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Integrating Climate Change Considerations into Natural Resource Planning—An Implementation Guide

Techniques and Methods 6-C2

U.S. Department of the Interior
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Cover. Cable Mountain near old lookout station, in Beaverhead-Deerlodge National Forest, Montana. (Photograph from U.S. Forest Service.)

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By Jessi Kershner, Andrea Woodward, and Alicia Torregrosa

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James F. Reilly II, Director

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.004047	square kilometer (km^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square meter (m^2)	0.0002471	acre
hectare (ha)	2.471	acre
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Abbreviations

CAIT	Climate Adaptation Integration Tool
CMIP	Coupled Model Intercomparison Project
NRAP	Northern Rockies Adaptation Partnership
SWE	snow water equivalent

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Executive Summary

Climate change vulnerability assessments and associated adaptation strategies and actions connect existing climate science with possible effects on natural resources and highlight potential responses. However, these assessments, which are commonly generated for large regional areas, suggest management options in general terms without guidance for choosing among strategies and actions under specific circumstances. Meanwhile, land and resource management plans[1] often address smaller geographies, and management actions must address specific rather than general situations. Thus, there is a need for tools that enable managers to bridge the gap by downscaling assessments, plans, and data generated at regional scales to identify adaptation actions and strategies appropriate for smaller management units and project-level planning.

To address this need, we have developed a tool–the Climate Adaptation Integration Tool (CAIT)–that helps resource managers use climate science and assessments, along with local knowledge, to identify those adaptation strategies and actions most appropriate for a given site or situation. Specifically, we provide:

1. Guidance for acquiring and using downscaled climate change projections;
2. Procedures for using these data to answer Critical Questions to make site-specific determinations of the appropriate management approach (specifically, resistance, resilience, transition, realignment, or no action);
3. Lists of potential adaptation strategies and actions appropriate to the chosen management approach; and
4. Supplemental information regarding adaptation strategies and actions to help managers choose among them.

The CAIT is meant to help managers integrate climate change science and assessments into management decisions. The CAIT also serves as a way for managers to document how they have incorporated climate change information into their decision-making and why certain actions were selected over others. A particular strength of the CAIT is that it leads to potential solutions (that is, adaptation strategies and actions) without inflexibly prescribing actions. This flexibility enables managers to incorporate other factors and constraints to create workable management plans and projects that strengthen their ability to achieve long-term conservation goals.

Introduction and Objectives

Climate change vulnerability assessments and associated adaptation strategies and actions are commonly generated at large spatial extents. While these assessments connect existing climate science with possible effects on natural resources and identify potential responses, they often suggest management options in general terms without guidance for choosing among actions given specific circumstances. Meanwhile, land and resource management plans[2] often address smaller geographies, and management actions must address specific rather than general situations. Thus, there is a need for tools that enable managers to bridge the gap by downscaling assessments and data generated at regional scales to identify relevant adaptation strategies and actions for smaller management units. While "downscaling" usually refers to increasing the resolution of climate projections, the concept is relevant to any data, processes, or structures that have a lower resolution than is useful to meet a particular need. The specific examples illustrated in this document come from experience addressing the management of recreation opportunities (for example, ski areas, hiking trails, campgrounds) and rangeland vegetation resources in USFS Region 1, but the concepts are widely applicable.

[1]EcoAdapt

[2]U.S. Geological Survey

[3]For example, U.S. Forest Service (USFS) plans, National Park Service (NPS) general management plans, Bureau of Land Management (BLM) resource management plans, and environmental compliance documents.

[4]Based on projections from Coupled Model Intercomparison Project 5 (CMIP5; western Montana) or CMIP3 (eastern USFS Region 1) for high emissions (A2 for CMIP3, RCP 8.5 for CMIP5) and low emissions (B1 for CMIP3; RCP 4.5 for CMIP5) scenarios.

The USFS Region 1 includes 183 million acres (74 million ha) in northern Idaho, Montana, northwestern Wyoming, North Dakota, and northern South Dakota. Projected changes in temperature and precipitation and their potential effects have been summarized by Halofsky and others (2018) for this region based on downscaled results from multiple global climate models and two emissions scenarios (box 1). The base period used to describe current conditions was 1970–2009; projections were for 2030–59 and 2070–99 to describe periods relevant to long-term management actions (for example, road building, vegetation restoration). Results of overall changes are expected to alter the productivity and structure of vegetation and physical processes with consequences for habitat quality, quantity, and distribution.

Several governmental and non-profit agencies have generated climate impact assessments, climate change vulnerability assessments, and/or adaptation strategies for individual or multiple resources within areas encompassed by or including USFS Region 1. Examples include assessments created by the Northern Rockies Adaptation Partnership (NRAP), BLM Ecoregional Assessments, and State Wildlife Action Plan Updates[3]. Because of their spatial breadth, the recommendations of these reports are general and lack detailed guidance regarding how, when, and where to adopt potential adaptation strategies and actions (box 2).

The Climate Adaptation Integration Tool (CAIT) described in this implementation guide is intended to help resource managers use climate science and assessments, along with local knowledge, to select the adaptation strategies and actions that are most appropriate for a given site or situation. Process elements of the tool include:

- Reviewing climate change vulnerability assessment and adaptation findings and downscaled climate information;
- Selecting a general management approach by considering the impacts of climate change on the resource of interest, the value of the resource, and its current condition; and
- Identifying the climate adaptation strategies and actions that may best support the selected management approach.

In some cases, consideration of climate effects may result in managers reassessing the feasibility of previously stated objectives or modifying planned actions (fig. 1). In formal decision-making processes (for example, structured decision making; Marcot and others, 2012), we anticipate that using the CAIT will influence the setting of objectives and identifying and analyzing alternative actions.

Box 1. Climate change in the northern Rocky Mountains (Halofsky and others, 2018)

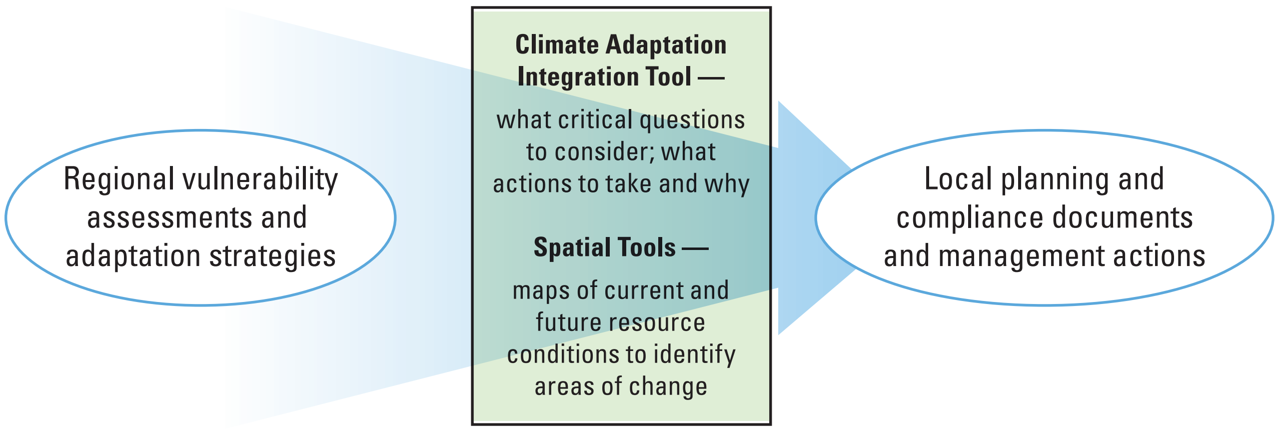
Climate Change Projections	Increase of 4–5 °Celsius (7.2–9 °Fahrenheit) in annual air temperature by 2050 Increased winter precipitation
Potential Changes in Hydrology	Decreased snowpack and earlier snowmelt Altered timing of streamflow Decreased summer flows Increased peak flows Increased water temperature
Potential Changes in Disturbance	Increased frequency and magnitude of droughts Altered fire regimes Increased insect and disease outbreaks
Potential Changes in Habitats and Species	Range and phenological shifts Loss of biodiversity Increase in invasive species Species displacement Exacerbation of existing stressors (for example, invasive species) Increase in grassland productivity Increased growth of cutthroat trout (*Oncorhynchus clarkii*) populations

[3]Bureau of Land Management (2019); Northern Rockies Adaptation Partnership (2019); State of Idaho (2019); State of Montana (2019)

Box 2. Adaptation strategies and actions to address climate change vulnerabilities for recreation in the northern Rocky Mountains (adapted from table 10.4 in Halofsky and others, 2018)

Climate change effect	Warm weather recreation season will increase in length		
Adaptation strategy	Provide sustainable recreation opportunities in response to changing demand		
Action	Assess changes in use patterns and identify demand shifts	Adjust capacity of recreation sites	Adjust timing of actions such as road and trail closures
Where to apply Action	At multiple levels (regional, forest-level, and local)	Where demand increases, as appropriate	All lands
Climate change effect	Increases in flooding, fire, and other natural disturbances will cause damage to infrastructure		
Adaptation strategy	Manage recreation sites to mitigate risks to public safety and infrastructure and continue to provide recreation opportunities		
Action	Assess what recreation sites and infrastructure are at risk from increased flooding and other natural hazards	Prioritize post-disturbance treatments, including relocation, armoring and other mitigation measures	Invest strategically in developed recreation facilities, prioritizing those that will be viable in the future, and accommodate changing use patterns
Where to apply action	All lands	All lands	All lands

Terminology varies such that our "actions" are called "tactics" by Halofsky and others (2018).



Example: Winter Recreation

Vulnerability: loss of sufficient snow	Identify current and future areas suitable for winter recreation based on snow depth, access, minimum area, etc. Where will current, high value opportunities for winter recreation change?	Adjust objectives: identify management actions to support objectives (such as adjust open/close dates for snowmobile trails)

Figure 1. Downscaling regional vulnerability assessments and adaptation strategies and actions for use in natural resource management plans and projects.

The following sections provide additional background and detailed guidance for using the CAIT. We first summarize the climate adaptation planning methodologies and decision-support concepts that informed the development of the CAIT. Next, we describe the process and considerations involved in selecting and applying downscaled results of general circulation models (GCMs) to smaller spatial extents and detail the methodology we used to develop the CAIT. Following this background information, we present the CAIT's four steps along with two supporting matrix tools and highlight two case studies (recreation, rangeland vegetation) where the CAIT was used. The final section discusses using the CAIT, including lessons learned, and provides guidance on how to modify the tool for other resources.

Concepts Informing The Climate Adaptation Integration Tool

The CAIT presented here was developed through collaboration with resource management and geographic information system (GIS) staff of USFS Region 1 (app. 1). The specific goal was to build on:

- The Climate-Smart Conservation guidebook (Stein and others, 2014);
- Guidance for choosing and using climate scenarios for impact assessment (Snover and others, 2013);
- Adaptation approaches described in Scanning the Conservation Horizon (Glick and others, 2011);
- The USFS's Climate Project Screening Tool (Morelli and others, 2012);
- The NRAP region-wide climate change vulnerability assessment and adaptation planning document (Halofsky and others, 2018); and
- A decision support framework for selecting climate-informed conservation goals and strategies for native salmonids (Nelson and others, 2016).

Ultimately, our approach addresses several steps in the climate-smart conservation cycle (fig. 2). Specifically, the CAIT helps managers assess climate impacts and vulnerabilities, clarify management goals, identify possible adaptation actions, and evaluate and justify actions selected for implementation (steps 2–5).

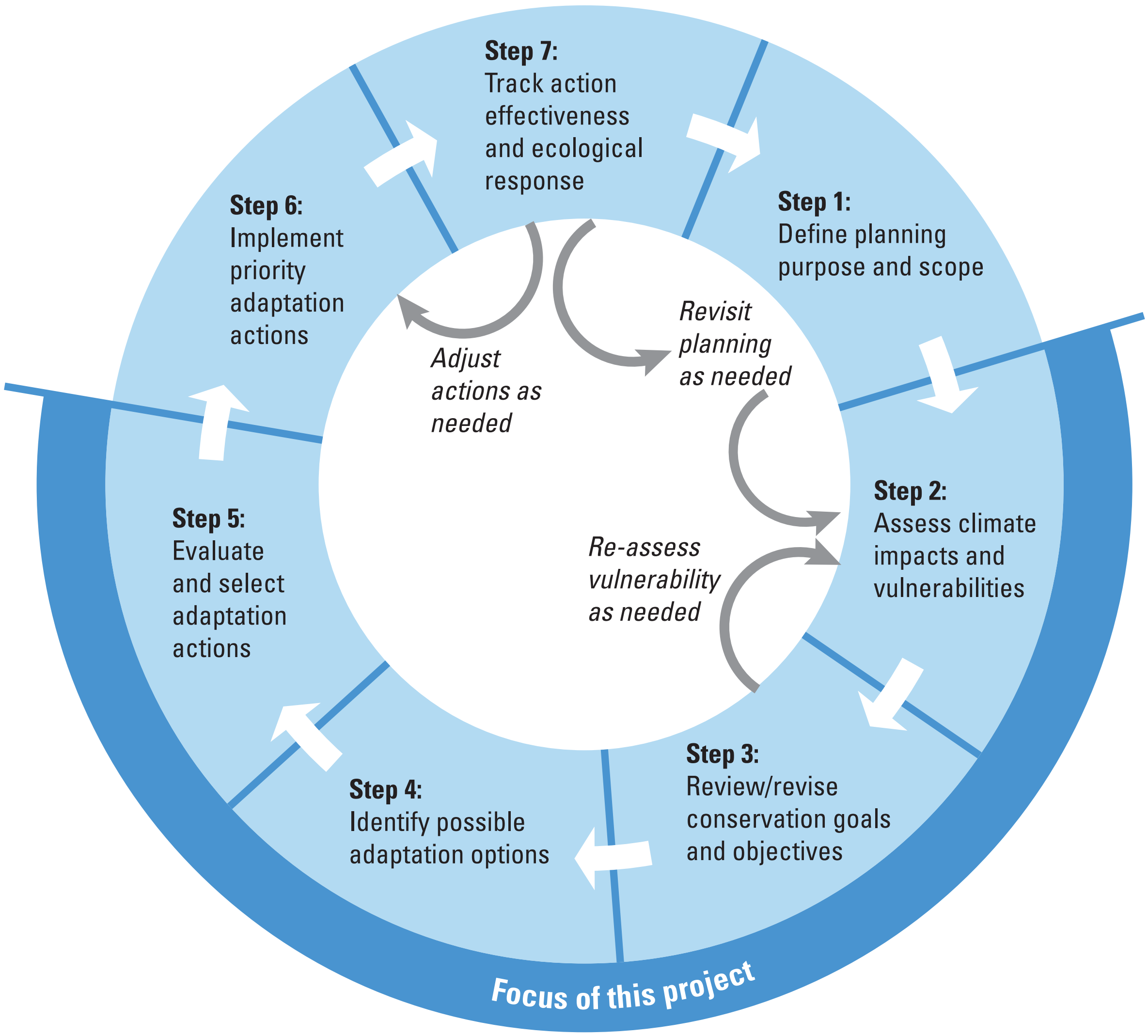


Figure 2. Conservation Cycle (adapted from Stein and others, 2014) describing a generalized framework for incorporating climate change considerations into conservation work. [Dark blue band indicates scope of this guide.]

Effective natural resource management in the era of climate change must be informed by future projections of resource-relevant climate parameters downscaled to illuminate local spatial patterns (fig. 2, step 2; Snover and others, 2013). During the development of the CAIT, we found that forecasts of changes in temperature and precipitation were not specific enough to inform local decisions. For example, projections of changes in winter precipitation that are reported as snow water equivalents (SWE) were insufficient to inform decisions regarding winter motorized recreation that require knowledge of snowpack depth. Similarly, output from GCMs, which typically project temperature and precipitation in cells that span multiple degrees of latitude and longitude, were much too coarse. Even downscaled GCM output at the 7.5 by 7.5 mi (12 by 12 km) scale most frequently used by Halofsky and others (2018) lacks the spatial resolution to describe an elevational gradient on a range of mountain peaks that is important to inform management decisions (for example, the siting of ski runs). Using concepts presented by Snover and others (2013) and knowledge gained from meetings with resource managers, we selected models and emissions scenarios to represent the widest range of future climate conditions (that is, warmest-coolest and driest-wettest), identified the set of most useful climate-derived variables for informing resource-specific decisions, and mapped variables at relatively small spatial extents.

Climate change adaptation strategies and actions have been organized into three general management approaches: resistance, resilience, and transition (Millar and others, 2007; Glick and others, 2011). Alternatively, a manager could choose to take no action or to change the management goal for a site (box 3). Glick and others (2011) recognize that while resilience is the more frequently recommended approach, managing ecological transition may become more prevalent in future conservation projects, and resistance may be the only way to address climate vulnerability of highly valued resources. Depending on potential climate effects, it may be appropriate to take one approach in the near term and another in the long term. We used these three types of management approaches, along with two others–realignment and no action (box 3)–to create a management approach matrix (see "CAIT Step 3" description). We then grouped adaptation strategies and actions identified by NRAP according to management approach (see "CAIT Step 4" description).

The CAIT also draws on the approach presented in the USFS's Climate Project Screening Tool (Morelli and others, 2012), which is designed to help managers integrate climate change considerations into management project-level planning, including developing adaptation strategies and actions. For a given management project, the Climate Project Screening Tool asks managers to examine climate change trends and local impacts, then use the information to answer a series of key questions about how climate changes may impact the management project activity and/or resource. Based on their answers to key questions, managers evaluate whether to proceed with the management project (that is, yes, no, or yes–with modification) and then are provided with recommendations for project-related climate adaptation strategies and actions. The CAIT builds on the structured question approach by adding guidance for using downscaled climate projections and incorporating information about current resource condition and value to select the most appropriate adaptation strategies and actions for a given situation.

The CAIT was developed in association with the authors of the three-step decision-support framework for climate adaptation for native salmonids in the Northern Rockies (Nelson and others, 2016). Similarities between tools are intentional, as we wanted managers of different resources (for example, fisheries, recreation opportunities, and rangeland vegetation) to have a common foundation for, and understanding of, how to reflect local and/or individual forest situations when selecting potential adaptation strategies and actions generated at the regional level.

Lastly, a primary goal of the CAIT is to help resource managers of USFS Region 1 integrate climate change considerations, including vulnerability and adaptation, into their forest plan revisions as well as project-level planning. Halofsky and others (2018) provide the necessary groundwork for considering climate change effects. This document takes managers to the next step of identifying what specific adaptation actions may be most appropriate to implement for a given situation and documenting the rationale for the selected approach.

