest plan components.
6. *Build tools that are immediately useful by placing them in a specific decision-making context*. It is easiest to have the attention of managers if the tools are built in the context of a specific planning effort. Managers can be engaged because the work relates immediately and directly to how they are supposed to be spending their time so the process is not collateral duty.
7. *Planning documents can be used to shape public expectations as well as provide tools for potential future decisions*. If managers think about what decisions they are likely to need to make in the future and how they would like to have the forest plan written to help them make those decisions, they can write a plan that facilitates rather than limits future decisions. The language of a forward-looking plan will also help the public understand what kinds of decisions will have to be made in the future. For example, it may be necessary to determine future road closures based on consideration of conditions that don’t currently pertain rather than opening/closing dates, as are currently used.

8. *Institutional knowledge grows through focused interaction among staff.* Bringing people together to evaluate and use the decision support tools created a synergistic exchange that perhaps deepened everyone's understanding of the resource. Also, it was an occasion for those with longer-term experience (e.g., those who'd experienced a number of extreme events) to impart how those events were dealt with at the time and may have to be dealt with more frequently in the future. The meetings were also a way for regional staff to use specific issues and examples to explain their vision for how a forest plan revision can be written to address climate impacts in a way that will be helpful rather than restrictive in the future.
9. *Ensure participation of GIS staff in workshops.* Climate change and the cascade of impacts that will arise from shifting environmental conditions is a spatial process. Spatial analysis and spatial data management are fundamental to understanding and communicating expected changes and exploring unexpected connections across the landscape and among species. GIS staff are uniquely positioned to link various organizational levels (regional to local) and facilitate interactive workshops.
10. *Attempt meetings that are region-wide for one resource and forest-wide for all resources.* Managers of different resources are competing for funding to implement needed and planned actions. Creating win-win situations where actions can benefit several resource areas simultaneously can only occur when these managers are simultaneously engaged in the planning process. Including representation from other resource areas in a workshop focused on one area (e.g., recreation) can take advantage of causal chains - such as vegetation impacting wildlife, which impacts recreation, which impacts infrastructure - to identify shared priorities. Also, workshop participants expressed the desire to interact with other managers of the same resource across the region so as to learn from other's experiences.

Two primary challenges also arose during this project: (1) dependency on the completion of another project prior to ours beginning, and (2) scheduling consistent meetings with resource managers. Initiation of this project was dependent on the completion of draft vulnerability and adaptation products from the NRAP effort, as our decision tools were intended to build off of the information in these products. Specifically, we were dependent upon the vulnerability information for gathering appropriate spatial data and drafting critical questions for a given resource, and the vulnerability and adaptation information for generating the vulnerability-adaptation tables and management approaches table in our decision framework. Draft NRAP vulnerability and adaptation products were not available until September 2015, resulting in a delayed start to several aspects of our project.

Meeting consistently with resource managers – either in person or via conference call – also proved challenging for several reasons. First, many of the resource managers we met with were filling multiple positions or roles within the agency, limiting the amount of time they had for engagement. Second, in addition to filling their current roles, managers were also busy contributing to the concurrent NRAP project, which had a more pressing timeline and was a precursor to our project. Third, frequent position changes within the agency made it difficult to retain the same resource management team throughout the project duration. And finally, it was important that our decision tools help inform forest plan revisions so we specifically targeted resource managers from forests that were engaged in this process. However, timelines for forest plan revisions are constantly changing, which resulted in shifts to our meeting and workshop timelines as well.

In the results presented here, we focused on decision tools for recreation managers. We are still working on creating a decision framework for non-forested vegetation managers with the goal of generating a more robust decision framework approach that can be applied to other resources. We have met with non-forested vegetation managers and created a draft list of critical questions, including those related to current ecological condition and value. Next steps include following up with non-forested vegetation managers to review critical questions, creating a draft decision framework based on the critical questions and adaptation strategies and tactics from NRAP, and convening a workshop with non-forested vegetation managers to review and test the decision framework. These decision frameworks have the potential to be replicated for other resource areas including forested vegetation, wildlife, hydrology, and ecosystem services.

With matching funds from the Wilburforce Foundation, we will be reaching out to additional experts to review the vulnerability-adaptation tables; the goal is to supplement the tables with additional supporting scientific literature and expert opinion. Based on testing of the non-forested vegetation tools, the feedback we have received on the recreation decision tools, and expert review of the vulnerability-adaptation tables, we will create an implementation handbook. This handbook will use the recreation and non-forested vegetation resources as case studies to demonstrate the application and integration of vulnerability and adaptation information in management plans and projects. We anticipate completion of the implementation handbook by Summer 2017. However, the products described in this report including the recreation decision framework, climate-informed maps, vulnerability-adaptation tables, and NEPA table have already been presented to and shared with resource managers from the FS and other agencies so that they may begin using them immediately to inform their planning efforts.

This project would have benefitted from a delayed start date given the dependency of this project on the completion of the NRAP products as well as dedicated resource management engagements. We recommend that any future projects dependent on completion of a collaborative project consider adopting a flexible timeline to better adjust to unanticipated delays.

9. MANAGEMENT APPLICATIONS AND PRODUCTS

This project produced a decision-support framework consisting of four types of decision support tools to help resource managers incorporate climate change into management decisions and planning documents. Our focus was on documents used by the FS, but the approach is adaptable to other agencies as well.

1. Climate-informed maps. Map layers of relevant parameters describe the spatial distribution of projected intensity of climate effects relative to geographic features and resource distribution. Map layers portray the most pertinent factors available or derivable from climate projections (e.g., snow-water equivalent and snow depth are more relevant to decisions regarding winter recreation than annual or winter precipitation).
2. Decision support framework. This framework helps managers determine a general approach for managing a resource or site (e.g., resistance, resilience, transition, etc.) and then consider potential adaptation responses. Selecting strategies and responses requires integrating map-based information with other site- or forest-related characteristics.
3. Vulnerability-adaptation tables. This tool facilitates selection of management tactics by linking tactics to the climatic and non-climatic factors each reduces or addresses and provides supporting references.
4. NEPA table. This table provides guidance for incorporating climate change into NEPA documents by specifying climate considerations relevant to sections of NEPA documents and suggesting sources for answers.

Together, these tools help managers narrow down a generic list of potential adaptation responses generated at the regional scale to a smaller and more targeted suite of options that applies to forests and projects. Tools also assist managers to justify their choice of actions from among alternatives and incorporate them into planning documents.

The FS uses three levels of documents to guide management activities: long-term planning is expressed in forest plans; mid-term, resource-specific planning is prescribed in program plans; while project plans specify near-term actions to be taken at particular locations. Forest plan revisions are an opportunity to look beyond annual variability in weather to longer-term climate trends. The forest planning process can consider what actions might be needed to facilitate writing a plan that enables rather than limits appropriate management decisions, shapes desired condition statements by what is possible in the future, and prepares the public for potential changes in resources. Program plans provide an integrated strategy for managing specific resources. These plans can be improved by considering the spatial distribution of climate change intensity so that individual decisions can be put in a broader context. Managers can consider the integrated outcome of individual decisions and prioritize potential actions at individual sites that will create the best outcome for the resource as a whole. At the project level, the likely sustainability of actions can be determined by evaluating site conditions relative to climate forecasts.

The process of developing these tools itself led to creative consideration of potential management futures and new ways of thinking about the structure of planning documents. We engaged many people throughout the course of developing these tools (Table 7).

Table 7. Resource managers, scientists, conservation practitioners, and others engaged throughout this project.

Name	Position (at time of involvement)	Role
Jim Barber	FS, R1 GIS Coordinator	Tested tools (MT), Advisor (spatial data)
Renate Bush	FS, R1 Inventory and Analysis	Advisor (spatial data)
Gunnar Carnwath	FS, Vegetation Specialist, Forest Plan Revision Team, Custer-Gallatin NF	Advisor
Elizabeth Casselli	FS, Recreation Specialist, Forest Plan Revision, Lewis & Clark NF	Provided feedback on early tools
Molly Cross	Wildlife Conservation Society	Advisor, Led development of similar decision support framework for fisheries managers
Jesse English	FS, R8 Recreation Program Manager	Tested tools (ID, MT)
Deb Entwistle	FS, Forest Plan Revision, Helena and Lewis & Clark NF	Advisor
Susan Graves	FS, R1 Civil Engineer	Tested tools (ID)
Linh Hoang	FS, R1 Inventory, Monitoring, Assessment and Climate Change Coordinator	Main contact, helped organize project, provided feedback and guidance
Steve Hostetler	USGS, Northern Rocky Mountain Science Center	Provided GIS data
Zach Holden	FS, R1 Fire Specialist	Advisor
Stu Hoyt	FS, R1 Regional Fuels Specialist	Advisor
Linda Joyce	FS, Rocky Mountain Research Station Quantitative Ecologist	Advisor
Virginia Kelly	FS, Forest Plan Revision Team Leader, Custer-Gallatin NF	Advisor
Jonathan Kempff	FS, R1 Forest Engineer Roads, Facilities, Trails, & Bridges	Tested tools (MT)
Jerry Krueger	FS, Planning Staff Office (?) listed at Black Hills NF	Advisor
Jordan Larson	FS, R1 Regional Economist	Tested tools (ID)
Tim Love	FS, District Ranger, Lolo NF	Advisor
Marsha Moore	FS, R1 Recreation/Wilderness Planner Revision Team	Tested tools (MT)
Regan Nelson	Crown Conservation Initiative	Advisor, Led development of similar decision support framework for fisheries managers
Lis Novak	FS, R1 Recreation Planner	Advisor, Provided feedback on early tools

Pam Novitzky	FS, R1 Recreation Planner Forest Plan Revision Team	Tested tools (MT)
Lauren Oswald	FS, Recreation, Wilderness, Wild and Scenic Rivers Program Manager, Custer-Gallatin NF	Tested tools (MT)
Meghan Oswalt	FS, R1 Sustainable Operations Coordinator	Tested tools (MT)
Timory Peel	FS, R1 Forest Planner	Tested tools, Provided feedback on early tools
Zach Peterson	FS, Lead Land Management Planner, Clearwater NF	Tested tools (ID)
Steve Shelly	FS, R1 Regional Botanist	Advisor
Mark Slacks	FS, Planner and Environmental Coordinator, Custer-Gallatin NF	Provided feedback on early tools
Norma Staaf	FS, Environmental Coordinator, Nez Perce-Clearwater NF	Tested tools (ID)
Jeff Ward	FS, R1 Recreation Business Program Manager	Provided feedback on early tools
Meredith Webster	FS, R1 Regional Soil Scientist	Advisor

10. OUTREACH

This is a highly collaborative project, involving FS staff at every step as described in the Approach section above. To date, our outreach efforts have included five workshops, four in-person meetings, and over a dozen conference calls and webinars with FS managers and other regional partners. We created a fact sheet describing our project and distributed at the NRAP workshops in late 2014; presented the recreation decision framework, vulnerability-adaptation tables, and NEPA table at the Natural Areas Conference in October 2016; and have one paper in preparation. We have plans to share the results of this project at the 2017 National Adaptation Forum, as well as through webinars with the Northwest CSC, North Pacific LCC, and Climate Adaptation Knowledge Exchange (CAKE, cakex.org).

Workshops, Meetings, Conference Calls & Webinars

1. Project planning meeting with FS Northern Region (Mar 2014). Missoula, MT.
2. Climate change vulnerability and adaptation workshop (Nov 2014). Northern Rockies Adaptation Partnership. Bozeman, MT.
3. Climate change vulnerability and adaptation workshop (Nov 2014). Northern Rockies Adaptation Partnership. Coeur D'Alene, ID.
4. Climate change vulnerability and adaptation workshop (Nov 2014). Northern Rockies Adaptation Partnership. Helena, MT.
5. Project planning meeting with FS Northern Region (Dec 2014). Conference call.
6. Monthly NRAP project planning (2014-2015). Conference calls.
7. Recreation managers decision framework development (Apr-Sept 2015). Conference calls, webinars.

8. Fisheries managers decision framework development; project led by Wildlife Conservation Society and Crown of the Continent Initiative (Mar-Dec 2015). Conference calls, webinars.
9. Recreation managers decision framework draft tool presentation (Jul 2016). Conference call, webinar.
10. Recreation managers decision framework discussion on application for forest plan revision (Aug 2016). Conference call.
11. Climate implementation tools for recreation managers workshop (Sept 2016). Butte, MT.
12. Non-forested vegetation managers decision framework development – critical questions meeting (Sept 2016). Bozeman, MT.
13. Climate implementation tools for recreation managers workshop (Sept 2016). Grangeville, ID.
14. Monthly FS project planning with regional office (2014-present). Conference calls, webinars.

Presentations and Publications

Hayward Watts, L. 2016. Science Without Borders. A look at how scientists and resource managers are hammering out useful tools and approaches to build habitat connectivity across political boundaries. Northwest Climate Magazine, Issue 2, pgs. 24-28.

Kershner, J.M. 2016. Decision support tools for integrating climate adaptation information into management plans, programs, and projects. Natural Areas Conference, Davis, CA.

Kershner, J., Torregrosa, A., Woodward, A. 2016. Moving from awareness to action: advancing climate change vulnerability assessments and adaptation planning for Idaho and Montana National Forests. NW CSC Program Review, Corvallis, OR.

Kershner, J.M., A. Woodward, and A. Torregrosa. *In preparation*. Decision support framework for integrating climate vulnerability and adaptation into recreation plans and projects.

NWCSC StoryMap – we would like to provide content for the development of a story map tab, details TBD.

Data

Climate-informed maps and downscaled climate data has been shared with FS R1. The data will be publicly available for download through the USGS GeoPortal once approved for release by the Bureau Approving Official (pers. comm., Alder and Hostetler, 2016).

Appendix

1. Vulnerability-Adaptation tables
    a. Non-forested vegetation
    b. Forested vegetation
    c. Wildlife
    d. Hydrology
    e. Fisheries
2. Examples of integrating climate language in NEPA

Appendix Table 1a. Non-forested vegetation vulnerability-adaptation table.

Key climate change vulnerabilities of non-forested vegetation linked to specific adaptation strategies and tactics. Implementation of adaptation strategies and tactics may help to directly reduce and/or address the impacts of identified climate and nong climate stressors and disturbance regimes. Adaptation tactics focused on research, monitoring, planning, and collaboration are included at the end of the table. Adaptation strategies and tactics listed in this table were identified by workshop participants, in the scientific literature, and in other similar efforts.

