Responding to Climate Change on National Forests: A Guidebook for Developing Adaptation Options

David L. Peterson, Constance I. Millar, Linda A. Joyce, Michael J. Furniss, Jessica E. Halofsky, Ronald P. Neilson, and Toni Lyn Morelli

Christopher W. Swanston, Steven McNulty, and Maria K. Janowiak

Lead Authors

David. L. Peterson is a research biological scientist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Pacific Wildland Fire Sciences Laboratory, 400 N. 34th St., Suite 201, Seattle, WA 98103; **Constance I. Millar** is a research paleoecologist, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, 800 Buchannan St., West Annex Building, Albany, CA 94710-0011; **Linda A. Joyce** is a quantitative ecologist, U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, 240 W. Prospect, Fort Collins, CO 80526; **Michael J. Furniss** is a hydrologist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, 333 SW First Ave, Portland, OR 97204; **Jessica E. Halofsky** is a research ecologist, University of Washington, College of the Environment, School of Forest Resources, Box 352100, Seattle, WA 98195-2100; **Ronald P. Neilson** is a research bioclimatologist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis Forestry Sciences Laboratory, 3200 SW Jefferson Way, Corvallis, OR 97331; and **Toni Lyn Morelli** is a postdoctoral fellow, University of California, Department of Environmental Science, Policy, and Management, 6 Mulford Hall, Berkeley, CA 94720, Furniss currently is located at the Pacific Southwest Research Station, Redwood Sciences Laboratory, 1700 Bayview Drive, Aracta, CA 95521-6013.

Contributing Authors

Christopher W. Swanston is a research ecologist, U.S. Department of Agriculture, Forest Service, Northern Research Station, 410 MacInnes Dr., Houghton, MI 49931; **Steven McNulty** is an ecologist, U.S. Department of Agriculture, Forest Service, Southern Research Station, 920 Main Campus Dr., Venture Center 2, Suite 300, Raleigh, NC 27606; and **Maria K. Janowiak** is a research scientist, Michigan Technological University, School of Forest Resources and Environmental Science, 1400 Townsend Dr., Houghton, MI 49931.

U.S. Department of Agriculture, Forest Service
Pacific Northwest Research Station
Portland, Oregon
General Technical Report PNW-GTR-XXX
Month year

This publication was developed by the WestWide Climate Initiative, a collaboration of the Pacific Northwest, Pacific Southwest, and Rocky Mountain Research Stations of the U.S. Forest Service, with assistance from the Northern and Southern Research Stations.

Abstract

Peterson, David L.; Millar, Connie I.; Joyce, Linda A. [et al.]. 201x. Responding to climate change on national forests: A guidebook for developing adaptation options. Gen. Tech. Rep. PNW-GTR-xxx. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Xxx p.

This guidebook contains science-based principles, processes, and tools necessary to assist with development of adaptation options on national forest lands. The adaptation process is based on partnerships between local resource managers and scientists who work collaboratively to understand potential climate change effects, identify important resource issues, and develop management options that can capitalize on new opportunities and reduce deleterious effects. Because management objectives and sensitivity of resources to climate change vary among national forests, appropriate processes and tools for developing adaptation options may also vary. Regardless of specific processes and tools, the following steps are recommended: (1) become aware of basic climate change science and integrate that understanding with knowledge of local resource conditions and issues (review), (2) evaluate sensitivity of specific natural resources to climate change (rank), (3) develop and implement strategic and tactical options for adapting resources to climate change (resolve), and (4) monitor the effectiveness of adaptation options (observe) and adjust management as needed. Results of recent case studies on adaptation in national forests and national parks can facilitate integration of climate change in resource management and planning and make the adaptation process more efficient. Adaptation to climate change will be successful only if it can be fully implemented in established planning processes and other operational aspects of national forest management.

Keywords: Adaptation, climate change, national forests, national parks, science-management partnership, vulnerability assessment.

Contents

Executive Summary

National forests are required to take significant steps to incorporate climate change in management and planning, including the development of options that facilitate adaptation of natural resources to potentially deleterious effects of an altered climate. Despite uncertainties about the timing and magnitude of climate change effects, sufficient information exists to begin the adaptation process, a form of risk management. It is recommended that the following steps, based on a science-management partnership, be used to facilitate adaptation on national forests: (1) become aware of the basic climate change science and integrate that understanding with knowledge of the local resource conditions and issues (review), (2) evaluate sensitivity of natural resources to climate change (rank), (3) develop and implement options for adapting resources to climate change (resolve), and (4) monitor the effectiveness of on-the-ground management (observe) and adjust as needed.

The “resolve” step is used to develop solutions that ensure sustainable resource management in meeting conservation goals, and four management categories—resistance, resilience, response, and realignment—encourage thinking about a range of possible options. The resistance strategy includes actions that enhance the ability of species, ecosystems, or environments (including social) to resist forces of climate change and that maintain values and ecosystem services in their present or desired rates and conditions. The resilience strategy enhances the capacity of ecosystems to withstand or absorb increasing impact without irreversible changes in important processes and functionality. The response strategy works directly with climate-induced changes to assist transitions to future states by mitigating and minimizing undesired and disruptive outcomes. The realignment strategy uses restoration techniques to enable ecosystem processes and functions (including conditions that may or may not have existed in the past) to persist through a changing climate.

Processes and tools used to accomplish adaptation vary, depending on local resource conditions, management objectives, and organizational preferences. Therefore, several processes and tools are presented here, all of which have been used and evaluated on federal lands. This guidebook provides the documentation of science-based principles, processes, and tools necessary for a credible and practical approach for adapting to climate change. This credibility is critical whether adaptation options are focused on general strategies (e.g., increasing resilience of dry forests to fire) or tactical actions (e.g., reducing stem densities and fuels to specific levels). Sharing of experiences from adaptation projects on national forests and other federal lands will enable others to implement adaptation more effectively and efficiently, and collaboration among different agencies, land owners, and stakeholders will ensure that diverse perspectives are included in climate-change adaptation. Integration of adaptation in operational management and administration of national forests, including established planning processes, will be challenging but necessary to ensure long-term sustainability of natural resources in a changing climate.

Introduction

Rapidly changing climate imposes a challenge to the mission of the Forest Service, which is to sustain the health, diversity, and productivity of the Nation's forests and grasslands to meet the needs of present and future generations. Ecosystems that the Forest Service manages have, of course, always been dynamic, and climate change exacerbates and compounds existing stressors such as fire, insects, fungal pathogens, atmospheric pollution, floods, and invasive species (McKenzie et al. 2009). Further, decreasing snowpacks, altered streamflows, prolonged droughts, and shifting plant and animal habitats are creating a kaleidoscope of new patterns and trends (Solomon et al. 2007). The need to respond to climate change is clear, and recent mandates from leadership in the Forest Service and U.S. Department of Agriculture clearly spell out this responsibility.

Forest Service Chief Tom Tidwell has begun an assertive program of action, outlined in an agency-wide strategic framework for responding to climate change (USDA FS 2008). As field units began to implement this framework, a need emerged for guidance from the national level to help the agency move from strategy to operations. Building on the strategic framework, the "National Roadmap for Responding to Climate Change" (USDA FS 2010c) was issued in July 2010 to aid field units in translating goals into action. Responses to climate change as defined in the roadmap include (1) assessing current risks, vulnerabilities, policies, and gaps in knowledge; (2) engaging internal and external partners in solutions; and (3) managing for resilience, in ecosystems as well as in human communities, through adaptation, mitigation, and sustainable consumption strategies. These actions are dynamic and mutually reinforcing, interconnected through monitoring and evaluation to inform adaptive management. Climate change adaptation, the primary focus of this publication, is defined by the Intergovernmental Panel on Climate Change (IPCC) as “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm of exploits beneficial opportunities” (McCarthy et al. 2001).

In addition to the national roadmap, the Chief recently issued the climate change performance scorecard for implementing the Forest Service climate change strategy (USDA FS 2010a). The scorecard provides a straightforward means of addressing specific goals and objectives described in the Department of Agriculture strategic plan, and concrete measures of success are described at the national forest level. The scorecard consists of 10 yes-or-no questions associated with actions that support the four dimensions of climate change response described in the roadmap (box 1). National forests are directed to use the scorecard annually to assess progress and document accomplishments. Similar to the roadmap, the scorecard describes how strategic goals can be implemented on the ground. Successful accomplishment of scorecard elements is mandated for all national forests by 2015.

Grounded in a strong commitment to assertively address climate change in land management, this new direction to field units will help translate climate change concepts and goals into action. However, little guidance is provided about specific decision tools, models, and planning instruments or on how to set priorities, assess vulnerabilities, and develop adaptation goals. Resource managers and planners in national forests need information and tools that will enable them to make specific decisions, develop concrete practices, and take timely action on the ground to address climate change.

In response to this need, Forest Service research scientists and cooperators have been working to develop tools and guidelines relevant for adaptation to climate change on national forests. Forest Service research stations and national forests have established science-management partnerships to develop scientific bases for adaptation and find effective ways to communicate and implement this knowledge. This effort builds on existing principles of adaptation to climate change, such as described in the U.S. Climate Change Science Program Synthesis and Assessment Product 4.4 (Joyce et al. 2008) (Julius and West 2008), Millar et al. (2007), and Bosworth et al. (2008) to provide science-based strategic and tactical approaches for adapting to climate change.

Recent collaborative projects among Forest Service research stations, national forests, national parks, and other stakeholders have focused on: (1) climate change education for resource managers, (2) potential vulnerabilities of natural resources to a changing climate, (3) options that facilitate adaptation to the effects of a changing climate, and (4) opportunities to implement adaptation in on-the-ground management and planning. Rapid communication of knowledge obtained from these collaborations is needed to inform adaptation strategies and facilitate preparation for a changing climate.

This guidebook is a summary of current knowledge on climate change adaptation from educational syntheses, specific tools, facilitated dialogues, workshops, and case studies. It is focused specifically on topics and approaches that are relevant to and compatible with resource management on national forests and potentially on other federal lands. Indeed, all adaptation options developed for case studies to date were conceived by resource managers and disciplinary specialists from national forests and national parks. It is our sincere hope that the tools and approaches presented here will help focus adaptation on the needs of resource managers and planners.

The guidebook is intended to assist the transition to "climate smart" approaches in resource management. It is not intended to be comprehensive of all scientific and management efforts on climate change adaptation, but rather a compilation of information and lessons learned that will inform adaptation planning and practice on national forests. The guidebook is intended to be dynamic and will continue to evolve as new knowledge becomes available[1], adaptation options on federal lands are implemented and evaluated, policy and guidelines are formalized, and the effects of a changing climate are documented.

This is part of the normal adaptive management process. The adaptation guidebook is one of many sources of scientific information and guidance that can be used by federal land managers to guide decision making and planning. Starting the process of adaptation in a timely way increases the likelihood that resource management objectives can be attained in a changing climate.

Background

Planning and managing for the anticipated effects of climate change on natural resources is in its infancy on public lands in the United States. Despite the fact that over 20 years of data are available from federally funded research programs, federal agencies have been slow to integrate climate change as a factor in future planning strategies or on-the-ground applications (GAO 2007, 2009). This slow response has been caused by insufficient local information on climate change effects; the magnitude and uncertainty of potential effects on ecosystem structure, processes, and function; lack of institutional capacity (budget, personnel) to address a major new topic; and until recently, absence of a mandate to incorporate climate change in agency operations.

An urgent need exists for policy makers, managers, scientists, stakeholders and the broader public to share specific evidence of climate change and its projected consequences on ecosystems, and to share their understanding of adaptation options, future opportunities, and risks (e.g., Climate Adaptation Knowledge Exchange 2010, Vogel et al. 2007). Although this guidebook focuses on national forests and draws mostly on examples from the western U.S., many recommendations are relevant to resource managers on privately owned and other publicly managed lands who manage for multiple objectives, in consideration of external influences on their lands.

Awareness of the need to incorporate climate change into resource management and planning increased globally in association with the Fourth Assessment by the Intergovernmental Panel on Climate Change (Solomon et al. 2007), and in western North America in association with well-publicized reports on regional climate and hydrologic trends (e.g., Hayhoe et al. 2004, Knowles et al. 2006, Mote et al. 2005).

Most efforts on adaptation to climate change have focused primarily on conceptual issues addressed through general scientific discussion (Easterling et al. 2004, FAO 2007, Hansen et al. 2003, MacIver and Dallmeier 2000, Wilkinson et al. 2002), social and economic adaptation (Kane and Yohe 2000), proposed actions by governmental institutions (Joyce et al. 2007, Ligeti et al. 2007, Rojas Blanco 2006, Snover et al. 2007, Solomon et al. 2007), individual adaptation strategies (Sadowski 2008, Slaughter and Wiener 2007), and adaptation recommendations for biological diversity (Heller and Zavaleta 2009). Recent information on climate change adaptation for natural resources provides general adaptation strategies (Innes et al. 2009, Joyce et al. 2008, Millar et al. 2007). Only a few sources contain information on adaptation to climate change that is relevant and usable for natural resource managers from a tactical or operational perspective (Halofsky et al., in press; Littell et al., in press; Ogden and Innes 2007a, 2007b, 2008; Peterson et al., in press).

Efforts to develop strategies that facilitate adaptation to documented (e.g., altered hydrologic systems [Barnett et al. 2008]) and expected (e.g., increased area burned by wildfire [Westerling et al. 2006]) responses to climate change are now beginning in earnest by the U.S. federal government. In the most substantive effort to date, the U.S. Climate Change Science Program developed a summary of adaptation options for federal land management agencies (Synthesis and Assessment Product 4.4) (Julius and West 2008), including one chapter devoted to adaptation on national forests (Joyce et al. 2008) and one chapter devoted to national parks (Baron et al. 2008). Recent discussions on adaptation emphasize the importance of implementing adaptive management (in a general sense, as opposed to adaptation to climate change), with resource monitoring as a critical feedback to evaluation of management strategies (Bosworth et al. 2008, Joyce et al. 2008, Millar et al. 2007).

Guidance to Forest Service managers states that “climate change is a factor to be considered in the delivery of our overall mission,” and managers are directed to use the “best available science on climate change that is relevant to the planning unit and the issues being considered in planning” (USDA FS 2010b). Guidance addressing climate change in national forest planning is one of several focal issues around which the new Forest Service planning rule is being developed. The planning rule draft environmental impact statement is currently in development, with a final rule not anticipated until 2012. No specific planning guidance on climate change is available at this time.

Guidance for considering climate change in project-level National Environmental Policy Act (NEPA) analysis describes agency authority to propose projects to increase the adaptive capacity of ecosystems it manages, mitigate climate change effects on those ecosystems, and to sequester carbon (USDA FS 2009b). Timely implementation of strategic and tactical adaptation options, with an emphasis on practical approaches that can be applied within the broader context of sustainable resource management, will be critical to meet the goals of restoring and enhancing ecosystems while providing and sustaining ecosystem services and benefits (Innes et al. 2009).

Guidance for project-level NEPA analysis (USDA FS 2009b) identifies two types of climate change effects to be considered:

- **The effect of a proposed project on climate change** (greenhouse gas [GHG] emissions and carbon cycling). Examples include short-term GHG emissions and alteration to the carbon cycle caused by hazardous fuels reduction projects, GHG emissions from oil and gas field development, and avoiding large GHG emissions pulses and effects to the carbon cycle by thinning overstocked stands to increase forest resilience and decrease the potential for large wildfires.
- **The effect of climate change on a proposed project**. Examples include effects of expected shifts in temperature and precipitation patterns on seed stock selection for reforestation after timber harvest, and effects of decreased snowfall on a ski area expansion proposal at a marginal geographic location (e.g., a southern aspect at low elevation).

The first type of climate change effect focuses on alterations or enhancements of the carbon cycle as affected by Forest Service management. This area is under continued discussion in management and policy arenas. Potential interactions between management actions that propose to enhance carbon sequestration need to be addressed to ensure that adaptation options are not foregone (McKinley et al., in press; Ryan et al. 2010). Similarly adaptation options can affect the potential for carbon sequestration in ecosystems.

This guidebook focuses on the second category and the adaptation response. Scientific understanding over the last 20 years has brought the issue of climate change and the vulnerability of ecosystems to climate change decisively into the public arena. However, as described above, no consistent framework or portfolio of operational strategies has evolved from this scientific understanding to identify appropriate resource management responses. Management activities and plans that reduce the vulnerability of natural and human systems to actual or expected climate change effects are considered adaptation. A large and potentially overwhelming amount of scientific information on climate change is available to communities of practice within different natural resource disciplines, although practical information on adaptation is less common. Science-management partnerships must facilitate two-way learning in which climate science can be melded with managers' knowledge and experience on characteristics of the land being managed.

Encouraging a learning environment in which novel approaches can be used experimentally to alleviate deleterious climate change effects will support federal land managers as they develop adaptation options. Scientists and managers will be called upon to sift through diverse approaches to understand the effects of climatic variability and change on ecosystems and management responses to a changing climate. Management actions intended to facilitate adaptation may over time appear to be "mistakes," but they are also opportunities to understand technical issues, underlying ecosystem processes, and successful management approaches in a changing climate.

This guidebook provides a framework for building management strategies in the face of climate change, processes to start the science-management dialogue about climate change and adaptation, and examples of adaptation options recommended by land managers. Uncertainty, complexity, and the uniqueness of individual national forests need to be considered when developing adaptive approaches for planning and management. Sources of uncertainty—sensitivity of resources, climate projections, staff time, funding, and public support—may influence decisions on whether it is best to develop **reactive responses** to changing disturbances and extreme events after they occur to protect current resource conditions, or **proactive responses** in anticipation of climate change to facilitate desired ecosystem functions and processes.

The inevitability of novelty and surprise in climate change effects, combined with a broad range of management objectives, means that it is certain that **no single approach will fit all situations**. The guidebook presents a toolkit of adaptation options that can be selected, modified, and combined to fit a particular situation. We define **tools** as resource management practices, educational and reference modules, decision support aids, and qualitative or quantitative models that address the adaptation of natural and cultural resources to climate change. Tools include the application of existing management practices, but in new locations, different seasons, or a slightly different context, as well as new tools, distinct from past management practices and strategies. The toolkit approach recognizes that management strategies may vary based on the spatial and temporal scales of decision making. We hope that the information, processes, and decision support tools presented here will motivate land managers to apply science-based adaptation principles in management and planning.

Analytical Scale, Models, and Scientific Information

As natural sciences became more formalized during the 19th and 20th centuries, scientists and land managers began collecting observational and experimental data over space and time, documenting patterns of variation in the physical and biological environment. Landscapes and ecoregions are large, and time scales of responses are long compared to the generation time of humans, so sampling of the natural world was sparse in space and time and may have been biased in ways not appreciated until much later.

The time scales of secondary succession for forested landscapes are often too long for direct assessment by an individual observer. The durations of various intermediate stages between a major disturbance event and a late-successional stage are often so long that “space-for-time” substitution was invented as a means of documenting the successional trajectories that any given patch of land would likely follow within a spatially coherent ecoregion. This approach assumes that spatial and temporal patterns of disturbances and succession are relatively stable over time. Under this assumption, simple statistical models can quantify spatial and temporal patterns of growth and successional change after a disturbance. Statistical models are generally limited in the number of variables that can be simultaneously considered in one model, such as productivity or simulations of individual species distributions. Therefore, two scientific perspectives have become entrenched, namely (1) sparse data, collected intermittently in space and time, are sufficient to accurately describe the space-time dynamics of large ecoregions or domains, and (2) acceptance of #1 presumes that any changes in these space-time dynamics of the natural world are very slow compared to the generation time of humanity and can be essentially ignored.

The rate and magnitude of recent climatic warming have largely negated the concept of stationarity in natural systems, leaving the space-for-time approach with little value for estimating future change in ecosystems. Ecosystems consist of life forms and processes that operate on different temporal scales, from short term (e.g., photosynthesis) to long term (e.g., forest stand dynamics). Computer simulation models can simulate space-filling and time-filling patterns and processes, including integration of processes interacting within ecosystems. Increasing knowledge of natural patterns and processes in ecosystems combined with increasing computational capacity have led to a better understanding of possible future ecosystem changes across a range of spatial scales.

Below, we explore spatial and temporal scale concepts and other factors that influence development and use of scientific knowledge on climate change. We address common types of climate and ecosystem models that managers are likely to encounter, including limitations for their use in small-scale projects. Finally, we provide guidance on evaluating and using credible scientific information.

Assessing Climate Change Effects at Different Spatial and Temporal Scales

A framework based on spatial and temporal scale (e.g., Peterson and Parker 1998) can help organize large amounts of information according to specific applications used to assess vulnerability of resources to climate change and to develop adaptation options**.** Selecting appropriate scales for assessing the effects of climate change and planning adaptive responses depends on the nature, magnitude, and mechanisms of potential effects; the nature and extent of linkages with ecological, social, and economic systems; information availability and value relative to the range of potential consequences; and personnel and budget availability.

The scale on which adaptation is focused is ideally based on the issues to be addressed and potential changes to existing management direction (table 1). Many biophysical issues have easily definable scales, such as the range of a plant species or hydrologic conditions of a river basin. Each issue may define the scale at which climate change effects are assessed, adaptation goals are defined, and project design objectives are established.

Broad-scale analysis (thousands to millions of hectares) can inform managers and interested parties of strategic intent for long-term adaptation to climate change, provide a context for finer scale analysis units (e.g., watersheds), and set priorities for detailed analysis and program planning. Although the watershed scale (thousands to tens of thousands of hectares) may be an appropriate scale for identifying opportunities to improve resilience of landscapes to climate change, detailed analysis at this scale over an entire national forest may not be necessary. Rather, detailed analysis can be focused initially on the most vulnerable watersheds identified by a broader analysis.

Broad-scale analysis helps establish context, provide guidance, allocate budgets and expertise, and establish schedules and accountability. Analysis at broad scales can also evaluate ecologically unique portions of the landscape, such as areas with particularly high value (e.g., domestic water supplies) or high vulnerability (e.g., landslide-prone terrain). Beginning assessment and planning at broad scales can (1) identify effects that can be detected only at broad scales (e.g., cumulative effects, species decline), (2) identify pivotal actions such as large land allocations (3) reframe administrative authorities to make optimal changes (e.g., collaboration among multiple national forests and other units), and (4) avoid collecting unnecessary information for land areas with low value or low vulnerability.

Broad-scale biogeographic patterns can be defined by biome boundaries, such as the transition from the Temperate zone, with a hard frost each year, to the Boreal zone, generally delineated by winter minimum temperatures cold enough to kill temperate trees. At the warm extreme, the Temperate zone transitions to a Subtropical zone, where a hard winter frost may not occur each year, grading to fewer and fewer as one moves south or down in elevation. These thermal boundaries demarcate major changes in the flora and fauna of ecosystems and are observed through elevation in western North America and through latitude in eastern North America. In the proximity of cold or warm boundaries, different ecoregions from either side are interspersed with one other and delineate microsites caused by variation in topography, radiation, and soils. These microsites are not well differentiated in core areas of the Temperate zone, and any given vegetation assemblage might be extensive but still within the Temperate biome. For example, in western North America, grass or shrublands might dominate south-facing slopes adjacent to forests on north-facing slopes at lower elevations. In eastern North America, with relatively gentle topography, the scale of contiguous microsites can be very large.