Evaluating Climate Data Across Scales

Fundamental to integrating climate change considerations into natural resource planning is projecting future climate conditions in order to assess future climate suitability for the resource under consideration. Two decisions must be made when using future projections of climate models for the assessment: which models to consider and which variables to use. These two decisions can occur in either sequence. In this section we describe the sequence that first selects a subset of GCMs followed by a subsequent sub-setting of model(s) based on climate variables. In appendix 2, we describe the alternative approach of first selecting appropriate models based on climate variables and then selecting a subset from those to arrive at a tractable number of models.

The first decision involves identifying a subset of models that adequately simulate current climate. In USFS Region 1, this meant reproducing seasonal cycles and a twentieth century warming trend of 0.8 °C (1.5 °F) (Mote and Salathé, 2010). The models can be evaluated using validation statistics found in the literature (for example, Rupp and others, 2013). While identifying useful models is complicated by the multiplicity of available models, resources from the Coupled Model Intercomparison Project (CMIP; box 4) are helpful. CMIP5, which is the latest iteration of this process, was released in 2014, with 20 modeling groups each contributing from 1–5 different models.

Next, from the set with the best simulations, a smaller subset of models is selected to represent the range of potential climate futures (best case, worst case, median). In USFS Region 1, we graphed the subset of models with good validation statistics to select representative extremes. In figure 3, the importance of downscaling becomes more evident when annual statistics are run for different states, such as Idaho (ID) and Montana (MT). For example, GFDL-ESM2M, the model with driest/warmest projections for ID is the National Center for Atmospheric Research (NCAR), whereas for MT it is MIROC3. The distribution of models will also differ with variables graphed. The AdaptWest portal for Western North American spatial data (AdaptWest, 2020) has a wealth of comparative tables helpful for climate-data selection (Wang and others, 2016) using the four-quadrant approach. Other sources of climate data and evaluation tools are available in appendix 3.

Box 3. Management approaches (definitions)

Resistance	A management strategy or action designed to limit climate change impacts on a resource and/or bolster a resource's capacity to retain fundamental structure, processes, and functioning in response to rapid environmental change (for example, promote native plant species). Near-term, management intensive approach.
Resilience	A management strategy or action designed to bolster a resource's ability to absorb and recover from rapid environmental change (for example, revegetate with species adapted to projected conditions). Management intensive in the near-term with the goal of getting a resource to a place where it has the capacity to reorganize and regain its fundamental structure, processes, and functioning when altered by stressors. Near- to mid-term approach.
Transition	A management strategy or action designed to intentionally accommodate change and adaptively respond to new conditions (for example, create new recreation opportunities at existing sites). Long-term approach.
Realignment	A management strategy or action aimed at revisiting and revising underlying management goals and priorities (for example, introduce endemic species into future climatically suitable areas). Long-term approach.
No Action	A deliberate management strategy to respond to change with no action beyond observation. Long-term approach.

Notes: 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.
Definitions were adapted from Holling (1973), Millar and others (2007), Heller and Zavaleta (2009), and Chambers and others (2017).

Box 4. Coupled Model Intercomparison Project (CMIP)

Models are periodically analyzed through the Coupled Model Intercomparison Project (CMIP), which compares model output from a variety of models all using the same inputs. Results clarify differences in methods for modeling climate dynamics, illuminate differences in modeled climate projections, and support international assessments of climate change (see app. 2 for more detail).

The models for CMIP3 and CMIP5 range in grid cell resolution from 30–500 km, which cannot capture important variation due to finer landscape patterns. Processes such as cold-air pooling, which is especially important in areas with significant topographic relief, strongly impact snowpack dynamics and affect assessments of snow-dependent resources (Curtis and others, 2015). Capturing the relevant level of climatic variability across the landscape requires downscaling GCM output to smaller grid sizes. Additionally, the projections are only useful if they describe future conditions at a scale appropriate for decision-making and illustrate a range of future climate scenarios (Mote and others, 2011; Rupp and others, 2013). To meet these needs, monthly temperature and precipitation output from 30 CMIP5 climate models run under the radiative forcing levels (watts per square meter) of four representative concentration pathways (RCP) emission scenarios are available at 800-meter resolution nationwide (Thrasher and others, 2013). Model output from two RCP scenarios were used by Hostetler and Adler (2016) to derive nationwide grids at 800 m for runoff, snow water equivalent, soil storage, and evaporative deficit using the Variable Infiltration Capacity (VIC) hydrologic model under two emission scenarios: RCP 4.5, a future trajectory of atmospheric greenhouse gas concentrations that peaks around 2040 and then declines and RCP 8.5, a trajectory that leads to a much hotter earth, and the expected trajectory if emissions continue to rise at the current rate.

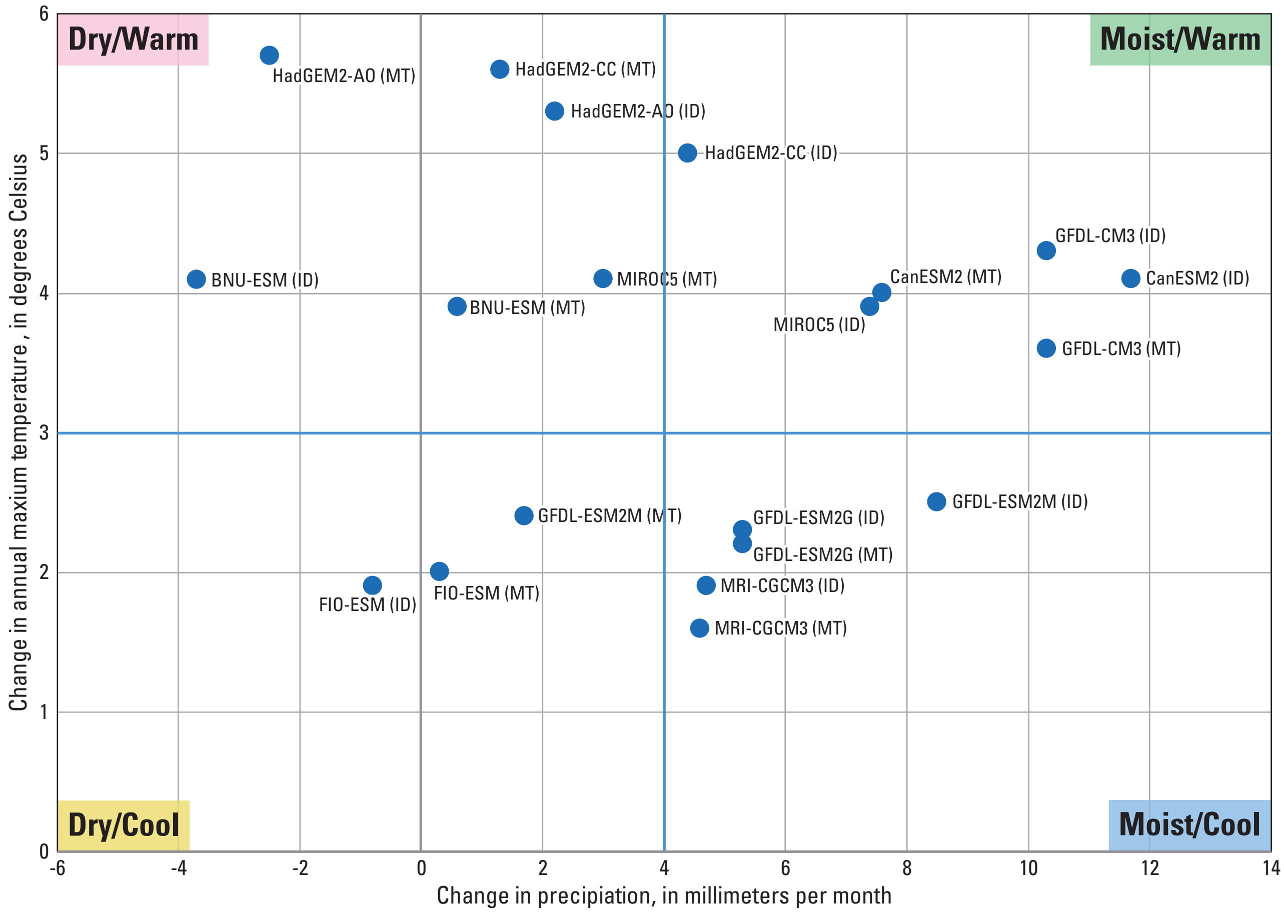


Figure 3. Illustrating change in projected future change in average temperature and precipitation (2050–74) from the historical period (1981–2010), using output from seven CMIP5 GCMs: BNU-ESM, CanESM2, FIO-ESM, GFDL-CM3, GFDL-ESM2G, HadGEM2-AO, HadGEM2-CC, MIROC5, and MRI-CGCM3 for Idaho (ID) and Montana (MT) with four quadrants demarcated: moist/cool, moist/warm, dry/cool, and dry/warm conditions (adapted from Alder and Hostetler, 2013). See appendix 2 for climate model acronyms and suggested steps for generating a similar quadrant graph for your area.

The second decision, picking climate variables, involves identifying the indicators that best inform the management discussion about the resource. In some cases, this is the climate variable that has the strongest impact on the functioning of the resource (for example, snowpack depth for snowmobiling). In other cases, it may be a climate variable that indirectly affects the resource (for example, minimum temperature as an indicator of early spring). Identifying the key climate change vulnerability factors (fig. 4) helps with the selection of the climate variable associated with the most significant threat. With the selection of a key variable, managers consider the model outputs with the widest range for that climate variable using the previously described four-quadrant approach. For example, we used snow layers from the CSIRO and Japanese MIROC3 models for the workshop with the Gallatin National Forest in Montana, whereas we used snow layers derived from the NCAR and MIROC3 models for the workshop with the Nez Perce-Clearwater National Forest in Idaho.

Developing The Climate Adaptation Integration Tool (CAIT)

In this section we provide an overview of the process used to develop the CAIT and details on how we tailored it to support recreation and rangeland vegetation management planning in USFS Region 1. The CAIT was developed through iterative interactions with USFS Region 1 resource managers, GIS spatial analysts, and regional coordinators via in-person workshops, conference calls, and emails (fig. 4). The tool itself is presented in the following section, with specific examples for recreation opportunities and rangeland vegetation presented in subsequent sections, respectively.

We initiated the process by having USFS staff identify high-priority resource topics of interest (fig. 4) for which to develop a draft CAIT. The staff selected recreation opportunities and rangeland vegetation as topics because those items were already receiving attention in forest plan revisions.

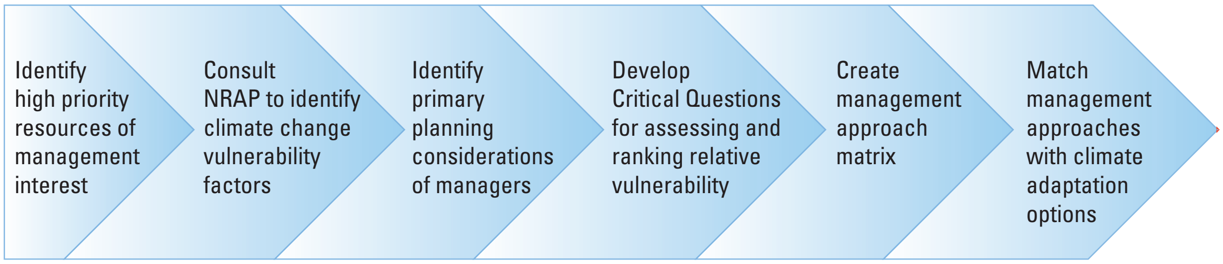


Figure 4. Process used to develop the Climate Adaptation Integration Tool (CAIT) in collaboration with U.S. Forest Service staff.

Besides being subjects of management planning efforts, these topics were of great interest to resource managers who were also available to provide input through in-person and remote engagements (app. 1).

We then used vulnerability assessment and adaptation planning documents produced by Halofsky and others (2018) to identify the key climate change vulnerability factors (fig. 4) influencing each resource topic (CAIT Step 1 below and case studies). For example, warmer winter temperatures and the amount, timing, and type of precipitation were key climate factors identified for winter recreation opportunities. Climate projections, expected impacts, vulnerability assessments, and local knowledge were all used to identify the ways in which climate change may affect a resource. For the purposes of the CAIT, it is important to select the factors that represent the most significant threat to the resource. For example, type and amount of precipitation significantly influence conditions for snowmobiling, a recreation activity that depends entirely on snow levels.

Simultaneous to our exploration of key climate change vulnerability factors, we experimented with several types of decision-support structures (for example, Oliver and others, 2012; Castro and others, 2015), testing these with managers to arrive at a framework that struck a balance between being too prescriptive to address a range of situations against too general to truly provide guidance. As part of this testing, we worked with both recreation and rangeland vegetation managers to describe their primary planning considerations when making decisions about a specific resource. Based on these discussions and a review of papers and reports, we identified three primary planning considerations (fig. 4):

- Future climatic suitability: To what extent will climate change impact the resource? For example, climate change can lead to the loss or creation of recreation opportunities, shift the timing or availability of access, and/or alter use patterns. Climate change can also lead to the loss or expansion of rangeland habitats, exacerbate the impacts of existing, non-climate stressors (for example, ungulate grazing), and increase the extent and severity of disturbance regimes (Halofsky and others, 2018).
- Resource/site value: How important and/or unique is the resource opportunity/site, and is it likely to persist? For example, a rangeland site may be considered highly valuable if it contains rare or endemic species or is recognized as an important grazing area. Similarly, a recreation site that provides the only snowmobiling opportunity within 100 miles (mi) of a population center may also be highly valued.
- Current condition: What is the current state of the resource opportunity/site being considered? For example, some recreation sites may already exist at the edge of climatic suitability (for example, ski resorts in lower elevation areas) and/or have degraded or marginal infrastructure that requires substantial investment. Similarly, the ecological condition of a given rangeland site may be currently degraded, for example, due to invasive species or uncharacteristic fire regimes.

Once the primary planning considerations were identified, we developed Critical Questions for assessing and ranking a resource's relative vulnerability (fig. 4) to climate change (see section, "CAIT Step 2"). The Critical Questions were designed to help managers document their logic and understanding of the likely impact of climate change, resource/site value, and current condition to justify decisions regarding management objectives and appropriate strategies and actions. The order in which the planning considerations and their questions are presented is intended to encourage managers to confront the projected degree of changing climatic conditions before addressing the site characteristics that are routinely considered in management plans and projects. Placing consideration of future suitability first is a powerful method of mental reorganization that serves to bring the reality of a changed climate to the forefront (Wollenberg and others, 2000; Cook and others, 2014).

Answering these three sets of Critical Questions gives an overall picture of relative vulnerability of the resource to climate change and helps narrow down the adaptation strategies and actions to those that may be most applicable. Recorded answers to Critical Questions can also be incorporated into justification statements for planning and decision-making in environmental compliance documents. For recreation and rangeland vegetation, the Critical Questions related to each of the planning considerations were drawn from a literature review and discussed with managers who were actively involved in updating forest plans and designing management projects. We found that preparing a draft set of Critical Questions and presenting them during a structured workshop with managers, as done by the Climate Project Screen Tool (Morelli and others, 2012), was the most effective approach for obtaining feedback. Post workshop feedback indicated that the group had attained more co-production of potential solutions to management challenges than they usually experienced in these types of situations. Participants and workshop leaders ascribed this result to the strategic inclusion of individuals with skills and expertise in each of the following:

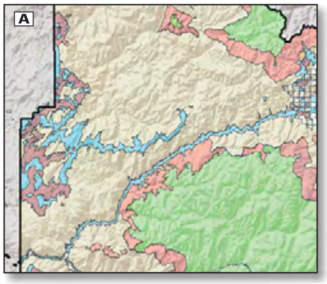
- Technical expertise in the resource topic (for example, recreation, rangeland vegetation);
- Region-wide understanding of institutionally specific planning mechanisms;
- Knowledge of and familiarity with plans and projects occurring across the region and an ability to use this perspective to cut across jurisdictional boundaries;
- Knowledge of and familiarity with USFS institutional geospatial holdings;
- 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.

Using the answers to the Critical Questions, we went on to create a management-approach matrix (fig. 4; see CAIT Step 3 and case studies below) that aligned relative vulnerability with different management approaches that could be taken in the near- or long-term (see box 3). For example, a high-value resource with good current condition that is likely to remain climatically suitable in the future is considered less vulnerable, and management approaches that maintain or enhance the resource will likely be appropriate. Conversely, a high value resource with marginal current condition that is likely to become climatically unsuitable in the future is considered more vulnerable, and managers may need to consider new or different approaches and adaptation strategies. Managers can also use the matrix to choose one approach to take now with the goal of implementing a longer-term approach later.

After linking management approaches with Critical Question responses, we matched approaches with climate adaptation strategies and actions (case studies sections and "CAIT Step 4" description) culled from the scientific literature and summary reports from regional climate adaptation workshops. The adaptation strategies and actions listed are not meant to be exhaustive but are representative of the ideas developed by managers and scientists in the region. Managers are encouraged to consider other ideas or actions they have developed or seen applied elsewhere.

Using CAIT to Evaluate and Select Climate Adaptation Actions for Natural Resource Planning

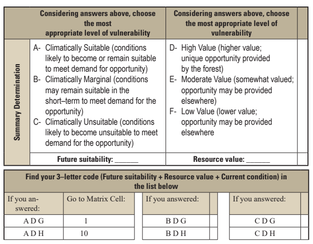
The CAIT involves four steps, which are detailed here. Two case studies describing use of the CAIT follow in subsequent sections. The CAIT can be used to evaluate and select adaptation strategies and actions at the project or site level as well as program or planning levels. In general, the Critical Questions (CAIT Step 2 described below) are aimed at project-level planning; however, several questions are intended to place the assessment of individual sites into a broader context (for example, considering the fate of nearby sites and whether the site's function is available elsewhere). For more holistic adaptation planning, we recommend answering the Critical Questions for multiple sites in a larger planning area (for example, watershed, forest), with the intention of considering the sites relative to one another. For example, looking at multiple sites that provide winter snowmobiling opportunities to better assess which sites may be more vulnerable and which adaptation actions may be best suited to a given site. This will help ensure that a portfolio of adaptation strategies and actions is selected, spreading risk across sites, rather than the implementation of the same adaptation strategy or action at all sites.