Key:

- ● Evidence-based
- ○ Expert opinion
- ✔ Recommended
- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors: ↑ Air temperature	Changes in precipitation (timing, amount, and type)	↓ Soil moisture	↑ Drought	↓ Snowpack; Earlier timing of snowmelt/runoff	Disturbances: Altered wildfire regimes	↑ Insect/disease outbreaks	Non-climate Stressors: Invasive species	Grazing/herbivory impacts	Development & land use change	Other: Tactic increases general resilience	EVALUATION: Tactic recommended for implementation	Quantity/quality of evidence supporting recommendation	Citations	Notes
Adaptation strategies and tactics that are based on enhancing resistance, promoting resilience, or facilitating transition																
Identify and protect priority non-forested habitats	Encourage private land owners to designate conservation easements in order to conserve intact and/or high-quality non-forested habitats										●	●	✔	High	Copeland et al. 2013; Pocewicz et al. 2011	> Targeted conservation easements focused on core sage grouse habitat areas reduced sage grouse declines due to development and habitat loss under future climate conditions (Copeland et al 2013) > Conservation easements reduced development pressure on sagebrush habitats under modeled future conditions, but did not reduce the presence of invasive species (Pocewicz et al. 2011)
	Identify and maintain public management of ecologically significant remnant plant communities (e.g., rough fescue, Palouse prairie)											○	✔ *(Likely)*	None		
Maintain and/or restore native plant vigor, cover, and species richness in grasslands and shrublands	Revegetate habitats with a diverse community of native species that are collectively adapted to the full range of potential future climatic conditions	●	●	○	●	○	○	○	●	○		●	✔ *(Mixed)*	High	Carter & Blair 2012; Richardson et al. 2010; Tilman et al. 2006	> Restoring plant communities by using high-density seeding with high species richness increased the success of restoration efforts, enhanced cover of native forbs, and reduced cover of invasive species; however, it did not increase drought resistance or recovery (Carter & Blair 2012) > Restored limestone grassland plant communities with high species richness and population abundance retained higher population abundances following a severe drought event compared to communities with lower richness and abundance (Richardson et al. 2010) > Grassland sites with high species richness had more stable biomass than sites with lower species richness on both annual and decadal scales, despite growing seasons that spanned a range of temperature and precipitation conditions (Tilman et al. 2006)
	Restore habitats using seed sources that include genotypes suited to future climate conditions	○	○	○	○	○	○	○	○			●	✔ *(Limited)*	High	Auestad et al. 2015; Butterfield et al. 2016; Miller et al. 2010	*> The literature focuses primarily on the effectiveness of using locally-adapted seed, though one study found that using seed/species adapted to future conditions would have limited effectiveness* > Restoring habitat with species suitable under both current and future climate conditions was successful in the short-term **but reduced habitat by 40% in mid-century; fewer than 10 species were able to compensate for the loss of current species** (Butterfield et al. 2016) > Restoring grasslands with a local species-rich seed mixture or hay transfer increased species richness over the course of 9 years compared to standard seeds from commercial sources, and restored grasslands were closer to reference conditions (Auestad et al. 2015) > Using local seed from transfer zones at the scale of Level III ecoregions maintained locally adaptive traits while preventing reduced genetic diversity in common species (Miller et al. 2011)
	Promote early-season native grassland/shrubland species								●	○			✔ *(Limited)*	Moderate	Bernstein et al. 2014; Whitson & Koch 1998	> Establishing cool-season grasses requires high winter and spring precipitation, which is difficult to predict and **may make restoration under future climate conditions unlikely** (Bernstein et al. 2014) > Restoring cool-season grasses after removal of downy brome was more effective at controlling downy brome than herbicide-only or intensive grazing treatments (Whitson & Koch 1998)
	Use prescribed and natural fires to actively promote native species and maintain plant cover, annual yield, and species diversity in grassland and shrubland habitats		○	●	○	○	○		●			●	✔ *(Mixed)*	High	Bates et al. 2009; Beck et al. 2009; Chambers et al. 2007; Davies et al. 2007; Hanna & Fulgham 2015; Kessler et al. 2015	*> This tactic is very context-dependent, because under some circumstances burning can increase invasions of annual grasses and/or decrease habitat value for greater sage grouse* > Herbaceous cover, annual yield, and grass seed production was higher in areas treated with prescribed fire compared to unburned areas in sagebrush steppe (Bates et al. 2009) > Grass and litter to provide nest/brood concealment recovered quickly following a fire in southeastern ID, but **forb cover/richness and shrub structural features important to sage grouse were lower and cheatgrass cover was higher than in unburned area** (Beck et al. 2009) > Burning increased soil moisture, nitrate availability, and native perennial biomass and seed production at low-elevation sites, limiting *Bromus* invasions (Chambers et al. 2007) > Fall burning increased herbaceous cover and production in WY sagebrush habitat, but **decreased soil moisture and total combined above-ground biomass for trees and shrubs** (Davies et al. 2007) > Native perennial grasses and shrubs successfully out-competed invasive grasses 30 years post-fire in sagebrush habitat, and juniper increases were lower than in unburned areas (Hanna & Fulgham 2015) > Prescribed burns reduced accumulated litter and encouraged the growth of native cool-season grass biomass; when combined with herbicide treatment, prescribed burns improved herbicide efficacy and increased native warm-season grass biomass (Kessler et al. 2015)
	Use low-intensity grazing or mowing to increase species diversity in grasslands						●					●	✔ *(Mixed)*	Moderate	Collins et al. 1998; Davies & Bates 2014; Tix & Charvat 2005	*> This tactic may be effective in some situations, but both mowing and grazing have the potential to increase invasive species and may have other unintended negative consequences (e.g., disturbing biological crusts)* > Grazing by native bison increased plant species diversity, ameliorating the impacts of frequent fire; mowing increased species diversity at sites undergoing prescribed burns compared to sites that were not mowed (Collins et al. 1998) > Mowing and seeding increased species diversity in shrub steppe understory vegetation, but **invasive grasses also increased in all treatments that involved mowing, and mowing reduced biological crusts** (Davies & Bates 2014) > Mowing followed by raking to remove biomass increased the establishment of some forbs and legumes, but mowing alone did not have any effect on vegetation (Tix & Charvat 2005)
Provide habitat for native pollinators to maintain healthy grassland/shrubland habitats	Revegetate grasslands and shrublands with a diverse mix of native species, including those with drought-tolerant genotypes, to provide ample habitat for pollinators		○	○	○	○		○				●	✔	Low	Pywell et al. 2006	> More bumblebee species were counted in agricultural field margins sown with pollen and nectar seed mixes compared to the field itself and margins sown with grass only (Pywell et al. 2006)
	Reduce or eliminate herbicide and pesticide use to minimize impacts on non-target species (e.g., native plants, pollinators)											○	✔ *(Likely)*	None		
	Educate agency staff and the public about the ecosystem benefits of native pollinators, potential threats, and existing/needed regulatory protections (e.g., Farm Bill)											○ *(indirect)*	✔ *(Likely)*	None		
Implement flexible grazing management practices to maintain non-forested habitats and reduce the impacts of overgrazing	Implement rotational and/or low intensity grazing practices to reduce the impacts of overgrazing									●			✔ *(Mixed)*	High	Briske et al. 2008, Courtois et al. 2004; Derner & Hart 2007; Gornish & Ambrozio dos Santos 2016; Hemstrom et al. 2002	*> While this tactic may be effective in some situations, multiple studies found no difference between grazed and ungrazed sites and/or that grazing was associated with higher invasive cover* > **No significant differences in plant production were found between rotational and continuous grazing** across all ecosystems in a metaanalysis that controlled for stocking rates (Briske et al. 2008) > **Grassland recovery rates are similar between moderately grazed and grazing exclusion sites** (including species richness and diversity) (Courtois et al. 2004) > **No significant difference between short-term rotational grazing and season-long continuous grazing** in short-grass steppe habitats (Derner & Hart 2007) > Grazing altered the relationship between native plant cover and invasive cover, and **was associated with higher proportions of invasive cover** (Gornish & Ambrozio dos Santos 2016) > Restoration of sagebrush habitat, including the reduction of livestock grazing impacts through changes in stocking rates and grazing systems, increased the amount of available sage grouse habitat under future climate conditions (Hemstrom et al. 2002)
	Manage the timing of grazing to promote native plant species (e.g., graze when undesirable are most palatable, avoid grazing native plants until after seed production is completed)		○	○	○	○	○		○	○			✔ *(Likely)*	None		
	Identify site-specific indicators of grazing impacts on sagebrush-grassland vegetation to trigger movement of animals to another site									○			✔ *(Likely)*	None		

Key:

- ● Evidence-based
- ○ Expert opinion
- ✔ Recommended
- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors					Disturbances		Non-climate Stressors			Other	EVALUATION		Citations	Notes
		↑ Air temperature	Changes in precipitation (timing, amount, and type)	↓ Soil moisture	↑ Drought	↓ Snowpack; Earlier timing of snowmelt/runoff	Altered wildfire regimes	↑ Insect/disease outbreaks	Invasive species	Grazing/herbivory impacts	Development & land use change	Tactic increases general resilience	Tactic recommended for implementation	Quantity/quality of evidence supporting recommendation		
Prevent woodland expansion into non-forested sites	Apply prescribed burns and/or facilitate wildfire to prevent woodland expansion	●	●	●			●			●			✔ (Mixed)	Moderate	Bachelet et al. 2000; Beck et al. 2009; Roundy et al. 2014	> *While this tactic is generally successful at maintaining habitat, studies found that burning may negatively impact habitat by increasing invasive grasses and/or decreasing habitat value for greater sage grouse* > Natural wildfire prevented forest encroachment into grasslands under simulated future climate conditions where forest encroachment was amplified by fire suppression and overgrazing (Bachelet et al. 2000) > Grass and litter to provide nest/brood concealment recovered quickly following a fire in southeastern ID, but **major forb cover and richness and shrub structural features important to sage grouse food supply and winter cover were lower than in unburned areas after 14 years, and was also associated with a large increase in cheatgrass cover** (Beck et al. 2009) > Removing pinyon and juniper trees encroaching on sagebrush habitats with prescribed fire or mechanical thinning was successful and increased the availability of soil moisture up to 4 years post-treatment (Roundy et al. 2014)
	Thin encroaching trees to reduce forest/woodland encroachment into non-forested habitats and conserve soil moisture	●	●	●	●		●						✔ (Mixed)	High	Baughman et al. 2010; Creutzberg et al. 2015; Roundy et al. 2014; Young et al. 2013	> *This tactic is generally considered effective, but one study found that it may increase invasive grasses* > Thinning encroaching pinyon and juniper trees increased native grass cover and diversity, but **also increased invasive species, depending on tree cover and native herbaceous species already present** (Baughman et al. 2010) > Increased restoration activities intended to reduce juniper encroachment (primarily cutting/thinning) slowed woodland expansion under a model of future climate conditions compared to 'no management' and 'current management' scenarios (Creutzburg et al. 2015) > Removing pinyon and juniper trees encroaching on sagebrush habitats with prescribed fire or mechanical thinning was successful and increased the availability of soil moisture up to 4 years post-treatment (Roundy et al. 2014) > Mastication of juniper trees from sagebrush habitat while maintaining the understory increased soil moisture available to shrubs and herbaceous species (Young et al. 2013)
Prevent invasive species establishment and spread	Create and apply early detection and rapid response protocols to control invasive species in priority non-forested habitats								○				✔ (Likely)	None		> *Although no studies were found for this tactic, multiple case studies demonstrate that this tactic has been effective in the past (e.g., Hegamyer et al. 2003 [https://www.invasivespeciesinfo.gov/toolkit/detect.shtml], Simpson et al. 2009)*
	Use integrated control strategies to manage invasive species (i.e., a combination of strategies)								●				✔	High	Calo et al. 2012; Kessler et al. 2015; Munson et al. 2015	> Prescribed burns followed by herbicide treatment reduced competitive invasive grasses and created favorable conditions for native vegetation (Calo et al. 2012) > Prescribed burns combined with herbicide treatment improved herbicide efficacy and increased native warm-season grass biomass compared to fire alone (Kessler et al. 2015) > A combination of seeding followed 3 years later by herbicide treatment was more effective in long-term reductions of *Bromus* than herbicide-only treatments or seeding followed by 2 years of herbicide (Munson et al. 2015)
	Maintain or enhance native plant cover and minimize bare ground to prevent establishment of invasive species	●	●				○		●	○			✔ (Mixed)	High	Abella et al. 2012; Booth et al. 2003; Chambers et al. 2007	> Selected native species used to restore Mojave Desert habitat reduced the biomass of invasive annual grasses (Abella et al. 2012) > Grassland plots with *Elymus* suppressed *Bromus,* indirectly facilitating Artemisia, by successfully competing with Bromus for soil moisture and nitrogen resources (Booth et al. 2003) > Maintaining or restoring native perennials in sagebrush habitat reduced establishment of *B. tectorum*, which was more likely to invade sites with warmer temperatures (e.g., low-elevation sites) and high precipitation variability (Chambers et al. 2007)
	Allow targeted low- to moderate-intensity grazing at sites where it may reduce the risk of invasion or slow the spread of already-established species						●		○				✔	Moderate	Davies et al. 2009; Gornish & Ambrozio dos Santos 2016	> *Although this tactic is effective in some cases, it is likely context-dependent and may have unintended negative consequences in some situations* > Grazing reduced litter accumulation by 50% and grazed areas had more post-burn perennial vegetation remaining and no substantial *Bromus* invasions compared to ungrazed burned areas (Davies et al. 2009) > Grazing altered the relationship between native plant cover and invasive cover, and **was associated with higher proportions of invasive cover** (Gornish & Ambrozio dos Santos 2016)
	Establish competitive vegetation barriers to protect non-forested habitats from invasive species								●				✔ (Mixed)	Moderate	Davies et al. 2010b	> A buffer of non-native perennial grasses around *Taeniatherum caput-medusae* infestations resulted in lower *T. caput-medusae* cover and density (42- and 47-fold less, respectively) in protected plant communities compared to the unprotected plant communities (Davies et al. 2010a)
	Use fire management practices to reduce/minimize the risk of invasive species establishment and spread						●		●				✔ (Mixed)	High	Calo et al. 2012; DiTomaso et al. 1999; Kessler et al. 2015; Simmons et al. 2007; Taylor et al. 2014	> *This tactic is very dependent on context and fire management technique used, because under some circumstances prescribed burns can increase invasive grasses* > Prescribed burns followed by herbicide treatment reduced competitive invasive grasses and created favorable conditions for native vegetation (Calo et al. 2012) > Prescribed burns in open grasslands of Sonoma County, CA reduced yellow starthistle seedbank by 74% and seedlings by 83% the first year and seedbank, seedling density, and vegetative cover by 92-98% in the second and third year. It also increased plant diversity and species richness by increasing native broadleaf species; however, this study did not include a control plot (DiTomaso et al. 1999) > Prescribed burns combined with herbicide treatment improved herbicide efficacy and increased native warm-season grass biomass compared to fire alone (Kessler et al. 2015) > Growing-season fires reduced the invasive *Bothriochloa ischaemum* one year post-treatment in two TX prairies (Simmons et al. 2007) > **Burning increased cheatgrass abundance** at multiple sites of sagebrush steppe across the western US, especially where temperatures were higher and/or summer precipitation was lower; one climatically intermediate site did not show this pattern (Taylor et al. 2014)
	Use mowing treatments to slow the spread of invasive species												✗	None	Davies & Bates 2014; Prevéy et al. 2014; Simmons et al. 2007	> *This tactic may be effective in a limited number of situations, but the majority of studies found that it was ineffective or may actually increase invasive species.* > Mowing and seeding increased species diversity in shrub steppe understory vegetation, but **invasive grasses also increased in all treatments that involved mowing, and mowing reduced biological crusts** (Davies & Bates 2014) > Mowing in spring and spring/summer reduced invasive grasses by 50%, but **increased invasive forbs by two times in spring-mowed plots and three times in spring/summer-mowed plots** in a CO grassland (Prevéy et al. 2014) > **Mowing had no effect on invasive *Bothriochloa ischaemum*** one year post-treatment in two TX prairies (Simmons et al. 2007)
Manage prescribed and natural fire to reduce the negative impact of changes in fire frequency and intensity in non-forested habitats	Design burn prescriptions that consider soil moisture requirements	○	○	●	○	○	○			●			✔	Moderate	Anderson et al. 1970; Bachelet et al. 2000	> Mid- and late-spring burning reduced soil moisture less than early-spring burning by leaving less unprotected bare soil, which reduced runoff, erosion, and evaporation (Anderson et al. 1970) > A dynamic vegetation model (DVM) simulated grassland response to overgrazing under projected future soil moisture conditions, showing a high likelihood of forest/woodland encroachment into SD grasslands that necessitated more frequent burning (Bachelet et al. 2000)
	Implement strategically-located non-burn fuel reduction techniques to reduce the risk of severe wildfire in non-forested habitats	○	○	○	○	○	●						✔	High	Davies et al. 2009; Gray & Dickson 2016; Schmidt et al. 2008	> Grazing reduced litter accumulation by 50% and grazed areas had more post-burn perennial vegetation remaining (Davies et al. 2009) > Creating a network of greenstrips using a model of fire connectivity would reduce the centrality in 19 of 25 cheatgrass patches in an invaded landscape in Arizona (Gray & Dickson 2016) > Mechanical fuel treatments effectively reduced surface fire (flame length) and crown fire behavior (torching index) at the stand level of analysis; using a "strategically placed area treatments" (SPLATs) design for arrangement of treatment type, amount, and location most effectively reduced fire spread and intensity at the landscape scale (Schmidt et al. 2008)
	Use low to moderate intensity grazing to reduce fuel loads and lower fire risk in non-forested habitats		○	○	○	○	●			○			✔ (Mixed)	Moderate	Davies et al. 2009; Davies et al. 2010a	> Grazing reduced litter accumulation by 50% and grazed areas had more post-burn perennial vegetation remaining (Davies et al. 2009) > Fuel accumulation and continuity was lower in moderate-grazed rangeland compared to areas with grazing exclusions (Davies et al. 2010b)
	Implement Burned Area Emergency Response (BAER) actions						○						✔ (Likely)	None		
Maintain areas of snow cover in montane habitats	Use snow fencing to increase snow drift accumulation and soil moisture		●	●	○	●							✔	Moderate	David 2013	> Snow fencing increased establishment of native sagebrush-steppe species in WY due to increased spring soil moisture (David 2013)
Reduce the impact of travel across grassland and shrubland habitats	Identify and manage trails/paths created by recreation users to minimize their impact on non-forested habitats								○		○	○	Unknown	None		