Temperature is expected to generally increase (with interannual variation) in the future, so if a site is near the northern or upper elevation limits of the Temperate zone, then one might expect microsites with temperate flora/fauna to expand, whereas Boreal microsites will contract (Solomon et al. 2007). Species composition in Temperate locales might change slightly, because migration of species from warmer climes will be from within the same broad ecoregions. However, at the southern or lower elevation limits of the Temperate zone, one might expect local vegetation assemblages to decrease, and species composition could change considerably as species from a nearby biome become established.

Magnitude and spatial variation of future precipitation are also important, but less certain and more complex than for temperature (Solomon et al. 2007). Each thermal zone can contain all moisture environments from wet to dry. Vegetation transitions along that gradient from closed cover (forest, chaparral, etc.) to open (woodlands, semi-arid to arid shrub-grass). The size of a “homogeneous” unit is largest in the center of a biome and becomes smaller as it merges with neighboring biomes. Microsites based on moisture are smaller and more sharply defined in the West than in the East. Inferring moisture trends can be difficult due to normal climatic variability caused by phenomena such as the El Niño-Southern Oscillation (<1 decade), Pacific Decadal Oscillation, and Atlantic Multi-Decadal Oscillation (>2 decades for the latter two).

Multiple National Forest scale—Landscape assessment, land management planning, and adaptation design are most effective if they are developed for specific spatial scales. In this section and the following two sections, various aspects of these topics are summarized with respect to spatial scale. These summaries are provided to generate ideas and are not intended as a comprehensive list.

These components of landscape assessment, land management planning, and adaptation design are relevant and feasible at the scale of large basins that would encompass multiple national forests and other lands (table 1):

- Defining scenarios of exposure of landscapes to climate changes, such as increased heat, changes in rainfall and snowfall, etc.
- Species ranges and vulnerability, and general locations of susceptible plant and animal populations of particular concern.
- Primary beneficial uses of water, such as fish populations, municipal water supplies, energy generation, and recreation.
- Expected changes in regional demographics, and how they could affect the demand for water, recreation, and other services, and how trends in demand could result in cumulative effects to valued resources.
- Patterns of land ownership and jurisdiction that control the decision space for adaptive responses and where stakeholders are crucial to comprehensive solutions.

National forest and ranger district scales—These components of landscape assessment, land management planning, and adaptation design are relevant and feasible at the scale of sub-basins, individual national forests, and one or a few ranger districts (table 1):

- Priorities and scheduling for acquiring detailed condition and vulnerability information, such as priority watersheds for fine-scale inventory and analysis needed to plan and set priorities for project work.
- Current land allocations and related standards and guides that affect the types of adaptation that are permitted, and how these could be modified based on the legal and administrative context.
- Defining "desired conditions" and condition goals to promote landscape resilience and establish broad priorities for adaptation based on the range of values at risk, adaptive potential of landscapes, and mosaic of current land allocations.
- Priorities for specific landscapes where assessment, planning, and design efforts are best focused based on differences in values, vulnerability, adaptive capacity, and land-use context.
- Existing capacity of administrative units to plan and accomplish adaptive responses and any needed adjustments to capacity
- Review and potential modification of ongoing or planned projects within or through the NEPA process for consistency with current information and assessments of vulnerability

Watershed scale—These components of landscape assessment, land management planning, and adaptation design are relevant and feasible at the scale of watersheds (table 1):

- Assessment of the vulnerability of important values and services in a watershed.
- Identifying and highlighting areas of special sensitivity, resource values, or both.
- Interactions of climate change with existing land uses and effects that may result in worsening or improving cumulative effects to important processes, values, and services.
- Planning and design for the type, amount, and distribution of adaptive treatments, land allocations,

and standards and guides for adaptation.

- Suggested priority locations for site-scale evaluation, project design, and the NEPA process.
- Specific locations and types of project opportunities that secure, restore, realign, and build resilience of the landscape to rapid climate change and related impacts, and location-specific design criteria for projects.

Temporal scales for analysis and planning—Natural and human-caused forces drive climate change at multiple time scales (Millar et al. 2006). Short-period cycles driven by changes in ocean circulation include the 2-7 year El Niño-Southern Oscillation and multi-decadal patterns such as the Pacific Decadal Oscillation. Forces influencing even longer duration climatic variability range from century-scale effects driven by alternations in solar activity to millennial patterns that reflect changes in Earth’s orbital proximity to the sun. Although these temporal scales may seem long relative to management contexts, interactions among mechanisms at various scales can catalyze rapid changes in climate.

Regardless of efforts to curtail emissions, GHGs will accumulate steadily in the atmosphere over the coming centuries, and these interact with the combined cycles of natural change (Solomon et al. 2007). Just as unusual climatic events result when natural cycles coincide, so are interactions of GHG emissions expected to catalyze surprises in Earth’s climate, many of which cannot be modeled. We anticipate climatic consequences related to GHG emissions to increase over time, although their expression will be amplified, attenuated, or reorganized by underlying natural mechanisms. The uncertainty of climate change effects increases with each additional decade into the future, a factor that must be considered when interpreting the output of models that predict climate change effects.

Temporal perspectives are an important component of vulnerability analysis (table 2). Temporal perspectives are also important for planning and priority setting (table 3) for adaptation to climatic warming, including the current year (relevant for ongoing projects, near to mid term (2-20 years hence; relevant for projects in development and project planning), and long term (>20 years; relevant for land management planning and adaptive management).

In the current year, quick assessment of in-process projects for their potential climatic vulnerability is important. Sometimes current projects originated years ago and under different directives, having taken a long time to get through NEPA review, and only now are nearing implementation. These projects might not have benefited from analysis of climatic effects and thus might not be appropriate to deploy without modification that accounts for climate.

For projects in development or near- to mid-term project planning (table 3), where human-caused effects on climate are anticipated to be generally within the range of natural climatic variability and extreme events, stop-gap measures can be effective. At this scale, institutional change will also be important, because this is generally the time frame of policy and behavioral adjustment within federal agencies. We anticipate that learning will spread throughout the Forest Service and other agencies during this time and that new models, tools, and applications will be developed during these transitional years.

At scales of planning for future decades (table 3), detailed analyses and proactive responses are increasingly important. Vulnerability assessments are defined by the IPCC as efforts that identify future risks induced by climate change, identify key vulnerable resources, and provide a sound basis for designing adaptation strategies (IPCC 2001). These assessments are needed to quantify cumulative effects of climate change. Proactive management goals and objectives at the broad scale of these assessments focus more on enabling and assisting ecosystem changes rather than in resisting undesired effects. Understanding the implications of vulnerability analysis and priority setting for different temporal scales can prevent confusion over best management practices.

Modeling Future Climates and Ecosystem Responses

No one can know the future for certain, and thus estimating climate change and its ecological effects requires using existing knowledge of physical and biological systems and applying that knowledge to project future response. Projections of future response to increased GHG concentrations and changing climate are most often generated through models (Bader et al. 2008). Numerous types of models that project future climate and ecological effects of climate change have been developed over the past 30 years.

Global climate models—Global climate models are the primary way to project the effects of increasing GHG concentrations on future climate. Climate models are computer-based simulations that use mathematical formulas to recreate chemical and physical processes that drive climate (NOAA 2007). To attain the highest confidence of future climatic projections, these complex models utilize a fundamental understanding of how the coupled components of the Earth's climatic system work.

For the last several decades, scientists have been coupling general circulation models (GCMs) of the atmosphere with those of the oceans (atmosphere-ocean GCM, or AOGCM), ice, and the terrestrial biosphere. These complex models exhibit interannual and interdecadal variation not unlike those observed in the real Earth system. Armed with the basic equations of biological processes, these models can simulate a terrestrial biosphere, placing forests, grasslands, and deserts in the appropriate locations. Output from 24 different GCMs was included in IPCC Fourth Assessment (Randall and Wood 2007). The models include a range of future possibilities for GHG emissions (Nakićenović and Swart 2000), and despite uncertainty in actual GHG emissions over the next century, considerable confidence exists in the ability of climate models to provide credible estimates of climate change at the global scale (Solomon et al. 2007). Because general agreement exists on basic principles of climate change, many models produce broadly similar responses (e.g., general amount of expected warming) (Randall and Wood 2007).

It is difficult to identify a single "best" climate model (Gleckler et al. 2008, Santer et al. 2009). Although a model may be good at modeling one variable in one location, it may not be as good at modeling another in another location. All models incorporate many assumptions, and uncertainty is included in every model projection. In addition, **the "mean model," or average of a group of climate models, consistently outperforms any single model in most respects**; the averaging seems to cancel out errors in individual models (Gleckler et al. 2008). Thus, using an ensemble of models provides the most accurate average projections for regional and global analyses (Pierce et al. 2009). Although projections from a mean model may be simpler to interpret than from multiple models, the mean of many models does not portray variability among models, masking potentially important temporal patterns (e.g., extremes).

The coarse resolution of global climate models is a major limitation. Regional climate models increase the resolution of global climate models, and are typically run at resolutions of 50 km or less. Unlike global climate models, regional climate models include the influence of mesoscale processes on climate such as orographic precipitation, convergence zones, and cold air drainage. This may be useful for a large land area such as the Tongass National Forest (Alaska) (69,000 km^2), but less useful for small land areas such as the Uwharrie National Forest (North Carolina) (200 km^2). Regional models are often run within a restricted portion of global climate models, which determine the large-scale climatic effects of increased GHG concentrations. The global climate model provides input and boundary conditions for the regional climate model, but large-scale biases of the global model are passed along to the regional model. Regional climate models are computationally demanding but can provide finer scale information for regional assessments (e.g., Salathé et al. 2010).

Several methods exist for downscaling global climate model output to smaller areas. Statistical downscaling is based on the view that regional climate is determined by the large-scale climatic state, but that regional and local physiographic features produce unique microclimates within the larger patterns (Wilby et al. 2004). The simplest and most widely used statistical approach, or “delta” approach, corrects for large-scale distortion or displacement of major circulation features, such as jet streams and storm tracks. This method determines large-scale changes in temperature and precipitation from the simulated current state to the simulated future state, then applies those “deltas” to a higher-resolution grid of observed climatic variables (e.g., Lettenmaier and Gan 1990). A more complex approach examines changes in large-scale upper air flow, which is then input to statistical models to estimate local and regional climate, statically for averages or dynamically for time series (Wilby et al. 2004).

Statistical approaches can project patterns of historical variability into the future, while retaining trends from the future climatic scenarios. However, if one relies entirely on AOGCM-generated temporal variability, then the richness of historical variability may not be adequately simulated. Changes in variability, such as increased persistence of long-term, wet-dry cycles, might emerge from AOGCM simulations, but would be missed if historical variability is forced onto future trends (Mote and Salathé 2010). There is no “best” approach for downscaling AOGCM output, and the choice of downscaling approach might depend on the topic. Hydrologists interested in daily peak flow might choose one method, while terrestrial ecologists interested in temporal variation in tree growth might choose another method. Because terrestrial and hydrologic systems are coupled, it is preferable to examine them simultaneously within a single model. Even if a good model of this type is unavailable, examining interactions from different perspectives and under different scenarios, downscaled or not, provides the best insights.

Climate change effects models—Models are often needed to project future ecosystem response to changing climate as a component of vulnerability assessment. Many models are available at different spatial (table 1) and temporal (table 2) scales. Mechanistic models (also called process-based models), gap models, and climate envelope models (CEMs) (also called species distribution models) are the ones most often used to project the effects of climate change on ecosystems, vegetation, and species. Landscape models, a subset of grid-based ecosystem models, are focused on a “visual” landscape and range from purely statistical to highly mechanistic (Scheller and Mladenoff 2007). Spatial extent and resolution vary greatly among landscape models. Each model type has characteristic spatial scales of application (figs.1 and 2) and various strengths and limitations.

Mechanistic (process-based) models use mathematical relationships to represent physical and biological processes and the interactions of those processes. Mechanistic models that simulate the effects of climate change on vegetation include dynamic general (global) vegetation models (DGVMs). DGVMs simulate physiological processes to infer vegetation life form over time (Robinson et al. 2008). DGVMs are based on soil, water, and climatic information (hourly to yearly), can respond to novel climate and carbon dioxide concentrations, and often produce their own fire regimes as an emergent property (e.g., Lenihan et al. 2008). DGVMs are based on processes that range from leaf physiology to competition (Prentice et al. 2006). They have been successfully implemented on landscape grids of 30-50 m resolution, but are typically used to simulate vegetation from subregions (e.g., >10,000 km^2) to the entire Earth surface. The grain, or cell size, of projections depends on the spatial scale of the gridded soil and climate data. Output shows distributions of broad vegetation functional types over time, which can be combined into a physiognomic classification, such as “Broad-leaved, Deciduous Forest or Savanna” (e.g., Bachelet et al. 2003). Boundaries between these classes define ecotones that can be compared to maps for verification. DGVMs can identify limiting factors in different regions, and can consider complex topography, land-use change, management, insects, and herbivores (Prentice et al. 2006).

Gap models simulate vegetation interactions and dynamics on a small land area. In-growth, growth, and death of trees of one or more species are simulated over time. The scale of gap models is that of a “gap” caused by a tree blowdown. They are usually implemented for areas <1 ha to a geographic province (Robinson et al. 2008). Dynamics in gap models are based on species-specific parameters, competition, light, temperature, and soil moisture. Output includes density, basal area, biomass, and leaf area index by species and by stand (Robinson et al. 2008). Information on each live tree is available (e.g., species and diameter). Gap models use monthly temperature and precipitation, and so can respond to novel climate. They are also sensitive to changes in soil moisture and carbon dioxide concentrations.

Climate envelope models are statistical models that predict future species (both plant and animal) distributions based on the relationship between current species distribution and climate variables (and sometimes other variables) (Guisan and Zimmermann 2000). The spatial resolution of CEMs varies, but usually ranges from about 1 km to >15 km. Output can be developed into maps of expected changes in species distribution with climate change. However, CEMs represent a snapshot in time and do not show variability in species distribution over time (Guisan and Thuiller 2005). These models assume that climate is the primary determinant of a species distribution and that the current relationship between a species and climate will remain constant in a warmer climate, assumptions that are nearly always incorrect (Pearson and Dawson 2003). Despite recent efforts to include ecological factors other than climate in CEMs (e.g., Williams et al. 2005), most models do not adequately account for competition, dispersal, evolutionary change, increased carbon dioxide, or changes in disturbance regimes (Guisan and Thuiller 2005). Thus, output from CEMs should be interpreted with caution. Output of CEMs is best applied with coarse resolution at continental scales and for highly dispersive species that are more likely to be able to fill their potential ranges as determined by future climate (Pearson and Dawson 2003).

Guidelines for using models for vulnerability assessments—Attention to some general concepts about uncertainty associated with climate models and climate change effects models in natural resource management will assist vulnerability assessments:

- Use climate change projections from a **range of models** if possible, but also consider variation among models.
- When assessing projected climate change and climate change effects, **focus on similarities** between different future climate and effects scenarios and the most likely trends, but remember "all models are wrong" and the one "outlier" might be the most accurate.
- For model output with discrete time points (e.g., 2050, 2100), consider the variability and uncertainty that exist between time points, and **incorporate (or at least take note of) uncertainty in time series data** and how it might affect applications of the data**.**
- Determine if it is possible or necessary to obtain downscaled data for a particular landscape, and recognize that **coarse-scale data may be sufficient** for most applications.
- To interpret model output, **focus on coarse-scale changes** and relate them to likely changes in ecosystems and species in a given area using local expertise and experience.
- When assessing sensitivity to climate change, **consider changes that have been observed with climatic variability** in the past or that have been observed with recent warming, but also consider how these observations could be modified under a higher carbon dioxide concentration with important physiological effects not represented in historical analogs.

Using and Assessing Scientific Information

“Information overload” makes it difficult to store, manipulate, analyze, and visualize scientific data, as well as to identify the best available science to incorporate in resource management. Most of the scientific literature on climate change is at regional and larger scales, although an increasing amount of information is available at sub-regional scales (e.g., Elsner et al. 2009). Finding and evaluating scientific information relevant for a vulnerability assessment can be challenging, and working with local scientific experts is often necessary. Predicted effects of climate change may be uncertain and conflicting, which requires users to consider the scientific credibility and applicability of different sources. The principles described below can help determine the best available science for a particular application (Peterson et al. 2007).

Keep processes objective and credible—Summarize the principles, information, and tools available for a particular topic, then determine if appropriate peer review has been conducted according to standards for the application of scientific information in resource management on public lands (Federal Register 2002, Office of Management and Budget 2004). Lack of peer review for a particular model does not mean it has no value, but that it has lower scientific stature and does not meet the normal standard for scientific rigor. Including a short description of limitations and uncertainty associated with various tools, models and other information is often appropriate.

Look for success stories—If you can identify cases in which tools and information have been successfully applied to a situation similar to yours, then you have a good recommendation for your application. This may be an actual adaptation case study in a national forest, or in the case of a recently developed hydrological model, it could be a demonstration in which positive feedback was received (app. 1). In either case, other users are available from whom you can obtain insight.

Consult with experts—It can be helpful to directly contact the developer of a particular tool or technique for additional information and insight on principles and applications. If you are considering an application somewhat outside the scope described for a particular technique (e.g., a forest growth model that claims to incorporate the effects of climate), get some feedback first. Although few tools are fully supported by technical personnel, a few experts on design and application are typically available. Seek them out for a consultation, and consider inviting them to work with you and your staff.

Compare alternatives—Even if you have a preferred source of scientific information for a particular application, it is usually best to compare it with other sources. Although no single information source of climatic information may be more “correct” than another, it is helpful to know the differences between sources. You may need to defend the value of your preferred choice, and documentation of alternative approaches for obtaining climatic information allows for ready comparison and development of rationale for your preferences.

Document the selection process—Take good notes as you go through the process of reviewing and selecting appropriate climatic information and tools. Keep a file with appropriate documentation of publications, user guides, scientists consulted, managers consulted, etc. A structured approach to compiling climatic information improves the overall credibility of analyses and adaptation planning.

Consult outside reviewers—After you have selected specific sources of information for a particular application, have technical experts review plans or reports that cite those sources. Reviewers can include scientists, managers, planners, policy makers, and informed stakeholders—basically anyone within the broader user community who has some technical knowledge about climate change and natural resources. Review comments help determine if your selection and use of scientific information are appropriate and if planning documentation contains sufficient justification.

Consult potential stakeholders—After you are confident that you have addressed relevant technical issues, it is often valuable to “preview” vulnerability analyses and adaptation plans with stakeholders who may be affected by your management actions. This requires nontechnical language to explain and justify your selection. Straightforward graphics and tables are often the best way to convey your ideas to interested parties who do not have technical expertise in natural resources.

Implementing these additional steps can require considerable time and effort, but they improve the scientific credibility of the final product and are a valuable investment in the long run. If local resource managers are not familiar or comfortable with this sort of scientific review, it can be useful to consult with another management unit that has experience with the process.

Facilitating Adaptation through Science-Management Partnerships

Our experiences in working with federal agencies to prepare for climate change have varied according to organizational structure, level of engagement in climate change issues, local involvement in planning processes, local emphasis on different resource objectives, and personal preferences regarding communication and collaboration. This variation is normal, and one would not expect that a single process or approach would necessarily work for all management units. In working with these diverse units, we have found several processes that facilitate the development of adaptation. These processes include developing a science-management partnership, sharing of climate change science by scientists, sharing of local management (and often climate) knowledge by managers, identifying available scientific information, identifying available tools to assess effects of climate change as a basis for setting priorities, and using facilitated workshops to develop adaptation options.

Developing a Science-Management Partnership

A science-management relationship is critical for both the scientific basis for proposed adaptation options and the management expertise to develop those options (Littell et al., in press). This partnership typically evolves from initial discussions between scientists and federal resource managers, followed by an agreement to work together. These discussions about climate change and adaptation identify the goals of the adaptation project and the process to reach those goals. Commitment to work together is critical, because a year or more may be needed to complete workshops, individual dialogues, and writing. The science-management partnership must have good communication, a consensus on specific objectives, an established schedule, and a clearly identified written product to document the results. A commitment by a national forest or other organization to the process of adaptation will need to endure for decades, because of the long-term nature of climate change effects.

Starting the conversation—A strong collaborative relationship between scientists and resource managers is the foundation for a successful adaptation effort on federal lands (Vogel et al. 2007). The approaches that we have used in case studies were tailored to specific resource conditions, resource staff capacity and priorities, and general readiness of units to discuss climate change and adaptation. The legacy of past management often sets the stage for current resource concerns, and national forests are often at different stages of the forest planning process or other planning processes such as travel management. In addition, availability of place-based research varies across national forests and adjacent lands. Differences among national forests in these conditions can result in different approaches for internal and external engagement regarding climate change issues.

An adaptation case study in Washington focused on Olympic National Forest and Olympic National Park. Forest Service and National Park Service resource managers on these adjacent management units were accustomed to working together on issues of common interest, so they could quickly engage with each other, as well as with the topic of climate change. The availability of scientific expertise on climate change science at the University of Washington Climate Impacts Group provided additional credibility to the scientific component of the case study. Resource managers were initially concerned about the time required for the adaptation process, including the eight planned workshops. With this concern in mind, all sessions were designed to efficiently communicate and elicit information in deference to the small amount of time most managers had available.

Adaptation case studies in California were conducted on Tahoe National Forest (northern Sierra Nevada), Inyo National Forest (southeastern Sierra Nevada), and Devils Postpile National Monument (central Sierra Nevada crest). Similar to the case studies in the Pacific Northwest, collaboration between the Forest Service and National Park Service staffs in this area of California helped to contribute to a collegial and effective partnership. The interest of Tahoe National Forest was focused on on-the-ground activities and addressing climate change considerations in those activities. Inyo National Forest was embarking on revision of its land management plan at the outset of the project, and Devils Postpile National Monument was embarking on development of a general management plan. These interests tended to focus the process on broader issues such as quaking aspen (*Populus tremuloides* Michx.) on the Inyo National Forest and the potential for climate refugia in Devils Postpile National Monument. Because Inyo National Forest encompasses large amounts alpine and semi-arid mountainous terrain, issues concerned wilderness, recreation, grazing, water, wetlands, forests, and fire. Although the initial focus was on incorporating climate change issues in the land management plan revision process, the appeal of the national planning rule shifted the case study objective to adaptation planning for resource projects. Several place-based research studies were available at Devils Postpile National Monument, offering valuable information to consider in the development of adaptation options.

We found that larger national forests (e.g., Inyo National Forest, where ranger districts are more autonomous) preferred a few large workshops including personnel from throughout the forest, whereas smaller national forests (e.g., Olympic National Forest, where management is more centralized) preferred several small workshops for personnel in the forest headquarters. It is better to customize a process to match personal preferences and experience with climate change issues in a given location, rather than impose an off-the-shelf process that may be poorly suited to local objectives or working styles.