CAIT Step 1: Assess the Vulnerability of the Resource to Climate Change

To begin this first step, define the focal resource (for example, recreation opportunity or rangeland vegetation) and assess its vulnerability to climate and non-climate stressors. Regional climate change vulnerability assessments can be used to identify the key climate and non-climate factors that influence the resource. For example, key climate vulnerabilities for winter-based recreation may include amount, timing, and type of precipitation, while non-climate vulnerabilities include increased human populations and deferred or neglected maintenance. Document the key climate and non-climate stressors for a resource, including the data and information that you consulted.

Use the list of key climate and non-climate vulnerabilities to help guide the choice of spatial information and maps to assemble and map and use as aids in answering the Critical Questions in CAIT Step 2.



	Considering answers above, choose the most appropriate level of vulnerability	Considering answers above, choose the most appropriate level of vulnerability	
Summary Determination	A- Climatically Suitable (conditions likely to become or remain suitable to meet demand for opportunity) B- Climatically Marginal (conditions may remain suitable in the short–term to meet demand for the opportunity) C- Climatically Unsuitable (conditions likely to become unsuitable to meet demand for the opportunity)	D- High Value (higher value; unique opportunity provided by the forest) E- Moderate Value (somewhat valued; opportunity may be provided elsewhere) F- Low Value (lower value; opportunity may be provided elsewhere	
	Future suitability: ______	Resource value: ______	

Find your 3–letter code (Future suitability + Resource value + Current condition) in the list below

If you answered:	Go to Matrix Cell:	If you answered:		If you answered:	
A D G	1	B D G		C D G	
A D H	10	B D H		C D H	

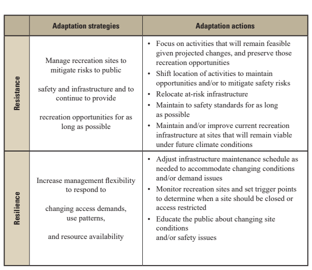
CAIT Step 2: Answer Critical Questions

Use the results compiled in CAIT Step 1: assessment of climate change vulnerabilities, expert knowledge, and spatial data and maps, to answer the Critical Questions for three planning considerations: future climatic suitability, value, and current condition. It is important to define a reference point[6] prior to answering Critical Questions for current condition, as these Critical Questions are intended to help you evaluate how much a resource departs from a given point. When considering Critical Questions regarding value, maps of value determined for multiple sites can put individual sites into the context of regional conditions so assessments of high, medium or low value are consistent. Consider and document your answers to the questions, including the data and information that you consulted and how it influenced your answers. Based on your responses to the Critical Questions, select the overall summary determination for each planning consideration.

Once summary determinations in the form of a three-letter code have been selected for each of the three planning considerations, go to
CAIT Step 3.

CAIT Step 3: Select Management Approach

Use the three-letter code summary determination made in CAIT Step 2 to locate the corresponding management approach matrix cell. Each cell in the matrix lists at least one management approach that reflects the summary determinations for climate suitability, value, and current condition. Management approaches include resistance, resilience, transition, realignment, and no action (box 3). Select the approach that best suits the given situation for your resource. Consider approaches to implement in the near- or short-term (that is, resistance, resilience) as well as those more suitable in the long-term (that is, transition, realignment). Once the preferred management approach has been selected, move on to CAIT Step 4.



	Adaptation strategies	Adaptation actions
Resistance	Manage recreation sites to mitigate risks to public safety and infrastructure and to continue to provide recreation opportunities for as long as possible	• Focus on activities that will remain feasible given projected changes, and preserve those recreation 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	Increase management flexibility to respond to changing access demands, use patterns, and resource availability	• Adjust infrastructure maintenance schedule as needed to accommodate changing conditions and/or demand issues • Monitor recreation sites and set trigger points to determine when a site should be closed or access restricted • Educate the public about changing site conditions and/or safety issues

CAIT Step 4: Select Adaptation Strategies and Actions to Implement Preferred Management Approach

Use the preferred management approach selected in CAIT Step 3 to locate the associated adaptation strategies and actions in the CAIT Step 4 reference table. Adaptation strategies may be most appropriately integrated into plans and programs, while adaptation actions may be most applicable to on-the-ground projects. Adaptation actions can also be integrated into the Potential Management Approaches section of a forest plan.

[6]For example, historical range of variation assessments provide baseline information on ecosystem conditions (composition, structure, and function) that can be compared to current conditions.

Additional Tool to Support Climate-Informed Natural Resource Management Planning: Ameliorates Vulnerability Table

To support the selection and prioritization of adaptation actions to implement, we created "ameliorates vulnerability tables" (appendices 4 and 5), which link potential adaptation actions with the climate and non-climate stressors they are thought to reduce or minimize. Based on scientific literature review and expert opinion, each action was evaluated according to whether it is likely to reduce the impact of a given climate and non-climate stressor, and/or likely to increase general resilience of the resource. In some cases, actions were classified as indirect, indicating that they may not immediately reduce a given impact but perhaps could if given time and/or an appropriate implementation response. Strategies and actions based on research, monitoring, and assessment, and planning and collaboration were primarily classified as indirect (based on expert opinion).

Information gathered during the four CAIT steps can be integrated directly into land and resource management plans (box 5). Generally, climate impacts and vulnerability assessment information can help resource managers articulate the purpose and need for a plan or project as well as the affected environment and environmental consequences; while adaptation strategies provide the proposed actions. In particular, the ameliorates vulnerability 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 guide the creation of monitoring indicators.

Box 5. Identifying the "need for change"

"Need for change" describes a strategic change to the current Forest Plan. As part of Forest Plan revisions, all forests are required to identify where and how the current plan requires modification in order to ensure long-term sustainability of resources given resource conditions, trends, and risks. Identifying the *"need for change"* provides the foundation for creating forest plan components, especially articulation of *"desired conditions."*

CAIT Steps 1 and 2, as well as the downscaled climate maps, provide important information to help develop "*need for change*" statements. Reviewing vulnerability assessment information for a given resource (CAIT Step 1) presents managers with a general overview of the current condition of the resource as well as current and projected future trends and risks to the resource due to climate change. Answering Critical Questions (CAIT Step 2) and using downscaled climate maps goes beyond generalities to more directly consider the long-term sustainability of the resource (for example, are climate conditions likely to become or remain suitable to meet demand for the recreation opportunity?) and provide critical support (for example, 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 "*desired conditions*" that encourage vegetation management in these sites to avoid the loss of these resources during catastrophic fire events.

While "need for change" statements are specific requirements of Forest Plans, the need to explain and justify changes in resource management is generally required across all government agencies.

Case Study: Recreation Opportunities

We worked with staff of the USFS regional office and Custer-Gallatin, Flathead, Helena-Lewis and Clark, and Nez Perce-Clearwater National Forests to test the CAIT using recreation opportunities. Recreation is notable because the topic generates the most public comments during Forest Plan revisions. Managers indicated that climate change generally is considered less relevant to recreation management than resources that are more strictly biological, so they were interested in exploring how changes in climate might affect management decisions regarding recreation. While discussions focused on using the CAIT in the context of Forest Plan revisions, the CAIT development group also explored how the tool supports site-based planning.

CAIT Step 1. Assess the Vulnerability of the Resource to Climate Change

Recreation opportunities were addressed for three categories: winter-based, warm-weather-based, and water-based. Unsurprisingly, climate vulnerabilities vary with category (table 1). In our discussions with resource managers, we focused on winter recreation.

We used the National Climate Change Viewer (based on Adler and Hostetler, 2013; fig. 5) (U.S Geological Survey, 2019) to familiarize USFS Region 1 managers with the range of climate projections available and the geography of impact, select a subset of climate projections relevant for winter recreation opportunities, and discuss how to plan for changing conditions. We layered relevant climate variables into an interactive mapping software platform GIS that included USFS-generated datasets. The goal of this activity was to tap the site-based knowledge and experience of managers while exploring familiar sites under several future climate scenarios. Placing familiar sites within the larger context of climate impacts across the region also served to expand the geography of options. For example, if a site was no longer climatically suitable for a given winter recreation opportunity, there may be another site in the region to replace it.

Through discussions with recreation managers, reduction in snow depth was identified as the most significant threat to winter recreation because it constrains opportunities for motorized activities. Specifically, resource managers identified the need to know the spatial distribution of snow depth by month to identify areas and times suitable for snowmobiling (fig. 6). Snow depth is not a climate variable output from GCMs; however, SWE is an output. We converted SWE to snow depth using calculations from snow research literature. The use of snow depth as the portal for viewing a potential future landscape condition opened the door for participants to incorporate their management expertise into the discussion regarding the logic, rationale, and issues associated with winter recreation decisions (for example, when to open or close a snowmobiling trail or relocate trailhead infrastructure)

Table 1. Climate change vulnerability of U.S. Forest Service Region 1 recreation opportunities based on region–wide assessment of Halofsky and others (2018).

Recreation opportunity	Key climate vulnerabilities
Winter–based (for example, downhill skiing, cross–country skiing, snowmobiling)	Maximum and minimum daily temperatures
	Amount, timing, and phase of precipitation
Warm–weather–based (for example, hiking, biking, camping, sightseeing)	Timing and number of days with comfortable temperature ranges
	Season length
	Wildfire (specifically, changes in site quality and characteristics, smoke)
Water–based (for example, rafting, kayaking, boating, swimming)	Changes in water levels due to increased temperatures, decreased snowpack, and increased precipitation variability
	Increasing temperatures
	Longer warm–weather seasons

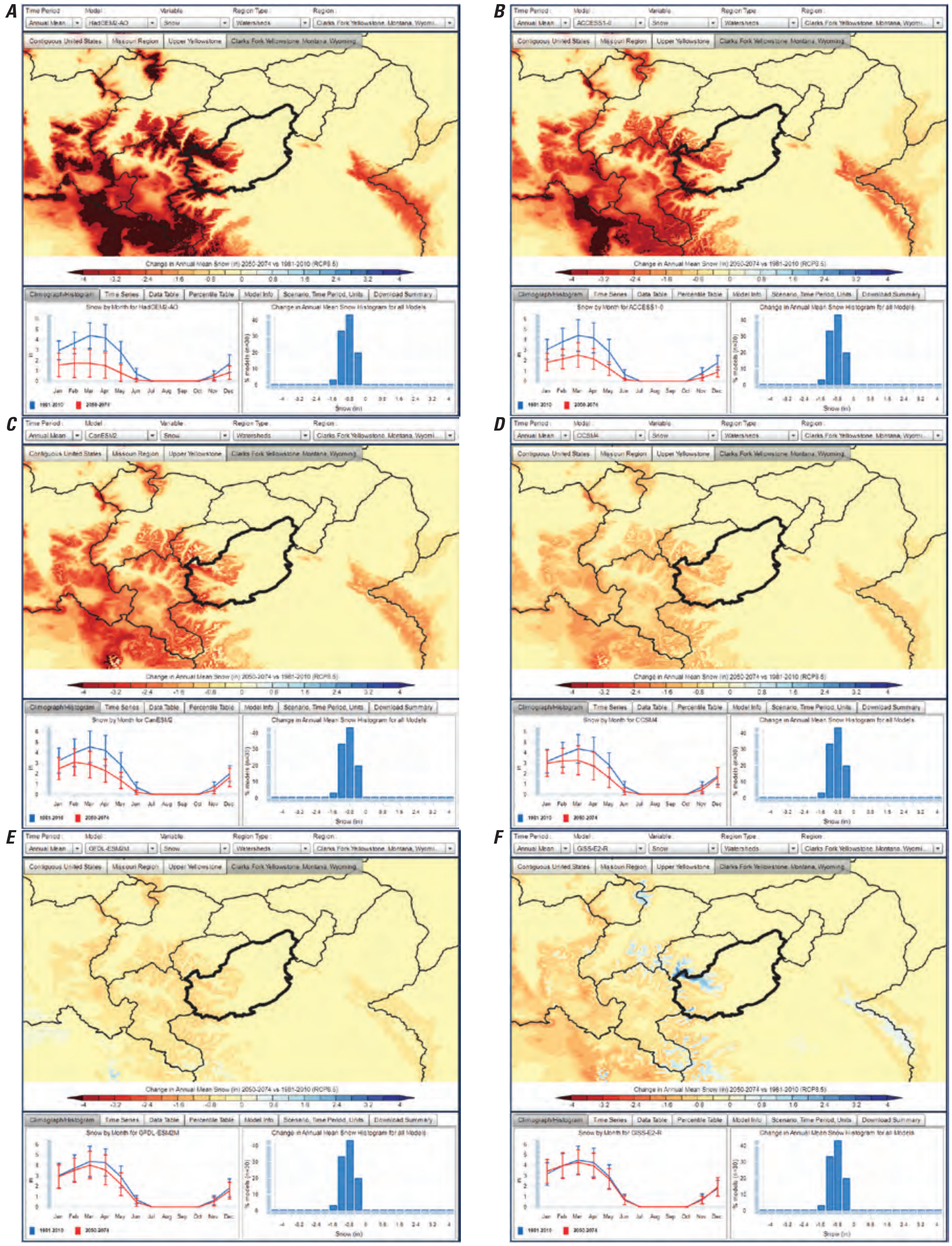


Figure 5. Annual snow water equivalent mapped for the Upper Yellowstone region at 800-meter resolution from six climate models. [The redder the shading is, the greater the decrease in snow water equivalent (SWE). The bluer the shading is, the greater the increase in SWE. Watershed boundaries appear in black, with the Clarks Fork Yellowstone Watershed highlighted in bold. The "climograph" on the left, underneath each map, shows historical (1950–2005) annual inches of SWE in blue for each month (January–December) and projected future (2050–74) in red. The histogram on the right, underneath each map, is identical for all models and shows the number of models (Y-axis) distributed by projected change in annual SWE (0", -0.4", -0.8", -1.2"), with the majority of models falling into the -0.4" change category. Climate models include: (1) HadGEM2, (2) ACCESS1, (3) CanESM2, (4) CCSM4, (5) GFDL-ESM2M, and (6) GISS-ER-R (see appendix 2 for more information on models and acronyms used in this Techniques and Methods; U.S. Geological Survey, 2019.]

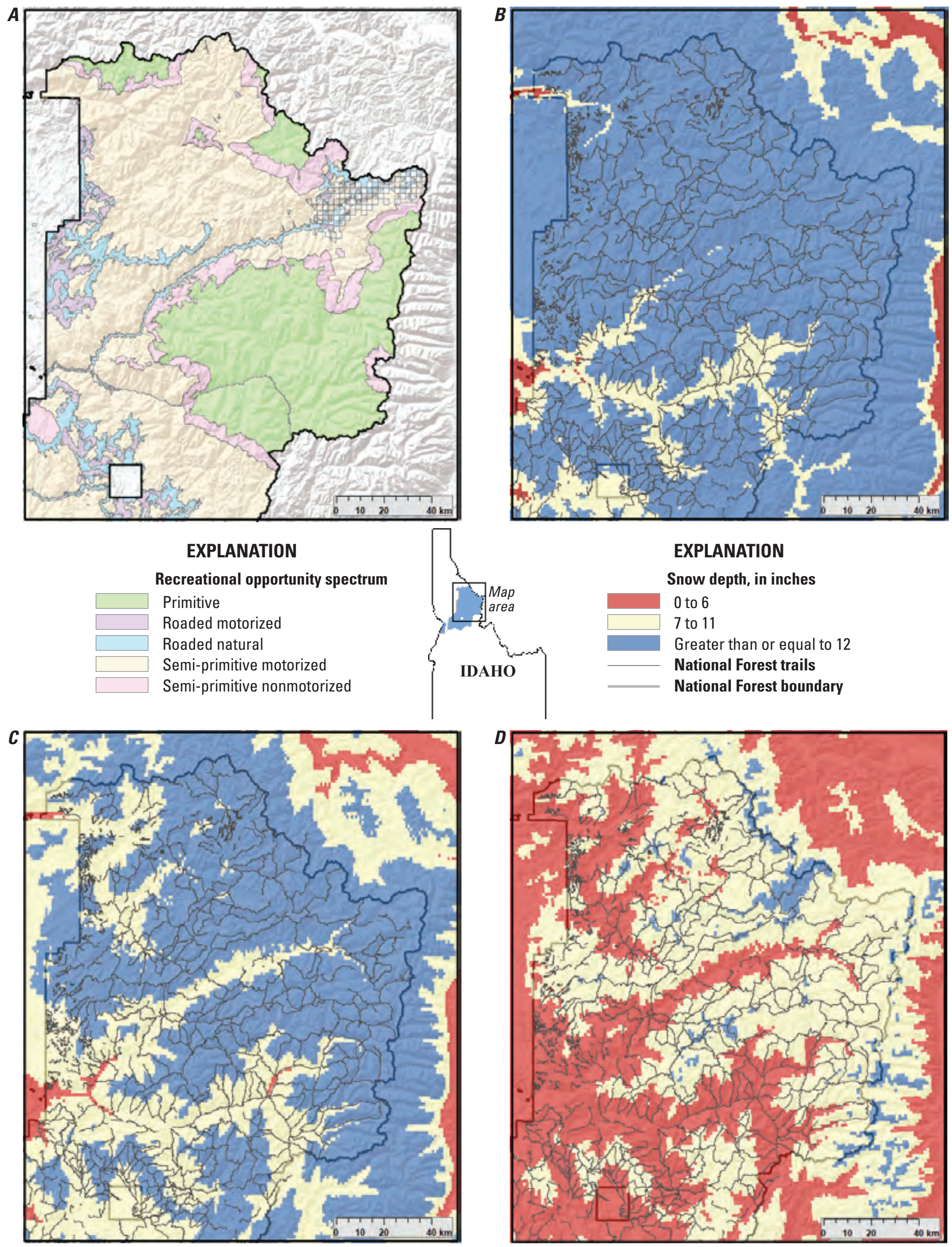


Figure 6. Motorized winter recreation vulnerabilities. A) Winter recreational opportunity spectrum (ROS) map showing semi-primitive motorized areas in yellow, B) depth of snow under current climatological condition, where all trails in the semi-primitive motorized area have adequate snow depth, C) depth of snow using CMIP5 RCP 4.5 under GFDL-ESM2M climate conditions (model that replicates historic data), and D) under MIROC-ESM (the model that describes most extreme loss of snow depth).