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- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors: ↑ Air temperature	Climate Stressors: Changes in precipitation (timing, amount, and type)	Climate Stressors: ↓ Soil moisture	Climate Stressors: ↑ Drought	Climate Stressors: ↓ Snowpack; Earlier timing of snowmelt/runoff	Disturbances: Altered wildfire regimes	Disturbances: ↑ Insect/disease outbreaks	Non-climate Stressors: Invasive species	Non-climate Stressors: Grazing/herbivory impacts	Non-climate Stressors: Development & land use change	Other: Tactic increases general resilience	EVALUATION: Tactic recommended for implementation	EVALUATION: Quantity/quality of evidence supporting recommendation	Citations	Notes
Adaptation strategies and tactics that are based on research, monitoring, and/or assessment																
Use research, monitoring, and assessment to increase knowledge of current conditions and projected changes	Develop and apply models that include consideration of climate change when projecting the area and location of invasive species establishment and spread	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			✔ *(Likely)*	None		*> Many studies demonstrate the use of this tactic, but do not evaluate whether it is effective for ameliorating the impact of climate stressors (e.g., Bachelet et al. 2000; Bradley et al. 2010)*
	Inventory and map weed-free sites and potential site invasibility to aid in prioritization of management and restoration activities								● *(indirect)*				✔	Moderate	Underwood et al. 2003; Williams & Hunt 2002	> Hyperspectral imagery is an effective way to map iceplant and jubata grass in CA coastal habitat, with the highest accuracy using the minimum noise fraction (MNF) method (Underwood et al. 2003) > Hyperspectral imagery performed well identifying and mapping leafy spurge invasions, especially in non-forested habitats (Williams & Hunt 2002)
	Monitor weed-free sites to increase early detection of new invasions								○ *(indirect)*				✔ *(Likely)*	None		
	Evaluate and include the role of native ungulate grazing and competition in grassland management plans									○ *(indirect)*			✔ *(Likely)*	None		
	Monitor post-fire effects beyond the scope of suppression and Burned Area Emergency Response (BAER) and implement appropriate actions						○ *(indirect)*						✔ *(Likely)*	None		
	Locate and map important grassland soil types, such as molisols, and prioritize these areas for restoration		○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*						○ *(indirect)*	✔ *(Likely)*	None		
	Determine whether individual sites are fire- or snow-maintained					○ *(indirect)*	○ *(indirect)*						✔ *(Likely)*	None		
	Map sites at risk of drought and monitor vegetation and water availability on these sites		○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*							✔ *(Likely)*	None		
	Improve understanding of the relationship between climate change and rangeland ecology	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			✔ *(Likely)*	None		
Adaptation strategies and tactics that are based on planning and/or collaboration																
Increase collaborations and incorporate climate change into planning processes	Develop criteria to help determine whether to resist or allow forest encroachment into non-forested habitats	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*		○ *(indirect)*	✔ *(Likely)*	None		
	Develop criteria to prioritize intact and/or high-quality non-forested habitat sites and redirect management resources to these sites as needed										○ *(indirect)*	○ *(indirect)*	✔ *(Likely)*	None		
	Create and implement a management plan for grasslands and/or shrublands based on thresholds/triggers for activities such as thinning, prescribed burns, and revegetation	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*		○ *(indirect)*	✔ *(Likely)*	None		
	Establish an interagency collaborative weed management program to improve coordination and resource use among multiple agencies, non-governmental organizations (NGOs), and private land owners									○ *(indirect)*			✔ *(Likely)*	None		*> Although no studies were found for this tactic, multiple case studies demonstrate that this tactic has been effective in the past (e.g., Hegamyer et al. 2003 [https://www.invasivespeciesinfo.gov/toolkit/detect.shtml], Simpson et al. 2009)*
	Include consideration of invasive species prevention in all restoration projects									○ *(indirect)*			✔ *(Likely)*	None		
	Communicate the implications of climate change on rangeland quality/availability and grazing management practices, as well as associated uncertainty, with ranchers and other stakeholders	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*		○ *(indirect)*			✔ *(Likely)*	None		
	Provide information to land owners and managers about the projected impacts of climate change and disturbances on rangeland ecology, including the effects of repeated burns, weed identification and reporting, and the importance of site potential when determining appropriate vegetation	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			✔ *(Likely)*	None		
	Increase collaboration among management agencies and ranchers to actively control grazing allotments and maintain low to moderate grazing intensity									○ *(indirect)*			✔ *(Likely)*	None		
	Update weed risk assessments (WRAs) to include potential climate change impacts and enhance integrated weed management	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*				✔ *(Likely)*	None		
	Develop funding and native seed sources for post-fire restoration of burned areas where grass and forb communities are not naturally regenerating						○ *(indirect)*						✔ *(Likely)*	None		

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- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors					Disturbances		Non-climate Stressors			Other	EVALUATION		Citations	Notes
		↗ Air temperature	Changes in precipitation (timing, amount, and type)	↘ Soil moisture	↗ Drought	↘ Snowpack: Earlier timing of snowmelt/runoff	Altered wildfire regimes	↗ Insect/disease outbreaks	Invasive species	Grazing/herbivory impacts	Development & land use change	Tactic increases general resilience	Tactic recommended for implementation	Quantity/quality of evidence supporting recommendation		

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Appendix Table 1b. Forested vegetation vulnerability-adaptation table.

Key climate change vulnerabilities of forested vegetation linked to specific adaptation strategies and tactics. Implementation of adaptation strategies and tactics may help to directly reduce and/or address the impacts of identified climate and nong climate stressors and disturbance regimes. Adaptation tactics focused on research, monitoring, planning, and collaboration are included at the end of the table. Adaptation strategies and tactics listed in this table were identified by workshop participants, in the scientific literature, and in other similar efforts.

Key:

- ● Evidence-based
- ○ Expert opinion
- ✔ Recommended
- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors: ↑ Air temperature	Climate Stressors: Changes in precipitation (timing, amount, and type)	Climate Stressors: ↓ Soil moisture	Climate Stressors: ↑ Drought	Climate Stressors: ↓ Snowpack	Disturbance Regimes: Altered wildfire regimes	Disturbance Regimes: ↑ Insect & disease outbreaks	Stressors: Grazing	Stressors: Invasive species	Other: Tactic increases general resilience	EVALUATION: Tactic recommended for implementation	EVALUATION: Quantity/quality of evidence supporting recommendation	Citations	Notes
Adaptation strategies and tactics that are based on enhancing resistance, promoting resilience, or facilitating transition															
Promote disturbance-resilient species, including western larch and western white pine on moist sites, ponderosa pine on dry sites, Douglas-fir on extremely dry sites, and lodgepole pine on harsh sites that are difficult to regenerate	Reduce abundance of mesic species on drought-prone sites (e.g., western hemlock, western redcedar)	○	○	○	○	○	○				●	✔	Moderate	Temperli et al. 2012	> Promoting unevenly-aged stands of drought-adapted species decreased losses of timber harvest due to dieback and increased species diversity (Temperli et al. 2012)
	Thin to favor disturbance-resilient species	○	○	○	●	○	●	○			●	✔ (Mixed)	Moderate	D'Amoto et al. 2013; Halofsky et al. 2014	> *Although it is often believed that thinning may reduce the extent or severity of insect outbreaks, there is little data to support this (Six et al. 2014), except under very limited circumstances (e.g., low insect densities where infested trees can be limited to >2.5 per hectare; Nelson et al. 2006)* > Thinning generally increased drought resistance and resilience in red pine forests, resulting in more large-diameter trees; however, over the long-term the low-density stands with large trees had reduced drought tolerance due to higher water demands (D'Amato et al. 2013) > Thinning and prescribed fire in high-density stands increased fire tolerance in central OR mixed-conifer forests with large-diameter trees in a model of future climate conditions, reducing projected loss of dry forest area; however, medium-sized trees declined, decreasing the pool of potential trees that may be recruited into larger size classes (Halofsky et al. 2014)
	Promote disturbance-resilient species with prescribed fire and/or natural fire use	○	○	○	●	○	●	○			●	✔ (Mixed)	High	Bailey & Covington 2002; Halofsky et al. 2014	> Repeated prescribed burns in ponderosa stands reduced stem density, created greater size-class heterogeneity, and encouraged the growth of fire-resistant trees over 10 cm dbh (Bailey & Covington 2002) > Thinning and prescribed fire in high-density stands increased fire tolerance in central OR mixed-conifer forests with large-diameter trees in a model of future climate conditions, reducing projected loss of dry forest area; **however, medium-sized trees declined, decreasing the pool of potential trees that may be recruited into larger size classes** (Halofsky et al. 2014)
	Plant disturbance-resilient species	○	○	○	○	○	○	○			○	✔ *(Likely)*	None		
	Use hot prescribed burns to reduce root disease and/or plant species that are more resistant to root diseases on sensitive sites							●			○	✔	Low	Filip & Yang-Erve 1997	> Fall burns (but not spring burns) reduced Armillaria oysterae at a depth of 8 cm in red alder within a mixed-conifer forest (Filip & Yang-Erve 1997)
	Restore fire-adapted ponderosa pine stands through planting, thinning to reduce competition (e.g., from Douglas-fir and grand fir), and prescribed burning	○	○	○	○	○	●				●	✔	Moderate	Bailey & Covington 2002	> Repeated prescribed burns in ponderosa stands reduced stem density, created greater size-class heterogeneity, and encouraged the growth of fire-resistant trees over 10 cm dbh (Bailey & Covington 2002)
Reduce forest density and increase structural diversity across the landscape	Conduct thinning treatments (pre-commercial and commercial) to maintain densities based on both past and projected future conditions	●	●	●	●	○	●	○			●	✔	High	Dodson et al. 2008; D'Amato et al. 2013; Dymond et al. 2014; Halofsky et al. 2014; North et al. 2007; Stephens et al. 2009; Stone et al. 1999; Strom & Fulé 2007; Temperli et al. 2012	> Thinning and burning treatments increased species richness in understory vegetation (Dodson et al. 2008) > Thinning generally increased drought resistance and resilience in red pine forests, resulting in more large-diameter trees; however, over the long-term the low-density stands with large trees had reduced drought tolerance due to higher water demands (D'Amato et al. 2013) > Thinning pine species contributed to increased species diversity, growing stock, and growth in old trees after beetle attacks under simulated future conditions (Dymond et al. 2014) > Thinning and prescribed fire in high-density stands increased fire tolerance in central OR mixed-conifer forests with large-diameter trees in a model of future climate conditions, reducing projected loss of dry forest area; **however, medium-sized trees declined, decreasing the pool of potential trees that may be recruited into larger size classes** (Halofsky et al. 2014) > Prescribed fire, especially when combined with thinning treatments, reduced stem density in young trees, creating greater size-class heterogeneity (North et al. 2007) > A combination of prescribed fire and mechanical whole-tree harvesting reduced the potential for torching and future high-severity wildfires more than fire-only or control treatments (Stephens et al. 2009) > Thinning post-settlement ponderosa pines increased soil water content from May-Aug and improved the condition of remaining trees (Stone et al. 1999) > Thinning to reduce stand density significantly decreased fire severity and increased tree survival (Strom & Fulé 2007) > Thinning to promote unevenly-aged stands of drought-adapted species decreased losses of timber harvest due to dieback and increased species diversity (Temperli et al. 2012)
	Use prescribed fire on overstocked sites to maintain structure and promote fire-tolerant conifer species	○	○	○	●	○	●	○			●	✔ (Mixed)	High	Bailey & Covington 2002; Dodson et al. 2008; Halofsky et al. 2014; North et al. 2007	> Repeated prescribed burns in ponderosa stands reduced stem density, created greater size-class heterogeneity, and encouraged the growth of fire-resistant trees over 10 cm dbh (Bailey & Covington 2002) > Thinning and burning treatments increased species richness in understory vegetation (Dodson et al. 2008) > Thinning and prescribed fire in high-density stands increased fire tolerance in central OR mixed-conifer forests with large-diameter trees in a model of future climate conditions, reducing projected loss of dry forest area; **however, medium-sized trees declined, decreasing the pool of potential trees that may be recruited into larger size classes** (Halofsky et al. 2014) > Prescribed fire, especially when combined with thinning treatments, reduced stem density in young trees, creating greater size-class heterogeneity (North et al. 2007)
	Use regeneration and planting to influence forest structure in dense stands where thinning cannot be done		○	○				○			○	✔ *(Likely)*	None		
Promote species and genetic diversity	Plant potential microsites with a mix of species	○	○	○	○	○	○	○			●	✔	Moderate	Dymond et al. 2014	> Mixed plantings and thinning treatments increased species diversity following beetle attacks (Dymond et al. 2014)
	Maintain species diversity during thinning	○	○	○	●	○	○	○			●	✔	Moderate	Dymond et al. 2014; Temperli et al. 2012	> Thinning pine species contributed to increased species diversity, growing stock, and growth in old trees after beetle attacks under simulated future conditions (Dymond et al. 2014) > Thinning to promote unevenly-aged stands of drought-adapted species decreased losses of timber harvest due to dieback and increased species diversity (Temperli et al. 2012)
	Interplant to supplement natural regeneration and genetic diversity	●	○	○	●	○	○	●		●	●	✔	High	Dymond et al. 2014; Leverkus et al. 2015	> Mixed plantings and thinning treatments increased species diversity following beetle attacks (Dymond et al. 2014) > Oak seedlings planted at higher elevation sites had increased survival due to reduced drought stress in cooler conditions (Leverkus et al. 2015)

Key:

- ● Evidence-based
- ○ Expert opinion
- ✔ Recommended
- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors					Disturbance Regimes		Stressors		Other	EVALUATION		Citations	Notes
		↑ Air temperature	Changes in precipitation (timing, amount, and type)	↓ Soil moisture	↑ Drought	↓ Snowpack	Altered wildfire regimes	↑ Insect & disease outbreaks	Grazing	Invasive species	Tactic increases general resilience	Tactic recommended for implementation	Quantity/quality of evidence supporting recommendation		
Promote ecosystem resilience	Promote legacy trees for forest regeneration and wildlife habitat (e.g., western larch, Douglas-fir, western white pine, Engelmann spruce, whitebark pine, subalpine larch)										○	✔ *(Likely)*	None		
	Collect seed for post-wildfire reforestation and other planting needs, prioritizing subalpine larch, whitebark pine, and high-elevation western larch	○	○	○	○	○	○	○			○	✔ *(Likely)*	None		
	Promote landscape heterogeneity and enhance connectivity at multiple scales	●	●	●	●	○	●	○			●	✔	High	Bailey & Covington 2002; North et al. 2007; Temperli et al. 2012	> Repeated prescribed burns in ponderosa stands reduced stem density, created greater size-class heterogeneity, and encouraged the growth of fire-resistant trees over 10 cm dbh (Bailey & Covington 2002) > Prescribed fire, especially when combined with thinning treatments, reduced stem density in young trees, creating greater size-class heterogeneity (North et al. 2007) > Thinning to promote unevenly-aged stands of drought-adapted species decreased losses of timber harvest due to dieback and increased species diversity (Temperli et al. 2012)
	Conserve ecologically high-value trees (e.g., cone producers, rare species) from insect outbreaks by using pheromones							●			○	✔	Moderate	Progar 2003; Progar et al. 2013	> Verbenone (a pheromone) decreases mountain pine beetle attacks and associated lodgepole pine mortality, but efficacy decreases under high beetle pressure (Progar 2003) > Verbenone decreases mountain pine beetle attacks in lodgepole pine where beetle populations increased gradually and/or when outbreaks were of moderate severity (Progar et al. 2013)
Promote resilient whitebark pine communities	Plant genetically-selected whitebark pine seedlings to promote blister rust resistance	○	○					○			○	✔ *(Mixed)*	Moderate	Keane et al. 2016	> Planting whitebark pine seedlings that were resistant to blister rust increased modeled basal area and percentage of the landscape dominated by whitebark pine compared to no-planting treatments under future climate conditions, although the effects were not apparent until the trees had matured after 100 years (Keane et al. 2016)
	Plant whitebark pine seedlings on sites that are more likely to remain suitable under changing climate conditions	○	○	○		○	○					✔ *(Likely)*	None		
	Actively manage prescribed and natural fires to promote whitebark pine stands						●				○	✔ *(Mixed)*	Moderate	Keane et al. 2016; Keane & Parsons 2010	> Restoration treatments that included thinning shade-tolerant competitors and prescribed burns increased modeled whitebark pine basal area and percentage of the landscape dominated by whitebark pine compared to no-restoration treatments under future climate conditions, although there was little change on less suitable sites or where the incidence of blister rust was very high (Keane et al. 2016) > **Prescribed fire did not increase whitebark pine regeneration** (Keane & Parsons 2010)
	Remove species that may compete with whitebark pine (e.g., subalpine fir, lodgepole pine, spruce)	○	○	○		○					●	✔ *(Mixed)*	High	Keane et al. 2007; Keane et al. 2016; Keane & Parsons 2010	> Harvesting competing vegetation increased diameter growth in whitebark pines, with the greatest increases in dense stands and in old trees (Keane et al. 2007) > Thinning shade-tolerant competitors increased modeled whitebark pine basal area and percentage of the landscape dominated by whitebark pine compared to no-restoration treatments under future climate conditions, although there was little change on less suitable sites or where the incidence of blister rust was very high (Keane et al. 2016) > Prescribed fire and/or thinning treatments successfully removed competing subalpine fir, creating conditions more suitable for whitebark pine regeneration (Keane & Parsons 2010)
	Identify sites that are less likely to be affected by climate change (refugia), and focus on those sites for whitebark pine restoration	○	○	○		○	○				○	✔ *(Likely)*	None		
Promote the health and vigor of aspen clones	Manage ungulate grazing to protect high-value aspen stands, especially while aspen is regenerating (e.g., slash barriers, hunting pressure, salt block placement)								●		○	✔	Moderate	Jones et al. 2009	> Livestock browsing that did not remove the terminal leader and/or that removed less than 25% biomass was correlated with a positive growth response in aspen suckers; growth was least impacted by early-season grazing only, compared to mid-season only or early- and mid-season (Jones et al. 2009)
	Use prescribed fire and/or actively manage wildfire to promote aspen regeneration						○				○	✔ *(Likely)*	None		
	Remove conifers around aspen clones to reduce competition		○	○	○						●	✔	High	Campos & Burnett 2014; Jones et al. 2005	> Mechanical treatments used to remove conifers from aspen stands reduced total canopy cover and increased herbaceous cover and the number of aspen stems; bird species associated with aspen stands also increased, especially cavity-nesters and species associated with early seral conditions (Campos & Burnett 2014) > Mechanical thinning of conifers was associated with an increase in aspen stems and regeneration size classes in the Sierra Nevada (Jones et al. 2005)
	Develop techniques for artificial regeneration, selecting for a drought-tolerant mother tree when appropriate		○	○	○						○	✔ *(Likely)*	None		
Adaptation strategies and tactics that are based on research, monitoring, and/or assessment															
Increase knowledge for agency land managers and stakeholders	Research habitat connectivity requirements for wildlife species that aid in forest regeneration and seed dispersal (e.g., squirrels, birds, insects)	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			○ *(indirect)*	✔ *(Likely)*	None		
	Determine connectivity needs for different tree species and guilds to promote migration and dispersal	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			○ *(indirect)*	✔ *(Likely)*	None		
	Track tree species regeneration and distribution	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			○ *(indirect)*	✔ *(Likely)*	None		
	Map tree species migration in response to shifting climate envelopes both at fine and broad scales for habitat connectivity	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			○ *(indirect)*	✔ *(Likely)*	None		
	Use vegetation models to predict where species may best establish and persist under future conditions	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*		○ *(indirect)*	○ *(indirect)*	✔ *(Likely)*	None		
	Conduct high-resolution mapping of priority species, such as whitebark pine and aspen	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			○ *(indirect)*	✔ *(Likely)*	None		
	Map loess soils to identify and prioritize areas with adequate soil moisture for successful whitebark pine restoration		○ *(indirect)*	○ *(indirect)*	○ *(indirect)*						○ *(indirect)*	✔ *(Likely)*	None		
	Map and monitor the extent and condition of new and existing aspen clones in order to prioritize areas most likely to successfully regenerate	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*					○ *(indirect)*	✔ *(Likely)*	None		

Key:

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- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors: ↑ Air temperature	Climate Stressors: Changes in precipitation (timing, amount, and type)	Climate Stressors: ↓ Soil moisture	Climate Stressors: ↑ Drought	Climate Stressors: ↓ Snowpack	Disturbance Regimes: Altered wildfire regimes	Disturbance Regimes: ↑ Insect & disease outbreaks	Stressors: Grazing	Stressors: Invasive species	Other: Tactic increases general resilience	EVALUATION: Tactic recommended for implementation	EVALUATION: Quantity/quality of evidence supporting recommendation	Citations	Notes
	Determine the effect of disturbance type, severity, and frequency on aspen survival (e.g., browsing, insects & disease, Sudden Aspen Decline) to determine whether strategic protection measures can be developed for clones				○ *(indirect)*		○ *(indirect)*	○ *(indirect)*	○ *(indirect)*		○ *(indirect)*	✔ *(Likely)*	None		
	Identify fire regimes for spruce and fir dominated systems						○ *(indirect)*				○ *(indirect)*	✔ *(Likely)*	None		
	Research and quantify the impact of root diseases on carbon sequestration							○ *(indirect)*			○ *(indirect)*	✔ *(Likely)*	None		
Monitor forest health and post-disturbance/post-treatment response	Monitor the establishment, survival and development of ponderosa by age class and across different stand conditions using Forest Inventory and Analysis (FIA) data	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*				○ *(indirect)*	✔ *(Likely)*	None		
	Gather information on forest trends by utilizing existing data (e.g., FIA datasets) or installing additional plots, targeting areas where changes are expected										○ *(indirect)*	✔ *(Likely)*	None		
	Expand reforestation and post-treatment monitoring with a consistent framework that can capture long-term change and support adaptive management	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	● *(indirect)*	✔	Low	Dickenson et al. 2016	> Data on horizontal forest complexity measured using freely-available aerial imagery was strongly correlated with ground-collected data at the scale of treatment units within a collaborative forest restoration project in CO, demonstrating that this would be a practical, inexpensive technique for post-restoration monitoring (Dickenson et al. 2016)
	Implement rapid post-fire assessment and response in high-value areas	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			○ *(indirect)*	○ *(indirect)*	✔ *(Likely)*	None		
	Monitor blister rust resistance within planted white pine stands, and improve knowledge on the relationship between infection rates and climatic drivers (e.g., fog)	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*		○ *(indirect)*			○ *(indirect)*	✔ *(Likely)*	None		
Adaptation strategies and tactics that are based on planning and/or collaboration															
Work across jurisdictions at larger spatial scales to increase collaboration among scientists and stakeholders	Review and revise existing seed collection strategies in management plans to prevent potential loss of genetic diversity	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			○ *(indirect)*	✔ *(Likely)*	None		
	Review and revise current reforestation strategies to prevent potential loss of genetic diversity	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			○ *(indirect)*	✔ *(Likely)*	None		
	Identify stands with high species and/or genetic diversity, and prioritize their protection from stand replacing fire and insect outbreaks						○ *(indirect)*	○ *(indirect)*			○ *(indirect)*	✔ *(Likely)*	None		
	Improve the integration between wildlife managers and forest ecologists, and between research and management										○ *(indirect)*	✔ *(Likely)*	None		
	Identify other resource management goals (not directly related to stand structure and composition) that may modify management strategies for forest vegetation, such as water yield, snow retention, and wildlife habitat	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	✔ *(Likely)*	None		
	Initiate annual meetings of managers and scientists, including the Rocky Mountain Research Station, to share knowledge and strengthen partnerships										○ *(indirect)*	✔ *(Likely)*	None		
	Align budgets and priorities for program of work with neighboring lands										○ *(indirect)*	✔ *(Likely)*	None		
	Communicate about projects adjacent to other lands, and coordinate on the ground										○ *(indirect)*	✔ *(Likely)*	None		
	Improve education and communication about responsible land owner tactics								○ *(indirect)*		○ *(indirect)*	✔ *(Likely)*	None		
	Work across boundaries to preserve roads, trails, and site access during fire and flood events		○ *(indirect)*				○ *(indirect)*				○ *(indirect)*	✔ *(Likely)*	None		

Key:

- ● Evidence-based
- ○ Expert opinion
- ✔ Recommended
- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors					Disturbance Regimes		Stressors		Other	EVALUATION		Citations	Notes
		↑ Air temperature	Changes in precipitation (timing, amount, and type)	↓ Soil moisture	↑ Drought	↓ Snowpack	Altered wildfire regimes	↑ Insect & disease outbreaks	Grazing	Invasive species	Tactic increases general resilience	Tactic recommended for implementation	Quantity/quality of evidence supporting recommendation		

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Appendix Table 1c. Wildlife vulnerability-adaptation table.

Key climate change vulnerabilities of wildlife linked to specific adaptation strategies and tactics. Implementation of adaptation strategies and tactics may help to directly reduce and/or address the impacts of identified climate and nong climate stressors and disturbance regimes. Adaptation tactics focused on research, monitoring, planning, and collaboration are included at the end of the table. Adaptation strategies and tactics listed in this table were identified by workshop participants, in the scientific literature, and in other similar efforts.

Key:

- ● Evidence-based
- O Expert opinion
- ✔ Recommended
- ✗ Not recommended

	Adaptation Strategies	Adaptation Tactics	Climate Stressors: ↑ Air temperature; ↑ Likelihood of extreme heat	Climate Stressors: Changes in precipitation (timing, amount, and type)	Climate Stressors: ↓ Soil moisture	Climate Stressors: ↑ Drought	Climate Stressors: ↓ Snowpack; Earlier timing of snowmelt/runoff	Disturbances: Altered wildfire regimes	Disturbances: ↑ Insect/disease outbreaks	Non-climate Stressors: Development & infrastructure	Non-climate Stressors: Pollution & poisons	Non-climate Stressors: Grazing	Non-climate Stressors: Invasive species	Other: Tactic increases general resilience	EVALUATION: Tactic recommended for implementation	EVALUATION: Quantity/quality of evidence supporting recommendation	Citations	Notes
Adaptation strategies and tactics that are based on enhancing resistance, promoting resilience, or facilitating transition																		
Birds	Protect, restore, and/or maintain grassland and sagebrush habitat for greater sage grouse and Brewer's sparrow	Maintain adequate shrub cover and vigor, promote a diversity of shrub age classes, and avoid bare ground to provide adequate cover for greater sage grouse	●	●	○	○	○	○				○	●	○	✔	Moderate	Chambers et al. 2007	> Maintaining or restoring native perennials in sagebrush habitat reduced establishment of B. tectorum, which was more likely to invade sites with warmer temperatures (e.g., low-elevation sites) and high precipitation variability (Chambers et al. 2007)
Birds	Protect, restore, and/or maintain grassland and sagebrush habitat for greater sage grouse and Brewer's sparrow	Restore formerly cultivated land to sagebrush habitat								○				○	✔ *(Likely)*	None		
Birds	Protect, restore, and/or maintain grassland and sagebrush habitat for greater sage grouse and Brewer's sparrow	Remove encroaching conifers to prevent woodland expansion into grasslands and sagebrush habitats for Brewer's sparrow and greater sage grouse	○	○	●	○		●				●		●	✔ *(Mixed)*	High	Bachelet et al. 2000; Baughman et al. 2010; Beck et al. 2009; Creutzburg et al. 2015; Farzan et al. 2015; Roundy et al. 2014	> While this tactic is generally successful at maintaining habitat, studies found that in some situations treatments may increase invasive grasses (Baughman et al. 2010) and/or degrade habitat value for sage grouse (Beck et al. 2009) > Natural wildfire prevented forest encroachment into grasslands under simulated future climate conditions where forest encroachment was amplified by fire suppression and overgrazing (Bachelet et al. 2000) > Thinning encroaching pinyon and juniper trees increased native grass cover and diversity, but also increased invasive species, depending on tree cover and native herbaceous species already present (Baughman et al. 2010) > Grass and litter to provide nest/brood concealment recovered quickly following a fire in southeastern ID, but major forb cover and richness and shrub structural features important to sage grouse food supply and winter cover were lower than in unburned areas after 14 years, and was also associated with a large increase in cheatgrass cover (Beck et al. 2009) > Increased restoration activities slowed juniper expansion and increased sage grouse habitat under a model of future climate conditions compared to 'no management' and 'current management' scenarios, but did not reduce invasive grasses (Creutzburg et al. 2015) > Increasing agency coordination and funding availability increased the success of juniper removal efforts, providing improved conservation benefits for greater sage grouse (Farzan et al. 2015) > Removing encroaching pinyon and juniper trees on sagebrush habitats with prescribed fire or mechanical thinning was successful and increased the availability of soil moisture up to 4 years post-treatment (Roundy et al. 2014)
Birds	Protect, restore, and/or maintain grassland and sagebrush habitat for greater sage grouse and Brewer's sparrow	Apply early detection and rapid response techniques for invasive vegetation in sagebrush habitats (e.g., mechanical treatments)	○	○				○					○	○	✔ *(Likely)*	None		
Birds	Protect, restore, and/or maintain grassland and sagebrush habitat for greater sage grouse and Brewer's sparrow	Limit extensive grazing, hunting, and other disturbances in greater sage grouse habitat										●		●	✔	Moderate	Hemstrom et al. 2002	> Restoration of sagebrush habitat, including the reduction of livestock grazing impacts through changes in stocking rates and grazing systems, increased the amount of available sage grouse habitat under future climate conditions (Hemstrom et al. 2002)
Birds	Protect, restore, and/or maintain grassland and sagebrush habitat for greater sage grouse and Brewer's sparrow	Use prescribed and natural fires to actively promote native sagebrush species												○	✗	High	Bates et al. 2009; Beck et al. 2009; Davies et al. 2007; Hanna and Fulgham 2015	*> Although evidence suggests that this tactic may promote herbaceous cover in sagebrush habitat, specific habitat features important to greater sage grouse may be negatively impacted by prescribed fire (Beck et al. 2009). Therefore, this strategy is not recommended.* > Herbaceous cover, annual yield, and grass seed production was higher in areas treated with prescribed fire compared to unburned areas in WY big sagebrush steppe (Bates et al. 2009) > Grass and litter to provide nest/brood concealment recovered quickly following a fire in southeastern ID, but **major forb cover and richness and shrub structural features important to sage grouse food supply and winter cover were lower than in unburned areas after 14 years, and was also associated with a large increase in cheatgrass cover** (Beck et al. 2009) > Fall burning increased herbaceous cover and production in WY sagebrush habitat, but **decreased soil moisture and total combined above-ground biomass for trees and shrubs** (Davies et al. 2007) > Native perennial grasses and shrubs successfully out-competed invasive grasses over a 30-year period following fire, and juniper increases were less significant than in areas that had not burned (Hanna & Fulgham 2015)
Birds	Restore fire-adapted ponderosa pine stands to provide habitat for flammulated owls and pygmy nuthatches	Reduce competition in mature ponderosa pine stands by thinning competitors (e.g., Douglas-fir and grand fir)		●	●	●		○						●	✔	Low	Stone et al. 1999	*> While there is evidence that thinning in general benefits dense ponderosa stands, no studies were available that specifically addressed competition from other species* > Thinning post-settlement ponderosa pines increased soil water content from May-Aug and improved the condition of remaining trees (Stone et al. 1999)
Birds	Restore fire-adapted ponderosa pine stands to provide habitat for flammulated owls and pygmy nuthatches	Use frequent prescribed burning to control the understory of ponderosa pine stands						●						●	✔	High	Bailey & Covington 2002; Bateman & O'Connell 2006	> Pygmy nuthatches, as well as cavity-nesters overall, were more abundant in ponderosa pine stands that had been burned (Bateman & O'Connell 2006) > Repeated prescribed burns in ponderosa stands reduced stem density, created greater size-class heterogeneity, and encouraged the growth of fire-resistant trees over 10 cm dbh (Bailey & Covington 2002)
Birds	Restore fire-adapted ponderosa pine stands to provide habitat for flammulated owls and pygmy nuthatches	Retain and protect current mature and older ponderosa pine stands from harvesting		●	●	○		○						●	✔	Medium	Scott 1979; Stone et al. 1999	> Retaining snags during harvest of ponderosa pine increased the density of pygmy nuthatches in AZ, compared to sites with snag removal (Scott 1979) > Thinning post-settlement ponderosa pines increased soil water content from May-Aug and improved the condition of remaining mature trees (Stone et al. 1999)
Birds	Restore fire-adapted ponderosa pine stands to provide habitat for flammulated owls and pygmy nuthatches	Plant ponderosa pine in locations that will remain suitable under future climate conditions	○	○	○	○	○	○						○	✔ *(Likely)*	None		
Birds	Promote resilient aspen stands to provide habitat for ruffed grouse	Manage ungulate grazing to protect high-value aspen stands, especially while aspen is regenerating										●		○	✔	Moderate	Jones et al. 2009	> Livestock browsing that did not remove the terminal leader and/or that removed less than 25% biomass was correlated with a positive growth response in aspen suckers; growth was least impacted by early-season grazing only, compared to mid-season only or early- and mid-season (Jones et al. 2009)
Birds	Promote resilient aspen stands to provide habitat for ruffed grouse	Use prescribed fire and/or actively manage wildfire to promote aspen regeneration in older stands						○						○	✔ *(Likely)*	None		
Birds	Promote resilient aspen stands to provide habitat for ruffed grouse	Thin conifers around aspen clones to reduce competition		○	○	○								●	✔	High	Campos & Burnett 2014; Jones et al. 2005	> Mechanical treatments used to remove conifers from aspen stands reduced total canopy cover and increased herbaceous cover and the number of aspen stems; bird species associated with aspen stands also increased, especially cavity-nesters and species associated with early seral conditions (Campos & Burnett 2014) > Mechanical thinning of conifers was associated with an increase in aspen stems and regeneration size classes in the Sierra Nevada (Jones et al. 2005)