Many kinds of collaborative approaches can be used to convene groups and elicit information for specific applications, and our efforts represent only a small sample. The value of collaborative approaches is enhanced by effective leadership, well organized sessions, and a strong commitment by all parties to participate. Collaborative processes will have a high probability of success if these characteristics are established early in the project. Climate change adaptation can also build on prior collaborations established for topics like ecological restoration and ecosystem management,

Sharing Scientific and Management Knowledge—Critical Roles for Scientists and Managers

Development of adaptation options depends on retrieving information from over 20 years of climate change science and the experience and place-based knowledge of resource management staffs. Both types of information must be brought into the discussion of adaptation. All personnel involved in the adaptation process need a fundamental, consistent understanding of the physical and biological phenomena affected by the changing climate. Similarly, scientists must be aware of local conditions and concerns.

Methods for communicating climate change science varied among the case studies from one-day science workshops to longer more focused short courses. These kinds of sessions are focused on education but have the additional benefit of confirming the commitment of local management units and line officers to prepare for climate change, as well as building the science-management partnership necessary to do so. These educational sessions may also set the stage for a focused dialogue on climate change adaptation.

A broad focus on climate change and climate change effects, including reference to local conditions and concerns, ensures a consistent scientific foundation prior the next steps in the process. Bringing the experience and place-based knowledge of resource managers into this discussion of adaptation options is critical. Managers have many years of experience, including experience with weather-related or climatically extreme events. Exploring past weather- or climate-influenced events may result in a basis for some adaptation strategies in the future. Managers can reflect on situations in which unusual weather-related conditions affected terrestrial or aquatic resources for which they were responsible. Discussion about the type of event and about what could have improved the management response may help focus the conversation with scientists on the types of information that would be helpful now and in the future (table 4).

Climate change education—*Preparing National Forests for adaptation*—Incorporating climate concerns into land management benefits from active dialogue between scientists and land managers, each providing the other with experience from their skills, knowledge, and

perspectives. In the northeastern and upper Midwestern U.S., the Northern Research Station has been working with the Eastern Region and other institutions to build awareness of climate change issues and explore how climate change can be incorporated in planning and management. Ongoing climate change education in these areas is viewed as a sustained dialogue. It is intended to increase institutional capacity to understand the likely effects of climate change and to begin taking reasonable actions in specific places to adapt ecosystems to these potential effects. Educational approaches used in the Eastern Region are summarized below. Similar approaches have been successfully used in other Forest Service regions as well.

***Overall approach*—**Recognizing the varied needs among national forests and resource areas, a multi-layered approach was developed to facilitate climate change education and dialogue. An effort to build a comprehensive regional education program incorporated several elements, including basic education, intensive training, and discipline-specific workshops (fig. 3). Although information is conveyed to different audiences at different levels of complexity, three fundamental components are common to each educational element: climate change science, ecosystem response to climate change, and management strategies and approaches for adaptation and mitigation. **Education goes in both directions, with scientists providing the latest high-quality information, and practitioners discussing important forest-level considerations and realistic management responses to ecosystem change.** The intent is to effectively use existing information and develop approaches, drawing from the combined expertise of all participants.

***Elements of the educational process*—**Each element within the integrated educational approach has a different structure designed around the educational objectives, needs of participants, and desired products. The outcomes may include general information sharing, integrating climate change adaptation into national forest plans, and altering or creating specific management tools.

Basic educational seminars convey fundamental principles of climate change and the effects of climate change on ecosystems and generate discussion of how different resource areas can adapt to projected changes. One- to two-day seminars consist of presentations on climate change, forest response, and management strategies, followed by a session customized to local needs. The latter session may include brainstorming and discussion or may be used to create lists of potential activities that can occur at the national forest and project levels. Facilitators are available to answer questions, provide continuity by sharing ideas from previous seminars, and maintain a dialogue focused on climate change activities. These seminars may be used to set the stage for subsequent training, activities, and intra-forest discussion.

Intensive training includes week-long courses providing more in-depth information than the seminars. The course includes pre-work and a final project to be concluded within the participants' forest. Intensive training provides participants with a detailed explanation of fundamental climate processes and interactions, as well as greater detail of the mechanisms of forest response to climate stressors. Tools and applications relevant to climate change are presented in by experienced instructors. Participants are given the opportunity to evaluate issues or resources in their own national forests using these tools. Strengths and limitations of the tools for management-related decision making are emphasized, and information gleaned from these exercises feeds into subsequent adaptation lectures and discussions.

Discipline-specific trainings allow for focused presentation and discussion of climate change implications for specific resource areas. Although much of the information on climate change science, forest response, and management strategies described for the above elements is also included in these trainings, information most relevant to particular resource areas is emphasized. This type of training is designed to draw upon participant expertise and interest. For example, a two-day regional silvicultural workshop incorporated scientific presentations on climate change effects on forest ecosystems, a brainstorming session on silvicultural considerations for climate change, and breakout sessions to develop regional strategies and local approaches for silviculture in the face of climate change. A similar approach could be used for trainings in other disciplines.

Targeted workshops draw upon the skills of land managers, with the intent of designing or altering techniques and programs to incorporate climate change considerations. These also involve collaboration between researchers and managers, with discussion facilitated by the questions “Which current management approaches are compatible with adaptation, and which need to be modified?” and “How can we modify management in response to climatic variability and change?” As climate change challenges become more clearly identified, targeted workshops help pool expertise to meet specific needs of land managers and focus on specific issues, resources, and locations.

Customizing the educational approach to meet local needs will address climate change issues that vary by national forest, resource area, level of knowledge, and availability of resources. Adapting educational elements to specific needs and outcomes of national forests and resource areas promotes efficient and productive discussions.

Identifying Available Scientific Information in Projects and Plans

Information sources—A relevant question for the planning process is “How is climate change likely to modify conditions on the planning unit?” (USDA FS 2010b). Scientific information on climate change is periodically synthesized into international, national, regional, and sometimes local (as in national forest) reports by different organizations. Examples range from IPCC reports (Solomon et al. 2007) at the international scale, to review of the status of aspen at the local scale for case studies at the Inyo National Forest and Tahoe National Forest (Morelli and Carr, in press). These assessments offer a synthesis of science (what is known), an evaluation of state-of-sciences information (what is not known), and often some recommendation on confidence about potential effects of climate change on resources and ecosystems (how well something is known). Syntheses and assessments may help identify risks and vulnerabilities within a planning unit. Rigorous scientific review of syntheses and assessments further enrich the value of that scientific information.

The Forest Service Renewable Resources Planning Act (RPA) assessment provides a snapshot of current U.S. forest and rangeland conditions on all ownerships, identifies drivers of change including climate change, and projects resource conditions 50 years into the future. This assessment by the Forest Service is the only legislatively required analysis with respect to climate change and Forest Service planning (1990 Organic Foods Production Act, which amended the Forest and Rangeland Renewable Resources Planning Act of 1974 [RPA]). The specific analysis of climate change required by the Forest Service is to assess the effect of climate change on renewable resources in forests and rangelands, and to identify the rural and urban forestry opportunities to mitigate the accumulation of atmospheric carbon dioxide. Since 1990, RPA assessments (e.g., USDA FS 2001)[2] have included an analysis of vulnerability of U.S. forests to climate change (Haynes et al. 2007, Joyce and Birdsey 2000). These national assessments synthesize current understanding about climate change and forest and rangelands and provide information to Forest Service strategic planning (Joyce 2007).

The 2010 RPA assessment is considering the climate change effects on water, wildlife, recreation, rangelands, and forest condition. In addition, the 2010 RPA assessment will use GHG emission scenarios from IPCC (2007) to explore future variability and uncertainty in resource conditions (fig. 4). Three scenarios (A2, A1B, B2) (see IPCC [2007]) applied to three climate models provide nine scenarios for analysis. The assessment focuses on opportunities for and vulnerabilities in renewable resource production in changing climates and different economic and population futures. These analyses at the national level offer a context for potential vulnerabilities of ecosystems, as well as opportunities and barriers for resource production at regional or smaller spatial scales. Individual resource analysis may identify sensitivities within regions, watersheds, and landscapes, as well as situations of high resilience to climate change or situations in which climate change effects might be locally buffered.

The U.S. Global Change Research Program is responsible for providing scientific knowledge to inform management of risks and opportunities associated with changes in climate and natural resources. To support its mission, 21 synthesis and assessment products (SAP) were written as the current state of science for a wide range of climate change issues. Two synthesis and assessment products are relevant to management of national forests and national grasslands: *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity* (SAP 4.3) (Backland et al. 2008), and

Preliminary Review of Adaptation Options for Climate-sensitive Ecosystems and Resources (SAP 4.4) (Julius and West 2008). SAP 4.3 describes how climate change will affect forest and arid land ecosystems, including variability in different regions. SAP 4.4 provides a synthesis of adaptation options for federally managed lands and waters, as well as the scientific basis for those options.

This guidebook builds mostly on the national forests and national parks chapters in SAP 4.4. Other sections of the guidebook highlight processes used by science-management partnerships to identify what is known about climate change, what is not known, and uncertainty about projecting future scenarios. This is relevant for workshops in which unique characteristics of a national forest are discussed in light of current information at regional and local spatial scales. Written reports, such as those recently prepared by Inyo National Forest and Shoshone National Forest on aspen and climate (Morelli and Carr, in press), also help to provide a common synthesis and assessment of scientific information relevant to a management unit in a particular geographic location.

Information on future climatic scenarios and effects of climate change provide insight on probable future conditions of ecosystems on federal lands. For example, DGVM modeling results have been used to depict future vegetation changes in the Pacific Northwest (fig. 5). This information assists land managers in identifying broad changes that may affect landscape condition and habitat for plant and animal species.

Climate Change Resource Center

The mission of the Climate Change Resource Center (USDA FS 2011b) is to provide U.S. land managers with an online portal to access science-based information and tools concerning climate change and ecosystem management options (table 5). The CCRC objectives are to (1) synthesize scientific literature on ecosystem response, adaptation, and mitigation, (2) highlight recent scientific research that has practical applications for practitioners on public and private lands, (3) support communication of information through a user-friendly interface and appropriate use of multimedia, and (4) work with scientists to develop educational presentations.

Management responses to climatic challenges depend on access to adequate decision-making tools. Climate change science is rapidly evolving as data are collected and analyzed and as changing climate contributes to ecosystem changes. Although a wealth of online information is available concerning climate change, it can be difficult to determine which sources are current and scientifically sound. The CCRC assembles relevant scientific knowledge and expertise to present a coherent picture of how climate change may affect land management planning and practices. The website highlights existing resources that are scientifically credible, peer reviewed, and relevant to managers, with regularly updated content.

An editorial board comprised of representatives from Forest Service research stations and other organizations has developed scientific standards and regularly reviews proposed revisions to the CCRC. The board also reviews content changes and additions that have potential policy relevance. Contributing editors, a group comprised of scientists, land managers, and communication professionals, contribute content and assist with special projects. A review team comprised of resource managers provides feedback to the production team on CCRC website content and its relevance and usability for land managers.

Assessing the Effects of Climate Change, Developing Adaptation Options, and Setting Priorities

Developing a vulnerability assessment—Vulnerability to climate change can be defined as “the degree to which geophysical, biological, and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change” (Solomon et al. 2007). Vulnerability is a function of the variation to which a system is exposed to a change in climatic conditions, its sensitivity to that change, and its adaptive capacity (Gallopín 2006, Solomon et al. 2007). In a climate change context, **exposure** can be thought of as the degree, duration, or extent of deviation in climate to which a system is exposed. **Sensitivity** is the degree to which a system is affected, either positively or negatively and directly or indirectly, by climate-related stimuli (Solomon et al. 2007). **Adaptive capacity** is the ability of a system to adjust to climate change (including climatic variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (Solomon et al. 2007). Adaptive capacity is often thought of as the ability of socio-economic systems to cope with climatic variability and associated impacts. Vulnerability to climate change can be reduced in two main ways: through mitigation of GHG emissions which reduces exposure to climate change, and through adaptation which reduces sensitivity and enhances adaptive capacity.

Vulnerability can be assessed at any spatial or temporal scale, and can apply to a forest stand, watershed, region, community, population, or any socio-ecological system of interest. Vulnerability has been applied to society, ecological systems, and coupled socio-ecological systems, depending on the area of interest (Gallopín 2006). In natural resource management, vulnerability is often referred to in the context of ecological systems, with greater focus on the exposure and sensitivity components of vulnerability. For the purpose of adaptation in resource management, assessment of climate change vulnerability can be qualitative, quantitative, or both. Most vulnerability assessments involve both quantitative and qualitative aspects, often incorporating quantitative estimates of exposure, but more qualitative estimates of system sensitivity and evaluation of human capacity to respond.

The first step in most vulnerability assessments is a review of available climate model projections to determine likely levels of exposure to climate change. Then, relevant literature and model projections of climate change effects are reviewed to identify likely climate change effects in various resources (e.g., hydrology, vegetation, etc.). Scientists and specialists can be consulted to interpret available information and apply it to local ecosystems, a step that is often necessary because information on climate change effects may be available only at a regional to subregional scale. This downscaling to finer scales of application can be quantitative, requiring manipulation of climatological data, or qualitative, based on expert judgment. Finally, current management activities and management constraints are identified to evaluate different aspects of adaptive capacity, or the capacity to implement adaptive actions.

Watershed vulnerability assessment as currently being developed in the Forest Service (Furniss et al. 2010) (app. 2) is a strategic assessment process that describes conditions, processes, and interactions at intermediate scales, adapting large-scale guidance, analysis, and approaches to ecosystem management to particular places at management-relevant scales (table 6). Design of useful strategies for reducing the effects of climate change on watershed goods and services requires the ability to (1) identify watersheds of highest priority for protecting amenity values (e.g., domestic and industrial water supplies, endangered species, and recreational uses), (2) identify watersheds in which climate-related risk to those amenity values is greatest and least, (3) detect evidence of the nature and likely magnitudes of change as early as possible, and (4) select actions appropriate for reducing effects in particular watersheds. Steps 3 and 4 need to consider both climate effects and other biophysical factors.

Watershed vulnerability assessment provides watershed-specific information needed to prioritize and design strategies for reducing the effects of climate change on watershed-sourced goods and services, and are applicable in the context of a Forest Service watershed condition assessment and as a stand-alone assessment procedure for use by anyone concerned about watershed dynamics. The types of questions to be answered using this assessment are summarized in tables 6 and 7. Watershed vulnerability assessment incorporates a large amount of data on existing species population status, location and distribution of key habitats, and projected changes in stream temperatures, low flows, peak flows, and disturbance regimes to determine species and locations that are most susceptible to climate change. Local managers and field specialists can identify local constraints on species and habitats, and opportunities to address them through management activities.

Rapid assessment of climate change effects and management options—An ideal decision support system for climate change adaptation promotes adaptation thinking, as well as specific adaptation options that can be implemented in resource management. The climate project screening tool (CPST) was developed to address this need and to formalize the process for incorporating climate change information (Morelli et al., in press[b]). The CPST is a process-oriented, priority-setting tool that allows users to consider effects of different actions and direct management. It also attempts to reduce uncertainty in decision making by identifying the range of effects that management actions may have on resource conditions.

The CPST is a straightforward, structured approach for evaluating specific kinds of projects for federal lands (table 8). For each project activity, the CPST: (1) summarizes climate change trends and local effects (vulnerability assessment), (2) poses key questions to resource managers regarding how those effects might influence the project activity, (3) requires managers to complete a narrative that summarizes responses to the questions in #2, and (4) concludes with a judgment to continue the project without modification, continue the project with modification, or not continue the project. All steps consider how potential climate effects may interact with other biophysical factors that affect resource conditions.

The CPST can be applied to a wide range of project activities, such as restoration (e.g., meadows, wetlands, wildlife habitat), fire and fuels management (e.g., forest thinning, prescribed burning), silvicultural activities (timber harvest, reforestation), road management (e.g., maintenance , culvert replacement), and recreation planning. These activities can be addressed by the CPST at large spatial scales (e.g., national forest) or smaller spatial scales (e.g., small watershed). They can be addressed for general and strategic cases (e.g., forest thinning) or for specific applications (e.g., forest thinning in a specific management unit).

The CPST can be applied directly to a land management plan, general strategic plan (e.g., fire management plan) or a specific project (e.g., forest thinning operation). It is especially useful before the preparation of NEPA documents, because the CPST can evaluate the effects of alternative activities in a warmer climate. Although not required within the CPST, scientific documentation (i.e., references from the scientific literature) can strengthen the rationale for each decision. The amount of detail included in each category of the CPST (table 8) may depend on the amount of information available on climate change effects and on preferences of individual users. If specific climate change trends and effects are uncertain, or there could be multiple outcomes, it is helpful to articulate all possibilities if the selection of one outcome is not possible, allowing multiple key questions and multiple responses to be summarized. An accurate representation of uncertainty is a valuable part of the decision-making process and should not be considered ambiguous (Granger et al. 2009).

Facilitated workshops to develop options for adapting to climate change—Building on educational sessions and review of available scientific information and tools, a science-management partnership can begin to focus on specific climate change adaptation issues and options for resource management. Adaptation options are developed after the scientific information available and tools to identify vulnerabilities have been completed. Adaptation options are typically generated for individual resource disciplines (e.g., vegetation, wildlife, water), although it is also possible to focus on adaptation for individual biogeographic entities (e.g., watersheds, subalpine forests, coastal ecosystems) and projects (e.g., forest thinning at a specific location, bridge design).

In general, **scientists provide information on climate change and climate change effects including vulnerability assessments (e.g., table 9), and resource managers provide strategic and/or tactical adaptation options (e.g., table 10) and guidance on how they can be implemented.** A research scientist or similar person with training in climate change science can provide scientific information and interact with resource management staff during the adaptation effort. A resource staff director or similar person with oversight of resource management can provide management leadership, coordinate with scientific experts, and ensure communication with local managers involved in the adaptation effort. Frequent discussions among all participants ensure that activities are proceeding according to schedule. Opportunities may also exist to include university scientists, nongovernmental organizations, and other stakeholders in the collaboration.

In the Olympic case study, Forest Service and National Park Service managers jointly requested that the case study focus on hydrology and roads, vegetation, wildlife, and fish. For each disciplinary topic (hydrology and roads, vegetation, etc.), a one-day workshop explored the vulnerability of each resource to a changing climate. Vulnerability assessment workshops consisted of several scientific presentations followed by facilitated discussion through which a list of potential effects was compiled. A subsequent workshop was convened to develop adaptation options based on the vulnerability assessment. This dialogue resulted in a list of adaptation options for management issues within each disciplinary topic. This entire process was documented and peer reviewed (Halofsky et al., in press) and is now used by resource managers when considering climate change issues in plans and projects.

In the Tahoe case study, resource managers requested a structured approach that would facilitate evaluation of a large number of management objectives and specific projects. Therefore, the CPST (Morelli et al., in press[b]) was used as a means of evaluating the relevance of climate change for projects on the Schedule of Project Actions (SOPA) list. This tool was used to compile a summary of expected climate change effects next to potential management actions that will help address those effects.

Inyo National Forest staff had several specific requests of scientists as part of the case study process: (1) compile a summary of climate trends and adaptation options relevant to the eastern Sierra Nevada (Morelli et al., in press[a]); (2) develop a regional bibliography of information on climate change (e.g., USDA FS 2011a); (3) establish a technical advisory board that includes climate scientists conversant in eastern Sierra regional issues (box 2); (4) prepare a report and field survey for a potentially novel climate threat to quaking aspen in the eastern Sierra (Morelli and Carr, in press); (5) participate in the public engagement process before the land management plan revision process; and (6) convene facilitated climate applications workshops (box 3). A primary objective was to implement resource treatments informed by case-study discussions and products, and to incorporate climate considerations in the land management plan revision. This process was documented and will be published so resource managers can use it when considering climate change issues in plans and projects.

As part of the Inyo case study, Devils Postpile National Monument, whose lands are surrounded by Inyo National Forest, identified as priorities a need for high-resolution climate monitoring, and the potential role of the Monument as a cold-air pool that could serve as a climate refugium for some species in a warmer climate. Interest in the latter prompted a request for scientists to develop an analysis of cold-air pooling in the upper watershed of the monument. In this case, focusing on a relatively small management unit required that scientific and management issues be considered at small spatial scales. Case study activities at the monument had a strong focus on science, including a combined field and classroom workshop, a summary of ongoing research, and a synopsis of research and monitoring efforts needed to guide future adaptation efforts. This process was documented and will be published so resource managers can use it when considering climate change issues in plans and projects. A scientific technical committee will be convened to consult on general management plan development and to advise on implementation of adaptation treatments.

In the Shoshone National Forest case study, resource managers were interested in a synthesis of the current literature on climate change effects of the area encompassing the Shoshone National Forest. This review describes what is currently understood about the climate of the Shoshone National Forest and the surrounding Greater Yellowstone Ecosystem, including paleoclimate, and how future climate change may affect plants, animals and ecosystems. Resource managers were also interested in a vulnerability assessment to provide information for the forest planning process. The ongoing vulnerability assessment focuses on key water and vegetation resources.

The variety of case study activities described above reflects the diversity of local needs and preferences for how climate change is integrated in management and planning. It also reflects different organizational cultures and management styles. These differences need to be respected as a component of the science-management partnership. Customizing conceptual and logistical aspects of the adaptation dialogue to accommodate local circumstances will contribute to effective discussions and outcomes.

Another important component of facilitated dialogue is capturing ideas and information that are relevant to preparing for a warmer climate but may not be explicit adaptation options (e.g., table 11). For example, it is helpful to summarize opportunities and barriers to adaptation as a context related to administrative process, policy, and budgets that affect all management issues (table 12). It is also helpful to compile a list of analytical tools and information needs that can assist the adaptation process (table 13). This provides a heads-up for the science-management partnership on future steps that may be needed to facilitate adaptation and informs scientists about specific ways in which they can help.

Documenting in reports all aspects of the workshops, scientific information, vulnerability assessments, and adaptation options ensures a unified statement on adaptation for the participating units and interested stakeholders. The reports are a reference for management, not an “official” planning document. To date, national forests and national parks have chosen to develop mostly strategic adaptation options, as opposed to specific actions at specific places, but both strategic and tactical adaptation are useful outcomes of facilitated workshops.

Implementing Climate Change Information in Planning

Climate change will influence many ecological and socio-economic components of national forests and interact with climate change effects on neighboring landscapes. If climate change is not considered, factors that could inhibit sustainability of ecosystem services may be overlooked. It will be important to anticipate and plan for surprise and threshold effects associated with climate change that are difficult to predict yet certain to result from the interaction of climate change and other stressors (e.g., unprecedented large fires and insect attacks). In addition, it will be increasingly important to include climate change considerations in planning to avoid appeals and litigation.

Although historical conditions are a useful reference, as the local effects of climate change become apparent, an adaptive management approach can be used to test assumptions about ecological change and make adjustments in desired future condition and in goals and objectives of plans (Joyce et al. 2009). Flexibility to address inherent uncertainty about local effects of climate change in the future could be achieved through enhancing the resilience of ecosystems now. These assumptions would allow the plan components to be designed in a way that allows for adaptation to climate change, even though the magnitude and direction of that change is uncertain.