CAIT Step 2. Answer Critical Questions

Because climate vulnerabilities vary with recreation opportunity (table 1), it is appropriate to separately answer the Critical Questions for each. After determining that the depth and duration of snow are important to winter recreation, particularly semi-primitive motorized winter recreation activities, we worked with Nez Perce-Clearwater staff to answer the Critical Questions (table 2). Answering the Critical Questions (table 2) based on maps of snow depth and other information led recreation managers from the Nez Perce-Clearwater National Forest to conclude that conditions may remain suitable for motorized winter recreation in the future (B; less than 6 inches of snow is considered suitable for snowmobiling), resources have high value (D), and most sites are currently in good condition (G). The final 3-letter code for this CAIT Step 2 example is BDG.

Table 2. Planning considerations and Critical Questions for recreation opportunities.

[Numbers in the bottom section direct the user to the appropriate cell in the management approach matrix (table 3), which reflects the answers in the upper section.]

	Future suitability What is the future climatic suitability of the recreation opportunity?	**Value** What is the value of the recreation opportunity?	**Current condition** What is the current condition of the recreation opportunity?
Critical questions	**Use projected future climate scenarios and maps to help answer the following questions:**	**Use expert knowledge of ecological, socio–economic, and cultural values to answer the following questions:**	**Use the defined reference point to 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 distributi)on of animal habitat–related visitor restrictions (for example, to avoid bear, lynx)? Are climate–driven changes in disturbance regimes (for example, fire, flooding, wind) likely to limit opportunity access (for example, close trails or facilities)? Will demand for the opportunity likely be met in future? *Winter-specific considerations* Is snowpack projected to decline beyond a suitable level for different winter recreation activities (for example, limit type or quality of activities)? *Water-specific considerations* Is the amount or timing of streamflow projected to limit water–based recreation activities (specifically, type or quality of activity)?	Is the opportunity highly valued by the public? Does the forest provide a unique recreation opportunity? (for example, 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 the local communities? Is the value of the opportunity likely to persist? • Near–term (less than 5 years) • Mid–term (5–10 years) • Long–term (greater than 10 years)	Are there sites that are currently climatically unsuitable or marginal (specifically, for providing the recreation opportunity)? Are there sites within the recreation category that have degraded or marginal infrastructure (specifically, for providing the recreation opportunity)?

Table 2. Planning considerations and Critical Questions for recreation opportunities.—Continued.

[Numbers in the bottom section direct the user to the appropriate cell in the management approach matrix (table 3), which reflects the answers in the upper section.]

	Answer the critical questions by choosing the most appropriate level of vulnerability	Answer the critical questions by choosing the most appropriate level of vulnerability	Answer the critical questions by choosing the most appropriate level of vulnerability
Summary Determination	A- Climatically Suitable (conditions likely to become or remain suitable to meet demand for opportunity) B- Climatically Marginal (conditions may remain suitable in the short–term to meet demand for the opportunity) C- Climatically Unsuitable (conditions likely to become unsuitable to meet demand for the opportunity)	D- High Value (higher value; unique opportunity provided by the forest) E- Moderate Value (somewhat valued; opportunity may be provided elsewhere) F- Low Value (lower value; opportunity may be provided elsewhere	G- Good Condition (most sites currently provide opportunity) H- Marginal Condition (some sites are climatically marginal or have degraded infrastructure for providing opportunity) I- Poor Condition (some sites are climatically unsuitable and/or have degraded infrastructure for providing the opportunity)
	Future suitability: ______	**Resource value: ______**	**Current condition: ______**

Find your 3–letter code (Future suitability + Resource value + Current condition) in the list below

If you answered:	Go to Matrix Cell:	If you answered:	Go to Matrix Cell:	If you answered:	Go to Matrix Cell:
A D G	1	B D G	2	C D G	3
A D H	10	B D H	11	C D H	12
A D I	19	B D I	20	C D I	21
A E G	4	B E G	5	C E G	6
A E H	13	B E H	14	C E H	15
A E I	22	B E I	23	C E I	24
A F G	7	B F G	8	C F G	9
A F H	16	B F H	17	C F H	18
A F I	25	B F I	26	C F I	27

CAIT Step 3. Select Management Approach

Based on the Summary Determination from the example in CAIT Step 2 (specifically, BDG, which points to matrix cell 2 in table 3), managers at Nez Perce-Clearwater National Forest determined that resistance, resilience, and transition are management approaches to consider for motorized winter recreation. Light green cells are those that have at least two of the following: (1) good current condition, (2) high value, or (3) suitable future climate conditions. Dark green cells are those that have at least two of the following: (1) poor current condition, (2) low value, or (3) unsuitable future climate conditions.

Table 3. Matrix of potential management approaches for recreation opportunities.

[Choice of appropriate matrix cell is determined by answers to Critical Questions shown in table 2.]

Current site condition	Value of resource	Area becomes or remains suitable	Area becomes marginal	Area becomes unsuitable
Good	High	1 No action, Resilience	2 Resistance, Resilience, Transition	3 Resistance, Realignment
	Moderate	4 Resilience, Transition	5 Resistance, Resilience, Transition	6 Resistance, Realignment
	Low	7 No action, Transition	8 Transition, Realignment	9 No action, Realignment
Marginal	High	10 Resilience	11 Resistance, Resilience, Transition	12 Resilience, Realignment
	Moderate	13 Resilience, Transition	14 Resistance, Resilience, Transition	15 Resilience, Realignment
	Low	16 No action	17 No action	18 No action
Poor	High	19 Resilience	20 Resilience, Transition	21 Transition, Realignment
	Moderate	22 Resilience	23 Resilience, Transition	24 Transition, Realignment
	Low	25 No action	26 No action	27 No action

CAIT Step 4. Select Adaptation Strategies and Actions to Implement Preferred Management Approach

We grouped adaptation strategies and actions from NRAP (table 4; Halofsky and others, 2018) according to management approach. Due to time constraints during the workshop, we did not explore this table in detail with recreation resource managers. However, we have seen adaptation strategies and actions incorporated into revised Forest Plans. For example, Flathead National Forest included the following Desired Condition and Potential Management Strategy in their revised Forest Plan (USDA Forest Service, 2018):

- Desired Condition: “Sustainable recreation opportunities are responsive to changing conditions due to system stressors such as climate change and changing use patterns and demands.”
- Potential Management Strategy: “Evaluate potential for new motorized over-snow vehicle opportunities and evaluate areas for restricting motorized over-snow vehicle opportunities.”

To help determine which strategies and actions to select, resource managers can consider which climate stressors, disturbances, and non-climate stressors each strategy helps to reduce or minimize (app. 4).

Lessons Learned

Discussions with recreation resource managers brought to light several things to consider when revising management plans. It became clear that revised forest plan components need to be written in a way that avoids limiting a manager’s ability to respond to changes in resource availability due to changes in climate; for example, adjusting opening or closing of facilities based on conditions (for example, snow depth) rather than a specific date. A plan that includes specific, detailed actions runs the risk of becoming an inflexible structure that cannot accommodate changing conditions. Desired conditions for a given area or resource, as described in a forest plan, could also be more flexible if they reflect projected or changing conditions. For example, areas that are projected to have marginal or poor ability to provide a particular resource (for example, a given recreation activity) in the future may have different desired conditions than those for areas projected to be less vulnerable to climate change. Lastly, in addition to the direct impacts of climate change on recreation opportunities, managers will need to consider the ways in which climate change will influence factors such as wildlife distribution, demographics, and technology so as to incorporate sufficient flexibility into plans.

Table 4. Adaptation strategies and actions for recreation opportunities.

Adaptation strategies		Adaptation actions
Resistance	Manage recreation sites to mitigate risks to public safety and infrastructure and to continue to provide recreation opportunities for as long as possible	• Focus on activities that will remain feasible given projected changes, and preserve those recreation 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	Increase management flexibility to respond to changing access demands, use patterns, and resource availability	• Adjust infrastructure maintenance schedule as needed to accommodate changing conditions and/or demand issues • Monitor recreation sites and set trigger points to determine when a site should be closed or access restricted • Educate the public about changing site conditions and/or safety issues
	Minimize synergistic impacts of climate changes, recreation use, and other stressors	• Modify existing infrastructure to better withstand future climate conditions • Maintain and/or improve current recreation infrastructure to respond to changing use patterns/demand • Prioritize post-disturbance treatments (for example, relocation, armoring)
Transition	Increase collaborations with partners and concessionaires to address changes in recreation opportunity supply and demand	• Develop new recreation sites designed for flexibility in use and/or resilient to climate impacts, or create new recreation opportunities at existing sites • Invest strategically in infrastructure that will accommodate new access needs and/or changes ivn existing access • 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 (for example, cat-skiing, helicopter skiing, higher-elevation runs)
	Make the necessary transitions to address changing use and seasonal patterns	• Develop additional access restrictions, which may include changes to permitting processes, seasonal closures, or allowable uses • Adjust the timing of actions (for example, open/close dates, road or trail closures, food storage orders, special use permits) to accommodate changing conditions and/or demand issues • Adjust capacity of recreation sites to accommodate changes in demand • Identify nearby areas where similar activities might still be possible and consider feasibility of developing
Realignment	Revisit and revise goals and priorities in response to changing supply and demand	• Create new/different recreation opportunities at existing sites • Develop additional access restrictions, which may include changes to permitting processes, seasonal closures, or allowable uses • Limit expansion and/or pioneering of new recreation sites in areas projected to be climatically unsuitable and/or marginal
Realignment	Use research and assessment to increase knowledge about current conditions and projected changes	• Conduct a cost-benefit analysis of maintaining the current opportunities over time in order to determine whether prioritized opportunities may need to change • Assess the long-term viability of snow-based recreation sites under future climate conditions • Assess changes in use patterns and identify expected shifts in supply and demand, demographics, and economic trends • Assess infrastructure vulnerability to climate change and natural hazards, and prioritize by seasonal use, viability, and required investment
No Action	Monitor site and/or resource conditions	• 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
	Implement preventative strategies in areas likely to remain or become climatically suitable	• Invest in regular site maintenance and/or upkeep

Case Study: Rangeland Vegetation

We worked with staff of the USFS Region 1 Regional Office and Custer-Gallatin National Forest on the rangeland vegetation resource. Our discussions initially addressed primary planning considerations and how they are incorporated into forest and project plans. Later discussions focused on refining draft Critical Questions (CAIT Step 2) to improve effectiveness and relevance for directing users to appropriate management approaches. We did not have the opportunity to explore spatial data by manipulating data layers with GIS; however, managers noted that using spatial data in combination with the Critical Questions (CAIT Step 2) would be most effective for their planning efforts.

CAIT Step 1. Assess the Vulnerability of the Resource to Climate Change

Key climate vulnerabilities for rangeland vegetation in the Northern Rockies include warmer temperatures, changes in precipitation timing and amount, declines in available soil moisture, and altered fire regimes (Halofsky and others, 2018; table 5).

CAIT Step 2. Answer Critical Questions

We held an initial meeting with staff from the USFS regional office and Custer-Gallatin National Forest to discuss the three primary planning considerations–future climate suitability, value, and current condition–for rangeland vegetation. As part of this meeting, we also presented a draft list of Critical Questions based on information from Halofsky and others (2018). While managers felt the three primary planning considerations were accurate, there were many other Critical Questions that needed to be added. For example, managers recommended we add a question about important endemic or rare species under the “value” planning consideration. Managers also recommended that we add explicit questions about climate vulnerabilities (specifically, changes in precipitation, altered fire regimes), rather than a single general question about whether climate change will alter suitability for rangeland vegetation.

We used the input from this initial meeting to develop a revised list of Critical Questions. The revised list was presented to another group of managers from the regional office, who helped to refine and organize the questions (table 6). Two important points arose from this additional meeting: (1) the “value” planning consideration includes both ecological and socioeconomic values, as rangeland habitats provide important biodiversity, grazing, and recreation ecosystem services; and (2) users need to define a reference point prior to answering Critical Questions. For users to effectively answer the Critical Questions under current condition and value, it is important to define a reference point in order to determine how departed a site is from a given point. For example, determining whether woody plant and/or conifer presence and abundance is appropriate for the site depends on the reference point selected. A site with significant woody plant presence may be appropriate if a recent reference point is defined (for example, within the last 10 years); however, it may not be appropriate if an earlier point is defined (for example, within the last 100 years). The reference point can be defined based on a historic, desired, legally mandated, or other condition.

CAIT Step 3. Select Management Approach

Management approaches reflect the overall direction that could be taken in the near- or long-term (table 7). Light green cells are those that have at least two of the following: (1) good current condition, (2) high value, or (3) suitable future climate conditions. Dark green cells are those that have at least two of the following: (1) poor current condition, (2) low value, or (3) unsuitable future climate conditions

CAIT Step 4. Select Adaptation Strategies and Actions to Implement Preferred Management Approach

We grouped adaptation strategies and actions from NRAP (table 8; Halofsky and others, 2018) according to management approach. Due to time constraints, we did not explore this table in detail with rangeland vegetation managers. However, managers did recommend including monitoring and preventative strategies and actions under the no action management approach (table 8). To help determine which strategies and actions to select, rangeland managers can consider which climate stressors, disturbances, and non-climate stressors each helps to reduce or minimize (app. 5).

Lessons Learned

An important point that arose during our discussions with rangeland vegetation managers was the need to go through the CAIT using a set of sites rather than a single site. Managers noted that it was particularly important to think about site values relative to one another, as responses to Critical Questions for a site may differ when considering it alone versus comparing it to other sites. Managers also noted that going through the CAIT using a set of sites encourages the selection of diverse adaptation strategies and actions rather than selecting the same action to be implemented at multiple sites. This ensures a portfolio of adaptation options are implemented across the landscape, helping diversify risk.

We did not have an opportunity to explore spatial datasets as part of our discussions in this case study. However, managers agreed that using the CAIT in conjunction with maps would provide the most powerful information for comparing across sites and selecting a portfolio of adaptation strategies and actions. In addition to climate projections, it would be instructive to map the outcomes of the Critical Questions for sites within a landscape to improve strategic decisions and selection of projects for investment.

Table 5. Climate vulnerabilities for rangeland vegetation in U.S. Forest Service Region 1.

Rangeland vegetation type	Key climate vulnerabilities
Northern Great Plains	Soil water availability and water stress influence plant species distribution and community composition.
	Increased winter precipitation, warmer temperatures, and higher levels of carbon dioxide could favor some herbaceous forbs, legumes, and woody plants.
	Warmer temperatures and longer growing seasons favor warm season (C4) grasses, but higher carbon dioxide may benefit cool season (C3) grasses.
Montane shrubs	More frequent, severe fires and drier conditions could lead to shifts from mesic species to more xeric species and expansion of non-native invasive plants.
	Warmer temperatures and drier soils may cause some mesic species to shift their distribution up in elevation or to cooler, moister sites.
Montane grasslands	More frequent, severe fires could lead to increased mortality of native species and invasion by nonnative plants.
	Increased winter and spring precipitation could facilitate establishment of exotic annual grasses.
	Warmer and drier conditions will likely lead to increased invasion of nonnative plants and shifts in dominance to more drought-tolerant species.
	Warmer temperatures and more frequent fires will likely lead to grassland expansion.
Wyoming big sagebrush and basin big sagebrush	Amount and timing of precipitation (affects seedling establishment); warmer minimum temperature and lower snow depth (affects germination and survival).
	Increasing drought leading to declines in soil water availability, with impacts on seedling germination and survival as well as growth and survival of adult plants.
	More frequent, intense fires could affect postfire recovery and reduce the extent of big sagebrush communities.
Black and low sagebrush	Increasing drought that leads to reductions of plant cover and increasing erosion could affect seedling establishment.
	Reduced precipitation, especially if combined with annual grass invasion, could eliminate low sagebrush species from some areas.
	Increased fire activity would negatively impact both species.
Threetip and silver sagebrush	Increased winter and spring precipitation could facilitate establishment of exotic annual grasses.
	More frequent, severe fires will likely shift community composition to dominance by fire-adapted shrub and herbaceous species, and nonnative species.
	Warmer, drier conditions may result in a shift to more xeric grassland species, and both sagebrush species may shift their distribution up in elevation or to cooler, moister sites.
Mountain bigsagebrush-shrublands	More frequent, severe fires will likely shift community composition to dominance by fire-adapted shrub and herbaceous species, and nonnative species.
	Increased winter and spring precipitation could facilitate establishment of non-native annual grasses.
	Warmer, drier conditions could shift herbaceous understory composition to more xeric species and/or invasive species, and the distribution of mountain big sagebrush may shift to cooler and moister sites.

Table 6. Planning considerations and Critical Questions for rangeland vegetation.

[Numbers in the bottom section direct the user to the appropriate cell in the management approach matrix (table 7), which reflects the answers in the upper section]

	Future suitability What is the future climatic suitability of the site?	**Value** What is the value of the site?	**Current condition** What is the current ecological condition of the site?
Critical questions	**Use projected future climate scenarios and maps to help answer the following questions:**	**Use expert knowledge of ecological, socio–economic, and cultural values to answer the following questions:**	**Use the defined reference point to answer the following questions:**
	What is the projected direction of change for the site? For example: • Is temperature expected to remain or become unsuitable for native species? • Is soil moisture/soil water availability expected to remain or become unsuitable for native species? • Will projected changes in the timing and amount of precipitation (for example, winter/ spring) likely encourage invasive species establishment and/or expansion? • Are fires projected to become more frequent and/or severe leading to significant site impacts (for example, reduced regeneration success, increased invasion)? Is the site in an area naturally buffered from changing climate conditions (for example, higher elevations, north-east aspects) Are native species likely to persist at the site given changing climate conditions and associated disturbance events (for example, wildfire, erosion, insects and disease) and/or will connectivity to nearby suitable sites remain? If invasive plants are currently present, might projected climate changes alter the influence of invasive plants on native species of concern (for example, via increased competition for limited water resources)? Are current or proposed Desired Conditions attainable in the future?	Does the site include important endemic or rare species or communities, high species diversity, or serve as an important botanical site? What is the current management function/ use of this site (for example, grazing, recreation, biodiversity)? • Does the site include important endemic or rare species or communities, high species diversity, or serve as an important botanical site? • What is the current management function/use of this site (for example, grazing, recreation, biodiversity)? Does the site provide critical wildlife habitat? Is the site highly valued by the public and/ or management? If the site provides an important service/ use (for example, grazing, recreation), can the service/use be made available (relocated) nearby and/or in another season? What is the fate of similar, nearby sites? Is the value of the site likely to persist over the: • Near-term (less than 5 years)? • Mid-term (5–10 years)? • Long-term (greater than10 years)?	*Biotic considerations* Does the presence and abundance of native plant species and/or functional groups indicate an intact, functioning plant community? If the site includes important endemic or rare species or communities, what is their current ecological condition (for example, highly degraded)? Is woody plant and/or conifer presence and abundance appropriate for the site (given disturbance/succession dynamics)? *Hydrologic Considerations* What is the apparent soil nutrient status (for example, is there a well-developed surface horizon)? What is the status of plant available soil moisture? *Site integrity Considerations* Are invasive plants currently present? If yes, what is the level of invasive species occupancy/impairment? What is the amount of bare ground? Is the site significantly departed/degraded/ disturbed owing to: • Climatic stressors (for example, temperature, precipitation)? • Disturbances (for example, insects, disease, wildfire, native ungulate herbivory)? • Management pressure (for example, grazing, land use conversion, recreation)? • Natural weather events? • Connected to a larger network of native plant species and communities? *Other Considerations* How far has the site departed from current Desired Conditions (for example, providing desired animal unit months (AUMs), habitat for wildlife)? What is the current direction of change? Is there any monitoring data showing problematic trends?