Mammals	Protect important breeding and roosting sites occupied by Townsend's big-eared bat	Protect hibernaculum from intense wildfires by using prescribed burning and fuel removal						○						○	✔ (Likely)	None		
		Improve public education on the spread of white-nose syndrome and emphasize decontamination procedures, especially among cave recreationists							○					○	✔ (Likely)	None		
		Maintain or create open wetland complexes near maternal colonies	○	○	○	○				●				●	✔	Moderate	Stahlschmidt et al. 2012	> Artificial wetlands in agricultural areas (e.g., retention ponds) have higher bat activity and nocturnal prey density than surrounding vineyards, and provide much better foraging habitat for bats despite the small amount of area that they cover (Stahlschmidt et al. 2012)
		Reduce pesticide application near bat-occupied sites and educate users about pesticide effects									○			○	✔ (Likely)	None		
	Minimize stressors and protect critical habitat for bighorn sheep	Improve connectivity and protect critical habitat between bighorn sheep seasonal ranges						●		●				●	✔	Moderate	Allen et al. 2016	> An individual-based model determined that a stepping stone approach would facilitate movement between bighorn sheep and suitable, unoccupied habitat; using prescribed fire and/or tree removal to mimic historic fire regimes also improved modeled connectivity (Allen et al. 2016)
		Use fences or other techniques to ensure that bighorn sheep are separated from domestic sheep to limit the transfer of diseases							○					○	✔ (Likely)	None		
	Maintain and/or restore fisher habitat, and promote future old-growth mesic forests for fishers	Create and/or maintain fisher habitat by reducing forest density in overstocked stands in order to increase drought tolerance of older trees		○	●	●	○	●						●	✔	High	D'Amato et al 2013; Stone et al. 1999	> Thinning generally increased drought resistance and resilience in red pine forests, resulting in more large-diameter trees; however, over the long-term the low-density stands with large trees had reduced drought tolerance due to higher water demands (D'Amato et al. 2013) > Thinning post-settlement ponderosa pines increased soil water content from May-Aug and improved the condition of remaining trees (Stone et al. 1999)
		Limit harvest of mature trees to protect fisher habitat and maintain connectivity at the watershed scale								○				●	✔	High	Truex & Zielinski 2013; Zielinski et al. 2010	> Mechanical thinning and prescribed fire reduced estimated fisher resting habitat suitability in the Sierra Nevada, but mechanical thinning was associated with less damage to individual trees compared to prescribed fire (Truex & Zielinski 2013) > Forest areas that were not thinned, or were thinned very lightly, provided greater estimated fisher habitat resting suitability than thinned areas in the Sierra Nevada (Zielinski et al. 2010)
		Use silvicultural techniques (e.g., regeneration harvests, gap harvests, strip harvests) in middle-aged mesic forests to promote the development of old-growth structure for fisher habitat		○	○	○		○						○	✔ (Likely)	None		
		Restore western white pine with a red cedar understory on appropriate sites to create future habitat for fishers												○	✔ (Likely)	None		
	Maintain healthy beaver populations and associated riparian habitats	Restore riparian beaver habitat and food resources (e.g., plant willow trees and other preferred species and multistoried canopy cover to trap snow, manage grazing, restore natural hydrology)	○	○	○	○	○						○	○	✔ (Likely)	None		
		Maintain mature riparian vegetation to provide large diameter trees and woody debris for beaver dams												○	✔ (Likely)	None		
		Attract and/or translocate beavers and actively manage trapping to maintain healthy population sizes								○				●	✔	Low	Pollock et al 2007	> The addition of beaver dam analogs (BDAs) increased the number of natural beaver dams in Bridge Creek, OR (Pollock et al. 2007)
Insects	Restore grasslands to protect pollinators	Revegetate grasslands and shrublands with a diverse mix of native species, including those with drought-tolerant genotypes, to provide ample habitat for pollinators	○	○	○	○		○					○	●	✔	Low	Pywell et al. 2006	> More bumblebee species were counted in agricultural field margins sown with pollen and nectar seed mixes compared to the field itself and margins sown with grass only (Pywell et al. 2006)
		Reduce or eliminate herbicide and pesticide use to minimize impacts on pollinators												○	✔ (Likely)	None		
All Wildlife	Identify and protect population connectivity, especially in sensitive areas (e.g., island mountain region)	Work with landowners to apply conservation easements and/or leases to critical habitats and limit fragmentation from development and infrastructure (e.g., roads, power line corridors)								●					✔	High	Copeland et al 2013; Pocewicz et al. 2011	> Targeted conservation easements focused on core habitat areas reduced sage grouse declines due to future development pressure and associated habitat loss compared to conservation efforts that did not utilize a "core area" strategy or allocate money for easements (Copeland et al 2013) > Conservation easements reduced modeled future development pressure on sagebrush habitats and were more frequently used by wildlife species (Pocewicz et al. 2011)
		Install fences or crossing structures in places where road mortality is high, as well as areas where road crossings by wildlife are successful								○					✔ (Likely)	None		
Adaptation strategies and tactics that are based on research, monitoring, and/or assessment																		
All Wildlife	Use research, monitoring, and assessment to increase knowledge of current conditions and projected changes	Identify and map maternal colonies and summer roosting locations for Townsend's big-eared bat	○ *(indirect)*	○ *(indirect)*					○ *(indirect)*	○ *(indirect)*				○ *(indirect)*	✔ (Likely)	None		
		Monitor environmental conditions at bat-occupied sites (e.g. hibernacula) to understand what conditions promote white-nose syndrome	○ *(indirect)*	○ *(indirect)*					○ *(indirect)*					○ *(indirect)*	✔ (Likely)	None		
		Work with the state wildlife departments to monitor West Nile virus							○ *(indirect)*					○ *(indirect)*	✔ (Likely)	None		
		Monitor and investigate the incidence of sheep diseases and identify the impacts of changing climate stressors on disease	○ *(indirect)*	○ *(indirect)*					○ *(indirect)*					○ *(indirect)*	✔ (Likely)	None		
		Conduct an inventory of current and potential beaver habitat								○ *(indirect)*				○ *(indirect)*	✔ (Likely)	None		
		Model future fisher habitat using both correlative and mechanistic approaches	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*				○ *(indirect)*	✔ (Likely)	None		
		Map pygmy rabbit distribution at a high-resolution and identify critical breeding areas	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*					○ *(indirect)*	✔ (Likely)	None		
		Identify the climatic sensitivities of pygmy rabbit and their current and future potential distribution	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*				○ *(indirect)*	✔ (Likely)	None		
		Model post-fire ecological succession in pygmy rabbit habitat, validating results when fires do occur						○ *(indirect)*						○ *(indirect)*	✔ (Likely)	None		
		Locate and map important soil types for grassland wildlife species, such as molisols, and prioritize areas for restoration for pollinators	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*								○ *(indirect)*	✔ (Likely)	None		
		Learn more about insect production and forb associations within moist areas and investigate possible changes in phenology for insects	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*									✔ (Likely)	None		
	Research and monitor population connectivity, especially in the island mountain region	Monitor population connectivity of priority species using remote sensing and genetic techniques	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*				○ *(indirect)*	✔ (Likely)	None		
		Map population connectivity and prioritize areas where connectivity may decrease under changing climate conditions	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*				○ *(indirect)*	✔ (Likely)	None		
		Identify how topography across a broad region may influence genetic variability and population connectivity												○ *(indirect)*	✔ (Likely)	None		
		Use tracking collars to study movement, dispersal patterns, and habitat needs (e.g., home range) for species such as wolverine and lynx												○ *(indirect)*	✔ (Likely)	None		
		Map areas where snow is likely to persist under changing climate conditions and evaluate connectivity between these patches	○ *(indirect)*				○ *(indirect)*							○ *(indirect)*	✔ (Likely)	None		
		Identify species-specific factors that influence dispersal ability												○ *(indirect)*	✔ (Likely)	None		

Adaptation strategies and tactics that are based on planning and/or collaboration																		
Insects	Increase education and public outreach	Educate agency staff and the public about the ecosystem benefits of native pollinators, potential threats, and existing/needed regulatory protections (e.g., Farm Bill)												○ *(indirect)*	✔ *(Likely)*	None		> Necessary step to improve species conservation; not directly related to climate change
Mammals	Increase collaboration among scientists and stakeholders	Improve communication among researchers, managers, and ranchers by sharing information on sheep diseases and population status							○ *(indirect)*					○ *(indirect)*	✔ *(Likely)*	None		
All Wildlife		Coordinate species monitoring activities across agencies, organizations, and landowners	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	✔ *(Likely)*	None		

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Appendix Table 1d. Hydrology vulnerability-adaptation table.

Key climate change vulnerabilities for hydrology linked to specific adaptation strategies and tactics. Implementation of adaptation strategies and tactics may help to directly reduce and/or address the impacts of identified climate and nong climate stressors and disturbance regimes. Adaptation tactics focused on research, monitoring, planning, and collaboration are included at the end of the table. Adaptation strategies and tactics listed in this table were identified by workshop participants, in the scientific literature, and in other similar efforts.

Key:

- ● Evidence-based
- ○ Expert opinion
- ✔ Recommended
- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors					Disturbance Regimes		Non-climate Stressors					Other	EVALUATION		Citations	Notes
		↑ Air temperature; ↑ Water temperature	Changes in precipitation (timing, amount, and type)	↑ Drought	↓ Low streamflow/baseflow; ↓ Water levels	↓ Snowpack; Earlier timing of snowmelt/runoff	↑ High peak flows/flooding	Altered wildfire regimes	Development & transportation infrastructure	Grazing	Agriculture	Water withdrawals (groundwater & instream)	Dams, levees, & water diversions	Tactic increases general resilience	Tactic recommended for implementation	Quantity/quality of evidence supporting recommendation		
Adaptation strategies and tactics that are based on enhancing resistance, promoting resilience, or facilitating transition																		
Identify and proactively decrease risk of flood damage to infrastructure	Remove, replace, or upgrade infrastructure to improve resilience to flooding (e.g., install bridges, improve road drainages, remove culverts)		●			○	●		●				○	○	✔	Moderate	Konrad et al. 2008; Stack et al. 2010	> Relocating levees (e.g., setback levees) increased the area of low-velocity flows (Konrad et al. 2008) > Upgraded culverts prevented damage from projected increases in precipitation, storm intensity, and high peak flows/flooding (Stack et al. 2010).
	Reduce the amount of infrastructure in floodplains (e.g., dams and levees, roads, campgrounds)		○			○	●		●				●	●	✔ (Mixed)	High	Burroughs et al. 2009; Konrad et al. 2008; Madej 2001	> Removing the Stronach Dam in MI caused sediment redistribution, resulting in wider, shallower channels and lower flow velocities downstream of the dam; narrower, deeper channels upstream; and gradual restoration of bedforms within the former impoundment (Burroughs et al. 2009) > Relocating levees (e.g., setback levees) increased the area of low-velocity flows (Konrad et al. 2008) > Removing roads significantly reduced the amount of sediment input into streams (Madej 2001)
	Implement flood early warning systems to minimize damage and loss of infrastructure		○			○	○							○	✔ (Likely)	None		
Decrease erosion and sediment delivery to improve water quality and protect municipal water supplies	Design and construct roads to minimize erosion and sediment production		○			○	●		●					○	✔	Moderate	Coe 2006; Stafford 2011	> Road sediment can be limited by rocking native-surface roads with coarse gravel, improving drainage, minimizing the number of stream crossings and road segment lengths, and rocking the approach to stream crossings (Coe 2006) > Road sediment was reduced by using at least 30% gravel cover on native-surface roads and improving the construction of water bars (Stafford 2011)
	Reduce the frequency of road grading to decrease the supply of readily-erodible sediment		●			●	●		●					○	✔	Moderate	Coe 2006; Stafford 2011	> Road sediment can be limited by reducing road-grading activity (Coe 2006; Stafford 2011), especially at elevations under 1,400 m (Coe 2006)
	Increase and/or relocate road cross drains to decrease hydrologic connectivity between roads and streams		●			○	○		●				○	○	✔	High	Abdi et al. 2012; Ramos-Scharrón 2012	> Strategic placement of additional culverts reduced sediment delivery within a modeled Iranian forest road network (Abdi et al. 2012) > Installing cross drains that direct runoff into a paved ditch decreased sediment yield on coastal roads in the Caribbean (Ramos-Scharrón 2012)
	Decommission unnecessary roads to reduce sediment delivery and restore stream hydrology disrupted by crossings		●			○	●		●					○	✔	Moderate	Madej 2001; McCaffery et al. 2007	> Decommissioning old logging roads in CA significantly reduced the amount of sediment input into streams (Madej 2001) > Streams near decommissioned roads had lower percentages of fine sediment in stream substrates than areas with actively-used roads (McCaffery et al. 2007)
Manage livestock grazing to restore ecological function of riparian vegetation and channels	Optimize grazing management practices to reduce sediment production from upland and riparian areas (e.g., increase forage base for calf raising in the uplands)									○				○	✔ (Likely)	None		
	Reduce disturbances in riparian areas to limit erosion (i.e. off-roading, grazing, riparian roads, etc.)								○	○				○	✔ (Likely)	None		
	Manage riparian vegetation to reduce fire severity and subsequent erosion in high-value areas						○	○		○				○	✔ (Likely)	None		*> Although many studies demonstrate the effectiveness of fuel treatments to reduce wildfire severity, no evidence was found that specifically demonstrate that fuel treatments within riparian areas reduce the impacts of fire on stream habitats and fisheries.*
Restore natural stream hydrology to decrease vulnerability to projected climate changes	Restore incised stream channels to reduce patterns of extreme scour and sediment entrainment and increase vertical connectivity between streams and adjacent floodplains	●	○		○		○	○						○	✔	Moderate	Pollock et al. 2007	> Using beaver dams to capture sediment and rebuild streambeds increased the area within 0.5 m elevation of the stream by five times, allowed the reestablishment of riparian vegetation, and created pockets of cool water behind the dams (Pollock et al. 2007)
	Create pool-riffle formations within stream channels to increase instream habitat heterogeneity (e.g., hyporheic exchange, substrate, flow velocity, and temperature)	●			●		●							●	✔	Moderate	Medina & Long 2004	> Creating riffle formations within eroded streambeds increased stream water levels, reduced bank erosion, and allowed riparian vegetation (e.g., sedges) to naturally revegetate edges (Medina & Long 2004)
	Maintain large woody debris within streams to increase heterogeneity and habitat value	○												●	✔	Moderate	Solazzi et al. 2000	> The addition of large woody debris to two streams in coastal OR increased overwinter survival of juvenile coho salmon and downstream migrant numbers the following spring, demonstrating that the treatment increased winter habitat (Solazzi et al. 2000)
	Restore floodplain connections to improve lateral connectivity with streams		○		○	○	●						○	●	✔	High	Konrad et al. 2008	> Setback levees along the Puyallup River, WA increased riparian/aquatic habitat and the area of low-velocity flows (Konrad et al. 2008)
	Limit/reduce floodplain development to increase hyporheic water exchange	○							○					○	✔ (Likely)	None		
	Identify and restore degraded riparian habitat to shade streams and provide floodwater storage	●	○			○	○							○	✔	High	Bond et al. 2015; Jorgensen et al. 2009	> Reforestation offset 50-100% of increases in stream temperature due to air temperature increases of up to 6°C on the North Fork of the Salmon River, CA (Bond et al. 2015) > Restoration actions focused on increasing tree cover resulted in a slight water temperature decrease in the Columbia River (Jorgensen et al. 2009
Identify and protect wetlands	Restore natural wetlands and/or consider constructing artificial wetlands in vulnerable watersheds		●	●	●	○	●							●	✔	High	Cooper et al. 1998; Schimelpfenig et al. 2014; Walters & Babbar-Sebens 2016	> Blocking a ditch within a Rocky Mountain fen successfully restored surface sheet-flow, late-summer water table levels, and anaerobic soil conditions, reducing the impacts of drought conditions experienced within the wetland pre-restoration (Cooper et al. 1998) > Ditch blocking increased the water table from 45 cm to 15 cm below the surface in restored fens (Schimelpfenig et al. 2014) > Wetland construction was able to reduce the magnitude and frequency of high peak flows under all projected climate scenarios (Walters & Babbar-Sebens 2016)
	Protect beaver dams and active lodges to maintain wetlands and areas of open water	●	●	●	●	○	●							●	✔	High	Bouwes et al. 2016; Hood & Bayley 2008; Malison et al. 2015; Pollock et al. 2007; Westbrook et al. 2006	> The addition of beaver dam analogs (BDAs) increased the number of natural beaver dams in Bridge Creek, OR, which were associated with an increase in the area of juvenile steelhead habitat, increased water residence time, groundwater levels, and summer flow, decreased water temperature in some areas and lower daily temperature fluctuations, increased habitat complexity, and a 175% increase in juvenile steelhead production without impacting upstream migration (Bouwes et al. 2016) > The presence of active beaver lodges increased open water in wetlands despite variations in temperature, precipitation, and drought (Hood & Bayley 2008) > Beaver damming of floodplain spring brooks produced larger juveniles and more biomass than beaver-free spring brooks, although the latter had greater survival and densities, demonstrating that the presence of beavers increases habitat variability and the range of potential growth conditions (Malison et al. 2015) > Using beaver dams to capture sediment and rebuild streambeds increased the area within 0.5 m elevation of the stream by five times, allowed the reestablishment of riparian vegetation, and created pockets of cool water behind the dams (Pollock et al. 2007) > Beaver dams and ponds enhanced the depth, extent, and duration of inundation during floods, and increased the water table during both high-flow and low-flow periods (Westbrook et al. 2006)
	Prevent degradation and fragmentation of wetlands from the construction of roads and structures		○				○		○				○		✔ (Likely)	None		

Key:

- ● Evidence-based
- ○ Expert opinion
- ✔ Recommended
- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors: ↑ Air temperature; ↑ Water temperature	Climate Stressors: Changes in precipitation (timing, amount, and type)	Climate Stressors: ↑ Drought	Climate Stressors: ↓ Low streamflow/baseflow; ↓ Water levels	Climate Stressors: ↓ Snowpack; Earlier timing of snowmelt/runoff	Disturbance Regimes: ↑ High peak flows/flooding	Disturbance Regimes: Altered wildfire regimes	Non-climate Stressors: Development & transportation infrastructure	Non-climate Stressors: Grazing	Non-climate Stressors: Agriculture	Non-climate Stressors: Water withdrawals (groundwater & instream)	Non-climate Stressors: Dams, levees, & water diversions	Other: Tactic increases general resilience	EVALUATION: Tactic recommended for implementation	EVALUATION: Quantity/quality of evidence supporting recommendation	Citations
Increase and/or moderate changes in streamflow	Alter the timing or amount of reservoir releases (e.g., pulsed flows) to manage stream temperature and flow volume	●	●	○	●		○						●	●	✔	High	Buccola et al. 2016; Payne et al. 2016
	Reduce water withdrawals from streams (e.g., agricultural/irrigation, municipal, industrial)		○	○	●				○		○	○	○	○	✔	Moderate	Trudel et al. 2016
	Improve irrigation efficiency to maximize return flows			○	○						○	○	○	○	✔ *(Likely)*	None	
	Improve diversion efficiencies (e.g., install headgates, convert from ditch to pipeline, install weirs)								○			○	○	○	✔ *(Likely)*	None	
	Secure instream flow water rights		○	○	○							○	○	○	✔ *(Likely)*	None	
Increase natural/built water storage to increase supply and capture floodwater	Build additional water storage by mirroring natural processes (e.g., constructed wetlands, beavers, road obliteration)		○	○	○	○	●					○		○	✔	Moderate	Babbar-Sebens et al. 2013
	Create distributed small-scale water storage (e.g., small dams, retention ponds, possibly swales in stream channels and upland, etc.)		○	○	○	○	●					○		○	✔	Moderate	Babbar-Sebens et al. 2013
Protect groundwater sources (e.g., seeps and springs) from potential development and degradation	Fence groundwater sources to prevent contamination from grazing and human activity								○	○	○			○	✔ *(Likely)*	None	
	Reduce water withdrawals from local groundwater sources by developing alternative water sources and/or imposing a moratorium on wells		○	○	○	○						○	○	○	✔ *(Likely)*	None	
Reduce evapotranspiration and loss of precipitation due to canopy interception	Harvest trees to increase water yield (i.e. patch clearcuts)			●	●	●								○	✔ *(Mixed)*	High	Brown et al. 2005; Troendle & King 1985; Troendle et al. 2010
Adaptation strategies and tactics that are based on research, monitoring, and/or assessment																	
Use research, monitoring, and assessment to increase knowledge of current conditions and projected changes	Identify and map areas at high risk for flooding in order to prioritize infrastructure for removal or upgrades		● *(indirect)*			○ *(indirect)*	● *(indirect)*		● *(indirect)*				○ *(indirect)*	○ *(indirect)*	✔	High	Stack et al. 2010
	Conduct a basin-wide risk assessment of hydrologic interactions with roads and other infrastructure to prioritize areas where the value of infrastructure and/or resources are highest		● *(indirect)*			○ *(indirect)*	● *(indirect)*	○ *(indirect)*	○ *(indirect)*				○ *(indirect)*	○ *(indirect)*	✔	High	Sherrill et al. 2008
	Update NWI maps for all wetlands, including information on hydrologic regime and type	○ *(indirect)*	● *(indirect)*	● *(indirect)*	● *(indirect)*	○ *(indirect)*	○ *(indirect)*							● *(indirect)*	✔	Moderate	Halabisky et al. 2016; Huang et al. 2014
	Assess wetland vulnerability to future climate change	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*							○ *(indirect)*	✔ *(Likely)*	None	
Manage livestock grazing to restore ecological function of riparian vegetation and channels	Improve reporting requirements for grazing allotments									○ *(indirect)*				○ *(indirect)*	✔ *(Likely)*	None	
	Identify and prioritize vacant allotments for retirement									○ *(indirect)*				○ *(indirect)*	✔ *(Likely)*	None	
	Implement standardized monitoring and data sharing for grazing practices to facilitate compliance with existing aquatic management plan and livestock and range management plan standards, guidelines, and laws									○ *(indirect)*				○ *(indirect)*	✔ *(Likely)*	None	
	Highlight successful programs for monitoring and management of grazing practices									○ *(indirect)*				○ *(indirect)*	✔ *(Likely)*	None	
Increase knowledge of groundwater resources	Map aquifers and alluvial deposits and identify groundwater-influenced streams	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*									○ *(indirect)*	✔ *(Likely)*	None	
	Map and inventory groundwater recharge zones, especially in areas where heavy water withdrawals occur (e.g., municipal watersheds)		○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*						○ *(indirect)*		○ *(indirect)*	✔ *(Likely)*	None	
	Develop map/inventory of springs and seeps locations	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*								○ *(indirect)*	✔ *(Likely)*	None	
	Determine legal and physical availability of water for aquifer recharge		○ *(indirect)*	○ *(indirect)*	○ *(indirect)*							○ *(indirect)*		○ *(indirect)*	✔ *(Likely)*	None	
	Monitor stream flow and groundwater to improve understanding of surface water-groundwater interactions and obtain real time data	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*		○ *(indirect)*					○ *(indirect)*		○ *(indirect)*	✔ *(Likely)*	None	
	Use piezometers to collect detailed groundwater flow info from prioritized representative springs		○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*						○ *(indirect)*		○ *(indirect)*	✔ *(Likely)*	None	
Determine response of streams and connected lakes and reservoirs to projected changes in climate	Continue monitoring river/stream gaging and SNOTEL sites, and add additional sites if needed		○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*					○ *(indirect)*		○ *(indirect)*	✔ *(Likely)*	None	
	Promote streamflow forecasting to allow more informed management of water resources and flood management		● *(indirect)*	○ *(indirect)*	● *(indirect)*	○ *(indirect)*	● *(indirect)*							● *(indirect)*	✔	Moderate	Chiew et al. 2003; Hamlet et al. 2002
	Collect information on aquatic connectivity and the interactions between streams and lakes (e.g., temperature influences, nutrient sinks and sources)	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*			○ *(indirect)*			○ *(indirect)*	✔ *(Likely)*	None	

Notes

> Allowing the Detroit Lake to begin refilling 30 days earlier, reducing minimum release rates in the summer, and utilizing a hypothetical floating surface-withdrawal structure reduced stream temperatures under modeled future conditions, and the floating structure also maintained higher flow levels (Buccola et al. 2016)
> A combination of allowing earlier refill of reservoirs and greater storage for instream flows increased streamflow in the Columbia River Basin under future climate conditions, but only with a loss in hydropower generated (Payne et al. 2016)
> Refining dam operations and flow prescriptions allowed the recovery of endangered cui-ui in NV, as well as riparian birds and cottonwood/willow stands (Rood et al. 2003)
> Reductions in water withdrawals according to alert levels based on streamflow reduced the number of days with extreme low flows under modeled future climate conditions (Trudel et al. 2016)

> Constructed wetlands with an average depth of 0.5 m stored greater amounts of flood water and reduced peak flows more than shallower natural wetlands in IN (Babbar-Sebens et al. 2013)
> Small constructed wetlands were as effective at reducing high peak flows as larger wetlands when they were strategically sized and placed within sub-watersheds (Babbar-Sebens et al. 2013)

> Forest harvest followed by regrowth **increased water yield in the short-term, but had no long-term effects** in a review of paired catchment studies worldwide (Brown et al. 2005)
> Forest harvest increased both annual and peak flows in the Fool River watershed of central Colorado over a 15-year period post-harvest (Troendle & King 1985)
> A review found that, **overall, this strategy typically results in little detectable impact on water yields, due to multiple compounding factors** including slope aspect, regional differences in climate, and amount/type of harvest, and treatments were unlikely to be effective unless precipitation amounts were greater than evaporative demand; however, **forest harvest can increase water yield under the right conditions** (Troendle et al. 2010)

> Evaluated and prioritized culverts for replacement based on projected increases in precipitation, storm intensity, peak flows, and risk of damage to the natural and built environment (Stack et al. 2010)

> Multi-scale GIS variables successfully modeled complex interactions between roads and streams and the resulting impacts on water flow and erosion (Sherrill et al. 2008)

> Spectral mixture analysis (SMA) of Landsat satellite imagery allowed the identification of wetland surface-water hydrographs at resolutions of less than 30 m in semi-arid landscapes (Halabisky et al. 2016)
> Landsat and LiDAR data allowed accurate mapping of wetland inundation at a 30-m resolution to allow analysis of changes in wetland inundation during dry, wet, and average precipitation years (Huang et al. 2014)

> Streamflow forecasts provided information on seasonal water availability for irrigation (Chiew et al. 2003)
> Simulations showed that utilizing streamflow forecasts for the Columbia River Basin increased revenue from hydropower dams without affecting reservoir storage or streamflow targets during years of increased precipitation (Hamlet et al. 2002)

Key:
- ● Evidence-based
- ○ Expert opinion
- ✔ Recommended
- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors: ↑ Air temperature; ↑ Water temperature	Changes in precipitation (timing, amount, and type)	↑ Drought	↓ Low streamflow/baseflow; ↓ Water levels	↓ Snowpack; Earlier timing of snowmelt/runoff	Disturbance Regimes: ↑ High peak flows/flooding	Altered wildfire regimes	Non-climate Stressors: Development & transportation infrastructure	Grazing	Agriculture	Water withdrawals (groundwater & instream)	Dams, levees, & water diversions	Other: Tactic increases general resilience	EVALUATION: Tactic recommended for implementation	Quantity/quality of evidence supporting recommendation	Citations
Build an information base to inform decision-making and ensure a timely response to disturbances	Collect pre- and post-disturbance data on stream conditions by continuously monitoring flow and water quality at high quality sites and/or sites most in need of protection		● *(indirect)*				● *(indirect)*	● *(indirect)*						○ *(indirect)*	✔	Low	Sherson et al. 2015
	Prioritize data collection based on forecasted drought (e.g., precipitation, streamflow, soil moisture, surface water, reservoirs, and groundwater)		○ *(indirect)*	○ *(indirect)*	○ *(indirect)*							○ *(indirect)*		○ *(indirect)*	✔ *(Likely)*	None	
Adaptation strategies and tactics that are based on planning and/or collaboration																	
Manage livestock grazing to restore ecological function of riparian vegetation and channels	Incorporate aquatic resource values into aquatic management plan and livestock and range management plan revisions								○ *(indirect)*					○ *(indirect)*	✔ *(Likely)*	None	
	Find different and/or innovative ways to fund implementation and maintenance of improvements to protect streams from grazing impacts (e.g., riparian fencing, rest rotation systems, riders, off-channel water, exclosures)								○ *(indirect)*					○ *(indirect)*	✔ *(Likely)*	None	
Build an information base to inform decision-making and ensure a timely response to disturbances	Create a clearinghouse for available funding and additional resources related to fire, drought, and other disturbances			○ *(indirect)*			○ *(indirect)*	○ *(indirect)*						○ *(indirect)*	✔ *(Likely)*	None	
Increase collaborations and incorporate climate change into planning processes	Create a clearinghouse of available information on projected and observed changes in climate conditions, including federal, state, tribal, and non-governmental organizations and agencies	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*						○ *(indirect)*	✔ *(Likely)*	None	
	Increase coordination between all partners (e.g., federal, state, regional/municipal, tribal, private)	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	✔ *(Likely)*	None	
Communicate with stakeholders and watershed users and form partnerships	Form watershed user groups to identify and protect shallow aquifer recharge zones		○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*		○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	✔ *(Likely)*	None	
	Communicate risk with all stakeholders, including public and private entities downstream		○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*						○ *(indirect)*	✔ *(Likely)*	None	
	Educate private landowners, county developers, and recreational users about the benefits of riparian vegetation and floodplain water storage and the negative impacts of floodplain development		○ *(indirect)*		○ *(indirect)*		○ *(indirect)*		○ *(indirect)*			○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	✔ *(Likely)*	None	

Notes

> Using continuous water quality sensors to collect data on nutrient levels, dissolved oxygen, and pH successfully captured the rapid and short-duration changes following monsoon events and wildfires (Sherson et al. 2015)

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Appendix Table 1e. Fisheries vulnerability-adaptation table.