The adaptive capacities of the social and economic environments in which national forests exist, as well as physical, institutional, social, political, economic, and technological barriers to adaptation influence the success of the planning process. Whereas the public is actively involved through commenting on proposed actions on national forests, the broader community of policy makers, managers, scientists, stakeholders, and the general public will benefit from evaluating specific evidence of climate change and its projected consequences in the context of desired choices, future opportunities, risks, and difficult tradeoffs. Neighboring land managers and private land owners will likely observe species, populations, and ecosystems changing across broad landscapes in a warming climate. Opportunities to address vulnerability to climate change will require collaboration, as well as the recognition that human communities and a range of economic sectors, which are also dynamic systems, benefit from natural resources. Consideration of climate change in the planning process thus calls for enhanced collaboration within the matrix of ownerships surrounding national forests and with interested stakeholders.

Federal, state, and local organizations are just beginning to consider how adaptation will be addressed in planning processes (GAO 2009). Most planning processes are premised on a climate that is stationary, constant frequencies of natural disturbances, and ecosystems that respond to climate and management as in the past. These assumptions, which are fundamental to the way organizations, institutions, and people make choices, are no longer valid. Current attempts to incorporate climate change considerations into planning at federal, state and local levels include a focus on assessing the effects of climate change, identifying vulnerabilities to climate change, and developing adaptation options (Cruce 2009, GAO 2009, Heinz 2007). Challenges for national forests engaged in planning for adaptation to climate change will be similar to those identified by most federal agencies and other organizations: competing priorities, lack of site-specific information about changes in climate and effects to ecosystems and economies, and lack of clarity on roles of various institutions in adapting to climate change.

Legislated Climate Change Analyses to be Completed by the Forest Service

The RPA (1974) requires a national renewable resource assessment to provide reliable information on the status and trends of the nation's renewable resources on a 10-year cycle. The RPA assessment provides a snapshot of current U.S. forest and rangeland conditions and trends on all ownerships, identifies drivers of change, and projects 50 years into the future. Analyses of the status and trends for recreation, water, timber, wildlife (biodiversity) and range resources as well as land-use change and urban forestry are included. With respect to climate change, two additional requirements were added as an amendment to the RPA in 1990: (1) an analysis of the potential effects of global climate change on the condition of renewable resources on the forests and rangelands of the United States, and (2) an analysis of the rural and urban forestry opportunities to mitigate the buildup of atmospheric carbon dioxide and reduce the risk of global climate change.

The 2010 RPA assessment is considering how future renewable resource conditions are influenced by common driving forces such as population change, economic growth, climate change, and land use change, as well as other drivers of change unique to individual resources (fig. 4). As noted previously, a scenario approach based on different GHG emission futures is being used to characterize the common demographic, socio-economic and technological driving forces underlying changes in resource condition and to evaluate the sensitivity of resource trends to a feasible future range of these driving forces. The use of scenarios links underlying assumptions of the individual analyses and frames the future uncertainty in these driving forces within the integrated modeling and analysis framework of the 2010 RPA assessment. Data on population projections at the county level, economic projections, and downscaled climate scenarios will be available (Coulson et al. 2010). As in previous assessments, these RPA results may offer information for other levels of planning.

Planning in National Forests

The Forest Service uses a two-stage approach to decisions guided by the National Forest Management Act (NFMA) and NEPA. National forests conduct a variety of assessments within their planning efforts (watershed analysis, landscape assessments, roads analysis) (fig. 6). Every national forest and national grassland must develop a forest plan which is guided by the NFMA. National forests also use other processes to gather information, such as landscape assessments. Watershed vulnerability assessment would be an example of a process (fig. 7, left side of the triangle) that gathers information about climate change and watersheds. Forest plans are to be amended as necessary and revised at least every 15 years. The process for the development and revision of the plans (fig. 7, right side of the triangle), along with prescribed content, is outlined in planning regulations, or the national planning rule, which addresses adherence to NEPA.

An initiative to develop a new planning rule began in December 2009 with a Federal Register Notice of Intent (NOI). The NOI outlines a process for developing a new national planning rule, as well as proposing substantive (content) principles and process principles that would guide how forest plans are developed and revised. Substantive principles emphasize: (1) restoration and conservation to enhance ecosystem resilience, (2) effects of climate change and role of monitoring, mitigation, and adaptation planning, (3) maintenance and restoration of watershed health, (4) provision for diversity of species and wildlife habitat, and (5) sustainable lands that support vibrant rural economies. Process principles emphasize: (1) collaborative engagement with all stakeholders, (2) an “all lands” approach that engages relevant ownerships to achieve management goals, and (3) use of the latest science to achieve effective decisions. Because the new planning rule will explicitly address climate change issues, and overlap many of the recommendations for addressing climate describe in this publication, national forest planning in regard to climate will be influenced by the new rule.

The Forest Service recently released guidance for climate change considerations in land management plan revisions and in NEPA processes (USDA FS 2009b, USDA FS 2010b), identifying the need to consider climate change in the delivery of the Forest Service mission (USDA FS 2010b) (box 4). The role of climate change is to be integrated, as opposed to being considered individually, in plan documents. Syntheses in the 2010 RPA assessment will offer another information source on climate change and natural resources. Finally, the Web-based tool, *Template for Assessing Climate Change Impacts and Management Options* (box 5), connects planning and best available science through a report generation service.

Forest Service guidance identifies the need to assess adaptation over time, including identification of risks and vulnerabilities, the ecological adaptation likely to occur, and how management can also adapt

(USDA FS 2010b). Processes described previously, such as facilitated workshops and watershed vulnerability assessment, may start the conversation and provide a framework for information gathering. Including the general public as reviewers of proposed actions and alternatives is a NEPA requirement, and including stakeholders throughout the planning process will increase opportunities for innovative ideas about adaptation.

Forest Service management decisions often involve other federal agencies, state agencies, and Native American tribes. Nearly a quarter of National Forest System land has been statutorily set aside—wildernesses, monuments, recreation areas, game refuges and wildlife preserves, wild and scenic rivers, scenic areas, and primitive areas—requiring collaborative management across these national systems. Checkerboard ownership patterns and private in-holdings associated with western national forests, and scattered land parcels of eastern national forests make it imperative to coordinate with neighboring agencies, tribes, and private land owners.

Developing Adaptation Options: A Toolkit Approach

In this section, we present a conceptual framework for developing adaptation options on federal lands. The strategic steps, tactical steps, and examples discussed here were developed in collaboration with resource managers, planners, and decision makers. We use a “toolkit approach,” offering an array of options from which approaches that are most effective and appropriate for specific projects, landscapes, time scales, resource areas, and budgets can be selected. Whereas the Forest Service is organized traditionally by resource areas (e.g., timber, range, watershed, recreation, wilderness), we move beyond disciplinary organization to introduce **process-oriented approaches**. This is intended to provoke innovative thinking about the challenges and opportunities that climate change brings, and to stimulate dynamic and effective solutions. Examples in text boxes show the relationship of familiar resource areas to the conceptual framework.

Ecosystem Management—the Basis for Action

An explosion of new scientific understanding in recent years appropriately and decisively brought the issue of climate change to center stage in resource management arenas. This heightened attention simultaneously triggered concerns among resource managers on what to do about it. One might expect that a large number of novel stresses would demand an overhaul of traditional resource management practices and replacement with new paradigms. Fortunately, ecosystem management as practiced in land management since the late 1980s (e.g., Grumbine 1994, Kaufmann et al. 1994, Kohm and Franklin 1997, Lackey 1995, USDA FS 1995) provides a foundation for addressing most aspects of climate change effects. Ecosystem management acknowledges that natural systems change continuously (Kohm and Franklin 1997, Millar and Woolfenden 1999, Tausch et al. 2004); recognizes that such dynamics bring high levels of uncertainty (Williams and Jackson 2007); stresses interconnections of natural processes with structure and composition (Heinimann 2010; Kohm and Franklin 1997; USDA FS 1993, 1995); embraces the integrated nature of watersheds and entire ecosystems (Folke et al. 2004, Heathcote 1998); focuses on species interactions with each other and their environment (Christensen et al. 1996, Costanza et al. 1992); and emphasizes disturbance processes as essential to species and ecosystem health (Folke et al. 2004, Kohm and Franklin 1997).

Ecosystem management utilizes strategic assessments and interdisciplinary analysis of whole ecosystems at large spatial scales (Christensen et al. 1996, Kohm and Franklin 1997). This perspective remains important for incorporating climate change in evaluations and strategic analysis. For terrestrial environments, ecosystem management promotes a landscape analysis process, in which natural processes and variability are evaluated relative to desired future conditions and processes (e.g., USDA FS 1995). In addition, watershed vulnerability assessment has been widely used to guide interdisciplinary teams to a robust understanding and basis for planning (Furniss et al. 1010, USDA FS 1994).

Natural climatic variability is one of the drivers of ecological change that ecosystem management has long recognized (Millar and Woolfenden 1999, Swetnam et al. 1999, Tausch et al. 2004), although resource attention to this has been mostly missing in operational practice (table 14). Resource managers have always considered climatic variability to some extent, because natural variability at interannual and interdecadal scales affects ecosystems regardless of human influences. Incorporating rapid human-caused climate change extends this long-term perspective, and knowledge of historic climatic variability can be helpful in planning for the future (box 6). However, we can no longer assume that future climate will be similar to past climate, or that ecological conditions are static or in equilibrium with climate.

Human-caused climate change creates the prospect of a warming climate interacting with other biophysical factors and stressors such as insects, fungal pathogens, and air pollution. For example, a combination of warmer temperatures, increased mountain pine beetle (*Dendroctonus ponderosae* Hopkins) attack, and increased fire occurrence in lodgepole pine (*Pinus contorta* Douglas ex Louden var. *latifolia* Engelm. ex S. Watson) forests is a stress complex that may alter disturbance regimes, productivity, and species composition (McKenzie et al. 2009). Some ecological effects of climate change may be gradual, such as mortality of some conifer species (van Mantgem et al. 2009). Some may be episodic and reversible, such as periods of high precipitation and severe flooding, accelerated expansions of exotic plant species, and periods of severe wildfires. The episodic nature of these events has been related to interaction of human-caused change with natural climate cycles at interannual (e.g., El Niño Southern Oscillation) and decadal (e.g., Pacific Decadal Oscillation, Arctic Oscillation) (Mantua et al. 1997, Millar et al. 2004, Wang et al. 2010). Others may be entirely unexpected and novel due to large-scale ecological responses to climate change (Jackson 1997, Jackson and Overpeck 2000, Williams and Jackson 2007) interacting with small-scale ecological processes that are poorly understood (Pepin and Lundquist 2008).

Effective climate adaptation strategies may need to emphasize ecological processes and ecosystem services rather than structure and composition (Chambers et al. 2004, Millar and Brubaker 2006). Ecological process refers to natural functions associated with a range of natural variation, such as periodic fire, insect and pathogen interactions, and flooding. Ecosystem services are those values deriving from natural processes that benefit humans, such as clean air and water (Corvalan et al. 2005). This might mean working with disturbance events (e.g., fire, insect outbreaks) to create landscape mosaics of forest patches, rather than designating fixed land units and expecting them to remain on a specific successional trajectory. Using disturbance processes (natural and managed) to stimulate natural regeneration is another example of managing for process, even if the species mix or life form (tree vs. shrub vs. grassland) differs from former vegetative cover. Planting with broader mixes of species and germplasm than may have formerly been present, and allowing natural selection to mediate tree survival, is an approach to managing for climate change. Expanding genetic guidelines for reforestation is experimental by design, and careful documentation and monitoring of treatments, seed sources, and planting locations will allow managers to learn about effectiveness of plant seed mixes.

Long-term monitoring of relevant ecological, climatic, and social variables is critical for effective adaptive management. The effects of changing climate are affecting species and ecosystems most commonly through altered disturbance regimes (Joyce et al. 2008), and managing multiple stresses and novel disturbance effects is the first line of defense for climate adaptation (Allen et al. 2010; Barnett et al. 2008; McKenzie et al. 2009; Peterson et al. in press; Raffa et al. 2008). Monitoring and adaptive management are challenging programs to maintain in the best of circumstances, dependent on sufficient personnel and sustained funding. As climate continues to change, the ability to detect change may become increasingly difficult and uncertain, yet ever more valuable. These variables and uncertainties place the success of adaptive management fundamentally at risk (Joyce et al 2009).

The conceptual framework and strategic steps outlined below offer a process for how to start integrating climate adaptation into resource management activities. The following sections are not a “cookbook” approach for incorporating climate, but an invitation to think about strategies that have proven useful for resource managers. Ultimately this approach may evolve, or other approaches, different reference terms, and changes in emphases may prove more useful. Effective approaches lead to the same end: understanding of the influence of climate change on natural resources and effective development of adaptation actions to address them.

Steps for Developing Adaptation Options

As discussed previously, efforts to identify adaptation options will be most effective when incorporated early in the planning and analysis process rather than during project implementation. In the planning and design phases, evaluations at large spatial scale are conducted, long-term effects projected, uncertainties assessed, and cumulative effects considered. However, significant changes may be made at the project scale because of climate-induced changes or information acquired from monitoring. Therefore, the steps and strategies below are applicable for both planning and project development.

Four practical steps can be used to organize activity when addressing climate-related resource conditions, assessments, plans, or projects (fig. 7):

- **Review**, that is, educate oneself, staffs, interdisciplinary teams, and the public about climate science and climate change effects on ecosystems and especially on potential implications of climate change for a project goal or other issue under consideration.
- **Rank**, that is, assess sensitivities of various resources to climate change and develop short-term and long-term priorities for vulnerable resources.
- **Resolve**, that is, develop solutions and implement conservation, management, and monitoring practices.
- **Observe** response to management practices and modify if necessary.

These steps are summarized in progressive order, but in practice, they are best considered iteratively, with repetitive review and rank phases even before plans are finalized, treatments implemented, or monitoring begun. The steps are repeated following evaluation of monitoring results, similar to the adaptive management process.

Step 1: Review—The review step brings knowledge into specific project analyses and planning efforts. At the onset of any resource management effort, a resource manager or team leader needs to determine whether climate change is affecting or likely to affect a project. This can be determined through targeted review of scientific literature, discussion with specialists, and in-depth assessments and vulnerability analyses (table 15).

Most existing and planned project plans and existing or developing forest plans have limited consideration of climate change. Some type of review of those efforts would be beneficial in terms of climate change effects and adaptation options. The CPST can be used as a checklist to review projects on current national forest SOPA lists. Using the question-answer format to elicit discussion about potential interaction of climate, one can determine if a warmer climate will affect a project. If so, then the project is identified as needing further attention, and those aspects most likely influenced by climate are highlighted for further consideration.

Climatic variability and other natural processes (e.g, fire, floods, insect outbreaks) are included in evaluations of ecological variability in the context of ecosystem management (Salwasser and Pfister 1994, USDA FS 1995). Climate change is considered to be a higher order process, essentially a moving stage on which other ecological dynamics (fire, succession, etc.) occur (Jackson 1997). Consultation with a scientific technical committee may be needed to address situations in which the potential effects of climate change are complex, long term, or highly uncertain. Consultation can range from one-time discussion with local scientists to interaction with regional science advisory boards (box 2).
Comprehensive evaluations are often necessary for large-scale and long-term projects. Existing protocols, such as those developed for watershed assessment (Furniss et al. 2010, Heathcote 1998, Hornbeck and Swank 1992) and ecoregional assessments (Johnson et al. 1999) sometimes address the role of climate, although they may need to be modified for emphasis on climate effects. These assessments are typically conducted by scientific specialists, but are more effective if resource managers are involved to assist with local information and priorities. Coordination within resource areas (e.g., headwater vs. downstream aquatic systems in a large watershed) and across resource areas (e.g., fuels management and wildlife management) will ensure that multiple perspectives are captured at the start of the adaptation process.

The nature of the review process evolves as increasing knowledge about climate change informs scientists and managers. More projects and plans can be developed with climate change considerations included at the start. As indicated by Forest Service guidance on NEPA analysis, “the effects of climate change on natural resource management are best considered when developing a proposal before initiating NEPA. In this way it is efficient to integrate climate change considerations together with the Agency mission objectives (USDA FS 2009b).” Tools such as the CPST may be replaced by processes identified in table 15 to review background material on climate change pertinent to national forest plans and projects.

Step 2: Rank—Once climate-related background materials have been adequately reviewed, plans, project proposals, and existing projects need to be ranked, that is, relative priorities for action determined, and priority locations evaluated. This ranking can be general or qualitative (e.g., low, moderate, high) as opposed to ordinal (1, 2, 3,…). After review of potential climate effects, details of management activities might not differ from what would be done otherwise, although relative priorities for projects may change because of climate concerns. National forests often have long lists of proposed and existing projects, as well as many long-term plans and projects. Due to limited staff and budgets, a key element of decision making is to rank projects for priority of implementation.

Three strategic junctures for incorporating climate change in resource priorities commonly arise (Joyce et al. 2008). First, major disturbances, such as fire, flood, or forest mortality present an opportunity for revising standard management approaches by resetting ecological trajectories in new climate-adapted directions. For example, tree planting after wildfire can promote species assemblages that are expected to have acceptable survival and growth in a warmer climate, thus mimicking historic processes by which species have adapted to natural climatic variability. Planting with new species mixes or new genotype combinations, or assisting development of new animal habitats after disturbance, are examples of actions that can be taken after a disturbance.

Second, incorporating climate-sensitive actions in planning is proactive adaptation that enables species and ecosystems to shift gradually to new states. Examples include using prescribed fire, introducing new species mixes, and moving species to new locations. Third, some priority-setting exercises may deem that no climate-related action is warranted. While no action might appear to be denial or avoidance of apparent needs, no action is defensible where resources are at low risk, species have stable populations not sensitive to a warmer climate, and refugial areas have minimal response to climate change. Additional guides for taking action or postponing action are summarized in fig. 7.

Priorities in a climate change context often differ for short-term versus long-term projects. Uncertainties increase over time, so ranking projects for the long term is riskier. As described previously, managers and decision makers routinely address many types of uncertainty (Granger et al. 2009). Uncertainties about how climate will change locally and how local species and ecosystems will respond are smaller in the near term, because there are fewer unknown variables. Climate change is relatively gradual, and the magnitude of ecological responses in 10-20 years is anticipated to be relatively small compared to those anticipated in 50-100 years. In the near term, interannual and decadal modes of climatic variability, such as the El Niño Southern Oscillation (Diaz and Markgraf 2000) and the Pacific Decadal Oscillation (Mantua et al. 1997), will continue to drive variation that affects natural systems and tend to swamp longer term trends. However this should not preclude proactive adaptation activities. Over a few decades or more, climatic warming will increase and dominate natural climatic mechanisms.

In the short term, managers can address climate concerns by minimizing and reducing detrimental human effects; taking actions to improve forest and ecological health; managing impacts of disturbance and multiple stresses; reducing cumulative effects to crucial habitats and services; and withdrawing or assigning low priority to projects that are likely to be unsuccessful because of long-term climatic trends (table 16). Examples of minimizing human effects include using fuel treatments and managed fire in areas affected by fire exclusion; restoring rangelands, meadows, and riparian corridors affected by overgrazing or recreational use of off-road vehicles; and improving and decommissioning roads; and removing exotic species (Joyce et al. 2008, 2009). Many of these satisfy a goal to improve species viability and ecosystem function regardless of climate effects, and are sometimes called **no-regrets strategies**.

Other examples might be administrative, such as changes in hiring schedules of fire suppression personnel to accommodate a longer fire season. An example of a project that has low probability to succeed is restoration of species into habitats that are unlikely to be suitable in the future due to effects of a changed climate. Tools are being developed to identify where cold-water fisheries habitats may be marginal already or non-existent in the future (Isaak et al. 2010). Reintroducing trout in streams where water temperatures are expected to be too high to support cold-water fish species will have a low probability of success, even if the stream was previously inhabited by trout (Batin et al. 2007).

Several different approaches can be used to facilitate the ranking process. The CPST was developed in conjunction with case study forests as a guide to setting priorities from SOPA lists. In addition to its value as a background review tool, the CPST improves decisions about which projects deserve further attention for climate adaptation and which are unlikely to be affected by climate. On Olympic National Forest, a reprioritization exercise involving paired workshops to review current information and to develop and rank adaptation options was used to address a wide range of management goals (box 7), thus arriving at outcomes similar to those achieved with the CPST.

As climate and ecosystem trajectories deviate significantly from natural variability over time, direct effects are expected on species and ecosystems. Species migrations, changes in vegetation and faunal assemblages, and altered watershed condition are anticipated. This suggests that it may be necessary to shift priorities to anticipate which effects might accrue in the future, minimize disruptive ecological conversions, and guide transitions to desired new ecological functions (table 16). Because uncertainty about climate change effects increases several decades into the future, risk assessment and uncertainty analyses are especially important for long-term projects (e.g., Turner et al. 2003).

Many tools and guides are available to help rank projects and actions (IPCC 2001, Moser and Luers 2008). As noted above, implementing no-regrets adaptation actions is usually a priority, because these practices benefit resources regardless of future climate. Related to this are **low-regrets adaptation options** which include situations for which project costs are relatively low, project effectiveness is high even given future uncertainties, and anticipated benefits are potentially high under anticipated future climate.

Win-win adaptation options are actions that provide benefits to many resources affected by climate change, and confer benefits for non-climate reasons. In all cases, these imply situations in which actions might be proposed, For example, actions proposed to reduce fire severity, restore watershed health, or improve forest productivity can also facilitate adaptation to climate change. **Climate-related projects can sometimes be implemented by "piggy-backing" them with other high-ranking projects**. For example, if fuel reduction projects are a high priority, and budgets are available to implement them in the wildland-urban interface, then climate-focused projects that coincide with targeted forest types and locations in the interface can be implemented concurrently.

Triage is another systematic approach to setting priorities (Millar et al. 2007, Mitchell 2008, Yohe 2000). Often misinterpreted as a reaction to crisis, triage is a process-based approach to treating emergency situations in which capacity to respond adequately is less than the immediate need. Projects are sorted into categories based on their need for immediate attention, urgency of condition, capacity for treatment to be implemented (budget, staff, skill), and likelihood of success given available capacity (fig. 8). A weighting factor can be added, or projects of similar value can be evaluated in separate triage exercises.

Collaborative approaches for ranking and priority setting are useful when values differ among parties interested in a particular issue, uncertainties are high, outcomes could be interpreted differently by different stakeholders, and treatments are costly. Many collaborative frameworks exist within resource contexts (e.g., Cortner and Moote 1999), and most can be adapted for application to climate contexts. Keys to the success of collaborative processes include representing all stakeholder positions; evaluating and reviewing all positions and appropriate input; clearly defining ground rules and constraints of law, policy, and decision-making; and implementing actions consistently from collaborative decision making.

Collaborative processes in the National Forest System were recently used to develop acceptable recommendations for managing travel patterns on road systems, and are also being recommended for revision of land management plans.