Table 6. Planning considerations and Critical Questions for rangeland vegetation.—Continued.

[Numbers in the bottom section direct the user to the appropriate cell in the management approach matrix (table 7), which reflects the answers in the upper section]

	Answer the critical questions by choosing the most appropriate answer	**Answer the critical questions the most appropriate answer**	**Answer the critical questions the most appropriate answer**
Summary determination	A- Climatically suitable (site likely to remain suitable for native species and/or uses) B- Climatically marginal (site likely to become marginal for native species and/or uses) C- Climatically unsuitable (site likely to become unsuitable for native species and/or uses)	D- High value (includes rare/endemic species and/or provides important management uses/service) E- Moderate value (may include some rare/endemic species; management uses/service may be provided nearby) F- Low value (no rare/endemic species; management uses/service can be provided nearby)	G- Good condition (includes healthy native vegetation; site is not significantly disturbed/degraded/departed) H- Marginal condition (may include some native vegetation; site exhibits some degradation) I- Poor condition (limited native vegetation and/or vegetation in degraded condition; site is significantly disturbed/departed)
	Future suitability: ______	**Resource value: ______**	**Current condition: ______**

Find your 3–letter code (Future suitability + Resource value + Current condition) in the list below					
If you answered:	Go to Matrix Cell:	If you answered:	Go to Matrix Cell:	If you answered:	Go to Matrix Cell:
A D G	1	B D G	2	C D G	3
A D H	10	B D H	11	C D H	12
A D I	19	B D I	20	C D I	21
A E G	4	B E G	5	C E G	6
A E H	13	B E H	14	C E H	15
A E I	22	B E I	23	C E I	24
A F G	7	B F G	8	C F G	9
A F H	16	B F H	17	C F H	18
A F I	25	B F I	26	C F I	27

Table 7. Matrix of potential management approaches for rangeland vegetation.

[Choice of appropriate matrix cell is determined by answers to Critical Questions (table 6)]

Current site condition	Value of resource	Area becomes or remains suitable	Area becomes marginal	Area becomes unsuitable
Good	High	1 No action, Resilience	2 Resistance, Resilience	3 Resistance, Realignment
	Moderate	4 Resilience, Transition	5 Resistance, Resilience	6 Resistance, Realignment
	Low	7 No action	8 Transition	9 No action, Realignment
Marginal	High	10 Resilience	11 Resistance, Resilience	12 Resilience, Realignment
	Moderate	13 Resilience	14 Resistance, Resilience	15 Resilience, Realignment
	Low	16 No action	17 No action	18 No action
Poor	High	19 Resilience	20 Resilience	21 Realignment
	Moderate	22 Resilience	23 Resilience	24 Realignment
	Low	25 No action	26 No action	27 No action

Discussion

Climate change requires resource managers to add a new dimension to the list of factors they routinely consider when setting conservation goals and developing plans and projects. The CAIT presented here provides a structured process to help managers integrate climate change effects and adaptation strategies and actions into ongoing management planning and articulate the logic for selecting specific strategies and actions. The CAIT combines fine-scale climate change projections with local knowledge to answer three sets of Critical Questions to assess likely future viability of a resource at a site. The CAIT suggests possible management approaches based on answers to the Critical Questions, and each management approach is associated with a distilled menu of effective adaptation strategies and actions for resource managers to consider. The CAIT is structured to facilitate discussion among resource managers rather than provide a single, prescriptive answer. Use of the CAIT may lead to modification of the tool itself if more useful Critical Questions and additional adaptation strategies and actions should come to light.

Table 8. Adaptation strategies and actions for rangeland vegetation.

	Adaptation strategies	Adaptation actions
Resistance	Maintain intact ecosystems and increase the resilience and resistance of native rangeland habitats	• Inventory intact areas with high native cover (specifically, weed-free areas) • Monitor areas with high endemism or biodiversity (for example, Pryor Mountains) or unique communities (for example, groundwater dependent ecosystems that are sentinels for larger landscapes) • Employ preventative measures to reduce the spread and introduction of invasive species into intact plant communities (see strategy below on preventing invasive species) • Promote the growth and occurrence of native species • Determine and implement proper grazing (for example, use rest and rotation and/or low-intensity grazing practices; manage the timing of grazing to promote native plant species); increase collaboration among management agencies and ranchers • Identify site-specific indicators of grazing impacts to trigger movement of livestock to another site • Employ preventative measures to reduce the spread and introduction of invasive species into intact plant communities (see strategy below on preventing invasive species) • Promote the growth and occurrence of native species • Determine and implement proper grazing (for example, use rest and rotation and/or low-intensity grazing practices; manage the timing of grazing to promote native plant species); increase collaboration among management agencies and ranchers • Identify site-specific indicators of grazing impacts to trigger movement of livestock to another site
	Prevent invasive species establishment and spread	• Apply early detection and rapid response (EDRR) and inventory and mapping • Conduct integrated weed management (specifically, spraying, chemical, biological, mechanical, manual control, targeted grazing) • Update weed risk assessments (WRAs) to include potential climate change impacts • Maintain or enhance native plant cover and minimize bare ground to prevent establishment of invasive species. • Implement prescriptive grazing, fire, herbicide, and re-seeding. • Establish competitive vegetation barriers to protect rangeland habitats from invasive species. • Use best invasive management practices to address vectors; emphasize invasive species education. • Develop weed management areas and coordinate with multiple agencies, nonprofit organizations, and the public.
	Restore natural disturbance regimes in rangeland habitats	• Apply prescribed burns and/or utilize natural fires to prevent woodland expansion. • Utilize mechanical treatments and harvest.
Resilience	Maintain, increase and/or restore native plant vigor, cover, and species richness in rangeland habitats	• Revegetate habitats with a diverse community of native species that are collectively adapted to the full range of potential future climatic conditions. • Restore habitats using seed sources that include genotypes suited to future conditions. • Promote early-season native species. • Develop funding and native seed sources for post-fire restoration of burned areas where grass and forb communities are not naturally regenerating. • Use prescribed and natural fires to actively promote native species and maintain plant cover, annual yield, and native species diversity. • Use low-intensity grazing or mowing to increase species diversity in grasslands. • Maintain adequate shrub cover, vigor, and species richness, and avoid bare ground; create different age classes and compositions of shrubfields. • Use snow fencing to increase snow drift accumulation and soil moisture in montane habitats.
	Maintain and restore natural rangeland habitat to ensure pollination	• Revegetate rangelands with a diverse mix of native species, including those with drought-tolerant genotypes, to support native pollinators. • Encourage native pollinators; provide other habitats for pollinators (nesting/feeding/brooding cover). • Restore and enhance habitat using tools such as grazing, fire, herbicide application, and re-seeding. • Educate agency staff and the public about the benefits of native pollinators, potential threats, and existing/needed regulatory protections. • Implement long-term monitoring of pollinators.

Table 8. Adaptation strategies and actions for rangeland vegetation.—Continued

Adaptation strategies		Adaptation actions
Resilience	Manage prescribed and natural fire to reduce the negative impact of changes in fire frequency and severity in rangeland habitats	• Design burn prescriptions that consider soil moisture requirements. • Implement strategically located non-burn fuel reduction techniques to reduce the risk of severe wildfire. • Use low- to moderate-intensity grazing to reduce fuel loads and lower fire risk. • Implement Burned Area Emergency Response (BAER) actions.
Resilience	Increase collaborations with agencies, NGOs, and private landowners	• Communicate the implications of climate change on rangeland quality and/or availability and grazing management practices, as well as associated uncertainty, with ranchers and other stakeholders. • Provide information to landowners and managers about the projected impacts of and responses to climate change and disturbances on rangelands, including the effects of repeated burns, weed identification and reporting, and site potential when determining appropriate vegetation.
Resilience	Identify and protect priority rangeland habitats (for example, high-quality rangelands)	• Encourage private landowners to designate conservation easements. • Identify and maintain public management of ecologically significant remnant plant communities (for example, rough fescue, Palouse prairie)
Realignment	Revisit and revise goals and priorities in response to changing conditions	• Develop criteria to help determine whether to resist or allow forest encroachment into rangeland habitats. • Develop criteria to prioritize intact and/or high-quality rangeland habitat sites and redirect resources to these sites as needed. • Create and implement a management plan for rangelands based on thresholds/triggers for activities such as thinning, prescribed burns, and revegetation. • Facilitate transition of endemic or rare species to future climatically suitable areas.
Realignment	Use research and assessment to increase knowledge about current conditions and projected changes	• Develop and apply models that include consideration of climate change when projecting the location and extent of invasive species establishment and spread. • Evaluate and include the role of native ungulate grazing and competition in grassland management plans. • Monitor post-fire effects beyond the scope of fire suppression and BAER and implement appropriate actions. • Locate and map important grassland soil types (for example, molisols). • Determine whether individual sites are fire- or snow-maintained. • Map sites at risk of drought and monitor vegetation and water availability. • Improve understanding of the relationship between climate change and rangeland ecology. • Identify areas where the interaction between existing stressors and climate change will be most pronounced.
No action	Monitor site and/or resource conditions	• Monitor climate variables and impacts. • Monitor fire activity in area to assess level of threat. • Monitor resource conditions and trends and incorporate that data into decision-making processes.
No action	Implement preventative strategies in areas likely to remain climatically suitable	• Employ preventative measures to reduce the spread and introduction of invasive species, insect pests, and disease. • Prevent and/or limit the impacts of non-climate stressors (for example, grazing, recreation, land use conversion).

The CAIT represents an evolution in the development of climate adaptation tools that help resource managers incorporate climate vulnerability and adaptation into plans and projects. Calls for the need to incorporate climate change in resource management (for example, summarized in Glick and others, 2011) were answered by the Climate Project Screening Tool for the USFS (Morelli and other, 2011). This tool asks users to consider broad-scale climate trends and answer specific questions to generate discussion about whether to proceed with a specific project. Nelson and others (2016) adopted the Critical Question approach and applied it to fish conservation, aided by the availability of fine-scale water temperature data from the NorWEST project (Isaak and others, 2015). We expanded the Nelson and others (2016) approach to additional resources by providing guidance for obtaining fine-scale information regarding derived climate parameters to help determine whether projected climate conditions allow for persistence of resources. Conclusions regarding resource viability are linked to suggested adaptation strategies and actions.

The particular strength of the CAIT is the use of downscaled climate data to enable regional natural resource climate change vulnerability assessment and adaptation planning efforts to be used in management plans and projects for smaller areas (for example, individual forest units). Often, the scale of climate conditions used in regional efforts is spatially coarse and limited to temperature and precipitation and other GCM outputs rather than more informative derived parameters (for example, snow depth, climatic water deficit). Moreover, management recommendations in adaptation plans usually lack specificity for when and where the recommendations may be most appropriate. The CAIT helps to identify useful climate parameters by asking managers to specify conditions that support where and when the resource can persist. These conditions are usually described by derivatives of temperature and precipitation and are affected by site characteristics such as elevation or soil properties. Maps of climate conditions and site characteristics at the finest available spatial scale are combined with local knowledge of thresholds or requirements to determine where and when a resource can occur. Together with other information about the site and/or resource, such as current condition and value, the most suitable management approach (specifically, resistance, resilience, transition, realignment, or no action) can be selected, which in turn directs the user to a limited list of potential adaptation strategies and actions.

A unique feature of the CAIT compared with other decision frameworks is the reliance on “value” questions. Based on answers to a set of questions, managers are asked to determine whether sites have low, medium, or high value. The assessment of site value is subjective and relative to other resources in the area. Consequently, managers must think about other locations in context with the site under consideration. Adding a “value” consideration to the framework results in more strategic decisions, including cost-effective selection of projects for investment.

The framework presented here is also useful for clearly documenting the reasoning behind selection of a given adaptation strategy or action. Transparent documentation provides accountability for agency mandates to consider climate change in management decisions (for example, USFS Climate Change Performance Scorecard, U.S. Forest Service, 2018) as well as an interpretable record of a decision’s rationale that will be available to future managers who may need to continue evaluating and responding to the consequences. Moreover, the CAIT provides information that supports planning and decision-making in environmental compliance documents (for example, National Environmental Policy Act) as well as explaining and justifying decisions to resource managers from other disciplines, other agencies, and the public.

The reliance of the CAIT on collaborative discussion provides an opportunity for managers to comprehensively consider how climate change will affect a given resource. For example, anticipating changes in wildlife distribution, demographics, and technology, in addition to climate changes and impacts, will help inform predictions about the availability and demand for recreational opportunities. The broad discussion of all relevant factors can help managers incorporate sufficient flexibility into management plans such that future managers can achieve management goals. Moreover, the discussion format facilitates the mining of institutional knowledge regarding management decisions that were useful in previous situations when climate-related events or conditions posed challenges to effective management.

Creating flexibility is an especially important aspect of forest plan revisions in the era of climate change. Forest plans are long-lived documents expected to last 15 years, but they often guide forest management for much longer than that. They are essentially a contract creating transparency between a national forest and the public. Through a lengthy public process, the plan details agreed-upon management desired conditions and the objectives to achieve them. Because a plan is legally binding, it must be written so that managers have the necessary tools to achieve goals stated in the plan even when a changing climate destabilizes historic conditions to create a “new normal.”

The CAIT described here was tested and applied by managers of recreation opportunities and rangeland vegetation resources. It matches the framework created by Nelson and others (2016) for fisheries managers. Prominent natural resource categories yet to be covered include forested vegetation, hydrology, and wildlife. Resource managers of these remaining topics can use this CAIT as well as the framework created by Nelson and others (2016) as a model to create their own Critical Questions and adaptation strategy and action tables. The first step is to establish planning considerations, which determine the categories of Critical Questions. For forested vegetation, these might include future habitat suitability, value, and current condition, in parallel with those used for rangeland habitats. Planning considerations for wildlife might be modeled on those used for fish (specifically, future habitat suitability, connectivity, and threats from non-native species or competitors). After Critical Questions are developed to help rate each situation by level within the planning considerations (for example, low, medium, or high future habitat suitability), a matrix of management approaches (resilience, resistance, transition, realignment, no action) can be developed. If the same planning considerations are used as for recreation and rangeland habitats, the same management approaches table will be appropriate. Adaptation strategies and actions developed during regional climate vulnerability and adaptation efforts can then be grouped by management approach to complete the tool.

Incorporating climate vulnerability and adaptation into resource management decisions is vital; however, it is only one of many dimensions that must be considered. In particular, the CAIT does not consider regulatory aspects and only superficially touches on social and economic aspects. Nevertheless, it can be incorporated into the overall decision process to ensure that climate change is effectively addressed.

Glossary

Adaptation Natural or human adjustments in a resource in response to changing climate conditions. Adaptation strategies and actions attempt to reduce the negative effects of and/or take advantage of opportunities presented by climate change.

Adaptation strategies Broad or general adaptation responses that consider ecological conditions and overarching management goals (Swanston and others, 2016).

Adaptation actions Specific adaptation responses that consider site and/or situational conditions and management objectives.

Climate impacts assessments The evaluation of the direct and indirect consequences of climate change on a resource.

Vulnerability The degree to which a resource is susceptible to, or unable to cope with, adverse effects of climate change. Vulnerability is a function of the sensitivity of a resource to climate changes, its exposure to those changes, and its capacity to adapt to those changes (International Panel on Climate Change, 2007).

Vulnerability assessments A tool for evaluating what resources are at risk due to climate change and why they are vulnerable (Glick and others, 2011).

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Appendix 1. Participants in Climate Adaptation Integration Tool (CAIT) Development

Table 1.1. Resource managers, scientists, conservation practitioners, and other contributors to this project.

[**Abbreviations:** FS, U.S. Forest Service; GIS, geographic information systems; ID, Idaho; MT, Montana; NF, National Forest; R1, Region 1]

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)
Shawn Heinert	FS, R1 Watershed, Wildlife, Fisheries & Rare Plants	Advisor; tested tools
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
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, Forest Plan Revision, Flathead NF	Advisor
Jordan Larson	FS, R1 Regional Economist	Tested tools (ID)
Tim Love	FS, District Ranger, Lolo NF	Advisor
Mary Manning	FS, R1 Vegetation Ecologist	Advisor; tested tools
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, Nez Perce-Clearwater NF	Tested tools (ID)
Katie Renwick	FS, R1 Assistant Planner	Advisor; tested tools
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

Appendix 2. A Primer on Selecting Downscaled Climate Projections

Envisioning how future environmental conditions might affect management of natural resources depends on having forecasts of what those conditions might be. Projections of future climate are based on general circulation models, also called "global climate models" (GCMs; table 2.1). Because they integrate the entire global climate system, limits of computing capacity force them to have spatial resolutions that are too coarse to adequately inform most management decisions. This appendix provides a brief primer on GCMs, how they are used, why they differ, how to choose among them, how they are down-scaled to describe finer spatial resolutions, and the availability of derived variables (for example, snow water equivalent, soil moisture deficit) that may be more informative than temperature and precipitation for resource managers.

Table 2.1 Abbreviated model name, source, and brief description of 56 global climate models.