Key climate change vulnerabilities of fisheries linked to specific adaptation strategies and tactics. Implementation of adaptation strategies and tactics may help to directly reduce and/or address the impacts of identified climate and nong climate stressors and disturbance regimes. Adaptation tactics focused on research, monitoring, planning, and collaboration are included at the end of the table. Adaptation strategies and tactics listed in this table were identified by workshop participants, in the scientific literature, and in other similar efforts.

Key:
- ● Evidence-based
- ○ Expert opinion
- ✔ Recommended
- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors: ↑ Air temperature; ↑ Water temperature	Climate Stressors: Changes in precipitation (timing, amount, and type)	Climate Stressors: ↑ Drought	Climate Stressors: ↓ Low flows/baseflows; ↑ Intermittent flows	Climate Stressors: ↓ Snowpack; Earlier timing of snowmelt/runoff	Disturbance Regimes: ↑ High peak flows/flooding; ↑ Erosion/sedimentation	Disturbance Regimes: Altered wildfire regimes	Disturbance Regimes: Disease outbreaks	Non-climate Stressors: Grazing	Non-climate Stressors: Invasive species	Non-climate Stressors: Recreation	Non-climate Stressors: Development & transportation infrastructure	Non-climate Stressors: Water withdrawals (groundwater & instream)	Non-climate Stressors: Dams, levees, & water diversions	Other: Tactic increases general resilience	EVALUATION: Tactic recommended for implementation	EVALUATION: Quantity/quality of evidence supporting recommendation	Citations	Notes
Adaptation strategies and tactics that are based on enhancing resistance, promoting resilience, or facilitating transition																				
Increase stream connectivity and patch sizes	Modify/remove barriers to increase patch sizes and promote connectivity to colder patches of water	○	○	○	○	○	●						○		●	●	✔ *(Mixed)*	High	Burroughs et al. 2009; Magilligan et al. 2016; Ogston et al. 2014	> *While dam removal is a very effective way to increase the size of habitat patches, sediment transport can result in unintended or negative changes to stream channels in some cases, which can be exacerbated by large disturbances (e.g., floods)* > Removal of a dam on the Pine River, MI led to sediment redistribution, resulting in wider, shallower channels and lower flow velocities downstream of the dam; narrower, deeper channels upstream of the dam; and gradual restoration of bedforms within the former impoundment (Burroughs et al. 2009) > The removal of a dam on Amethyst Brook, MA caused downstream bed aggradation and **a decrease in fish abundance and species richness downstream and immediately upstream; however, complicating factors included a major flood 6 months after removal and the emergence of a new crib dam**. Four new species of fish were present upstream, including spawning anadromous lamprey (Magilligan et al. 2016) > Construction and/or reconnection of side channels increased available habitat for spawning, rearing, and overwintering coho in the Chilliwick River, BC, contributing to a 27-34% increase in coho smolt out-migration (Ogston et al. 2014)
	Increase aquatic organism passage by designing and placing appropriate structures, or improving existing structures	○	○	○	○	○	○						●		●	●	✔ *(Mixed)*	High	Bryant et al. 1999; Diebel et al. 2014; Neville et al. 2016; Schmetterling et al. 2002	> Increasing stream connectivity effectively increased habitat availability, but these benefits must be balanced with the risk of invasion by non-native species (see Fausch et al. 2009) > The installation of a fish ladder at a 7-m falls in Margaret Creek, AK resulted in the upstream colonization of multiple anadromous salmonid species, including steelhead, coho, pink salmon, and cutthroat trout (Bryant et al. 1999) > Upgrading or replacing existing culverts with fish passage structures would increase habitat connectivity in a prioritization model for the Pine-Popple watershed in WI (Diebel et al. 2014) > Replacing 3 existing culverts and an irrigation diversion in Maggie Creek, NV with structures that allowed fish passage increased the density of Lahontan cutthroat trout in the two reaches that were completely blocked (no change in fish density in the two that were only partially blocked), with no change or a slight reduction in genetic diversity over the course of 4 years; additionally, a strategically-placed barrier prevented invasion by non-native species (Neville et al. 2016) > Fish ladders placed on irrigation diversions in tributaries of the Blackfoot River, MT allowed the passage of westslope cutthroat and brown trout at rates similar to control sites, although longer ladders appeared to limit brown trout movement and ladders required frequent repair and maintenance (Schmetterling et al. 2002)
	Connect lakes with streams to support fish with adfluvial life histories (i.e., fish that are reared in streams and migrate to lakes during adulthood)	○	○	○	○	○	○						○		○	○	✔ *(Likely)*	None		
Manage non-native species proactively to reduce existing populations and prevent spread into new areas	Encourage increased harvest of non-native species (e.g., recreational fishing), especially at the front edge of invasions and where long-term strongholds for native species exist										○					○	✔ *(Likely)*	None		
	Remove non-native species (e.g., manually, chemically, electrically, genetic swamping), focusing first in coldwater strongholds	○									●					○	✔ *(Mixed)*	Low	Ruiz-Navarro et al. 2013	> *Although this strategy is generally effective, it does not always lead to a straightforward decline because populations of some species are density-dependent, and may respond to removal by increased recruitment* > Mosquitofish were successfully eradicated in a semi-arid Mediterranean stream after several years of constant active and passive removal efforts; however, this species initially compensated with increased recruitment under low-density conditions (Ruiz-Navarro et al. 2013)
	Create physical or electrical barriers to exclude non-native species from areas that have not yet been invaded										●					○	✔ *(Mixed)*	Moderate	Dawson et al. 2006; Savino et al. 2001	> *The effectiveness of barriers is context-dependent, and can vary based on target species, habitat, and conditions; barriers also have the potential to limit movement of non-target species* > Electrical barriers prevented movement of round goby upstream in the Shiawassee River, MI (Savino et al. 2001) > Electrical and bubble barriers both prevented some crossings of Eurasian ruffe in Duluth Harbor of Lake Superior, but were only moderately effective (Dawson et al. 2006)
Reduce anthropogenic stressors on native fish to bolster their ability to handle changing climate conditions	Limit recreational disturbances (e.g., angling), especially in areas that are at or near temperature thresholds	○										○				○	✔ *(Likely)*	None		
	Reduce non-aquatic invasive species and diseases								○		●					●	✔ *(Mixed)*	High	Lennox et al. 2009; Roelle & Gladwin 1999; Taylor & McDaniel 1998	> A survey of riparian revegetation sites found that eradicated **exotic shrubs increased nonlinearly with age,** suggesting the need for ongoing management (Lennox et al. 2009) > Removing tamarisk from a NM cottonwood stand **did not significantly impact the water balance** (Moore & Owens 2012) > Regular, controlled fall flooding prevented the establishment of tamarisk at a naturally reforested site in an alluvial sand and gravel mine in CO (Roelle & Gladwin 1999) > A combination of herbicide, burning, and mechanical control techniques reduced invasive species and restored diverse riparian habitats in a NM wildlife refuge (Taylor & McDaniel 1998)
	Limit/reduce floodplain development to increase hyporheic water exchange	○	○	○	○	○	○						○			○	✔ *(Likely)*	None		
	Strategically upgrade, relocate, or decommission roads within riparian habitat to disconnect roads from stream networks and reduce sedimentation		●			●	●	○					●			○	✔	High	Abdi et al. 2012; Coe 2006; Madej 2001; McCaffery et al. 2007; Stafford 2011; Ramos-Scharrón 2012	> Strategic placement of additional culverts reduced sediment delivery within a modeled Iranian forest road network (Abdi et al. 2012) > Road sediment was reduced by rocking native-surface roads with coarse gravel, improving drainage, minimizing the number of stream crossings and road segment lengths, rocking the approach to stream crossings, and reducing road-grading activity at elevations under 1,400 m (Coe 2006) > Decommissioning old logging roads in CA significantly reduced the amount of sediment input into streams (Madej 2001) > Streams near decommissioned roads had lower percentages of fine sediment in stream substrates than areas with actively-used roads (McCaffery et al. 2007) > Road sediment was reduced by using at least 30% gravel cover on native-surface roads, improving the construction of water bars, and reducing road-grading activity (Stafford 2011) > Installing cross drains to direct runoff into a paved ditch decreased sediment yield on coastal roads in the Caribbean (Ramos-Scharrón 2012)
Increase and/or moderate changes in streamflow	Alter the timing or amount of reservoir releases (e.g., pulsed flows) to manage stream temperature and flow volume	●	●	○	●	○	○								●	●	✔	High	Buccola et al. 2016; Payne et al. 2016	> Allowing the Detroit Lake to begin refilling 30 days earlier, reducing minimum release rates in the summer, and utilizing a hypothetical floating surface-withdrawal structure reduced stream temperatures under modeled future conditions, and the floating structure also maintained higher flow levels (Buccola et al. 2016) > A combination of allowing earlier refill of reservoirs and greater storage for instream flows increased streamflow in the Columbia River Basin under future climate conditions, but only with a loss in hydropower generated (Payne et al. 2016) > Refining dam operations and flow prescriptions allowed the recovery of endangered cui-ui in NV, as well as riparian birds and cottonwood/willow stands (Rood et al. 2003)
	Reduce water withdrawals from streams (e.g., agricultural/irrigation, municipal, industrial)		○	○	●								○	○	○	○	✔	Moderate	Trudel et al. 2016	> Reductions in water withdrawals according to alert levels based on streamflow reduced the number of days with extreme low flows under modeled future climate conditions (Trudel et al. 2016)
	Improve irrigation efficiency to maximize return flows				○									○	○	○	✔ *(Likely)*	None		
	Secure instream flow water rights				○									○	○	○	✔ *(Likely)*	None		

Key:

- ● Evidence-based
- ○ Expert opinion
- ✔ Recommended
- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors: ↑ Air temperature; ↑ Water temperature	Climate Stressors: Changes in precipitation (timing, amount, and type)	Climate Stressors: ↑ Drought	Climate Stressors: ↓ Low flows/baseflows; ↑ Intermittent flows	Climate Stressors: ↓ Snowpack; Earlier timing of snowmelt/runoff	Disturbance Regimes: ↑ High peak flows/flooding; ↑ Erosion/sedimentation	Disturbance Regimes: Altered wildfire regimes	Disturbance Regimes: Disease outbreaks	Non-climate Stressors: Grazing	Non-climate Stressors: Invasive species	Non-climate Stressors: Recreation	Non-climate Stressors: Development & transportation infrastructure	Non-climate Stressors: Water withdrawals (groundwater & instream)	Non-climate Stressors: Dams, levees, & water diversions	Other: Tactic increases general resilience	EVALUATION: Tactic recommended for implementation	EVALUATION: Quantity/quality of evidence supporting recommendation	Citations	Notes
Protect and enhance stream habitat for fish	Protect and/or restore riparian vegetation to increase shading and reduce water temperatures	●														○	✔	High	Bond et al. 2015; Jorgensen et al. 2009	> Reforestation offset 50-100% of increases in stream temperature due to air temperatures warming by up to 6°C on the North Fork of the Salmon River, CA (Bond et al. 2015) > Restoration actions focused on increasing tree cover resulted in a slight water temperature decrease in Chinook salmon habitat of the Columbia River (Jorgensen et al. 2009)
	Restore incised stream channels to reduce patterns of extreme scour and sediment entrainment and increase vertical connectivity between streams and adjacent floodplains	●	○	○	○	○	○	○								●	✔	Moderate	Pollock et al. 2007	> Using beaver dams to capture sediment and rebuild streambeds increased the area within 0.5 m elevation of the stream by five times, allowed the reestablishment of riparian vegetation, and created pockets of cool water behind the dams (Pollock et al. 2007)
	Create pool-riffle formations within stream channels to increase instream habitat heterogeneity (e.g., hyporheic exchange, substrate, flow velocity, and temperature)	●			●		●									●	✔	Moderate	Medina & Long 2004	> Creating riffle formations within eroded streambeds increased stream water levels, reduced bank erosion, and allowed riparian vegetation (e.g., sedges) to naturally revegetate edges (Medina & Long 2004)
	Reconnect rivers to floodplains to increase habitat area and complexity	○	○	○	○	○	●								●	●	✔	High	Jeffres et al. 2008; Konrad et al. 2008	> Juvenile Chinook salmon placed in reconnected ephemeral floodplains grew larger than fish placed in perennial ponds or in downstream tidally influenced river habitat in the Central Valley of CA (Jeffres et al. 2008) > Setback levees along the Puyallup River, WA increased riparian/aquatic habitat and the area of low-velocity flows (Konrad et al. 2008)
	Reintroduce beaver and/or encourage/protect beaver colonization in locations where beaver and native fish management are compatible (e.g., no impact on barriers, where reaches =/> 1 mile, brook trout are not present)	●	●	●	●	○	●									●	✔	High	Bouwes et al. 2016; Hood & Bayley 2008; Malison et al. 2015; Pollock et al. 2007; Westbrook et al. 2006	> The addition of beaver dam analogs (BDAs) increased the number of natural beaver dams in Bridge Creek, OR, which were associated with increased area of juvenile habitat, increased water residence time, groundwater levels, and summer flow, decreased water temperature in some areas and lower daily temperature fluctuations, increased habitat complexity, and a 175% increase in juvenile steelhead production, without impacting upstream migration (Bouwes et al. 2016) > The presence of active beaver lodges increased open water in wetlands despite variations in temperature, precipitation, and drought (Hood & Bayley 2008) > Beaver damming of floodplain spring brooks produced larger juveniles and more biomass than beaver-free spring brooks, although the latter had greater survival and densities, demonstrating that the presence of beavers increases habitat variability and a range of potential growth conditions (Malison et al. 2015) > Using beaver dams to capture sediment and rebuild streambeds increased the area within 0.5 m elevation of the stream by five times, allowed the reestablishment of riparian vegetation, and created pockets of cool water behind the dams (Pollock et al. 2007) > Beaver dams and ponds enhanced the depth, extent, and duration of inundation during floods, and increased the water table during both high-flow and low-flow periods (Westbrook et al. 2006)
	Install beaver mimic dams to obtain some of the positive benefits (e.g., water storage, higher water tables, decreased flow velocities) without the conflict associated with real dams	●	○	○	●	○	○									●	✔	Moderate	Bouwes et al. 2016	> The addition of beaver dam analogs (BDAs) increased the number of natural beaver dams in Bridge Creek, OR, and these were associated with increased area of juvenile habitat, increased water residence time, groundwater levels, and summer flow, decreased water temperature in some areas and lower daily temperature fluctuations, increased habitat complexity, and a 175% increase in juvenile steelhead production, without impacting upstream migration (Bouwes et al. 2016)
	Maintain large woody debris within streams to increase heterogeneity and habitat value	○			○											●	✔	Moderate	Solazzi et al. 2000	> The addition of large woody debris to two streams in coastal OR increased overwinter survival of juvenile coho salmon and downstream migrant numbers the following spring, demonstrating that the treatment increased winter habitat (Solazzi et al. 2000)
Increase the ability of the stream and associated fisheries to recover after disturbance events	Create replicated/redundant fish populations that are spread out to help cope with stochastic climate-driven events						○	○								○	✔ *(Likely)*	None		
	Increase habitat complexity to increase the possibility of refuge during disturbance events						●	○								●	✔	High	Jeffres et al. 2008, Malison et al. 2015	> Juvenile Chinook salmon displayed variable responses in growth and mortality when placed and held in restored floodplain reaches in the Central Valley of CA, demonstrating the importance of providing habitat heterogeneity so that fish can find suitable locations during variable flow conditions (Jeffres et al. 2008) > Beaver damming of floodplain spring brooks produced larger juveniles and more biomass than beaver-free spring brooks, although the latter had greater survival and densities, demonstrating that the presence of beavers increases habitat variability and a range of potential growth conditions (Malison et al. 2015)
	Use fuel treatments (e.g., thinning, prescribed burning) to reduce wildfire severity and size, especially in dense conifer forests						○	●									✔	Moderate	Schmidt et al. 2008; Stephens et al. 2009	> *Although many studies demonstrate the effectiveness of fuel treatments to reduce wildfire severity, no evidence was found that specifically demonstrates that fuel treatments within riparian areas reduce the impacts of fire on stream habitats and fisheries* > Mechanical fuel treatments effectively reduced surface fire (flame length) and crown fire behavior (torching index) at the stand level; Finney's optimal SPLATs design for arrangement of treatment type, amount, and location most effectively reduced fire spread and intensity at the landscape scale (Schmidt et al. 2008) > Mechanical fuel treatments (whole-tree harvest), prescribed burning, and combinations of these were effective at reducing fire severity (Stephens et al. 2009)
	Install erosion control structures after fire						○	○									✔ *(Likely)*	None		
Adaptation strategies and tactics that are based on research, monitoring, and/or assessment																				
Use research, monitoring, and assessment to increase knowledge of current conditions and projected changes	Identify and map barrier passability to prioritize restoration activities (e.g., modifications or removal) and restore fish movement and watershed connectivity	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	● *(indirect)*	○ *(indirect)*	● *(indirect)*						● *(indirect)*		○ *(indirect)*	○ *(indirect)*	✔	High	Diebel et al. 2014; Bourne et al. 2011	> The proposed method successfully prioritized the barriers that would improve connectivity the most while balancing connectivity gains with overall cost; barriers were impassable because of outlet drop, water depth, water velocity, barrier length, constriction, and scour (Diebel et al. 2014) > Using the Dendritic Connectivity Index (DCI) was an effective way to map barrier passability and prioritize barriers for restoration/removal because it not very sensitive to inventory methods and provided the same top results 96% of the time (Bourne et al. 2011)
	Map groundwater inputs to better understand where and when patches of cold water may exist	○ *(indirect)*														○ *(indirect)*	✔ *(Likely)*	None		
Adaptation strategies and tactics that are based on planning and/or collaboration																				
Improve communication with recreational users of stream habitats	Improve public messaging related to recreational fishing and native fish conservation (e.g., the public wants opportunities to fish, not necessarily for native cutthroat)										○ *(indirect)*	○ *(indirect)*					✔ *(Likely)*	None		