Step 3: Resolve—Decisions about appropriate strategies and treatments are resolved after the effects of climate change have been reviewed and project priorities have been ranked. **Appropriate adaptation options are determined by the conditions and context of the resource; social and ecological values; time scales for management; and feasible goals for treatment relative to climate effects.** Adaptation literature most commonly focuses on resilience as a primary goal to address these factors (Hansen et al. 2003). We expand this framework to address potential adaptation strategies that fit one or more of the following objectives: resistance, resilience, response, and realignment (Joyce et al. 2008, Millar et al. 2007). These four categories encourage thinking about the range of possible options and do not imply that a treatment fits into one specific category. Some treatments may reflect only one strategy, and others may combine them. The overriding objective is to construct effective management solutions that fit a specific situation.

Promote resistance to climate change—This strategy includes actions and treatments that enhance the ability of species, ecosystems, or environments (including social) to resist forces of climate change and that maintain values and ecosystem services in their present or desired rates and states (table 17). This may seem counter to working with change, focusing on dynamics, and moving beyond static solutions. However, situations exist in which resisting the effects of climate is appropriate. For example, where steep slopes have been altered by road construction, resisting erosion and landslides is always an objective, especially if increased flooding accompanies climate change, and not inconsistent with a dynamic view. Resisting change is often appropriate for situations and resources associated with high social or ecological value that are vulnerable to direct or indirect effects of climate change.

Adaptation examples include constructing fuel breaks around a vulnerable population of a valued plant species to prevent extinction from climate-aggravated wildfire; rescuing a highly valued and climate-vulnerable animal species by captive propagation (e.g., California condor [*Gymnogyps californianus*]); prescribing methods otherwise socially undesired (e.g., insecticides) to aggressively combat insect mortality that threatens high value resources (e.g., insect- and pathogen-infected young bristlecone pine (*Pinus longaeva* D.K. Bailey) forests in the White Mountains); requesting more than otherwise allotted water rights to maintain a unique and ecologically critical aquatic ecosystem (e.g., Mono Lake, California, relative to water delivery to Los Angeles for human use); and taking drastic measures to remove invasive species (box 8).

Actions that attempt to resist climate change are usually successful only in the short term, and become less effective over time as effects of climate change accumulate or management priorities change. As climate pressure increases, not only will it become more difficult to resist change, but when change occurs, it may exceed physical and biological thresholds and result in undesirable outcomes (e.g., severe wildfire, forest mortality, species extinction). Some resistance approaches, such as managing high value species in designated refugial networks, involve relatively low risk or investment. An example is refugial networks proposed for American pika (*Ochotona princeps* Richardson 1828), a small mammal that lives primarily in high elevation habitats and is considered at risk from a warmer climate (box 9) (Millar and Westfall 2010).

Another interpretation of the resistance strategy is to defer proposed (or approved) projects that are unlikely to succeed because of increasing climate pressure and future conditions. Examples include removing lodgepole pine (*Pinus contorta* subsp. *murrayana* [Balfour] Engelmann 1880) seedlings that invade alpine meadows such as Tuolumne Meadows, Yosemite National Park; re-introducing salmon in streams where future water temperatures will be too high to support them; and chaining (removing) junipers (*Juniperus* spp.) that are becoming established in Great Basin sagebrush (*Artemisia* spp.) steppe communities.

Develop resilience to climate change—Promoting resilience is the strategy most often recommended for adaptation (Folke et al. 2004, Hansen et al. 2003). Resilience, which has both ecological and socioeconomic implications, can range from short-term response to disturbance to long-term tolerance of prolonged droughts. As mentioned above, agreement on definition is less important than how the range of meanings informs development of effective adaptation plans. In an engineering context, resilience refers to the capacity of a system or condition to return to its prior state after disturbance (Holling 1996). In an ecological context, a forest that regenerates and restores its former vegetation structure, composition, and function after wildfire is resilient (Holling 1996). In a climate change context, resilience refers to the capacity of a system or environment to withstand or absorb increasing impact without changing state (Chapin et al. 2006). Because climate change will exert directional change (e.g., increasing temperature, rising atmospheric carbon dioxide levels) over time, a resilient system is one that retains its original character and function in the face of such pressure. Examples of resilient systems include conifer forests that regenerate to forest rather than to shrublands or grasslands after repeated wildfire (e.g., pine forests of the Colorado Plateau); animal species that retain viable populations despite climate-induced habitat degradation; and watersheds that retain erosion control, adequate water supply, and fish habitat despite floods, fires, insect epidemics, or spread of exotic plant species.

Life-history characteristics of plant and animal species provide clues about the how well a species might be buffered to a changing climate. Characteristics of resilient plant species include tolerance of a wide range of climatic conditions over millennia (e.g., bristlecone pine), long-lived seeds that persist in soil banks, wind-pollinated flowers, high seed production, and wind-dispersed seeds. These traits can be negated by the spread of insects and pathogens that may thrive in new climatic conditions. Characteristics of resilient animal species include high mobility (birds, bats, flying insects), being a seasonal migrant (e.g., deer, migratory bat species, neotropical bird species), flexible behavioral thermoregulation, and ability to store large amounts of body fat[3]. Studies on direct effects of climate change over the past 100 years, such as the Grinnell resurveys in California (Moritz et al. 2008) corroborate that these life-history elements confer resilience to species such as the California ground squirrel (*Spermophilous beecheyi)* and yellow-bellied marmot (*Marmota flaviventris*).

Similarly, characteristics, conditions, and trends can be described for physical systems, whole ecosystems, and watersheds that help determine resilience. Traditional approaches to watershed assessments have been modified to add analyses about effects of climate (Furniss et al. 2010), and these point to characteristics that confer resilience. Those features that buffer watersheds and hydrologic systems against loss of natural function and ecosystem services relate primarily to geologic substrate and history of disturbance. Some ecosystems experience considerable disturbance, such as desert landscapes with naturally high erosion rates, and may have fewer changes in physical processes over time (higher resilience) than systems that currently experience low disturbance. Extensive road networks, overgrazing, and large areas of eroded and compacted soils can cause watersheds to have low resilience even under quasi-static climate. A warmer climate may exacerbate loss of functional integrity for damaged watersheds, which may be partially offset by timely actions to increase resilience.

Adaptation treatments with a goal of increasing resilience reduce species or system vulnerability to acute or chronic stress. Examples include reducing forest densities (e.g., mechanical thinning, prescribed fire), thereby minimizing water stress to trees, fire hazard, and some types of insect outbreaks (box 10); increasing the stocking of seed banks for post-disturbance regeneration; enhancing and widening riparian zones; relocating, improving, and decommissioning roads; restoring water tables in degraded montane meadows; buffering road projects against extreme precipitation and floods (box 11); and projects to remove exotic species. In a recreation context, ski resorts that can expand operations to summer or year-round activities can improve their economic resilience.

Assist response to climate change—The most proactive strategic actions are those that work directly with the changes that climate is provoking, that is, they assist transitions to future states by mitigating and minimizing undesired and disruptive outcomes. Adaptation options that follow this strategy include all actions that ease transitions in response to climate. Examples include assisting migration, whereby species (individuals or their propagules) are moved to locations currently outside native ranges and projected to be favorable future habitat (McLachlan et al. 2007); planting novel species mixes in regeneration or restoration projects; reducing the effects of past management by removing roads; modifying grazing patterns; managing recreation to emphasize locations that can tolerate recreational activities; modifying gene transfer and restoration rules to incorporate genotypes more adapted in the future than local genotypes; enhancing riparian habitats and other dispersal corridors to encourage natural migration; minimizing habitat fragmentation (e.g., checkerboard ownership) and encouraging collaborative, ecoregional management to promote natural movements and natural selection; and in a rural community context, easing economic transition from dependence on single resources (e.g., timber) to diverse sources of generating revenue (e.g., timber plus multiple forms of recreation). Response strategies can be similar to or closely aligned with resilience strategies.

***Realign highly disturbed ecosystems*—**When ecosystems have been disturbed beyond historic ranges of natural variability, restoration goals are often prescribed to return structure, composition, process, and ecosystem services to prior states. Conditions of the project area before disturbance are often used to describe restoration goals. This approach is sensible where disruption has been so severe (e.g., urban development) that restoration is deemed successful if it returns the site to any quasi-natural condition (e.g., daylighting a buried stream). In other cases, historic and pre-disturbance conditions make inappropriate targets for restoration, because climate change will create significant differences from historic conditions (Millar and Brubaker 2006). For example, old-growth forests of western North America that established 300-500 years ago and grew under the cold climates of the Little Ice Age, are unlikely to be appropriate examples of forests that will be adapted to drought anticipated for the 21st century. Rather than restoring to conditions of the past, a climate-centric strategy is to realign disrupted systems to present and future conditions.

This strategy is commonly used in watershed restoration. The Mono Lake ecosystem (California) is an inland sea system that is critical for migrating waterfowl (Millar and Woolfenden 1999). Tributary streams were first diverted to serve water needs of metropolitan Los Angeles in the early 1940s, and continued diversions led to extreme lowering of lake levels, increasing lake salinity and reducing habitat quality and biological diversity. Warmer temperature will magnify these effects and stresses. Water-balance models that incorporated current and future precipitation, evaporation, snowpack, and air temperatures were used to develop adaptation and realignment goals. These continue to be modified as information about future climates and impacts to Mono Lake water status become better known. Similar measures have been used to realign forest diversity from conditions that have been highly altered because of decades of heavy timber harvest (box 12).

Step 4: Observe—A final step for incorporating adaptation strategies is to observe the effects of adaptation actions through monitoring, assess the efficacy of those actions, and modify them as appropriate. This step injects adaptive management into the climate toolkit. Many guides for adaptive management are available (e.g., Margoluis and Salafsky 1998**,** Walters 1986) that are readily modified for climate contexts. Although intuitively reasonable, formal adaptive management projects are rarely completed successfully due to their long-term nature, staff requirements, analytical demands, difficulty of attributing cause and effect in resource conditions, and high costs. In a climate context, “observe and modify” is more flexible than for adaptive management. For example, low-technology observations such as repeat photos may be as valuable as intensive monitoring if they can be implemented successfully.

The key to this adaptation step is to observe responses over time; learn from successes, surprises, novelty, and failure; and use this knowledge to modify future actions (box 13). Effective communication that shares experiences across space and time can greatly increase the effect of lessons learned. Not every adaptation practice will necessarily be successful, but every attempt at adaptation is a learning opportunity. Therefore, organizational support for resource managers to participate in long-term monitoring of adaption practices and to feel “safe to fail” will facilitate learning and effective adaptation to climate change over decades to centuries.

Conclusions

This guidebook presents a framework on which to build adaptation, processes that facilitate dialogue between scientists and managers, and examples from the efforts of scientists and managers working in national forests that are moving forward with adaptation. Ecosystem management as practiced in land management agencies remains the foundation for addressing most aspects of climate change.

Ecosystem management recognizes continuous change within ecosystems, the role of climate as an ecosystem driver, interconnections of natural processes with structure and composition, and the integrated nature of watersheds, landscapes and entire ecosystems. The present challenge is to incorporate into the ecosystem management framework novel changes resulting from human-caused climate change and their interactions with the natural background of environmental change.

Science-management partnerships are the foundation for the development of adaptation strategies and practices. Much has been said about how different the culture of science is from that of management, hence the need to begin the dialogue carefully and thoughtfully to enhance mutual learning. Reaching mutual understanding and agreement about resources, goals, and expectations can lead to thoughtful exchanges of information on climate change science and on management knowledge on national forests.

The steps for developing adaptation options can be described as **review***,* **rank***,* **resolve***,* and **observe**. To **review** means to educate oneself, one's staffs, stakeholders and communities of interest on climate science, effects on ecosystems, and desired futures for landscapes being managed. The educational process can involve short courses, a checklist to review projects as affected by climate change, or a more involved process of consultation with a scientific technical committee. **Rank** requires identifying and assessing vulnerabilities of the national forest to climate change and to develop short- and long-term priorities for management. Tools such as watershed vulnerability assessment can identify priorities for management. Over the short term, managers can address climate concerns by minimizing and reducing non-climatic stressors, taking actions to improve ecological health, and managing the effects of disturbances. **Resolve** is the step whereby adaptation options are developed and conservation and management are implemented. Here the four categories of managing for **resistance**, **resilience**, **response** and **realignment** encourage thinking about the range of possible options. Management treatments may fall into one or more of these categories with the overriding objective of constructing management solutions that fit the situation at hand. The last step of **observe** refers to a treatment response being detected (monitoring) as climate changes, with modifications being made if necessary and appropriate (adaptive management).

Adaptation options vary by ecosystem, landscape, and the socioeconomic environment in which landscapes are embedded. No single approach will work in all ecosystems, and no single approach will work repeatedly over time in a changing climate. Rather, managers will need a portfolio of options, or toolkit, from which a variety of tools and experiences can be used to match the current need. **We define tools** as **resource management practices, educational and reference modules, decision support aids, and qualitative or quantitative models that address the adaptation of natural and cultural resources to climate change**. This guidebook offers a number of tools, often developed in the context of workshops, such as the adaptation options for roads, wildlife, fish, and water on Olympic National Forest. Many others exist and no doubt more will be developed in time.

The guidebook offers examples of collaboration where federally managed land encompasses large landscapes. Similarity of ecosystem services across agencies provides an opportunity to share adaptation options for common issues such as roads, water, and wildlife. Increased collaboration can facilitate accomplishing common goals that can be attained only on larger connected (or contiguous) landscapes. Common goals under climate change might include protection of threatened and endangered species habitats, maintenance of land and water productivity, integrated treatment of fuels or insect and disease conditions that place adjacent ownerships at risk, and developing effective strategies to minimize loss of life and property in the wildland-urban interface. Attempting to collaborate multi-institutionally across large landscapes can bring into focus opportunities, as well as unexpected institutional barriers and societal responses.

What might adaptation to climate change look like in the future for the Forest Service? We present this optimistic vision:

- Climate change considerations will be incorporated into on-the-ground activities, project planning, and forest plans as seamlessly as other considerations commonly addressed now, such as fire, insects, and human drivers of change.

- Monitoring activities will include indicators that detect change in specific species and ecosystems in relation to changing climate. Periodic summaries of this information become the basis on which to evaluate the need for management adjustments or to amend the land management plan.
- An assessment of how future ecosystem services will be affected by the many natural and human drivers of change including climate change will be periodically developed as a joint effort of science and management for large landscapes.
- The forest planning process will be sufficiently flexible that climate change assessments and management objectives can be used to identify the advantages of managing across boundaries or within agency boundaries. Planning options will include the land management plan as well as new planning instruments that bridge neighboring federal and state lands, with considerations of social and economic systems surrounding these lands.
- The effects of climate change on ecosystem services will be examined in terms of whether near-term management options exist to reduce undesirable future effects. For example, how will management actions (or inactions) affect valuable ecosystem services?
- Investment in restoration activities will be evaluated in light of potential challenges that climate change will have on the success of those restoration activities.
- Management activities that sequester carbon will be developed in concert with adaptation options.
- Institutional capacity will expand such that technical expertise for questions on adaptation and mitigation is available within the National Forest System, perhaps the regional staffs, or even interagency regional staffs.
- Research will continue to explore the boundaries of knowledge about how the many natural and human drivers of change will affect natural resources and landscapes and the role of ecosystem management in restoring, sustaining, and enhancing forests and grasslands in the U.S.

Even in this optimistic vision, uncertainty about future climate and how to respond to it will remain. Science-management partnerships will need to facilitate the identification of new questions about natural resources and climate change, and climate change science will need to expand our knowledge of the nature of climate change and its effects on ecological, economic, and social systems. Application of this knowledge at fine spatial and temporal scales on national forest landscapes will be limited by the stochastic nature of climate and ecosystems. If scientists and managers begin to reframe and quantify uncertainty about climate change effects as confidence levels, then it will be possible to compare climate-related issues with many other factors that contain uncertainty and decision making.

Like most federal agencies and other institutions, the Forest Service is in transition from viewing climate as unchanging to viewing climate as dynamic and mediating changes in the environment. Continual advancement within science, developments of climate policy and regulations, and near-term changes on national forest landscapes will necessitate a continual evolution of adaptation options appropriate for land management. Climate change science is rapidly changing with new information about the effects of a changing climate on ecosystems. National forest managers are experiencing near-term changes in weather and disturbances such as fire and insect outbreaks, are responding to those changes in on-the-ground management, and learning in real time about adaptation. Hence, this guidebook is meant to be a dynamic collection of information, a platform on which to document the effectiveness of adaptation practices. By sharing this information, adaptive management in the broadest sense of the term will facilitate ecosystem change and maintenance of ecosystem processes.

Acknowledgments

We thank Jill Baron and three anonymous reviewers for timely and insightful comments on an earlier draft of the manuscript. We also thank the many resource managers and planners from the U.S. Forest Service, National Park Service, and other organizations who provided valuable content for this publication and helpful reviews of previous drafts. We are especially grateful to resource managers at Inyo National Forest, Olympic National Forest, Shoshone National Forest, Tahoe National Forest, Devils Postpile National Monument, and Olympic National Park—dedicated collaborators in adaptation case studies—for their insight on adapting to climate change. Ellen Eberhardt and Crystal Raymond assisted with editing the manuscript. Funding for preparation of this publication was provided by an award from the U.S. Forest Service Global Change Research Program to the WestWide Climate Initiative, and by the U.S. Forest Service Pacific Northwest Research Station, Pacific Southwest Research Station, and Rocky Mountain Research Station.

English Equivalents

When you know:	Multiply by:	To find:
Meters (m)	3.28	Feet
Kilometers (km)	.621	Miles
Square kilometers (km^2)	.386	Square miles
Hectares (ha)	2.47	Acres

References Cited

Allen, C.D.; Macalady, A.K.; Chenchouni, H. [et al.]. 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. Forest Ecology and Management. 259(4): 660–684.

Bachelet, D.; Neilson, R.P.; Hickler, T. [et al.] 2003. Simulating past and future dynamics of natural ecosystems in the United States. Global Biogeochemical Cycles. 17: 1–21.

Backland, P. Janetos, A.; Schimel, D. [et al.]. 2008. The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States: a report by the U.S. Climate Change Science Program and Subcommittee on Global Change Research. Washington, DC: U.S. Department of Agriculture. 362 p.

Bader, D.C.; Covey, C.; Gutkowski, W.J. [et al.]. 2008. Climate models: an assessment of strengths and limitations—report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington, DC: Department of Energy, Office of Biological and Environmental Research. 124 p.

Barnett, T.P.; Pierce, D.W.; Hidalgo, H.G. [et al.] 2008. Human-induced changes in the hydrology of the western United States. Science. 319: 1080–1083.

Baron, J.S.; Allen, C.D.; Fleishman, E. [et al.]. 2008. National parks. In: Julius, S.H.; J.M. West, J.M., eds., and Baron, J.S.; Joyce, L.A.; Kareiva, P., [et al.], eds. Keller, B.D.; Palmer, M.A.; Peterson, C.H.; Scott, J.M., authors. 2008. Preliminary review of adaptation options for climate-sensitive ecosystems and resources: a report by the U.S. Climate Change Science Program and the Subcommittee on Climate Change Research. Washington, DC: U.S. Environmental Protection Agency: 4-1 to 4-68.

Batin, J.; Wiley, M.W.; Ruckelshaus, M.H. [et al.] 2007. Projected impacts of climate change on salmon habitat restoration. Proceedings of the National Academy of Sciences. 104: 6720–6725.

Bosworth, D.; Birdsey, R.; Joyce, L.; Millar, C. 2008. Climate change and the nation's forests: challenges and opportunities. Journal of Forestry. 106: 214–221.

Centers for Water and Wildland Resources [CWWR]. 1996. Status of the Sierra Nevada: summary of the Sierra Nevada ecosystem project report. Wildland Resources Center Report 39. Davis, CA: University of California, Centers for Water and Wildland Resources. 24 p.

Chambers, J.C.; Miller, J.R.; Germanoski, D.; Weixelman, D.A. 2004. Process-based approaches for managing and restoring riparian ecosystems. In: Chambers, J.C.; Miller, J.R., eds. Great Basin riparian ecosystems. Washington, DC: Island Press: 261–292. Chapter 9.

Chapin III, F.S.; Hoel, M.; Carpenter, S.R. [et al.]. 2006 Building resilience and adaptation to manage arctic climate change. Ambio. 35(4): 198–202.

Christensen, N.L.; Bartuska, A.M.; Brown, J.H. [et al.]. 1996. The report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. Ecological Applications. 6: 665–691.

Climate Change Knowledge Exchange. 2010 CAKE: Climate adaptation knowledge exchange. http://www.cakex.org. (3 February 2010).

Cortner, H.J.; Moote, M.A. 1999. The politics of ecosystem management. Washington, DC: Island Press. 178 p.

Corvalan, C.; Hales, S.H.; McMichael, A. [et al.]. 2005. Ecosystems and human well-being: health synthesis. A report of the Millennium Ecosystem Assessment. Geneva, Switzerland: World Health Organization. 53 p.

Costanza, R.; Norton, B.; Haskill, D.G. 1992. Ecosystem health. Covelo, CA: Island Press. 269 p.

Coulson, D.P.; Joyce, L.A.; Price, D.T. [et al.]. 2010. Climate scenarios for the conterminous United States at the 5 arc minute grid spatial scale using SRES scenarios A1B and A2 and PRISM climatology. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. http://www.fs.fed.us/rm/data_archive/dataaccess/US_ClimateScenarios_grid_A1B_A2_PRISM.shtml. (8 February 2011).

Cruce, T.L. 2009. Adaptation planning: what U.S. states and localities are doing. A special report prepared for the Pew Center on Global Climate Change, November 2007 (updated August 2009). 25 p. http://www.pewclimate.org/docUploads/state-adaptatoin-planning-august-2009.pdf. (4 February 2011).

Di Luzio, M.; Johnson, G.L.; Daly, C. [et al.]. 2008. Constructing retrospective gridded daily precipitation and temperature datasets for the conterminous United States. Journal of Applied Meteorology and Climatology. 47: 475–497.

Diaz, H.F.; Markgraf, V. 2000. El Niño and the southern oscillation: multiscale variability, global, and regional impacts. Cambridge, UK: Cambridge University Press. 512 p.

Easterling, W.E.; Hurd, B.; Smith, J. 2004. Coping with global climate change: the role of adaptation in the United States. Prepared for the Pew Center on Global Climate Change. 52 p**.** http://www.pewclimate.org/docUploads/Adaptation.pdf. (8 February 2011).

Elsner, M.M.; Littell, J.; Binder, L.W., eds. 2009. The Washington climate change impacts assessment. Seattle, WA: University of Washington, Center for Science in the Earth System, Joint Institute for the

Study of the Atmosphere and Oceans.414 p. http://cses.washington.edu/db/pdf/wacciareport681.pdf. (8 February 2011).

Federal Register. 2002. Guidelines for ensuring and maximizing the quality, objectivity, utility, and integrity of information disseminated by federal agencies. 67: 8452–8460.

Folke, C.; Carpenter, S.; Walker, B. [et al.]. 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Annual Review of Ecology, Evolution, and Systematics. 35: 557–581.

Food and Agriculture Organization of the United Nations [FAO]. 2007. Adaptation to climate change in agriculture, forestry and fisheries: perspective, framework and priorities. Rome, Italy: FAO Information Division. 32 p.