Model	Source and description
ACCESS1.0	Australian Community Climate and Earth System Simulator 1.0
ACCESS1.3	Australian Community Climate and Earth System Simulator 1.3
BCC-CSM1.1	Beijing Climate Center - Climate System Model BCC-CSM1.1(m)
BCC-CSM1.1(m)	Beijing Climate Center - Climate System Model (moderate resolution)
BNU-ESM	Beijing Normal University- Earth System Model
CCSM4	NCAR Community Climate System Model
CESM1(BGC)	NCAR Community Earth System Model (biogeochemistry)
CESM1(CAM5)	NCAR Community Earth System Model (Community Atmosphere Model 5)
CESM1(FASTCHEM)	NCAR Community Earth System Model (Component CAM-CHEM)
CESM1(WACCM)	NCAR Community Earth System Model (Whole Atmosphere Community Climate Model)
CFSv2-2011	NCEP (NOAA National Cnt for Environmental Prediction) Climate Forecast System
CMCC-CESM	Centro Euro-Mediterraneo per I Cambiamenti Climatici -Climate Model with resolved Stratosphere
CMCC-CM	Centro Euro-Mediterraneo per I Cambiamenti Climatici -Coupled Model
CMCC-CMS	Centro Euro-Mediterraneo per I Cambiamenti Climatici -CMS
CNRM-CM5	Centre National de Recherches Météorologiques - Climate Model
CNRM-CM5-2	Centre National de Recherches Météorologiques - Climate Model2
CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organisation - Mk3 stage of model code
CSIRO-Mk3L-1-2	Commonwealth Scientific and Industrial Research Organisation-Mk3 lagrangian additions
CanAM4	Canadian Centre for Climate Modelling and Analysis 4th generation atmospheric model
CanCM4	Canadian Centre for Climate Modelling and Analysis 4th generation coupled model
CanESM2	Canadian Centre for Climate Modelling and Analysis 2nd generation earth system model
EC-EARTH	European community Earth-System Model (couples 6 models using Oasis-3 MCT coupler)
FGOALS-g2	Flexible Global Ocean-Atmosphere-Land System Model -Grid Point, version 2 Sate Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences (Sate)
FGOALS-gl	Flexible Global Ocean-Atmosphere-Land System Model -grid/low res (Sate)
FGOALS-s2	Flexible Global Ocean-Atmosphere-Land System Model -coupled (Sate)
GEOS-5	Goddard Earth Observing System v5 Atmosphere-Ocean-Global-Climate-Model
GFDL-CM2.1	Geophysical Fluid Dynamics Laboratory climate model 200 kilometer grid cell (NOAA)
GFDL-CM3	Geophysical Fluid Dynamics Laboratory -climate model to focus on aerosol chemistry
GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory earth system model -ocean model uses vertical pressure
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory earth system model -ocean model uses isopycnal (density)
GISS-E2-H	Goddard Institute for Space Studies (NASA) atmosphere coupled to hycom ocean model
GISS-E2-H-CC	Goddard Institute for Space Studies (NASA) same as E2-H adding interactive carbon cycle
GISS-E2-R	Goddard Institute for Space Studies (NASA) atmosphere coupled to rusell ocean model
GISS-E2-R-CC	Goddard Institute for Space Studies (NASA) same as -R adding interactive carbon cycle
HadCM3	Hadley Center (Met Office) Climate Model (good for decadal)
HadGEM2-A	Hadley Center (Met Office) Earth System Model atmosphere
HadGEM2-AO	Hadley Center (Met Office) Earth System Model coupled atmosphere-ocean
HadGEM2-CC	Hadley Center (Met Office) Earth System Model coupled carbon
HadGEM2-ES	Hadley Center (Met Office) Earth System Model
INM-CM4	Institute of Numerical Mathematics of the Russian Academy of Sciences- climate model v4
IPSL-CM5A-LR	Institut Pierre Simon Laplace (Paris) Earth System Model, 5th IPCC report low resolution
IPSL-CM5A-MR	Institut Pierre Simon Laplace (Paris) Earth System Model, 5th IPCC report medium resolution
IPSL-CM5B-LR	Institut Pierre Simon Laplace (Paris) Earth System Model B, 5th IPCC report low resolution
MIROC-ESM	Japanese Institutes (AORI, NIES, JAMSTEC) Earth System Model

Table 2.1 Abbreviated model name, source, and brief description of 56 global climate models.—Continued

Model	Source and description
MIROC-ESM-CHEM	Japanese Institutes (AORI, NIES, JAMSTEC) Earth System Model (aerosol Chemistry)
MIROC4h	Japanese Institutes (AORI, NIES, JAMSTEC) version 4h
MIROC5	Japanese Institutes (AORI, NIES, JAMSTEC) version 5
MPI-ESM-LR	MPI-ESM - Max-Planck-Institut für Meteorologie- Earth System Model -low resolution
MPI-ESM-MR	MPI-ESM - Max-Planck-Institut für Meteorologie- Earth System Model -medium resolution
MPI-ESM-P	MPI-ESM - Max-Planck-Institut für Meteorologie- Earth System Model -paleo experiments
MRI-AGCM3-2H	Meteorological Research Institute - Atmospheric General Circulation Model - 2H
MRI-AGCM3-2S	Meteorological Research Institute - Atmospheric General Circulation Model - 2S
MRI-CGCM3	Meteorological Research Institute - Atmosphere Ocean Coupled General Circulation Model - 2S
MRI-ESM1	Meteorological Research Institute - Earth System Model - version 1
NorESM1-M	Norwegian Earth System Model -medium resolution
NorESM1-ME	Norwegian Earth System Model -emission driven

Characteristics and Uses of Global Climate Models

Global climate model (GCM) forecasts are often aggregated into monthly averages to project conditions decades and centuries into the future using the same equations as weather models. They project future conditions by including interactions that are not included in day-to-day regional weather models such as change in global ice cover extent or solar radiation. Extensive improvements have been made since the first GCM in 1955, including much better meteorological and oceanic data, better understanding of weather dynamics, more realistic coupling of ocean, atmosphere, and biological system physics, and increased spatial resolution of model grid cells. Most GCMs currently have a grid cell width of about 70 mi (110 kilometers [km]) but some are as fine as 20 mi (30 km) and as coarse as 350 mi (560 km). Each GCM grid cell runs coded calculations for each timestep passing the results in the next timestep to adjacent grid cells. The timestep interval is based on how fast the atmospheric or oceanic processes occur within the cell. The finer the spatial resolution the shorter the timestep must be. To be realistic, cells 70 mi wide must have timesteps no longer than 8 minutes. As computational power increases so does the capacity to add equations to represent physical processes and increase the spatial resolution of the GCM. For an account of the development of the science in GCM models, see Weart and American Institute of Physics (2018).

The GCMs do what a model is intended to do: reduce the complexity of a system so that the system can be understood and system outcomes under different conditions can be predicted. Each model reduces complexity differently. Global climate dynamics are so massively complex that none of the models can attempt to provide a full representation of the system, but each can give valuable insights. Each model tends to optimize for specific dynamics. The international community has invested in more than 50 model configurations to conduct simulations under multiple greenhouse gas emissions scenarios to produce hundreds of climate projections. Comparisons among models using an ensemble of agreed-upon emissions scenarios (box 4), and model-year start points are conducted under the Climate Model Intercomparison Project (CMIP). The goals of CMIP are to comprehensively examine differences among model dynamics and model results and to better understand the underlying assumptions embedded in each model's code. The results of climate projections are detailed in Assessment Reports (AR) that use CMIP results. The ARs are a product of the Intergovernmental Panel on Climate Change (IPCC), an international group of thousands of scientists who produce reports detailing the latest scientific consensus on climate dynamics, climate projections, and potential impacts. In our project, we have used models from AR4 and AR5 that use results from CMIP3 and CMIP5, respectively. The AR6 Report, due in 2020, will be using CMIP6 model outputs that are also being used to run 23 experiments each designed to deepen our understanding of specific climate relationships: carbon dioxide removal, volcanic eruption, glacial ice melt, sea ice, geoengineering, and others (World Climate Change Program, 2020).

A graphical comparison of model results for global annual temperature from 29 GCMs used in CMIP5 show the consequences of different representation of atmospheric processes among models (fig. 2.1). Model results do not diverge in the short-term (that is, to 2025) but continue to diverge substantially in the long term through 2100.

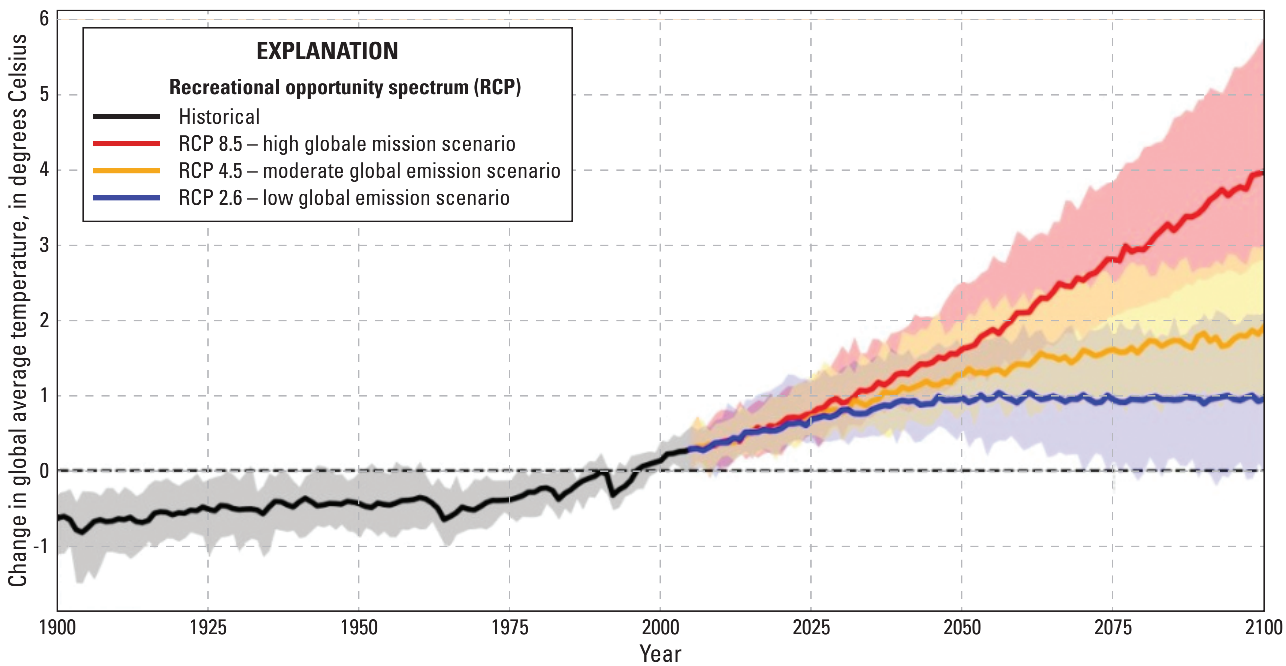

Figure 2.1. Graph of global annual temperature as simulated for past years and projected for future years by 29 Global Climate Models used in Climate Model Intercomparison Project 5. [Solid black lines indicate data and solid colored lines indicate model averages; grey and colored areas indicate the range of model results. From Government of Canada (2019)]

Down-Scaling

The climate change research community recognizes that grid cell resolutions of 20–350 mi (30–560 km) do not provide sufficient detail for many planning purposes and that planners cannot wait for the next generation of higher resolution GCMs. Consequently, higher resolution versions of GCM results are being provided using a variety of methods ranging from simple schemes that divide each large GCM grid cells into smaller area grid cells with the same values to much more complicated schemes that run GCM results through regional climate models. The latter method, called dynamic downscaling, requires high-powered computations and more input data than are usually available. An intermediate approach uses statistical methods to compare GCM model output with historical climate data at a finer resolution than the GCM. Projections of future climate are then adjusted by the amount needed to describe the finer scale as determined using historical data.

The Climate Impacts Group, the source of climate projections in Halofsky and others (2018), used the bias-correction and spatial disaggregation statistical approach to downscale GCMs at 60–180 mi (100–300 km) grid cell resolution to a 7.5 mi (16 km) grid cell spatial resolution (Littell and others, 2011; Rupp and others, 2013). These downscaled results were used to generate sub-regional assessments that more realistically differentiate the western, central, and eastern Rockies from the Greater Yellowstone Area and the grasslands of Montana and the Dakotas. Even at this scale, the projections proved too general for site-specific application. Complex terrain and local weather patterns create conditions that are not discernable at coarse scales. To address these concerns, we sought projections at higher spatial resolution and adopted the 800 m resolution (Thrasher and others, 2013) dataset available for the conterminous U.S. and applied the selective region-specific parameter extraction approach to be described below.

Choosing Among Models

Selecting a minimum number of models to represent the wide range of projected climate futures is often based on standard climate variables such as temperature and precipitation. Other relevant criteria are often added, such as whether the model has been selected by other partner groups or whether it captures important regional dynamics such as seasonal cycles. Downscaled GCM model output often highlights the striking regional differences that emerge among models. Model output differs especially in topographically complex settings due to the various ways GCMs couple different earth system components: atmosphere, ocean, and land, and the different methods for incorporating interactions among heat, moisture, wind, evaporation, and other physical dynamics. Models will change as surprising discoveries are integrated such as the increased melt of Greenland ice sheets due to lubrication between the ice and underlying ground or increased outgassing of methane from wetlands and peat. A challenge to your model selection process will be incorporating the new information that continues to be produced at an accelerated rate.

The next four steps illustrate an approach for selecting a subset of climate models by first deciding which are best for the resource-relevant climate variables. We illustrate the steps below using only the CMIP5 output.

1. Decide on the climate parameters that best represent the change that will impact the resource in question. The most frequently chosen parameters are precipitation and temperature. However, many other parameters are available from CMIP5 models that may link more closely to the extreme conditions that put the resource at risk, including maximum and minimum temperature, precipitation, runoff, snow water equivalent, soil moisture storage, and evaporative deficit. These can all be viewed on the National Climate Change Viewer (U.S. Geological Survey, 2019). We determined that snow water equivalent was most relevant to the changing availability of winter recreation opportunities, while soil moisture parameters were most useful for determining changes in distribution of rangeland vegetation. The range of model projections for multiple relevant parameters can be visualized as illustrated in figure 4 (main text). Relationships among models will depend on the parameters graphed. The CMIP6 process will provide even more parameters.

2. Decide on the level of downscaling needed based on the spatial extent of the resource. The National Climate Change Viewer offers summary statistics at the national, state, county, and watershed scale. Depending on the parameters, the change in scale may substantially change the summary statistics (fig. 2.2).

3. Identify other criteria beyond the GCM climate parameter projections that are relevant to the decision-making process. In some cases, comparative analyses of the GCMs conducted by the scientific community to understand the differences among the global models can augment and guide the selection of downscaled versions of the GCMs (fig. 2.3). Other criteria might include the use of particular models by partners or repeating the use of models from previous projects when comparison is desired.

4. Assemble statistics on the climate parameters of interest and other criteria relevant for answering CAIT Step 2 Critical Questions (figure 2.4). Values describing model projections are available from the “data table” tab on the National Climate Change Viewer (U.S. Geological Survey, 2019).

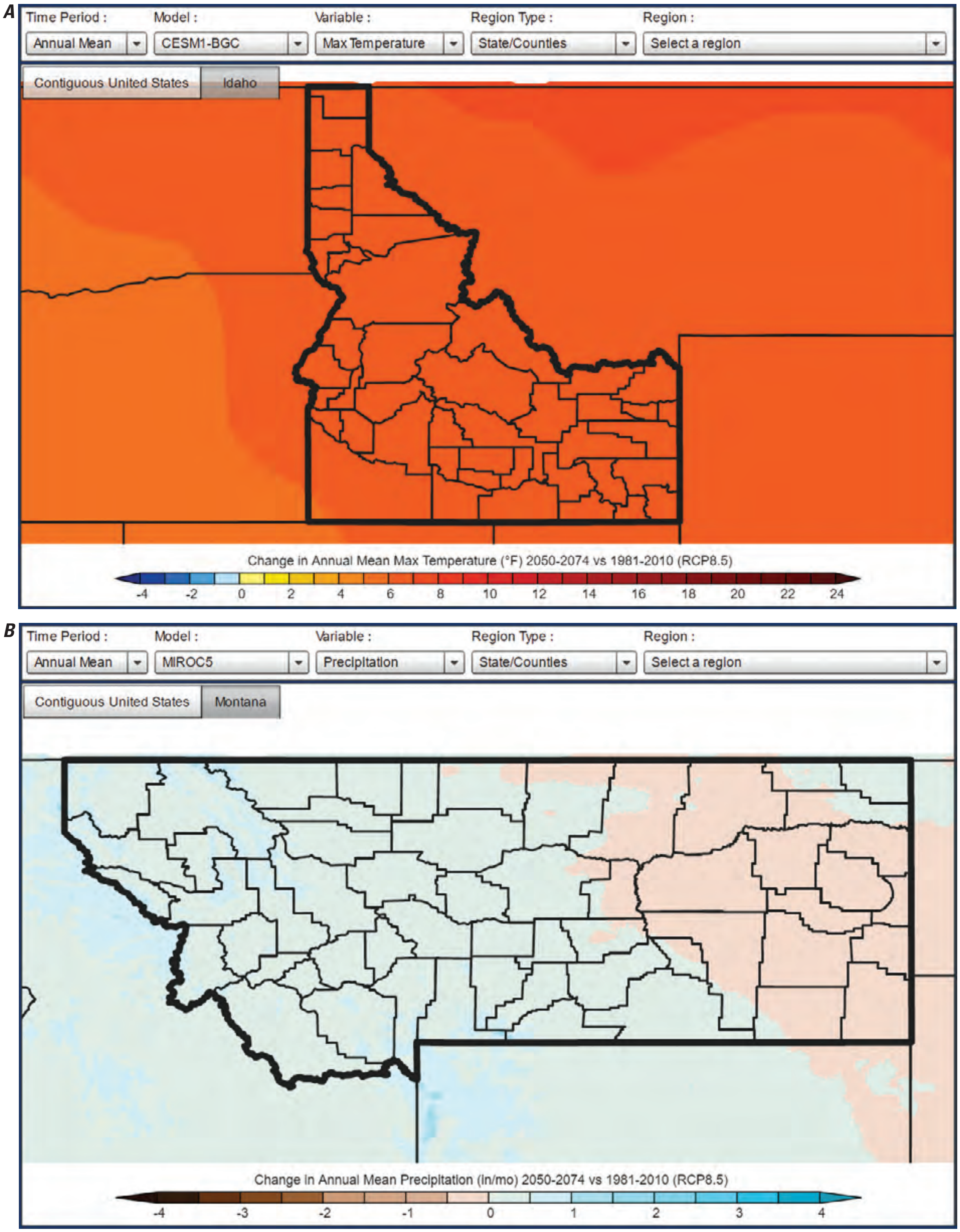

Figure 2.2. Screenshots of (A) the map of the mean maximum temperature projections from the CESM1-BGC model shows little difference across Idaho, whereas (B) the map of precipitation projected by the HadGEM2-ES model shows significant differences among the counties of Montana (U.S. Geological Survey, 2019).