Key:
- ● Evidence-based
- ○ Expert opinion
- ✔ Recommended
- ✗ Not recommended

Adaptation Strategies	Adaptation Tactics	Climate Stressors					Disturbance Regimes			Non-climate Stressors						Other	EVALUATION		Citations	Notes
		↑ Air temperature; ↑ Water temperature	Changes in precipitation (timing, amount, and type)	↑ Drought	↓ Low flows/baseflows; intermittent flows	↓ Snowpack; Earlier timing of snowmelt/runoff	↑ High peak flows/flooding; ↑ Erosion/sedimentation	Altered wildfire regimes	Disease outbreaks	Grazing	Invasive species	Recreation	Development & transportation infrastructure	Water withdrawals (groundwater & instream)	Dams, levees, & water diversions	Tactic increases general resilience	Tactic recommended for implementation	Quantity/quality of evidence supporting recommendation		
Manage livestock grazing to restore ecological function of riparian vegetation and channels	Implement standardized monitoring and data sharing for grazing practices to facilitate compliance with existing aquatic management plan and livestock and range management plan standards, guidelines, and laws									○ *(indirect)*							✔ *(Likely)*	None		
	Identify and prioritize vacant grazing allotments for retirement	○ *(indirect)*			○ *(indirect)*		○ *(indirect)*			○ *(indirect)*							✔ *(Likely)*	None		
	Highlight successful programs for monitoring and management of grazing practices									○ *(indirect)*							✔ *(Likely)*	None		
	Incorporate aquatic resource values into aquatic management plan and livestock and range management plan revisions									○ *(indirect)*							✔ *(Likely)*	None		
	Find different and/or innovative ways to fund implementation and maintenance of improvements to protect streams from grazing impacts (e.g., riparian fencing, rest rotation systems, riders, off-channel water, exclosures)									○ *(indirect)*							✔ *(Likely)*	None		
	Improve reporting requirements for grazing allotments									○ *(indirect)*							✔ *(Likely)*	None		
Continue and/or improve coordination for fisheries and habitat conservation	Look for opportunities to partner with private landowners in downstream reaches to improve partnerships between public and private lands															○ *(indirect)*	✔ *(Likely)*	None		
	Convene annual regional meetings to identify and prioritize key fisheries areas, share project updates (restoration and monitoring), and coordinate goals															○ *(indirect)*	✔ *(Likely)*	None		
	Revise documents (e.g., management/implementation plans, MOUs, etc.) to include consideration of climate change impacts	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*	○ *(indirect)*								✔ *(Likely)*	None		

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2. Examples of integrating climate language in NEPA

PURPOSE AND NEED

Yakima River Basin Integrated Water Resource Management Plan (Integrated Plan)[14]

Need: The current water resources infrastructure, programs, and policies have not been capable of consistently meeting aquatic resource demands for fish and wildlife habitat, dry-year irrigation demands, and municipal water supply demands. Specific problems that the Integrated Plan is proposed to address include:

- Climate change projections indicate that there will be changes in runoff and streamflow patterns, which would increase the need for prorationing and reduce flows for fish. These changes include: decreased snowpack; decreased spring and summer runoff; increased crop and municipal water demand; increased frequency of drought conditions; and increased impacts to fish from decreased flows, increased air and water temperature, and changes in timing of streamflows affecting fish migration.

The identified problems have created a need to restore ecological functions and provide more reliable and sustainable water resources for the health of the riverine environment, and for agricultural, municipal, and domestic needs. The specific needs include:

- Climate change. Increased flexibility in the water supply to adapt to changes, including increased crop demand, increased municipal and domestic demand, earlier runoff, and more frequent droughts; and improved streamflows and habitat conditions to help resident and anadromous fish withstand climate change.

Purpose: Implement a comprehensive program of water resource and habitat improvements in response to existing and forecast needs and develop an adaptive approach for implementing these initiatives and for long-term management of basin water supplies that contributes to the vitality of the regional economy and sustains the health of the riverine environment.

Idaho and Southwestern Montana Greater Sage-Grouse Approved Resource Management Plan Amendment[15]

Need: This effort responds to the USFWS's 2010 Finding which identified the inadequacy of existing regulatory mechanisms (i.e., conservation measures embedded in Land Use Plans) as a significant threat to Greater Sage-Grouse (GRSG) habitat or range. Changes in management of GRSG habitats are necessary to avoid the continued decline of populations that are anticipated across the species' range. These plan amendments will focus on areas affected by threats to the GRSG habitat; major threats to GRSG include wildfire, expansion of invasive species, conifer invasion, infrastructure, grazing, human development and uses, and climate change, among others.

Purpose: The purpose of the Land Use Plan Amendment is to identify and incorporate appropriate conservation measures into Land Use Plans to conserve, enhance, and restore GRSG habitat by reducing, eliminating, or minimizing threats to that habitat.

[14] http://www.usbr.gov/pn/programs/yrbwep/reports/FPEIS/fpeis.pdf

[15] https://eplanning.blm.gov/epl-front-office/projects/lup/31652/63338/68680/IDMT_ARMPA_web.pdf

ALTERNATIVES AND PREFERRED ALTERNATIVE/PROPOSED ACTION

Yakima River Basin Integrated Water Resource Management Plan (Integrated Plan)

Preferred Alternative: The Integrated Plan is also intended to provide the flexibility and adaptability to address potential climate changes and other factors that may affect the basin's water resources in the future.

Biscayne Bay Coastal Wetlands Integrated Project Implementation Report and Environmental Impact Statement[16]

Preferred Alternative: Taking into account sea level rise, the period of maximal project benefits will occur during the period between 10 and 20 years post construction. After 20 years until the end of the project life 30 years later, project benefits are expected to decrease as a result of sea level rise. Within the 20-year planning horizon, less than 10% of the project ecosystem benefits are likely at risk to sea level rise.

AFFECTED ENVIRONMENT AND ENVIRONMENTAL CONSEQUENCES

Willapa Bay National Wildlife Refuge: Final Comprehensive Conservation Plan and Environmental Impact Statement[17]

Alternative 1: Under this alternative, current maintenance and management actions would continue as defined by the refuge purposes, and no significant changes to the hydrology are anticipated. If predicted trends and models on climate change continue, with sea level rise over time, dike maintenance would prove much more difficult, and extensive repairs may be required.

Yakima River Basin Integrated Water Resource Management Plan (Integrated Plan)

Fish

No Action Alternative: With the No Action Alternative, existing problems with water availability and habitat quality would likely worsen with current land use activities, increased population and climate change. Anadromous fish would continue to have no access to headwater streams because no fish passage facilities would be provided at major reservoirs. Streamflow conditions would continue to be unfavorable to enhancing fish populations.

Integrated Plan Alternative: All of these Integrated Plan elements will provide improved habitat conditions that will benefit fish and help meet fish production and survival targets. These improvements may help fish withstand the impacts of climate change.

Climate Change

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[16] http://141.232.10.32/pm/projects/project_docs/pdp_28_biscayne/010612_fpir/010612_bbcw_vol_1_main_report_rev_mar_2012.pdf

[17] http://www.fws.gov/willapa/pdf/CCP/Willapa Final CCP-EIS Vol 1_web%5B1%5D.pdf

No Action Alternative: Changes in precipitation, snowmelt, and runoff that may occur as a result of climate change could affect river operations as well as projects. There may be changes in water availability for irrigation, fish, and municipal uses. Without a comprehensive, integrated management program, projects would be completed in a piecemeal fashion, reducing the potential for coordination and increased efficiencies in implementation. An uncoordinated approach may reduce the potential to adapt water management strategies and adjust to changing climatic conditions. Depending on its severity, climate change could cause existing water supply shortages and adverse effects on streamflows and fish in the basin to become significantly worse. Because of predicted increased temperatures and decreased summer streamflow, adverse effects on water quality due to climate change are also likely.

Integrated Plan Alternative: As an integrated package, this alternative would provide multiple benefits to water supply, agriculture, and fish while improving the ability of water managers to adapt to future climate changes. Approaching management on a basin-wide level could provide additional consistency in water management across agencies and jurisdictions. Additional water storage and improved irrigation operations would provide a more reliable water supply for agriculture during dry periods. Improved streamflows and fish habitat, along with access to upper river tributaries, would produce enhanced fish populations that would be better able to withstand habitat changes caused by climate change. As climate change places new stresses on water resources and aquatic habitats in the future, the Yakima River basin's upper watersheds will become even more vital to ecosystem health and water supply. Reopening historic fish habitat through fish passage facilities will improve conditions for anadromous fish.

Socioeconomics
No Action Alternative: Current economic patterns and trends would likely continue into the foreseeable future. Climate change and population increases would impact the relation between natural resources and the economy in the basin.

Integrated Plan Alternative: Potential increase in the value of goods and services derived from the basin's water and related resources in the long term; reduction in uncertainty and risk.

Draft Environmental Impact Statement for Greys Mountain Ecological Restoration Project[18]
No Action Alternative: There would be no direct effects to late seral, closed canopy coniferous habitat under this alternative. There is a potential for indirect effects under the no action alternative, as the continued immediate threat of wildfire would remain unabated. In failing to make an attempt at density management of the stands, the eventual changes through drought stress and subsequent insect and disease mortality acceleration would exacerbate the threat of stand replacing fire. Additionally, the high probability of a drying climate throughout the Western United States would have the potential to further compound these effects.

Alternative 2/Proposed Action: Channel stabilization and conifer removal would improve hydrologic function of the meadows and would have a beneficial effect on the watershed. Meadow condition would move towards upper moderate or high ecological condition where

[18]http://a123.g.akamai.net/7/123/11558/abc123/forestservic.download.akamai.com/11558/www/nepa/76328_FSPLT2_067054.pdf

late successional species are well represented on the site, which is the desired condition. Restoration effects in the long term may improve resiliency of the meadow and riparian vegetation in relation to climate change.

Alternative 2/Proposed Action: Alternative 2 actions attempt to change forest structure so that the forest is capable of surviving climate changes as well as reduce fuels to adapt fire behavior that occurs under current climate and ignition conditions.

Idaho and Southwestern Montana Greater Sage-Grouse Approved Resource Management Plan Amendment

Alternative B: Under Alternative B, restoration projects would be prioritized in seasonal GRSG habitats thought to be limiting the distribution and abundance of GRSG. Re-establishment of sagebrush cover and desirable understory plants would be the highest priority for restoration efforts. Native seed would be required for restoration treatments and the establishment of designated seed harvest areas for sagebrush seed collection in fire prone areas. Climate change would be a consideration when proposing native seed collection. Management under Alternative B would ensure the long-term availability and resiliency of native seed for restoration treatments by establishing native seed harvest areas which incorporate climate change effects. This and post-treatment management plans would improve the success of restoration treatments and the future persistence of GRSG and their habitat. Vegetation treatment rates would be greater than under Alternative A and would further reduce the impacts of invasive grasses, affecting the population areas where invasive grasses are a substantial threat. Treatment rates would further reduce the impacts of conifer encroachment on the population areas where conifer is a substantial threat. Trends for habitat at 10 and 50 years would improve compared with Alternative A.

Alternative D: When reseeding following fire, using species varieties that are adapted to a warmer climate may, in combination with potential climate change, reduce potential for unnatural levels of fire frequency and intensity.

Ross Lake National Recreation Area General Management Plan/Environmental Impact Statement[19]

No Action Alternative: In response to severe weather events and the destruction of facilities, clear and repair damage to campground entrance road in the event that the campground is impacted by flooding, debris flow, and/or erosion, as necessary.

Alternative B: In response to severe weather events and the destruction of facilities, take proactive management actions to prevent campground from being impacted by flooding, debris flow, and erosion. Close affected portions of the campground, as necessary, in the event that the campground is impacted by these events.

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[19]http://parkplanning.nps.gov/document.cfm?parkID=327&projectID=16940&documentID=43172