Forest and Rangeland Renewable Resources Planning Act of 1974 [RPA]. 16. U.S.C. 1601 (note).

Furniss, M.J..; Staab, B.P.; Hazelhurst, S. [et al.]. 2010. Water, climate change, and forests: watershed stewardship for a changing climate. Gen. Tech. Rep. GTR-PNW-812. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 75 p.

Füssel, H.M. 2007. Adaptation planning for climate change: concepts, assessment approaches, and key lessons. Sustainability Science. 2: 265–275.

Gallopín, G.C. 2006. Linkages between vulnerability, resilience, and adaptive capacity. Global Environmental Change. 16: 293–303.

Gleckler, P.J.; Taylor K.E.; Doutriaux, C. 2008. Performance metrics for climate models. Journal of Geophysical Research. 113: D06104, doi:10.1029/2007JD008972. 20 p.

Government Accountability Office [GAO]. 2007. Climate change: agencies should develop guidance for addressing the effects on federal land and water resources. GAO-07-863. Washington, DC: Governmental Accountability Office. 184 p.

Government Accountability Office [GAO]. 2009. Climate change adaptation: strategic federal planning could help government officials make more informed decisions. GAO-10-113. Washington, DC: Governmental Accountability Office. 86 p. http://www.gao.gov/new.items/d10113.pdf. (8 February 2011).

Granger Morgan, M.; Dowlatabadi, H.; Henrion, M. [et al.], eds. 2009. Best practice approaches for characterizing, communicating, and incorporating scientific uncertainty in decisionmaking. Climate Change Science Program Synthesis and Assessment Product 5.2. Washington, DC: National Oceanic and Atmospheric Administration. 94 p.

Grumbine, R.E. 1994. What is ecosystem management? Conservation Biology. 8: 27–38.

Guisan, A.; Thuiller, W. 2005. Predicting species distribution: offering more than simple habitat models. Ecology Letters. 8: 993–1009.

Guisan, A.; Zimmermann, N.E. 2000. Predictive habitat distribution models in ecology. Ecological Modelling. 135: 147–186.

Halofsky, J.E.; Peterson, D.L.; O'Halloran, K.A.; Hawkins Hoffman, C. [In press]. Adapting to climate change at Olympic National Forest and Olympic National Park. Gen, Tech. Rep. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Hansen, L.J.; Bringer, J.L.; Hoffman, J.R., eds. 2003. Buying time: a user's manual for building resistance and resilience to climate change in natural systems. Berlin, Germany: World Wildlife Fund. 244 p.

Hayhoe, K.; Cayan, D.; Field, C.B. [et al.]. 2004. Emissions pathways, climate change, and impacts on California. Proceedings of the National Academy of Science. 101: 12422–12427.

Haynes R.W.; Adams D.M.; Alig R.J. [et al.]. 2007. The 2005 RPA timber assessment update. Gen. Tech. Rep. PNW-GTR-699. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 212 p.

Heathcote, I. 1998. Integrated watershed analysis. Principles and practice. New York, NY: Wiley and Sons. 415 p.

Heinimann, H.R. 2010. A concept in adaptive ecosystem management. An engineering perspective. Forest Ecology and Management. 259: 848–856.

The H. John Heinz III Center for Science, Economics, and the Environment [Heinz]. 2007. A survey of climate change adaptation planning. 52 p. http://www.heinzctr.org/publications/PDF/Adaptation_Report_October_10_2007.pdf

Heller, N.E.; Zavaleta, E.S. 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. Biological Conservation. 142: 14–32.

Holling, C.S. 1996. Engineering resilience versus ecological resilience. In: Schulze, P.C., ed. Engineering within ecological constraints. Washington, DC: National Academy Press: 31-44.

Hornbeck, J.W.: Swank, W.T. 1992. Watershed ecosystem analysis as a basis for multiple-use management of Eastern forests. Ecological Applications 2: 238–247.

Innes, J.; Joyce, L.A.; Kellomäki, S. [et al.]. 2009. Management for adaptation. In: Seppälä, R.; Buck, A.; Katila, P., eds. Adaptation of forests and people to climate change: a global assessment report. IUFRO World Series Volume 22. Vienna, Austria: International Union of Forest Research Organizations: 135–169.

Intergovernmental Panel on Climate Change [IPCC]. 2001. Climate change 2001. Third assessment report of the Intergovernmental Panel on Climate Change. Working Group III. Mitigation. Cambridge; UK: Cambridge University Press. 753 p.

Isaak, D.J.; Luce, C.; Rieman, B.E. [et al.]. 2010. Effects of climate change and recent wildfires on stream temperature and thermal habitat for two salmonids in a mountain river network. Ecological Applications. 20: 1350–1371.

Jackson, S.T. 1997. Documenting natural and human-caused plant invasions using paleoecological methods. In: Luken, J.O.; Thieret, J.W., eds. Assessment and management of plant invasions. New York, NY: Springer-Verlag: 37–55.

Jackson, S.T.; Overpeck, J.T. 2000. Responses of plant populations and communities to environmental changes of the late Quaternary. Paleobiology. 25: 194–220.

Johnson, K.N.; Swanson, F.; Herring, M; Greene, S. eds. 1999. Bioregional assessments: Science at the crossroads of management and policy. Washington, DC: Island Press. 392 p.

Joyce, L.A. 2007. The impacts of climate change on forestry, In: Adams, D.M.; Haynes, R.W., eds. Resource and market projections for forest policy development: twenty-five years of experience with the US RPA timber assessment. Dordrecht, The Netherlands: Springer: 449-488.

Joyce, .LA.; Birdsey, R. 2000. The impact of climate change on America's forests. RMRS-GTR-59. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 133 p.

Joyce, L.A.; Blate, G.M.; Littell, J.S. [et al.]. 2008. National forests. In: Julius, S.H.; West, J.M., eds. Preliminary review of adaptation options for climate-sensitive ecosystems and resources. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research Washington, DC: U.S. Environmental Protection Agency: 3-1–3-127.

Joyce, L.A., Blate, G.M.; Littell, J.S. [et al.]. 2009. Managing for multiple resources under climate change. Environmental Management. 44: 1022–1032.

Joyce, L.; Haynes, R.; White, R.; Barbour, J. 2007. Bringing climate change into natural resource management. Gen. Tech. Rep. GTR-PNW-932. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 150 p.

Julius, S.J.; West, J.M., eds. 2008. Preliminary review of adaptation options of climate-sensitive ecosystems and resources. Washington, DC: U.S. Environmental Protection Agency. 873 p.

Kane, S.; Yohe, G. 2000. Societal adaptation to climate variability and change: an introduction. Climatic Change. 45: 1–4.

Kaufmann, M.R.; Graham, R.T; Boyce, D.A. [et al.]. 1994. An ecological basis for ecosystem management. Gen. Tech. Rep. RM-GTR-246. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 22 p.

Knowles, N.; Dettinger, M.D.; Cayan, D.R. 2006. Trends in snowfall versus rainfall in the western United States. Journal of Climate 19: 4545–4559.

Kohm, K.A.; Franklin, J.F. 1997. Creating a forestry for the 21st century. The science of ecosystem management. Washington, DC: Island Press. 475 p.

Lackey, R.T. 1995. Seven pillars of ecosystem management. Landscape and Urban Planning. 40: 21-30.

Lenihan, J.M.; Bachelet, D.; Neilson, R.P.; Drapek, R. 2008. Simulated response of conterminous United States ecosystems to climate change at different levels of fire suppression, CO_2 emission rate, and growth response to CO_2. Global and Planetary Change. 64: 16–25.

Lettenmaier, D.P.; Gan, T.Y. 1990. Hydrologic sensitivities of the Sacramento–San Joaquin River basin, California, to global warming. Water Resources Research. 26: 69–86.

Ligeti, E.; Penney, J.; Wieditz, I. 2007. Cities preparing for climate change: a study of six urban regions. Toronto, ON, Canada: Clean Air Partnership. 90 p. http://www.cleanairpartnership.org/pdf/cities_climate_change.pdf. (8 February 2011).

Littell, J.S.; Peterson, D.L.; Millar, C.I.; O'Halloran, K. [In press]. U.S. national forests adapt to climate change through science-management partnerships. Climatic Change.

MacIver, D.C.; Dallmeier, F. 2000. Adaptation to climate change variability: adaptive management. Environmental Monitoring and Assessment. 61: 1–8.

Mantua, N.J.; Hare, S.R.; Zhang, Y. [et al.]. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society. 78: 1069–1079.

Margoluis, R.; Salafsky, N..1998. Measures of success: designing, managing, and monitoring conservation and development projects. Washington, DC: Island Press. 384 p.

McCarthy J.J.; Canziani, O.F.; Leary, N.A. [et al.], eds. 2001. Climate change 2001. Third assessment report of the Intergovernmental Panel on Climate Change. Working Group II. Impacts, adaptation and vulnerability. Cambridge; UK: Cambridge University Press. 976 p.

McKenzie, D.; Peterson, D.L.; Littell, J. 2009. Global warming and stress complexes in forests of western North America. In: Bytnerowicz, A.; Arbaugh, M.J.; Riebau, A.R.; Anderson, C., eds. Wildland fires and air pollution. The Hague, Netherlands: Elsevier Publishers: 317–337.

McKinley, D.C.; Ryan, M.G.; Birdsey, R.A. [et al.]. [In press]. A synthesis of current knowledge on forests and carbon storage in the United States. Ecological Applications.

McLachlan, J.S.; Hellmann, J.J.; Schwartz. 2007. A framework for debate of assisted migration in an era of climate change. Conservation Biology. 21: 297–302.

Millar, C.I.; Brubaker, L.B. 2006. Climate change and paleoecology: new contexts for restoration ecology. In: Palmer, M.; Falk, D.; Zedler, J., eds. Restoration science. Covelo, CA: Island Press: 315–340. Chapter 15.

Millar, C.I.; Neilson, R.N.; Batchelet, D. [et al.]. 2006. Climate change at multiple scales. In: Salwasser, H.; M. Cloughesy, eds. Forests, carbon, and climate change: a synthesis of science findings. Portland, OR: Oregon Forest Resources Institute Publication: 30–60. Chapter 3.

Millar, C.I.; Stephenson, N.L.; Stephens, S.L. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecological Applications. 17: 2145–2151.

Millar, C.I.; Westfall, R.D. 2010. Distribution and climatic relationships of American pika (*Ochotona princeps*) in the Sierra Nevada and western Great Basin, USA; Periglacial landforms as refugia in warming climates. Arctic, Antarctic, and Alpine Research. 42: 76–88.

Millar, C.I.; Westfall, R.D.; Delany, D.L. [et al.]. 2004. Response of subalpine conifers in the Sierra Nevada, California, USA, to 20th-century warming and decadal climate variability. Arctic, Antarctic, and Alpine Research. 36: 181–200.

Millar, C.I.; Woolfenden, W.B. 1999. The role of climatic change in interpreting historic variability. Ecological Applications. 9: 1207–1216.

Mitchell, G.W. 2008. A brief history of triage. Disaster Medicine and Public Health Preparedness. 2(S1): S4-S7.

Mladenoff, D.J. 2004. LANDIS and forest landscape models. Ecological Modelling. 180:7–19.

Morelli, T.L.; Carr, S.C. [In press]. A review of the potential effects of climate change on quaking aspen (*Populus tremuloides*) in the western United States and a new tool for surveying sudden aspen decline. Res. Pap. Albany, CA; U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Morelli, T.L.; McGlinchy, M.C.; Neilson R.P. [In press (a)]. A climate change primer for land managers from the Sierra Nevada. Gen. Tech. Rep. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Morelli, T.L.; Yeh, S.; Smith, N.: Millar, C.I. [In press(b)]. Climate project screening tool: an aid for climate change adaptation. Gen. Tech. Rep. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Moritz, C.; Patton, J.L.; Conroy, C.J. [et al.]. 2008. Impact of a century of climate change on small-mammal communities in Yosemite National Park, USA. Science. 322: 261–264.

Moser, S.; Luers, A.L. 2008. Managing climate risks in California: the need to engage resource managers for successful adaptation to change. Climatic Change. 87: S309–S322.

Mote, P.W.; Hamlet, A.F.; Clark, M.; Lettenmaier, D.P. 2005. Declining mountain snowpack in western North America. Bulletin of the American Meteorological Society. 86: 39–49.

Mote, P.W.; Salathé E.P., Jr 2010. Future climate in the Pacific Northwest. Climatic Change. 102: 29–50.

Nakićenović, N.; Swart, R., eds. 2000. Special report on emissions scenarios: a special report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY: Cambridge University Press. 599 p.

National Environmental Policy Act of 1969 [NEPA]; 42 U.S.C. 4321 et seq.

National Oceanic and Atmospheric Administration [NOAA]. 2007. The first climate model. http://celebrating200years.noaa.gov/breakthroughs/climate_model/welcome.html#model. (3 February 2011).

Office of Management and Budget. 2004. Final information quality bulletin for peer review. 45 p. http://www.whitehouse.gov/omb/memoranda/fy2005/m05-03.pdf. (10 February 2010).

Ogden A.E.; Innes, J.L. 2007a. Incorporating climate change adaptation considerations into forest management and planning in the boreal forest. International Forestry Review. 9: 713–733.

Ogden A.E.; Innes, J.L. 2007b. Perspectives of forest practitioners on climate change adaptation in the Yukon and Northwest Territories of Canada. Forestry Chronicle. 83: 557–569.

Ogden, A.E.; Innes, J.L. 2008. Climate change adaptation and regional forest planning in southern

Yukon, Canada. Mitigation and Adaptation Strategies for Global Change. 13(8): 833–861.

Organic Foods Production Act of 1990; 7 U.S.C. 6501 et seq.

Pearson, R.G.; Dawson, T.P. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography Letters. 12: 361–371.

Pepin, N.C.; Lundquist, J.D. 2008. Temperature trends at high elevations: patterns across the globe. Geophysical Research Letters. 35: L14701, doi: 10.1029/2008GL034026. 6 p.

Peterson, D.L.; Evers, L.; Gravenmier, R.A.; Eberhardt, E. 2007. A consumer guide: tools to manage vegetation and fuels. Gen. Tech. Rep. PNW-GTR-690. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 151 p.

Peterson, D.L.; Halofsky, J.; Johnson, M.C. [In press]. Managing and adapting to changing fire regimes in a warmer climate. In: McKenzie, D.; Miller, C.: Falk, D., eds. The landscape ecology of fire. New York, NY: Springer Verlag.

Peterson, D.L.; Parker, V.T. 1998. Ecological scale: theory and applications**.** New York, NY: Columbia University Press. 608 p.

Pierce, D.W.; Barnett, T.P.; Santer, B.D.; Gleckler, P.J. 2009. Selecting global climate models for regional climate change studies. Proceedings of the National Academy of Sciences. 106: 8441–8446.

Prentice, I.C., Bondeau, A.; Cramer, W. [et al.]. 2006. Dynamic global vegetation modelling: quantifying terrestrial ecosystem responses to large-scale environmental change. In: Canadell, J.G.; Pataki, D.; Pitelka, L.F., eds. Terrestrial ecosystems in a changing world. Berlin, Germany: Springer-Verlag: 175–192.

Raffa, K.F.; Aukema, B.H.; Bentz, B.J. [et al.]. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: The dynamics of bark beetle eruptions**.** Bioscience. 58: 501–517.

Randall, D.A.; Wood, R.A. 2007. Climate models and their evaluation. In: Solomon, S.; Quin, D.; Manning, M. [et al.], eds. Climate change 2007: the physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY: Cambridge University Press: 598–662.

Ray, A.J.; Barsugli, J.J.; Averyt, K.B. [et al.]. 2008. Climate change in Colorado: a synthesis to support water resources management and adaptation—a report for the Colorado Water Conservation Board. Boulder, CO: University of Colorado. 53 p.

Regional Ecosystem Office. 1995. Ecosystem analysis at the watershed scale: federal guide for watershed analysis. Version 2.2. Revised August 1995. Available from Regional Ecosystem Office, PO Box 3623, Portland, Oregon 97208-3623. http://www.reo.gov/library/reports/watershd.pdf. (10 February 2011).

Reid, L.M.; Furniss, M. J. 1998. On the use of regional channel-based indicators for monitoring. Unpublished report. Arcata, CA: U.S. Department of Agriculture, Forest Service, Redwood Sciences Laboratory. 24 p. http://www.treesearch.fs.fed.us/pubs/8519. (3 February 2011).

Robinson, D.C.; Buekema, S.J.; Grieg, L.A. 2008 Vegetation models and climate change: workshop results. Vancouver, BC, Canada: ESSA Technologies Ltd. 50 p. Unpublished report. http://www.essa.com/documents/Vegetation%20Models%20and%20Climate%20Change%20-%20Workshop%20Results.pdf. (8 February 2011).

Rojas Blanco, A.V. 2006. Local initiatives and adaptation to climate change. Disasters. 30: 140–147.

Ryan, M.G.; Harmon, M.E.; Birdsey, R.A. [et al.]. 2010. A synthesis of the science on forests and carbon for U.S. forests. Issues in Ecology. 13: 1-16.

Sadowski, M. 2008. An approach to adaptation to climate changes in Poland. Climatic Change. 90: 443–451.

Salathé Jr., E.P.; Leung, L.R.; Qian, Y.; Zhang, Y. 2010. Regional climate model projections for the State of Washington. Climatic Change. 102: 51–75.

Salwasser, H.; Huff, M. 2001. Social and environmental challenges to restoring white pine ecosystems. In: Tomback, D.F.; Arno, S.F.; Keane, R.E., eds. Whitebark pine communities: ecology and restoration. Washington, DC: Island Press: 402–405.

Salwasser, H.; Pfister, R.D. 1994. Ecosystem management: from theory to practice. In: Covington, W.W.; DeBano, L.F. eds. Sustainable ecological systems: implementing an ecological approach to land management. Gen. Tech. Rep. RM-247. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 150–161.

Santer, B.D.; Taylor, K. E.; Gleckler, P.J. [et al.] 2009. Incorporating model quality information in climate change detection and attribution studies. Proceedings of the National Academy of Sciences. 106: 14778–14783.

Scheller, R.M.; Mladenoff, D.J. 2007. An ecological classification of forest landscape simulation models: tools and strategies for understanding broad-scale forested ecosystems. Landscape Ecology. 22: 491–505.

Slaughter, R.; Wiener, J.D. 2007. Water, adaptation, and property rights on the Snake and Klamath

Rivers. Journal of the American Water Resources Association. 43: 308–321.

Snover, A.K.; Whitely Binder, L.C.; Lopez, J. [et al.]. 2007. Preparing for climate change: a guidebook for local, regional, and state governments. Oakland, CA: ICLEI - Local Governments for Sustainability.

Solomon, S.; Quin, D.; Manning, M. [et al.], eds. 2007. Climate change 2007: the physical science basis. Contribution of working group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom: Cambridge University Press. 996 p.

Swetnam, T.C.; Allen, C.; Betancourt, J. 1999. Applied historical ecology: using the past to manage the future. Ecological Applications. 9: 1189–1206.

Tausch, R.J.; Nowak, C.L.; Mensing, S.A. 2004. Climate change and associated vegetation dynamics during the Holocene: The paleoecological record. In: Chambers, J.C.; Miller, J.R. eds. Great Basin riparian ecosystems. Washington, DC: Island Press: 24–48. Chapter 2.

Turner, B.L.; Kasperson, R.E.; Matson, P.A. [et al.]. 2003. A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences. 100: 8074–8079.

U.S. Department of Agriculture, Forest Service [USDA FS]. 1993. A first approximation of ecosystem health: National Forest System lands. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 109 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 1995. Sustaining ecosystems; a conceptual framework. R5-EM-TP-001. San Francisco, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Region. 216 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 1999. Roads analysis: Informing decisions about managing the national forest transportation system. Misc. Rep. FS-643. Washington, DC: U.S. Department of Agriculture, Forest Service. 222 p.

U.S. Department of Agriculture, Forest Service [USDA FS]. 2001. 2000 RPA assessment of forest and range lands. Washington, DC. http://www.fs.fed.us/research/2000rpa/rpaasses.pdf. (February 2011).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2008. Forest Service strategic framework for responding to climate change: version 1.0. http://www.fs.fed.us/climatechange/documents/strategic-framework-climate-change-1-0.pdf. (3 February 2011).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2009a. Climate change considerations in land management plan revisions. http://www.fs.fed.us/emc/nepa/climate_change/includes/cc_land_mgmt_plan_rev.pdf (3 February 2011).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2009b. Climate change considerations in project level NEPA analysis. http://www.fs.fed.us/emc/nepa/climate_change/includes/cc_nepa_guidance.pdf. (3 February 2011).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2010a. A performance scorecard for implementing the Forest Service climate change strategy. http://www.fs.fed.us/climatechange/pdf/performance_scorecard_final.pdf. (July 2010).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2010b. Climate change considerations in land management plan revisions. http://www.fs.fed.us/emc/nepa/climate_change. (3 February 2011).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2010c. National roadmap for responding to climate change. http://www.fs.fed.us/climatechange/pdf/roadmap.pdf. (3 February 2011).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2011a. Eastern Sierra climate change bibliography. http://www.fs.fed.us/psw/topics/climate_change/wwci_toolkit/escc_bib/. (4 February 2011).

U.S. Department of Agriculture, Forest Service [USDA FS]. 2011b. Climate change resource center. http://www.fs.fed.us/ccrc. (8 February 2011).

U.S. Department of Agriculture, Forest Service; U.S. Department of the Interior, Bureau of Land Management [USDA USDI]. 1994. Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl: standards and guidelines for management of habitat for late-successional and old-growth forest related species within the range of the northern spotted owl. 1994-589-11/0001. Washington, DC: U.S. Government Printing Office. [Pages unknown].

van Mantgem, P.J.; Stephenson, N.L.; Byrne, J.C. [et al.]. 2009. Widespread increase of tree mortality rates in the western United States. Science. 323: 521–524.

Vogel, C.; Moser, S.C.; Kasperson, R.E.; Dabelko, G. 2007. Linking vulnerability, adaptation and resilience science to practice: players, pathways and partnerships. Global Environmental Change. 17: 349–364.

Walters, C. 1986. Adaptive management of renewable resources. New York, NY: Macmillan. 374 p.

Wang, J.; Bai, X.; Leshkevitch, G. 2010. Severe ice cover on Great Lakes during winter 2008-2009. EOS. 91: 41 R5-EM-TP-001. 43.

Westerling, A.L.; Hidalgo, H.G.; Cayan; D.R.; Swetnam, T.W. 2006. Warming and earlier spring increase western U.S. forest wildfire activity. Science. 313: 940–943.

Wilby, R.L.; Charles, S.P.; Zorita, E. [et al.]. 2004. Guidelines for use of climate scenarios developed from statistical downscaling methods. Bristol, United Kingdom: Environment Agency of England and Wales. 27 p.

Wilkinson, R.; Clarke, K.; Reichman. J. 2002. Preparing for climate change: the potential consequences of climate variability and change: a report of the California Regional Assessment Group for the U.S. Global Change Research Program*.* Final draft report. Washington, DC: National Science Foundation. 431 p. http://www.ncgia.ucsb.edu/pubs/CA_Report.pdf. (3 February 2010).