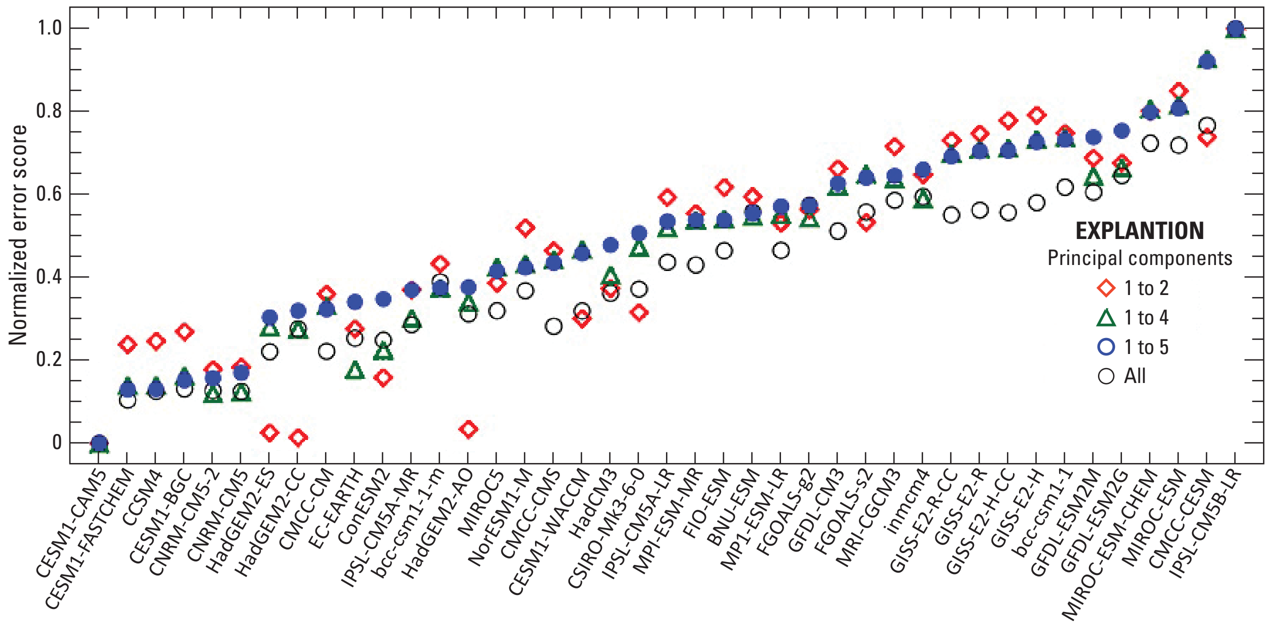

Figure 2.3. This graph from Rupp and others (2013) arrays the results from statistical analyses that explore the fidelity to regional climate patterns of each of the 35 Coupled Model Intercomparison Project 5 (CMIP5) models. [Scores are based on results from five principal component axes that describe how well each model simulated seasonal and regional 20th century climate patterns for the Pacific Northwest. A larger error (y-axis) indicates poorer simulation of regional patterns.]

Used by Partnering Stakeholder Criteria B	Rupp et al. (2013) score Criteria A	Montana: Change in Maximum Temperature and Change in Precipitation																		
		PPT (mm)		-2.5 - 0		0 - 1		1 - 1.5		1.5 - 2		2 - 3		3 - 4		4 -5		5 - 7		7 -11
		T (oC)	+ 2-3		+ 3-4		+ 4-5		+ 5-6		+ 6-7		+ 7-8		+ 8-9		+ 9-10		+ 10-11	
1	3	CCSM4				1							1							
	4	CESM1-BGC											1	1						
	6	CNRM-CM5										1							1	
1	7	HadGEM2-ES					1											1		
	8	HadGEM2-CC				1			1											
	9	CMCC-CM			1			1												
1	11	CanESM2			1					1										
	12	IPSL-CM5A-MR			1							1								
	13	bcc-csm1-1-m						1					1							
1	14	HadGEM2-AO		1							1									
1	15	MIROC5	1																	1
	16	NorESM1-M								1	1									
	20	CSIRO-Mk3-6-0				1			1											
	21	IPSL-CM5A-LR													1			1		
	22	MPI-ESM-MR						1	1											
	23	FIO-ESM		1									1							
	24	BNU-ESM										1					1			
	25	MPI-ESM-LR									1									1
	26	FGOALS-g2											1	1						
	27	GFDL-CM3					1			1										
	29	MRI-CGCM3				1							1							
	30	inmcm4											1			1				
1	34	GISS-E2-R						1			1									
	37	bcc-csm1-1					1							1						
1	38	GFDL-ESM2M						1	1											
	39	GFDL-ESM2G							1											1
	40	MIROC-ESM-CHEM			1					1										
	41	MIROC-ESM															1	1		
	42	IPSL-CM5B-LR					1									1				
	99	ACCESS1-0										1							1	
		Total Models in Temp Bin	1		4		4		5		4		7		1		2		2	30

Figure 2.4. Projected average change in maximum temperature (T) and precipitation (PPT) from 1981–2010 to 2050–74 for Montana from 30 CMIP5 models run over RCP 8.5 conditions. [The amount of change is arrayed horizontally in bins. Each model is represented by two bins, one for T (color-coded red) and one for PPT (color-coded in blue); models at the extremes of the ranges are circled These models are also graphically arrayed in figure 2.5. The circled models in this figure can be found at the outer edges of the cluster (fig. 2.5) in each of the four quadrants. Additional selection criteria are marked for each model in columns 1 and 2 (see fig. 2.3 for criteria details).

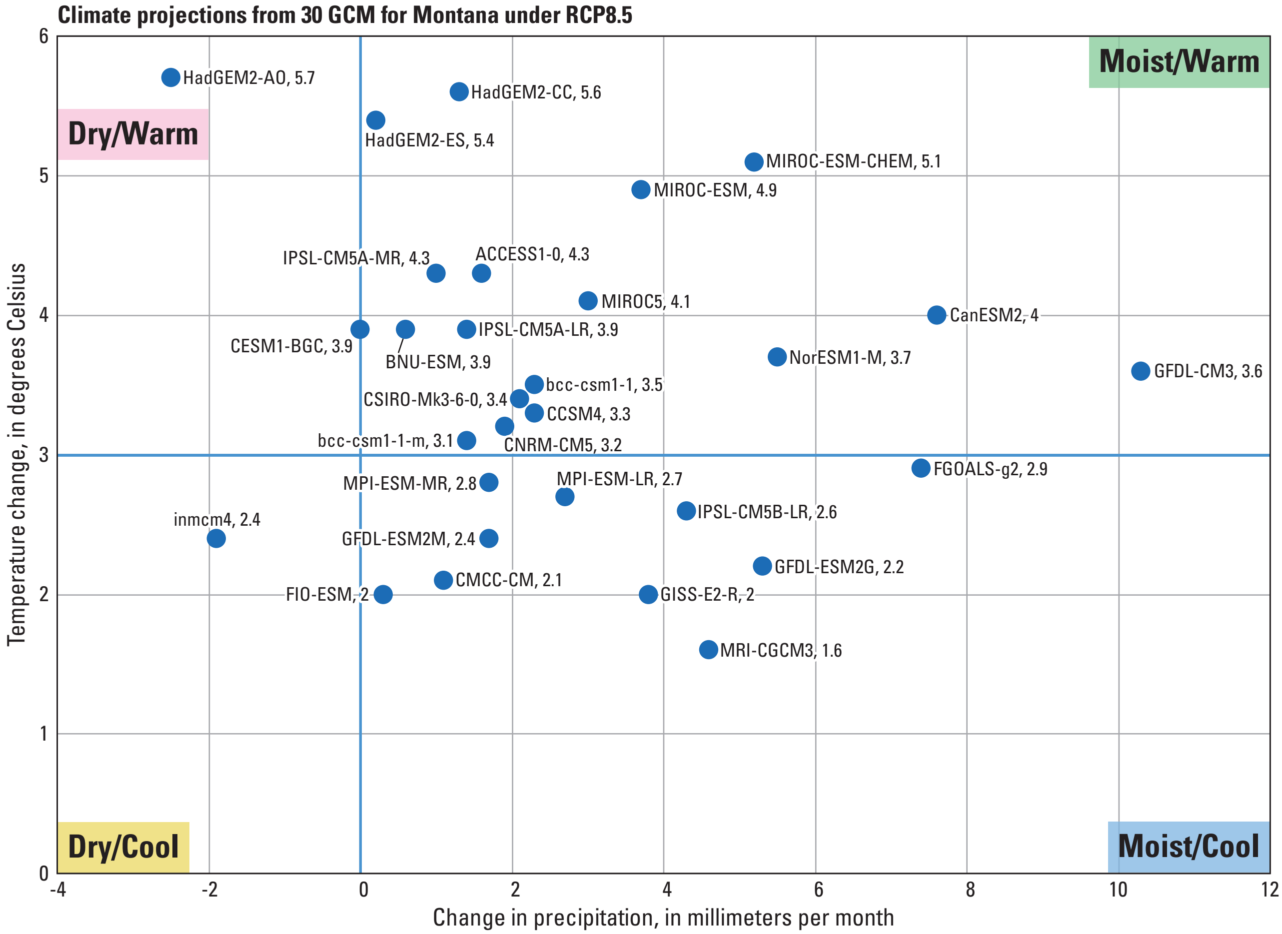

Figure 2.5. Projected average change in temperature (T) and precipitation (PPT) from 1981–2010 to 2050–74 for Montana from 30 CMIP5 models run under RCP 8.5 conditions superimposed with 4-square quadrant subdivisions (see fig. 4).

Appendix 3. Selected Sources of Climate Data

Table 3.1. Selected sources of climate data.

[All websites were accessed June 12, 2019. **Abbreviations:** CMIP, Climate Model Intercomparison Project; GCM, global circulation model; NA, not applicable; SWE, snow water equivalent]

Name of source	Description of available information	Climate variables or other details	Website
Climate Impacts Group	Portal for downloading daily and monthly downscaled (coarse ~55 kilometers; fine ~800 meters) hydroclimate projections for various spatial extents throughout Pacific Northwest	Runoff, snow water equivalent, April 1st snowpack ratio[1], soil moisture, potential evapotranspiration and others depending on spatial extent	https://cig.uw.edu/resources/data/cig-datasets/
The Nature Conservancy Climate Wizard	Future Climate Viewer (Global) and dataset downloader	Global views of GCMs	https://climatechange.lta.org/tnc-climate-wizard/
National Climate Change Viewer	Future Climate Viewer (United States) and dataset downloader	Runoff, snow water equivalent, soil storage, evaporative deficit	https://www2.usgs.gov/landresources/lcs//nccv.asp
AdaptWest portal for Western North American	Extensive and growing collection of spatial data for conservation planning	Location specific, wide range of climate variables	https://adaptwest.databasin.org/
Andreas Hamann's website	Current and projected climate and climate velocity data for North America, South America, and software download	Excellent source of analytic results in graphic form to compare models based on extremes and validation statistics.	http://www.ualberta.ca/~ahamann/data/climatewna.html
World Climate Research Programme (WCRP)	Background on the multiple CMIPs and future efforts for improving global climate projections	Links to CMIP iterations	https://www.wcrp-climate.org/modelling-wgcm-mip-catalogue/modelling-wgcm-cmip6-endorsed-mips
Northern Rockies Adaptation Project (NRAP)	Extensive regional datasets and reports	Links to Climate Impacts Group (see first item in this list)	http://adaptationpartners.org/nrap/docs/NRAP_climate_projections.pdf).
American Institute of Physics	Historical description of global circulation models with general descriptions of the scientific advance accomplished by each generation of models	NA	https://history.aip.org/climate/GCM.htm

[1]April 1 snowpack ratio is equal to the total SWE accumulative by April 1 for that year divided by the 30-year average annual SWE

Appendix 4. Ameliorates Vulnerability Table for Recreation

Table 4.1. Potential adaptation strategies and actions linked with the climate and non-climate stressors and disturbance regimes they are thought to reduce or minimize.

Key:
↑, increasing
↓, decreasing
● Evidence based
<u>●</u> Evidenced based, indirect
○ Expert opinion
<u>○</u> Expert opinion, indirect

Adaptation strategies	Adaptation actions	↑Air temperature; ↑extreme heat	Changes in precipitation	↑Drought	↓Low flows/water levels	↓Snowpack; earlier melt/runoff	↑Water temperature	↑High peak flow/flooding	Altered wildfire regime	Pollution and poisons	↑Water demand—downstream users	Action increases general resilience	Citations
		Climate stressors						Disturbances		Non-climate stressors		Other	
Adaptation strategies and actions that are based on enhancing resistance, promoting resilience, or facilitating transition													
Manage recreation sites to mitigate risks to public safety and infrastructure; continue to provide recreation opportunities	Modify existing infrastructure to better withstand future climate conditions	●	●	○	○	○	●	●	○	●		○	Bass and Baskaran (2003); Bratelbo and Booth (2003); DeNardo and others (2005); Stack and others (2010)
	Adjust infrastructure maintenance schedule as conditions change	○	●	○	○	○	○		○			○	Stafford (2011); Coe (2006)
	Relocate at-risk infrastructure (such as move from lower elevations)	○					○	○			○		
	Develop new recreation sites designed for flexibility of use, or create new opportunities at existing sites	●	●	○	○	●	○	○	○	○	○	○	Balbi and others (2013)
	Prioritize post-disturbance treatments (such as relocation, armoring)	○					○	○			○		
Increase management flexibility to respond to changing access demands and resource availability	Invest in infrastructure for new access needs and/or changes in access	●	●	○	○	●	○	○	○	○	○	○	Balbi and others (2013)
	Monitor recreation sites and set trigger points determining when a site should be closed or access restricted	○	○	○	○	○	○	○	○	○	○	○	
	Develop new access restrictions (changes to seasonal closures, permitting processes, or allowable uses)	○	○	○	○	○	○	○	○	○	○	○	
	Vary whitewater permit season to adapt to changes in peak flow and duration	○	○	○			○			○	○		
	Inform public about changing conditions (snowpack, lake levels, streamflow)	○	○	○	○	○	○	○	○		○	○	

Table 4.1. Potential adaptation strategies and actions linked with the climate and non-climate stressors and disturbance regimes they are thought to reduce or minimize.—Continued

Key:
↑, increasing
↓, decreasing
● Evidence based
●̲ Evidenced based, indirect
○ Expert opinion
○̲ Expert opinion, indirect

Adaptation strategies	Adaptation actions	Climate stressors						Disturbances		Non-climate stressors		Other	Citations
		↑Air temperature; ↑extreme heat	Changes in precipitation	↑Drought	↓Low flows/water levels	↓Snowpack; earlier melt/runoff	↑Water temperature	↑High peak flow/flooding	Altered wildfire regime	Pollution and poisons	↑Water demand—downstream users	Action increases general resilience	
Adaptation strategies and actions that are based on enhancing resistance, promoting resilience, or facilitating transition—Continued													
Provide sustainable recreation opportunities in response to changing supply and demand	Adjust capacity of recreation sites (enlarge campgrounds, install fences and gates, collect added fees)	○	○	○	○	○	○	○				●	Beunen and others, 2008
	Adjust the timing of actions (open/close dates, road/trail closures, food storage orders, special use permits) in response to changing conditions	○	○	○	○	○	○	○	○			○	
	Focus on activities that will remain feasible given projected changes; preserve existing opportunities (such as invest in snow-making)	○	○	○	○	○	○	○	○			○	
	Adopt new technology that may help disperse use, direct users, and provide facts about impacts of climate change	○	○	○	○	○	○	○	○			○	
	Limit expansion or pioneering of new recreation sites in riparian areas (restrict access, revegetate, add signage)	○	○	○	○	○	○				○	○	
Make necessary transitions to address shorter winter recreation seasons and changing use patterns	Develop options for diversifying snow-based recreations (such as helicopter or cat-skiing, higher-elevation runs)	●	●			●							Balbi and others 2013; Scott and others, 2006, 2008
	Increase safety education to warn the public of increased risk of avalanches and thin ice	●	●			●							Burkeljca, 2013; McCammon and Hageli, 2007; Espiner, 1999
	Maintain/improve current recreation infrastructure at sites that will remain viable under future climate conditions	●	●			●							Balbi and others, 2013
	Shift location of winter activities to maintain opportunities and/or mitigate safety risks (such as move ski trails)	○	○			○							

Table 4.1. Potential adaptation strategies and actions linked with the climate and non-climate stressors and disturbance regimes they are thought to reduce or minimize.—Continued

Key:
↑, increasing
↓, decreasing
● Evidence based
●̲ Evidenced based, indirect
○ Expert opinion
○̲ Expert opinion, indirect

Adaptation strategies	Adaptation actions	Climate stressors						Disturbances		Non-climate stressors		Other	Citations
		↑Air temperature; ↑extreme heat	Changes in precipitation	↑Drought	↓Low flows/water levels	↓Snowpack; earlier melt/runoff	↑Water temperature	↑High peak flow/flooding	Altered wildfire regime	Pollution and poisons	↑Water demand—downstream users	Action increases general resilience	
Adaptation strategies and actions that are based on enhancing resistance, promoting resilience, or facilitating transition—Continued													
Protect users from contaminated water/sediments	Cap/harden contaminated water areas	○	○	○	○	○		○		○	○		
	Provide other water-based recreation in areas with lower exposure risk	○	○	○	○	○		○		○	○		
	Provide transportation to safer and more develop water-based recreation sites in economically depressed areas	○	○	○	○	○		○		○	○		
Adaptation strategies and actions for cultural heritage sites													
Protect cultural and heritage sites and the use of cultural landscapes	Develop interpretation/education opportunities in cultural/heritage sites most vulnerable to climate change	○	○	○	○	○	○	○	●			○	Brown and others, 2008
	Develop a vegetation plan to mitigate natural hazards, promote resilience in cultural landscapes (such as encourage age/size class heterogeneity, manage invasive species, restore native plants)			○̲			○̲	○̲	○̲			○	
	Identify and prioritize management of cultural and heritage sites most vulnerable to climate change	●̲	●̲	●̲	●̲	●̲	●̲	●̲	●̲			○	Dupont and Van Eetvelde (2013)
	Increase use of surveys and monitoring at cultural and historic sites	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○	