Williams, J.W.; Jackson, S.T. 2007. Novel climates, no-analog communities, and ecological surprises: past and future. Frontiers in Ecology and the Environment. 5: 475–482.

Williams, P.; Hannah, L.; Andelman, S. [et al.]. 2005. Planning for climate change: identifying minimum-dispersal corridors for the Cape Proteaceae. Conservation Biology. 19: 1063–1074.

Yohe, G. 2000. Assessing the role of adaptation in evaluating vulnerability to climate change. Climatic Change. 46: 371–390.

Appendix 1—Example Documents from Climate Change Case Studies

These documents are posted on the Climate Change Resource Center Web site:

http://www.fs.fed.us/ccrc/adaptationguide

Example 1. Agenda from an Olympic National Forest and Olympic National Park case study workshop

Example 2. Analysis of cold air pooling at Devils Postpile National Monument

Example 3. Inyo National Forest case study—collaboration workshop agenda

Example 4. Inyo National Forest case study—collaboration workshop summary

Example 5. Inyo National Forest case study—climate workshop summary

Example 6. Inyo National Forest case study—planning and project implementation summary

Example 7. Inyo National Forest case study—Eastern Sierra digital bibliography

Example 8. Devil's Postpile National Monument—science day agenda

Example 9. Devil's Postpile National Monument—science day summary

Example 10. Devil's Postpile National Monument—science day abstracts

Example 11. Devil's Postpile National Monument—resource planning workshop summary

Appendix 2—Assessing Vulnerability to Climate Change: The Watershed Vulnerability Assessment Approach

Resource managers need locally based information to develop adaptive strategies for climate change and other issues. Intermediate scales, including sub-basin, watershed, and sub-watershed, are an essential scale and unit for assessing vulnerability, because different exposures to climatic variability and change produce a wide range of effects on resource values in different watersheds. Therefore, appropriate adaptive responses, priorities, and prescriptions are needed for different locations (Reid and Furniss 1998). Priority setting, planning, project design, and decision making are conducted most often at intermediate scales, so assessment at these scales is typically relevant and applicable to specific programs and projects. After relative ecological vulnerabilities are determined, and administrative and logistic feasibilities are determined, land managers can target watersheds where resources can be most effectively invested to sustain or improve resilience.

In 2010, a pilot watershed vulnerability assessment (WVA) project, using a national forest-research collaboration, developed a draft assessment process that was then pilot tested by watershed and aquatic specialists on 11 national forests (table A1).The goal of the pilot WVA was to quantify the current and projected future condition of watersheds as affected by climate change to inform management decision making (fig. A1). Because locally-based evaluation is a key component of the process, pilot forests were given latitude in geographic scale assessed, issues addressed, and reporting units used. Pilot forests were asked to include infrastructure, aquatic species, and water uses in the assessments. It was also agreed that the analysis area would include at least one “river basin” watershed (hydrologic unit code 4, HUC-4).

A principal objective of the pilot WVA was to develop a generalized process that could be tailored to local data availability and resource investment (box A1). Pilot forests were selected to provide a range of water resource issues and environmental factors, and each forest brought different levels of staffing and expertise to the project. Some forests had already begun to consider climate change and had some climate science available. The pilot results represent a range of analytical intensities, geographic settings, organizational settings, and subject-matter focus. The Sawtooth National Forest and Umatilla National Forest had established strong working relationships with Forest Service research, resulting in the most detailed assessments. The six-step WVA process, which drew heavily from the process in watershed analysis (Regional Ecosystem Office 1995), is described below in outline form, including results from individual pilot assessments.

Step 1: Set Up the Assessment

Establish the geographic area for assessment, decide who will participate, and identify water resource values and essential information that will drive the assessment. Assessments need to be conducted over large areas, typically an entire national forest, with distinctions made at the subwatershed scale (HUC-6). Assessments can be simplified if they concentrate on only the highest priority values. Usually, lists of values can be prioritized to focus the analysis, and other values or issues can be evaluated during future iterations or other assessment efforts. For the pilot project, selection of resource values to be assessed included floodplain and in-channel infrastructure, water uses (diversions and improvements), and aquatic species (fig. A2). The location and relative importance (within the analysis area) of the selected resources were characterized in this step (fig. A3).

Who participates in the assessment? Assessment of vulnerability is an important interdisciplinary issue for national forests. The assessment should include those specialists and staff who are relevant to the identified values. This may represent many specialties, because water resources affect and are affected by most components of the environment and management activities. Available time and staff often limit participation, and limits should be noted so that the next iterations of assessment include missing input or involvement.

Which information is needed? Existing data, model results, assessments, and plans are used whenever possible. Information needs differ according to the values and scope of each assessment. Whereas some important information may be acquired during the assessment, some may be too difficult, costly, or time-consuming to obtain, and the assessment must proceed without it. This should be explicitly acknowledged, and the missing information can be prioritized for future acquisition. A useful outcome of assessments is knowledge of what is not known but is considered to be important.

Important considerations for Step 1 include:

- Determine which relevant broad-scale evaluations, assessments, and plans are available.
- Describe why a particular place is important. At a minimum, consider water uses, aquatic species and infrastructure (roads and recreational facilities) that could be affected.
- Identify the most important places, categorize their value (high, moderate, low), and map them.
- Consider potential uses (species, diversions, etc.) downstream of the watershed.
- Identify ecological thresholds (flow requirements, temperatures, etc.) associated with specific resource values.
- Document critical data gaps, rationale and assumptions for inferences, references for data sources, and confidence (or uncertainty) associated with assessment outputs.

Step 2: Assess Exposure

Identify observed and projected climate change for the assessment area. “Exposure” is defined as the extrinsic climatic changes that have been documented or are projected to occur in the watershed. In this step, climatic data and modeled climatic projections provide a picture of how climate in the area has changed and is likely to change in coming decades.

Projections of future climate should be based on the best available (generally more recent multi-model) published information on simulated changes in annual and seasonal average temperature and precipitation (fig. A4). Projections through 2050 have relatively high confidence, and although projections beyond 2050 can be considered, they have lower confidence. It is useful to document a range of scenarios (e.g., warm/dry, warm/wet) from multiple model projections. Considering projections based on moderate to high GHG emissions will allow a range of socioeconomic futures to be explored (e.g., projected air temperature in Colorado) (fig. A4). Local historic data are especially valuable in providing context for climate change projections, because the data can be directly linked with local water resource values relevant to resource management (e.g., snow depth) (fig. A5).

Important considerations for step 2 include:

- Identify the effects of an altered climate on watershed processes.
- Identify hydrologic processes important to the identified resource value.
- Determine how an altered climate will affect each resource value.
- Quantify the magnitude of differences in effects, as well as spatial and temporal variation (fig. A5).
- Include disturbance regimes in the analysis and quantify any disturbance-related effects.
- Quantify trends in available, relevant climate metrics. Local and regional data that display significant changes during the historical record show potential for future changes. Include an example in the assessment if possible.
- Document critical data gaps, rationale and assumptions for inferences, references for data sources, and confidence (or uncertainty) associated with assessment outputs.

Step 3: Evaluate Sensitivity of Identified Values

Determine how identified values are likely to be affected by observed and projected exposure to climate change. This step of the assessment evaluates how natural and human-caused climatic variability and change will affect the response of each watershed to hydrologic changes resulting from observed and projected climatic changes. Some factors might minimize effects (buffers) and some might amplify effects (stressors). This step considers intrinsic characteristics of the watershed (geology, size, slope, aspect, etc.) (fig. A6) and management-related characteristics (road density, grazing, water withdrawals, etc.) that affect the condition of the water resource value in question, and combine to influence the overall response of each resource. This combined assessment describes the likelihood that climate-induced hydrologic change will occur.

The product of this step is a ranking (e.g., low, moderate, high probability of response) for each watershed, typically at the HUC-5 or HUC-6 scale, in the assessment area relative to each water resource issue identified in step 1. Recent trends and projected future trends in resource conditions should also be included. For example, water diversions would exacerbate effects on a resource, whereas anticipated road improvements would improve condition and reduce effects that might otherwise occur.

This step is likely to include factors of short-term importance to individual forests, but that may drive priorities for management. For example, duration of snowpack is critical for water supply and a wide range of other resource values (figs. A7 and A8), and spatial extent of tree mortality caused by insects and wildfire affects vegetation condition, fuels, and water yield (fig. A9). It may also be possible to use fire regime condition class to estimate the potential effects of wildfire on water quality and water yield.

Important considerations for step 3 include:

- Determine the sensitivity of watershed values to anticipated changes in natural features (geology, slope, etc.).
- Determine the sensitivity of watershed values to changes in existing and anticipated human-caused factors (roads, reservoirs, etc.) (figs. A7 and A8).
- Evaluate trends or expected trends in stressors, and how they might affect restoration activities, as well as planned changes to management activities (e.g., changes to range allotments, water releases) (fig. A9).
- Document critical data gaps, rationale and assumptions for inferences, references for data sources, and confidence (or uncertainty) associated with assessment outputs.

Step 4: Evaluate and Categorize Vulnerability

Combining exposure and sensitivity, determine the vulnerability of watersheds and subwatersheds to climate change. In this step, the location and extent of exposure are merged with the location and relative risk to water resource values (fig. A10). The product is a classification, typically by sub-watershed (HUC-6), that displays relative vulnerability of the identified values (fig. A11). Results are described in narrative form, and mapped for the entire assessment area.

For example, relative vulnerabilities of water resources to climate change on the Umatilla National Forest (fig. A10) were determined by displaying the relative density of water resource values by sub-watershed, relative risk of change, and sensitivity of each sub-watershed; these factors were combined to yield relative vulnerability. Relative risk of change to infrastructure for sub-watersheds on the White River National Forest (fig. A11) was based on factors affecting peak flows. Relative rating of watershed condition on the Ouachita National Forest was based on guilds of aquatic species affected by sediment, where sediment production was a function of projected changes in precipitation. Locations where changes in condition are expected can be used to prioritize management actions.

Important considerations for step 4 include:

- Identify the highest risks of changes to hydrologic processes (e.g., using a risk-severity matrix).
- Determine how changes in hydrologic processes affect water resource values.
- Determine the relative vulnerabilities of sub-watersheds across the assessment area (e.g., low, moderate, high) to inform priorities for adaptive response. In places where vulnerabilities are high, can resource values be sustained?
- Identify administrative factors that should be factored into the rating, such as mixed ownership, likely partners, and potentially irreversible impacts such as dams and highways.
- Document critical data gaps, rationale and assumptions for inferences, references for data

sources, and confidence (or uncertainty) associated with assessment outputs.

Step 5: Set Priorities for Adaptive Responses

Establish priorities for adaptive management actions intended to maintain values and services in the assessment area. Overlaying administrative and social considerations on physical and biological vulnerabilities helps define priority watersheds for adaptive response. This step depicts where funding and personnel might be best focused to ensure desired resource conditions and watershed services. Recommendations for monitoring may also be included and should validate the effectiveness of adaptive responses. Results for the step are displayed in narrative form and mapped.

Important considerations for step 5 include:

- Identify approaches that can enhance resilience and resistance sufficiently to protect resource values. Consider which effects of climate change might be irreversible, and how that can inform priority setting.
- Identify management practices that would enhance restoration and realignment in both the short and long term, including the magnitude of treatment that would be required.
- Determine if land ownership and administrative status are conducive to planning and implementing treatments.
- Identify partners who would improve the likelihood of success.
- Determine if sufficient technical and financial capacity is available to implement treatments.
- Consider if additional information, analysis, or consultation is needed before setting priorities, including what is needed and when it is likely to be provided.
- Identify monitoring opportunities that should be prioritized in to validate assumptions made in the assessment, track trends in key resource values, and provide data that inform key adaptive responses.
- Document critical data gaps, rationale and assumptions for inferences, references for data sources, and confidence (or uncertainty) associated with assessment outputs.

Step 6: Critique the Assessment

Summarize understanding that was gained in the assessment to make subsequent assessments more efficient and useful. This step captures lessons learned, and recommends ways to improve the WVA process (box A2). This is primarily a qualitative evaluation that benefits from broad participation by resource managers, scientists, and others in the assessment. Although the evaluation can be obtained through a roundtable discussion, documenting and distributing the comments in written form is recommended as a legacy of the project.

Important considerations for step 6 include:

- Determine which information that was not available would have improved the assessment.
- Determine which partners or participants, if included, would have improved the assessment.
- Identify which components of the process were necessary, which made the biggest contribution, and which were not efficient or necessary.
- Make general and specific recommendations on how the next iteration of WVA could be improved.

Summary: Lessons Learned

Watershed and aquatic specialists from participating pilot forests were able to develop an approach for quantifying watershed vulnerability within a relatively short period of time, and move forward with assessments. Four national forests were able to complete the process within eight months. Box A2 summarizes some of the lessons learned during this pilot assessment.

One of the most difficult aspects of the assessment process was acquiring suitable exposure data, which had not been used to any degree by the participants. Project completion could have been accelerated by making exposure data available at the regional level at the outset. Species and water use values of concern varied widely across the pilot forests. In one case, brook trout (*Salvelinus fontinalis*) was viewed as a stressor on one forest and a valued resource on another. The differences suggest that while information on various processes and resource conditions can be shared among forests, local (forest- and watershed-scale) assessments have the greatest value.

Connecting the pilot assessments with potential effects of climate change resulted in a more detailed analysis. Linkages with ongoing research were especially fruitful, resulting in assessments with a high level of scientific detail. Ongoing collaborative work in downscaling climatic projections to assess future stream temperature provided critical information at a useful spatial scale. In a few locations, national forest or regional managers had identified climate change effects on water resources as a concern, so some pilot forests had a head start in terms of funding, support, and data availability.

As with most endeavors, the resulting products were strongly influenced by the experience and expertise of those participating. Those participants with the best local knowledge of forest resources and interactions tended to have the easiest time with the process. Use of the pilot participants as trainers or facilitators for future assessments will make future efforts more credible and efficient.

Footnotes

[1] We anticipate that this guidebook will become an online resource through the Climate Change Resource Center (http://www.fs.fed.us/ccrc), and that information about adaptation efforts on national forests and other federal lands will continually be added and discussed. This will encourage rapid communication of experiences with various aspects of adaptation, thus accelerating the learning process and implementation of adaptation on national forests and other federal lands.

[2] U.S. Department of Agriculture, Forest Service [USDA FS]. Manuscript in preparation. 2010 RPA assessment of forest and range lands. http://www.fs.fed.us/research/rpa/pubs-supporting-2010-rpa-assessment.shtml. [4 February 2011].

[3] Zielinski, Bill. 2010. Personal communication. Research ecologist. U.S. Forest Service, Pacific Southwest Research Station, 1700 Bayview Drive, Arcata, CA 95521-6013.

Appendix Footnotes

Appendix 7

[1] Mai, C.; Bachman, S.; Levitan, F. 2011**.** Shasta-Trinity National Forest watershed vulnerability assessment: a climate change case study. Unpublished report. On file with: Shasta-Trinity National Forest Headquarters, 3644 Avtech Parkway, Redding, CA 96002.

Appendix 8

[1] Clifton, C.; Day, K.; Johnson, A. 2011. Umatilla National Forest watershed vulnerability assessment: a climate change case study. Unpublished report. On file with: Umatilla National Forest, 2517 SW Hailey Ave, Pendleton, OR 97801. 15 p.

Appendix 9

[1] Clifton, C.; Day, K.; Johnson, A. 2011. Umatilla National Forest watershed vulnerability assessment: a climate change case study. Unpublished report. On file with: Umatilla National Forest, 2517 SW Hailey Ave, Pendleton, OR 97801. 15 p.

Figure Caption Footnotes

Table 1—Relevance of spatial scale for assessing vulnerability to climate change

	Spatial scale		
	Large[a]	**Intermediate**[b]	**Small**[c]
Availability of information on climate and climate change effects	High for future climate and general effects on vegetation and water	Moderate for river systems, vegetation, and animals	High for resource data, low for climate change
Accuracy of predictions of climate change effects	High	Moderate to high	High for temperature and water, low to moderate for other resources
Usefulness for specific projects	Generally not relevant	Relevant for forest density management, fuel treatment, wildlife, and fisheries	Can be useful if confident that information can be downscaled accurately
Usefulness for planning	High if collaboration across management units is effective	High for a wide range of applications	Low to moderate

[a] More than 10,000 km^2 (e.g., basin, multiple national forests)

[b] 100 to 10,000 km^2 (e.g., sub-basin, national forest, ranger district)

[c] Less than100 km^2 (e.g., watershed)

Table 2—Relevance of temporal scale for assessing vulnerability to climate change

	Temporal scale		
	Large[a]	**Intermediate**[b]	**Small**[c]
Availability of information on climate and climate change effects	High for climate, moderate for effects	High for climate and effects	Climate change and effects predictions not relevant
Accuracy of predictions of climate change effects	High for climate and water, low to moderate for other resources	High for climate and water, moderate for other resources	Low
Usefulness for specific projects	High for temperature and water, low to moderate for other resources	High for water, moderate for other resources	Low due to inaccuracy of information at this scale
Usefulness for planning	High	High for water, moderate for other resources	Low

[a] more than 50 years

[b] 5 to 50 years

[c] less than 5 years

Table 3—Relevance of temporal scale for planning and priority setting for adaptation to climate change

	Temporal scale		
	Current[a]	**Near to mid term**[b]	**Long term**[c]
Potential applications	Ongoing projects	Projects in development, project planning	Land management plans, adaptive management
Useful activities	Conduct rapid assessment of projects for vulnerability	Promote internal and external education on climate change	Conduct detailed analyses, implement proactive responses
Adaptation strategy	Begin to understand vulnerabilities, implement no-regrets projects	Resist adverse effects, implement some activities that promote ecosystem resilience, promote institutional change	Implement many activities that promote ecosystem resilience

[a] 1 year

[b] 2 to 20 years

[c] More than 20 years

Table 4—General questions that can be used to facilitate initial dialogue on climate change adaptation[a]

- What are priorities for long-term resource management (e.g., 50 years)? How can climate change be integrated in planning at this time scale?
- What is the policy and regulatory environment in which management and planning are currently done?
- What are the biggest concerns and ecological/social sensitivities in a changing climate?
- Which management strategies can be used to adapt to potentially rapid change in climate and resource conditions?
- Which information and tools are needed to adequately address the questions above?
- Which aspects of the policy and regulatory environment affect (enable, inhibit) management that adapts to climate change?

---

[a] These questions are intended to establish the local management context, elicit overarching management responses to climate change, and promote mutual learning within the science-management partnership. Questions can be designed to accommodate local interests and preferences.

Table 5—The operating principles for the Climate Change Resource Center guide its mission to provide land managers with an online portal to easily access credible, science-based, and relevant information and tools concerning climate change and ecosystem management options

- Provides access to scientifically credible, peer reviewed resources and to primary literature within its focus area of climate change and ecosystem response, ecosystem adaptation and mitigation.
- Selects and highlights climate change resources that are relevant to land managers and practitioners, are tied to articulated needs, and based on simple, user-oriented taxonomies.
- Solicits the development of original materials within its focus area.
- Presents materials in compelling and varied ways, using multimedia and featuring case studies that demonstrate management actions. It offers an interface that allows users to easily navigate the site and to find desired information via multiple channels and at multiple levels of specificity.
- Provides timely and current information on a rapidly changing subject, using periodic updates to fulfill the information needs of returning users.
- Openly discloses limitations and assumptions of the resources it provides.
- Seeks diverse feedback and evaluation to determine if it is meeting the needs of users.
- Works with other websites and organizations to share information fluidly and to complement the resources they provide.
- Maintains a positive focus on what can and is being done in ecosystem management to cope with climate change.

Table 6—Steps defining the watershed vulnerability assessment process and the types of questions to be addressed

- Steps for the watershed vulnerability assessment process:
  - Step 1- Set up the analysis and establish the scope and water resource values that will drive the assessment
  - Step 2- Assess exposure
  - Step 3- Assess sensitivity
  - Step 4- Evaluate and categorize vulnerability
  - Step 5- Recommend responses
  - Step 6- Critique the vulnerability assessment
- Typical questions to be address in a watershed vulnerability assessments:
  - Which places are vulnerable?
  - Which places are resilient?
  - Where are the potential refugia?
  - Where will conflicts arise first, and worst?
  - Which factors can exacerbate or ameliorate local vulnerability to climate change?
  - What are the priorities for adaptive efforts?
  - How to design context-sensitive adaptations?
  - What needs tracking, monitoring?

Table 7—Benefits accrued through use of watershed vulnerability assessments

Watershed vulnerability assessments provide managers with answers to the following questions:

- What is the local, regional, or national importance of ecosystem services, including ecological, economic, and social resources?
- Which important aquatic species may be at risk of population decline or habitat loss due to changes in water flows or levels?
- In which watersheds is the risk to these resources greatest?
- Which watersheds may serve as climate change refugia because they are expected to experience the least impact?
- Which watersheds are high priorities for management to sustain desired hydrologic functions under changing climate?
- Which ecosystem services are most vulnerable to climate shifts or to the land- and water-use changes likely to accompany them?
- Which watershed properties are likely to be affected by climate trends, such as changes in runoff from shrinking snowpacks, changing patterns of groundwater recharge, and loss of habitat for sensitive species?
- Which management actions can reduce the unwanted effects of climate change, protect high value watershed resources, or increase watershed resilience?
- Which measures can be used to detect and track evidence of climate-related change as early as possible?

Table 8—The climate project screening tool in tabular format, with an example project activity[a]

Project activity	Climate change trends and local impacts	Key questions for managers	Response narrative	Continue with project?
- - - - - - - - - - - - - - - - - - - Completed by specialists or scientists - - - - - - - - - - - - - - - - - - -			*- - - - - - - - - - Completed by managers- - - - - - - - - -*	
Thinning for reduction of hazardous fuels	**Trends:** Increased fuel buildup and risk of uncharacteristically severe and widespread forest fire; longer fire seasons; higher elevation insect, disease, and wildfire events; increased interannual variability in precipitation, leading to fuels build up and causing additional forest stress; increased water temperatures in rivers and lakes and lower water levels in late summer; increased stress to forests during	• Will the projected density of the stand after it has been thinned withstand extreme wildfire events? Does spacing between trees need to increase? • Should stands be thinned at a more frequent interval to mitigate for increased forest stress and fire susceptibility or for altered growth patterns? • Does the project area include anticipated future fire prone areas (i.e. higher elevation sites, or riparian areas)? • Given reduced snow pack and extreme flood events, will season of harvest need to change to mitigate for ground		Yes, without modification Yes, with modification No

periodic multi-year droughts; decrease in water quality from increased sedimentation **Local Impacts:** Increased risk for extreme fire behavior; decreased window of opportunity for acceptable prescribed fire conditions; increased risk of fire spread in high elevation areas; flashier, drier fuels; decreased water storage in soils.	disturbance? Will it need to change, given shorter and less reliable snowpack? • Will the proposed project help offset projected effects caused by climate change?