Table 4.1. Potential adaptation strategies and actions linked with the climate and non-climate stressors and disturbance regimes they are thought to reduce or minimize.—Continued

Key:
↑, increasing
↓, decreasing
● Evidence based
●̲ Evidenced based, indirect
○ Expert opinion
○̲ Expert opinion, indirect

Adaptation strategies	Adaptation actions	↑Air temperature; ↑extreme heat	Changes in precipitation	↑Drought	↓Low flows/water levels	↓Snowpack; earlier melt/runoff	↑Water temperature	↑High peak flow/flooding	Altered wildfire regime	Pollution and poisons	↑Water demand—downstream users	Action increases general resilience	Citations
		Climate stressors						Disturbances		Non-climate stressors		Other	
Adaptation strategies and actions that are based on research, monitoring and assessment													
Use research, monitoring, and assessment to increase knowledge of current conditions and projected change	Assess infrastructure vulnerability to climate change, natural hazards; prioritize by seasonal use, viability, and required investment	○̲	●̲	○̲	○̲	○̲	○̲	●̲	○̲			○̲	Stack and others (2010)
	Assess changes in use patterns; identify expected shifts in supply and demand, demographics, and economic trends	●̲	●̲	●̲	●̲	●̲	●̲	●̲	●̲		○̲	○̲	Richardson and Loomis (2004); Richardson and others (2006); Balbi and others (2013); Pena and others (2015)
	Monitor climate variables critical to current and future site use	●̲	●̲	○̲	○̲	●̲	○̲	○̲	○̲			○	Yu and others (2009)
	Use monitoring results to decide to maintain current site use, develop other opportunities, or abandon the site			○̲	○̲		○	○	○	○̲	○̲	○̲	Yu and others (2009)
	Analyze costs, benefits of keeping current opportunities to decide whether prioritized uses should change	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲	
	Assess viability of snow-based recreation sites under future climate	○̲	○̲			○̲					○̲	○̲	Balbi and others (2013); Yu and others (2009)
	Monitor snow dates, event dates, and snowpack depth using SNOTEL data; incorporate data into decisions	●̲	●̲			●̲						○̲	Yu and others (2009)

Table 4.1. Potential adaptation strategies and actions linked with the climate and non-climate stressors and disturbance regimes they are thought to reduce or minimize.—Continued

Key:
↑, increasing
↓, decreasing
● Evidence based
●̲ Evidenced based, indirect
○ Expert opinion
○̲ Expert opinion, indirect

Adaptation strategies	Adaptation actions	↑Air temperature; ↑extreme heat	Changes in precipitation	↑Drought	↓Low flows/water levels	↓Snowpack; earlier melt/runoff	↑Water temperature	↑High peak flow/flooding	Altered wildfire regime	Pollution and poisons	↑Water demand—downstream users	Action increases general resilience	Citations
		Climate stressors						Disturbances		Non-climate stressors		Other	
Adaptation strategies and actions 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	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲			○̲	
	Develop management strategies to maintain/shift Recreation Opportunity Settings in areas likely to change under future climate conditions	●̲	●̲	●̲	●̲	●̲	●̲	●̲	●̲			○̲	Yu and others (2009)
	Coordinate with concessionaires, partners to identify possible recreation impacts from change in supply/demand	○̲	○̲	○̲	○̲	○̲	○̲	○̲			○̲	○̲	
	Collaborate with local Chambers of Commerce, other businesses and organizations that entice visitors to address changes in supply and demand												McAvoy and others (1991)
	Incorporate projected changes in concentrated winter use into forest management planning	○̲	○̲	○̲	○̲	○̲	○̲	○̲				○̲	
	Determine if changes in recreation are addressed in Master Development Plan; add these considerations if needed (add permitted uses, extend season)	○̲	○̲	○̲	○̲	○̲	○̲	○̲				○̲	

Appendix 5. Ameliorates Vulnerability Table for Rangeland Vegetation

Table 5.1. Potential adaptation strategies and actions linked with the climate and non-climate stressors and disturbance regimes they are thought to reduce or minimize.

Key:
- ↑, increasing
- ↓, decreasing
- ● Evidence based
- <u>●</u> Evidenced based, indirect
- ○ Expert opinion
- <u>○</u> Expert opinion, indirect

Adaptation strategies	Adaptation actions	Climate stressors: ↑Air temperature	Climate stressors: Changes in precipitation	Climate stressors: ↓Soil moisture	Climate stressors: ↑Drought	Climate stressors: ↓Snowpack; earlier melt/runoff	Disturbances: Altered wildfire regime	Disturbances: ↑Insect/disease outbreaks	Non-climate stressors: Invasive species	Non-climate stressors: Grazing/herbivory	Non-climate stressors: Land-use and recreation	Other: Action increases general resilience	Citations
Adaptation strategies and action that are based on enhancing resistance, promoting resilience, or facilitating transition													
Identify and protect priority rangeland vegetation habitats	Urge private land owners to designate conservation easements to conserve intact and/or high-quality rangeland habitats										●	●	Pocewicz and others (2011); Copeland and others (2013)
	Identify and maintain public management of ecologically significant remnant plant communities (rough fescue, Palouse prairie)											○	
Maintain and/or restore native plant vigor, cover, and species richness in grasslands and shrublands	Revegetate habitats with a diversity of native species collectively adapted to the range of potential future climatic conditions	●	●	○	●	○	○	○	●	○		●	Tilman and others (2006); Richardson and others (2010); Carter and Blair (2012)

Table 5.1. Potential adaptation strategies and actions linked with the climate and non-climate stressors and disturbance regimes they are thought to reduce or minimize.—Continued

Key:
↑, increasing
↓, decreasing
● Evidence based
●̲ Evidenced based, indirect
○ Expert opinion
○̲ Expert opinion, indirect

Adaptation strategies	Adaptation actions	Climate stressors: ↑Air temperature	Climate stressors: Changes in precipitation	Climate stressors: ↓Soil moisture	Climate stressors: ↑Drought	Climate stressors: ↓Snowpack; earlier melt/runoff	Disturbances: Altered wildfire regime	Disturbances: ↑Insect/disease outbreaks	Non-climate stressors: Invasive species	Non-climate stressors: Grazing/herbivory	Non-climate stressors: Land-use and recreation	Other: Action increases general resilience	Citations
Adaptation strategies and action that are based on enhancing resistance, promoting resilience, or facilitating transition—Continued													
Maintain and/or restore native plant vigor, cover, and species richness in grasslands and shrublands	Restore habitats with seed sources including genotypes suited to future climate conditions	○	○	○	○	○	○	○	○				Miller and others (2011); Auestad and others (2016); Butterfield and others (2016)
	Promote early-season native grassland-shrubland species								●	○			Whitson and Koch (1998); Bernstein and others (2014)
	Use prescribed and natural fires to actively promote native species and maintain plant cover, annual yield, and species diversity in grassland and shrubland habitats		○	●	○	○	○		●				Chambers and others (2007); Davies and others (2007); Bates and others (2009); Beck and others (2009); Hanna and Fulgham (2015); Kessler and others (2015)
	Use low-intensity grazing or mowing to increase species diversity in grasslands						●					●	Collins and others (1998); Tix and Charvat (2005); Davies and Bates (2014)
Provide habitat for native pollinators to maintain healthy grassland habitats	Revegetate grasslands and shrublands with diversity of native species, including drought-tolerant genotypes, to support pollinators		○	○	○	○		○					Pywell and other (2006)
	Reduce/eliminate herbicide and pesticide use to minimize impacts on non-target species (such as native plants, pollinators)											○	
	Educate agency staff and public about ecosystem benefits of native pollinators, potential threats, and existing/needed regulatory protections (such as Farm Bill)											○̲	

Table 5.1. Potential adaptation strategies and actions linked with the climate and non-climate stressors and disturbance regimes they are thought to reduce or minimize.—Continued

Key:
↑, increasing
↓, decreasing
● Evidence based
●̲ Evidenced based, indirect
○ Expert opinion
○̲ Expert opinion, indirect

Adaptation strategies	Adaptation actions	Climate stressors: ↑Air temperature	Climate stressors: Changes in precipitation	Climate stressors: ↓Soil moisture	Climate stressors: ↑Drought	Climate stressors: ↓Snowpack; earlier melt/runoff	Disturbances: Altered wildfire regime	Disturbances: ↑Insect/disease outbreaks	Non-climate stressors: Invasive species	Non-climate stressors: Grazing/herbivory	Non-climate stressors: Land-use and recreation	Other: Action increases general resilience	Citations
Adaptation strategies and action that are based on enhancing resistance, promoting resilience, or facilitating transition—Continued													
Implement flexible grazing management practices to maintain rangeland vegetation habitats and reduce the impacts of overgrazing	Implement rotational and/or low intensity grazing to reduce the impacts of overgrazing									●			Hemstrom and others (2002); Courtois and others (2004); Derner and Hart (2007); Briske and others (2008); Gornish and Ambrozio dos Santos (2016)
	Manage timing of grazing to promote native plant species (such as graze when undesirable species are most palatable; after native plants have produced seed)		○	○	○	○	○		○	○			
	Identify site-specific indicators of grazing impacts on sagebrush-grassland to trigger movement of animals to another site									○			
Prevent woodland expansion into rangeland	Apply prescribed burns and/or facilitate wildfire to prevent woodland expansion	●	●	●			●			●			Bachelet and others (2000); Beck and others (2009); Roundy and others (2014)
	Thin trees to reduce forest/woodland encroachment into rangeland vegetation habitats and conserve soil moisture	●	●	●	●		●						Baughman and others (2010); Young and others (2013); Roundy and others (2014); Creutzberg and others (2015)

Table 5.1. Potential adaptation strategies and actions linked with the climate and non-climate stressors and disturbance regimes they are thought to reduce or minimize.—Continued

Key:
↑, increasing
↓, decreasing
● Evidence based
●̲ Evidenced based, indirect
○ Expert opinion
○̲ Expert opinion, indirect

Adaptation strategies	Adaptation actions	Climate stressors: ↑Air temperature	Climate stressors: Changes in precipitation	Climate stressors: ↓Soil moisture	Climate stressors: ↑Drought	Climate stressors: ↓Snowpack; earlier melt/runoff	Disturbances: Altered wildfire regime	Disturbances: ↑Insect/disease outbreaks	Non-climate stressors: Invasive species	Non-climate stressors: Grazing/herbivory	Non-climate stressors: Land-use and recreation	Other: Action increases general resilience	Citations
Adaptation strategies and action that are based on enhancing resistance, promoting resilience, or facilitating transition—Continued													
Prevent invasive species establishment and spread	Create and apply early detection and rapid response protocols to control invasive species in priority rangeland habitats								○				
	Use integrated control strategies to manage invasive species	●	●						●				Calo and others (2012); Kessler and others (2015); Munson and others (2015)
	Maintain or enhance native plant cover and minimize bare ground to prevent establishment of invasive species						○		●	○			Booth and others (2003); Abella and others (2012); Chambers and others (2007)

Table 5.1. Potential adaptation strategies and actions linked with the climate and non-climate stressors and disturbance regimes they are thought to reduce or minimize.—Continued

Key:
↑, increasing
↓, decreasing
● Evidence based
●̲ Evidenced based, indirect
○ Expert opinion
○̲ Expert opinion, indirect

Adaptation strategies	Adaptation actions	Climate stressors: ↑Air temperature	Climate stressors: Changes in precipitation	Climate stressors: ↓Soil moisture	Climate stressors: ↑Drought	Climate stressors: ↓Snowpack; earlier melt/runoff	Disturbances: Altered wildfire regime	Disturbances: ↑Insect/disease outbreaks	Non-climate stressors: Invasive species	Non-climate stressors: Grazing/herbivory	Non-climate stressors: Land-use and recreation	Other: Action increases general resilience	Citations
Adaptation strategies and action that are based on enhancing resistance, promoting resilience, or facilitating transition—Continued													
Prevent invasive species establishment and spread (continued)	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						●		○				Davies and others (2009); Gornish and Ambrozio dos Santos (2016)
	Establish competitive vegetation barriers to protect rangelands from invasive species								●				Davies and others (2010b)
	Use fire management practices to reduce/minimize the risk of invasive species establishment and spread								●				DiTomaso and others (1999); Simmons and others (2007); Calo and others (2012); Taylor and others (2014); Kessler and others (2015)
	Use mowing treatments to slow the spread of invasive species						●		●				Simmons and others (2007); Davies and Bates (2014); Prevey and others (2014)

Table 5.1. Potential adaptation strategies and actions linked with the climate and non-climate stressors and disturbance regimes they are thought to reduce or minimize.—Continued

Key:
↑, increasing
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● Evidence based
●̲ Evidenced based, indirect
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Adaptation strategies	Adaptation actions	Climate stressors: ↑Air temperature	Climate stressors: Changes in precipitation	Climate stressors: ↓Soil moisture	Climate stressors: ↑Drought	Climate stressors: ↓Snowpack; earlier melt/runoff	Disturbances: Altered wildfire regime	Disturbances: ↑Insect/disease outbreaks	Non-climate stressors: Invasive species	Non-climate stressors: Grazing/herbivory	Non-climate stressors: Land-use and recreation	Other: Action increases general resilience	Citations
Adaptation strategies and action that are based on enhancing resistance, promoting resilience, or facilitating transition—Continued													
Manage prescribed/natural fire to reduce negative effect of changes in fire frequency and intensity	Design burn prescriptions that consider soil moisture requirements	○	○	●	○		○			●			Anderson and others (1970); Bachelet and others (2000)
	Implement strategically-located non-burn fuel reduction techniques to reduce risk of severe wildfire in rangeland vegetation habitats	○	○	○	○		●						Schmidt and others (2008); Davies and others (2009); Gray and Dickson (2016)
	Use low to moderate intensity grazing to reduce fuel loads and lower fire risk in rangeland vegetation habitats		○	○	○		●			○			Davies and others (2009); Davies and others (2010a)
	Implement Burned Area Emergency Response (BAER) actions		●				○						
Maintain snow cover	Use snow fencing to increase snow drift accumulation and soil moisture		●	●	○	●							David (2013)
Reduce travel impact	Identify and manage trails/paths created by recreation users to minimize their impact on rangeland vegetation habitats								○		○	○	

Table 5.1. Potential adaptation strategies and actions linked with the climate and non-climate stressors and disturbance regimes they are thought to reduce or minimize.—Continued

Adaptation strategies	Adaptation actions Key: ↑, increasing ↓, decreasing ● Evidence based ●̲ Evidenced based, indirect ○ Expert opinion ○̲ Expert opinion, indirect	Climate stressors: ↑Air temperature	Climate stressors: Changes in precipitation	Climate stressors: ↓Soil moisture	Climate stressors: ↑Drought	Climate stressors: ↓Snowpack; earlier melt/runoff	Disturbances: Altered wildfire regime	Disturbances: ↑Insect/disease outbreaks	Non-climate stressors: Invasive species	Non-climate stressors: Grazing/herbivory	Non-climate stressors: Land-use and recreation	Other: Action increases general resilience	Citations
Adaptation strategies and actions that are based on research, monitoring and assessment													
Use research, monitoring, and assessment to increase knowledge of current conditions and projected changes	Develop and apply models that consider climate change when projecting the area and location of invasive species establishment and spread	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲			
	Inventory and map weed-free sites and potential site invasibility to aid in prioritization of management and restoration activities								●̲				Underwood and others (2003); Williams and Hunt (2002)
	Monitor weed-free sites to increase early detection of new invasions								○̲				
	Evaluate and include the role of native ungulate grazing and competition in grassland management plans									○̲			
	Monitor post-fire effects beyond the scope of suppression and Burned Area Emergency Response (BAER) and implement appropriate actions						○̲						
	Locate and map important soil types, such as mollisols, and prioritize them for restoration		○̲	○̲	○̲	○̲						○̲	
	Determine whether individual sites are fire- or snow-maintained					○̲	○̲						
	Map sites at risk of drought and monitor vegetation and water availability		○̲	○̲	○̲	○̲							
	Improve understanding of link between climate change and rangeland ecology	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲			

Table 5.1. Potential adaptation strategies and actions linked with the climate and non-climate stressors and disturbance regimes they are thought to reduce or minimize.—Continued

Key:
↑, increasing
↓, decreasing
● Evidence based
●̲ Evidenced based, indirect
○ Expert opinion
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Adaptation strategies	Adaptation actions	Climate stressors: ↑Air temperature	Climate stressors: Changes in precipitation	Climate stressors: ↓Soil moisture	Climate stressors: ↑Drought	Climate stressors: ↓Snowpack; earlier melt/runoff	Disturbances: Altered wildfire regime	Disturbances: ↑Insect/disease outbreaks	Non-climate stressors: Invasive species	Non-climate stressors: Grazing/herbivory	Non-climate stressors: Land-use and recreation	Other: Action increases general resilience	Citations
Adaptation strategies and actions that are based on planning and-or collaboration													
Increase collaborations and incorporate climate change into planning processes	Create and implement a management plan for grasslands and/or shrublands based on thresholds/triggers for activities such as thinning, prescribed burns, and planting	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲		○̲	
	Establish interagency collaborative weed management program to improve coordination and resource use among agencies, nongovernmental organizations, and private land owners									○̲			
	Communicate implications of climate change on rangeland quality/availability and grazing management practices and associated uncertainty with stakeholders	○̲	○̲	○̲	○̲	○̲	○̲	○̲		○̲			
	Provide information to land owners and managers about projected impacts of climate change and disturbances on rangeland ecology, including effects of repeated burns, weed identification and reporting, and the importance of site potential	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲			
	Develop criteria to help determine whether to resist or allow forest encroachment into rangeland vegetation habitats	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲		○̲	
	Develop criteria to prioritize intact and/or high-quality rangeland sites and redirect management resources to them as needed										○̲	○̲	
	Increase collaboration among management agencies and ranchers to actively control grazing allotments and grazing intensity									○̲		○̲	
	Update weed risk assessments (WRAs) to include potential climate change impacts	○̲	○̲	○̲	○̲	○̲	○̲	○̲	○̲				
	Develop funding and native seed sources for postfire restoration of burned areas where plant communities are not regenerating						○̲						

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Forest and Rangeland Ecosystem Science Center
U.S. Geological Survey
777 NW 9th St., Suite 400
Covallis, Oregon 97330
https://www.usgs.gov/centers/fresc/

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