---

[a] Project activities can be general or specific, and of large or small spatial scale.

Table 9—Anticipated effects of climate change on natural resources in Olympic and Tahoe National Forests

Natural resource status or condition	**Olympic National Forest**	**Tahoe National Forest**
Climate–		
Temperature	2.0°C increase by 2040s, 3.3°C increase by 2080s	1.6°C increase by 2040s, 3.4°C increase by 2090s
Precipitation	Small increase in winter	Small decrease in winter
Snow	Decrease at <1500 m; decrease in snow:rain ratio	Large decrease at all elevations
Water–		
Surface runoff[1]	Increase in winter, decrease in summer	Increase in winter, decrease in summer
Streamflow[a]	Large increase in winter, large decrease in summer	Increase in winter, decrease in summer
Tree growth	Decrease at low elevation, increase at high elevation	Decrease at all elevations
Vegetation distribution and abundance	Significant shifts but poorly quantified; no change in forest cover	Significant shifts but poorly quantified; large decrease in forest cover
Aquatic systems	Decrease in habitat quality for anadromous and resident fish	Large decrease in habitat quality for anadromous and resident fish; extirpations possible
Disturbance –		
Wildfire area burned	Small increase[b]	Large increase
Insect attack	Possible increase	Large increase
Windstorms	Unknown, but increased storms would have major impact	Unknown

[a] Expected trends for surface runoff and streamflow will be especially prominent in basins dominated by snow hydrology, with magnitude of impact dependent on how much rain:snow ratio increases.

[b] Threshold relationships may exist in forest ecosystems with high-severity fire regimes that dominate the Olympic Peninsula. Although fires have historically been infrequent (200- to 500-year fire-free intervals), they are often very large (hundreds of thousands of hectares) when they do occur.

Source: Littell et al. (in press)

Table 10—Options identified by resource managers for adapting to climate change in Olympic and Tahoe National Forests

- General adaptation options–
  - Prioritize treatments, manage for realistic outcomes
  - Manage for resilience, reduce vulnerability
  - Manage dynamically and experimentally
  - Manage for process
  - Consider tradeoffs and conflicts
- Specific adaptation options–
  - Increase landscape diversity
  - Treat large-scale disturbance as a management opportunity
  - Promote education and awareness about climate change
  - Increase resilience at large spatial scales
  - Increase management unit size
  - Maintain biological diversity
  - Implement early detection / rapid response for invasive species
  - Match engineering of infrastructure to expected future conditions
  - Collaborate with a range of partners on adaptation strategies

Source: Littell et al. (in press).

Table 11—Key adaptation recommendations developed from workshops at Olympic and Tahoe National Forests

1. Increase interagency coordination and information and resource sharing
2. Increase communication of ongoing research and results from scientists to land managers and across disciplines–

    This could be partly accomplished by hiring a climate change coordinator to work with the forest
3. Conduct more/better monitoring and develop monitoring as integral to adaptive management–

    Create and prioritize a list of data gaps

    Use new technology and citizen participation to help with monitoring

    Create a monitoring coordinator position on the Forest to organize research, plan research and collect data, and make sure that research and monitoring are applicable to management plans and actions
4. Develop a broad-scale, dynamic perspective at the program level–

    Manage habitat, not species

    Manage for process and ecosystem services

    Reconsider targets: for example, it might be more valuable to treat a small area of pepperweed than a large area of another species, but the current system is geared to quantity of widgets

    Reconsider naturalness and historic range of variability

    Reconsider definitions of wilderness

    Develop a realistic approach to invasive species vs. current zero-tolerance stance

    Managers need latitude to take chances
5. Educate the public about climate change, changes in the environment, and changes to management strategies needed–

    Communicate why the Forest Service is managing differently, for example, with fire

    Educate the public about need for changes to forest, aquatic, range, and recreation management

    Use new and traditional means

    Include more interpretation of management actions
6. Increase resilience on the landscape by focusing on minimizing human impacts on sensitive

resources–

    Work with disturbance

    Minimize stressors

    Promote healthy ecosystems (cultural and natural)

    Rebuild diversity

7. Consider mitigation/sustainability options for new proposed actions/renewed permits–

    For example, require increased energy efficiency, renewable resource use, recycling

8. Reassess seed bank rules to allow more flexibility

9. Develop a strong but flexible policy for water management as resources become more strained

10. Conduct social science analyses on how recreation will change–

    Move to different elevations? Different activities? Different season?

Table 12—Opportunities and barriers for adapting to climate change in Olympic and Tahoe National Forests

Opportunities—
Collaborate with adjacent landowners and the general public
Integrate climate-change science into planning and management guidelines
Coordinate planning among multiple management units
Improve science-management collaboration
Expand internal and external education about climate change
Expand fuel treatments due to decreased snowpack
Barriers—
Limited financial resources and management personnel
Constraints imposed by policies, laws, and regulations that are static relative to climate
National and regional budget policies and processes
Traditional focus on historical references for restoration and management
Legacy of past management and regulatory constraints, including small management units
“Checkerboard” pattern of land ownership
Expansion of residential development and recreational activities on private land
Regulatory standards that restrict quantity and timing of management actions
Appeals and litigation of proposed projects

Source: Littell et al (in review).

Table 13—Tools and information needed to facilitate adaptation to climate change in Olympic and Tahoe National Forests

- Long-term science-management partnership focused on landscape and project planning
- Web-based clearinghouse with scientific information, tools, and guidelines to inform adaptation, planning, and priority setting
- Simulations of quantity, seasonal patterns, and temperature of stream flow for river systems
- Simulations of future climate, vegetation, and species movements, and uncertainties associated with these projections
- Assistance with interpreting simulation output, so projections can be reconciled with management priorities for adaptation
- Data on genetic variability of dominant and rare plant species to determine vulnerability to a warmer climate
- Case studies of planning and practices for adaptive responses to climate, including specific examples that can be documented and quickly communicated to others
- Seed banks of native species for vegetation establishment following disturbance

Source: Littell et al. (in review).

Table 14—Ecosystem management acknowledges the importance of natural climatic variability by incorporating this knowledge into landscape assessment, watershed analysis, and restoration planning[a]

Sierra Nevada Ecosystem Project	During the period of recent human settlement in the Sierra Nevada, climate was much wetter, warmer, and more stable than climates of the past two millennia; successful ecosystem evaluations and planning for the future must factor climate change into analyses. Many resource assessments and consequent land-use and management decisions have been made under the assumption that the current climate is stable and indicative of recent past and future conditions. Water delivery systems in the Sierra have been designed under the recent favorable climate, and fire management strategies now being planned reflect forest conditions that developed under the current unusually wet climate. Periods of century-long droughts have occurred within the last 1,200 years and may recur in the near future.
Whitebark pine	Climate change is a significant factor in all aspects of ecosystem management. We have abundant evidence that older forests (>400 years old) were established during a period of much different climate than we now experience, probably wetter and colder. Some white pines, e.g., Great Basin bristlecone pine, approach 4,000 years old, and thus could have been established during the Holocene warm period. Future climatic variability and change will affect the elevations and aspects where restoration of white pines can be successful. Climate change will affect species distribution and the processes that govern ecosystem dynamics (e.g., fire, precipitation, storm disturbance, insect infestations, growing season length, erosion rates).

[a] Examples include: (1) climate as a critical finding of the Sierra Nevada Ecosystem Project report on the Sierra ecoregion (CWWR 1996), and (2) climate as a key factor affecting whitebark pine (*Pinus albicaulis* Engelm.) ecosystems (Salwasser and Huff 2001).

Table 15—Examples of specific opportunities and resources for reviewing background material on climate change pertinent to national forest issues and projects

---

- Conduct climate-change workshops.
- Conduct scenario exercises.
- Consult climate-change regional bibliographies (e.g., Eastern Sierra Climate Change Digital Bibliography: http://www.fs.fed.us/psw/topics/climate_change/wwci_toolkit/escc_bib).
- Participate in climate-change online short courses (e.g., Adapting to Climate Change: A Short Course for Managers: http://www.fs.fed.us/psw/topics/climate_change/wwci_toolkit/escc_bib).
- Participate in classroom climate-change short courses.
- Consult with decision-support groups such as the University of Washington Climate Impacts Group (http://cses.washington.edu/cig) and the University of Arizona Climate Assessment for the Southwest (CLIMAS, http://www.climas.arizona.edu).
- Form discussion groups to interpret local effects of regional climate projections.
- Review climate policy-guidance documents, such as Forest Service guidelines for project/NEPA preparation (USDA FS 2009b) and land management plan revisions (USDA FS 2009a).

Table 16—Considerations to aid ranking of project priorities for short-term projects and long-term planning, given uncertain climatic futures in all cases

- Priorities for short-term projects (1–20 years):
  - Context—
    - New risks and uncertainties due to climate are lower in short term than in the long term; effects of climate change are felt primarily as multiple stresses and through altered disturbance regimes; natural climatic variability remains dominant relative to effects of directional human-caused climatic trends.
  - Priorities—
    - Minimize and reduce detrimental human effects on ecosystem condition, ecological processes, and ecosystem services.
    - Improve forest and ecosystem health.
    - Withdraw or assign low rank to projects that are unlikely to succeed as a result of long-term climate effects.
- Priorities for long-term projects (>20 years):
  - Context—
    - Risks and uncertainties are high; direct effects of climate change are widely apparent and affect ecological and environmental condition and process; directional climatic trends overwhelm short-term natural climatic variability.
  - Priorities—
    - Anticipate significant conversions in vegetation and faunal types and migration of species to novel habitats and geographic regions.
    - Anticipate significant and novel changes in ecological condition, processes, and successional paths.
    - Enable species and systems to move to new states with minimal loss of biological diversity, functional integrity, and ecosystem services.

Table 17—Examples of strategies and actions to promote ecosystem resistance, resilience, and response from the Olympic Climate Change case study

Resistance	Utilize prescribed fire and post-fire planting to maintain native species and prevent tree encroachment in alpine meadows.
	Use early detection-rapid response to control exotic species.
	Place fuel reduction treatments around high-value riparian areas to prevent (temporary) habitat loss and aquatic habitat degradation
Resilience	Focus on maintaining, reconnecting, and reestablishing ecosystem processes and functions.
	Reducing existing pressures on species from sources other than climate change.
	To reduce the incidence of human-caused landslides (and associated sediment loading and stream aggradation), decommission unstable roads, remove sidecast material, and increase the size and number of culverts to reduce the potential for plugging or flow diversion.
	Move roads out of floodplains to prevent flood and storm damage and alteration of natural ecosystem function through restrictions in channel meanders, acceleration of flow velocity, and alteration of large wood recruitment.
	Conduct restoration thinning in landslide-prone areas to accelerate establishment of

large trees that provide wood to streams.

On hillslopes and in steep headwater streams that have previously been intensively managed for timber production, reduce erosion by adding large wood to channels to reestablish the sediment storage and routing function that large wood provides.

Maintain a tree seed inventory with high quality seed for a range of species.

Develop a gene conservation plan for *ex situ* seed collections for long-term storage, including seed collections from rare species and encompassing the range of variation in widespread species.

Identify new areas that may become important for *in situ* gene conservation.

Continue to increase disease resistance in susceptible species, such as western white pine (*Pinus monitocola* Douglas ex D. Don) and whitebark pine.

Increase the amount of restoration thinning in young stands to reduce competition and drought stress, increase tree growth and vigor, increase structural complexity, increase species diversity, and improve wildlife habitat quality, and shift the strategy in placement of thinning treatments to increase resilience across large landscapes.

Modify thinning prescriptions to further decrease forest density and increase gap size to provide for establishment and vigorous growing conditions for desired tree, shrub, and herbaceous species, and to reduce fire hazard.

Increase wildlife habitat quality through creation and protection of legacy structures, including old-growth trees, snags, and large downed wood.

Response

Increase culvert size and prevent road failures to allow streams to respond to increased flooding.

Increase the capacity to restore forest lands after large disturbances by doing the following:

> Increase seed storage for native tree species that are either adapted to a drier climate and/or to greater variation in climate.
>
> Be prepared to treat increases in invasive plant species from disturbances by continuing to implement the early detection, rapid response program.
>
> Be prepared to seed/plant appropriate native and nonnative plant species after flooding by increasing the native plant materials program.
>
> Protect and conduct restoration treatments in riparian areas to provide corridors for species movement.

Collaborate with neighbors about where to strategize treatments and increase extent of protected areas to increase habitat quality and connectivity.

Reduce late-successional habitat fragmentation by conducting restoration thinning treatments near existing late-successional forest.

Maintain and restore connectivity and fish passage in headwater areas that are likely to go dry, and restore damaged habitat in headwater streams that are expected to retain adequate streamflows to help maintain viable resident fish populations in as many areas as possible.

Correct fish passage barriers as funds are available.

Protect cold water refugia and wild fish strongholds to help ensure continued wild fish population viability in the face of climate change

---

The adaptation strategy of realignment was not addressed in this case study.

Table A2. National forests included in the pilot watershed vulnerability assessment

Pilot forest(s)	Lead	Scale of analysis	Reporting scale	Water resource values assessed
Chequamegon-Nicolet	Dale Higgins	Forest	HUC-6 (subwatershed)	Wetlands, coldwater fishes, groundwater
Chugach	Ken Hodges	Eyak Lake basin	HUC- (subbasin)	Salmon, hydropower, infrastructure
Coconino	Rory Steinke	Five 5th-field watersheds	HUC-6 (subwatershed)	Amphibians, stream and riparian habitat, infrastructure, water uses
Gallatin	Laura Jungst	Forest	HUC-6 (subwatershed)	Westslope cutthroat trout, Yellowstone cutthroat trout, water uses, infrastructure
Grand Mesa, Uncompahgre, and Gunnison	Carol Howe	Forest	HUC-6 (subwatershed)	Aquatic habitats and species, water uses, infrastructure
Helena	Joan Louie	Forest	HUC-6 (subwatershed)	Westslope cutthroat trout, bull trout, recreational fisheries, infrastructure

Ouachita	Alan Clingenpeel	Forest	HUC-6 (subwatershed)	Warmwater fishes, infrastructure
Sawtooth	John Chatel	National recreation area	HUC-6 (subwatershed)	Salmon, bull trout, water uses, infrastructure
Shasta-Trinity	Christine Mai	Forest	HUC-6 (subwatershed)	Springs, salmon, redband trout, infrastructure, water uses
Umatilla	Caty Clifton	Forest	HUC-6 (subwatershed)	Salmon, water uses, infrastructure
White River	Mark Weinhold	Forest	HUC-6 (subwatershed)	Amphibians, Colorado River cutthroat trout, water uses, infrastructure

Box 1—Four dimensions of response to climate change from the *National Roadmap for Responding to Climate Change* (USDA FS 2010c) are addressed by 10 specific kinds of action. The performance scorecard (USDA FS 2010a) has a series of questions to assist national forests in determining if those actions are being accomplished.

Agency capacity

1. Educate employees
2. Designate climate change coordinators
3. Develop program guidance and training

Partnerships and education

4. Integrate science and management
5. Develop partnerships and alliances

Adaptation

6. Assess vulnerability
7. Set priorities
8. Monitor change

Mitigation and sustainable consumption

9. Assess and manage carbon
10. Reduce environmental footprint

Box 2—Scientific review, advice, and consultation can be achieved through diverse formats that depend on national forest needs and regional contexts (fig. box2). A sample charter for a federal science advisory board to provide input on national forest issues is given below.

[Insert Fig. Box 2]

Example of charter for a national forest science advisory board

Inyo National Forest
Science Advisory Board
CHARTER
May 2009

Purpose

As the National Forest System Land Management Planning Final Rule (36 CFR Part 219) states, “The responsible official must take into account the best available science” and to do this “may use a science advisory board...to evaluate the consideration of science in the planning process”, a science advisory board is established for issues concerning Inyo National Forest, including project design and implementation, the development and subsequent updates of the comprehensive evaluation report (CER), and the update of the Inyo National Forest Land Management Plan.

Objectives and Duties

The Inyo National Forest Science Advisory Board (SAB) is an interdisciplinary, independent board of academic, agency, and NGO scientists dedicated to providing expert input on scientific and land management issues to employees of Inyo National Forest. Membership on the SAB and opinions put forth by the SAB are the sole responsibility of the SAB.

Board members will be chosen for the knowledge in the geographic area, in addition to their ability to consider the context in which single issues relate to other issues of concern for the Inyo National Forest. Moreover, in their role as advisors, board members will be expected to consider the mission of the Forest Service: to achieve quality land management under the “sustainable multiple-use management concept”. Board members will be appointed to a two-year term initially, renewable for three consecutive terms. Each member will be expected to provide expert scientific assistance intermittently throughout their tenure through technical assistance on projects, expert opinion, peer review, and collaboration.

The SAB will meet at least once per year, although this meeting need not take place in person. Members of the SAB will not be compensated for their services.

Box 3

Example of a Facilitated Workshop to Assess Adaptation Options

Below is an example agenda from a facilitated workshop involving the public (day 1) and national forest staff (day 2).

[Insert Fig. Box 3]

Box 4

Principles for Incorporating Climate Change Considerations in Forest Service Land Management Plan Revisions

- The focus of Forest Service land management is multiple use management with ecological, social, and economic sustainability. Climate change is a factor to be considered in the delivery of our overall mission.
- Use the best available science on climate change that is relevant to the planning unit and the issues being considered in planning.
- Where necessary to make informed decisions and provide planning direction responsive to changing climate, use climate change science and projections of change in temperature and precipitation patterns at the lowest geographic level (national, broad, mid-, base) that is scientifically defensible. Given the uncertainty involved and limits to modeling capability, this is most likely at much broader scales than appropriate for the planning unit.
- Address climate change during land management plan (LMP) revision (USDA FS 2010b) in terms of “need for change” from current LMP direction, so that the unit will continue contributing to social, economic, and ecological sustainability.
- Place increased value on monitoring and trend data to understand actual climate change implications to local natural resource management.
- Include adjacent land managers and stakeholders in the planning process and review components.

Box 5

Template for Assessing Climate Change Impacts and Management Options (TACCIMO)[1], a Web-Based Tool Connecting Planning and Science Through a Report Generation Service

TACCIMO inputs are (1) projected climate change, (2) effects and management options derived from a literature review, and (3) Forest Service land and resource management plans. The Web-based interface (4) uses a relational database environment to synthesize inputs based on user selections to generate a report. Forest Service planners will be able to readily construct a current situation report (8) from the planning template report (6), while state and private users will focus mainly on forecasts and effects (5). Feedback tracking will ensure completeness of information and usefulness of functionalities (7).

Climate change factors impacting ecosystems form the core that links TACCIMO content and the basis of user interactions. Direct impact and management option quotations are derived from current peer reviewed literature and stored in an easily updated database that will grow as climate change science evolves. Projected climate change is available through the TACCIMO geospatial interface, including temperature and precipitation forecasts in ⅛ ^{o}C (~12 km) resolution. Users can generate standard and custom maps, tables, and figures documenting the magnitude and direction of anticipated change for a given location. This information serves as context for evaluating direct impacts and management options.

Land and resource management plan components (including forest-wide desired conditions, objectives, design criteria, and monitoring questions) are stored in an easily updated database that allows users to connect climate change factors affecting ecosystems directly with the planning language with which they are familiar. Users can directly link current management capabilities and conditions with emerging climate change science. This aids planners, managers, and scientists in indentifying current management opportunities, potential limitations, and areas for future study.

[1] http://www.forestthreats.org/taccimo

[Insert Fig. Box 5]

Box 6

Using Past Climate to Place Projected Temperatures in Context of Management Experiences.

[Insert Fig. Box 6]

Box 7

Ranking and Reprioritization of Management Actions with Climate Change on Olympic National Forest

Olympic National Forest (ONF) has developed a forest strategic plan, integrating aquatics, wildlife, silviculture, and fire, which helps to identify priority areas for management activities such as habitat restoration, road decommissioning, forest thinning, and fuel reduction treatments. Activities are prioritized based on factors such as habitat improvement potential, economic viability of activities, and existing priorities and land allocation restrictions. Although it is not currently a factor, ONF is also working to incorporate climate change into the forest strategic plan.

As a part of the forest strategic plan, ONF developed a road management strategy to help prioritize road management activities on the ONF. The road management strategy assesses the risks that individual road segments pose to various resources, especially aquatic resources, against the need for access that the road provided. This information is used for setting priorities for road maintenance, upgrading, and decommissioning.

Factors used to assess road risk to aquatic resources include (but are not limited to) riparian zone proximity and upslope hazard, which are both likely to be influenced by climate change. To incorporate climate change predictions, ONF proposes to modify the upslope hazard factor to consider the amount of area upslope that is in the transient snow zone or rain-on-snow (ROS) zone. With increasing temperatures, there will be shifts in the location and extent of ROS zones. Future locations of ROS zones can likely be predicted using a model that accounts for factors such as climate, snow cover, and elevation. ONF proposes to model the area within the ROS zone in the hillslope areas directly above and connected to road segments. Road segments will be evaluated for ROS under current conditions and for the future projected conditions (e.g., 2040). The current and future hazard evaluations will be compared, and those areas with a higher hazard rating under projected future conditions will be prioritized for maintenance, upgrading or decommissioning. This comparative evaluation will likely result in recommendations for increased frequency and/or intensity of road treatments for specific roads, including the recommendation to decommission some road segments rather than try to maintain them.

Riparian area and stream proximity are other factors used to evaluate the risks that roads present to aquatic systems at ONF. Stream adjacent or riparian area roads are recognized as risky because they often have direct impacts on stream channels. Stream adjacent roads also have high potential for frequent damage from floods and stream channel changes that result in higher maintenance costs. To incorporate climate change predictions, ONF proposes to modify the riparian area/stream proximity factor by manually validating the locations of stream adjacent roads and degree of connectivity of these roads to streams. Roads will be assessed under current and future projected conditions. Those roads that are determined to be within a proposed flood hazard corridor (in a potential area of inundation or channel migration zone, and/or in a geotechnical setback buffer) will be assigned a higher riparian zone proximity hazard rating. Roads that have a higher hazard rating under future projected conditions (e.g., due to increased flood risk) will be considered as high priority for maintenance, upgrading or decommissioning.

The forest strategic plan identifies focus areas for restoration and where projects, such as commercial thinning, may achieve multiple objectives. The strategic plan currently emphasizes restoring and connecting fragmented terrestrial and aquatic habitats. However, increasing habitat connectivity could be further emphasized, and modification of treatment prioritization could help to make the plan “climate smart.” For example, thinning treatments could be prioritized around existing late-successional forest to increase late-successional habitat connectivity and help increase wildlife resilience to climate change. A GIS analysis could be used to identify gaps in desirable conditions and determine where treatments would be most effective. Also, surveys could help in determining where the best corridors for movement exist on the peninsula, and treatments could be positioned accordingly. Wildlife could also be given greater consideration in prioritization of road decommissioning on the forest; roads that inhibit species movement could be prioritized for decommissioning.

Another way to potentially increase late-successional habitat connectivity is through restoration thinning treatments and protection of headwater stream areas on ONF, because forests that surround headwater streams are widespread and connected along continuous slopes. Protection of headwater streams and encouraging vigorous conifer growth could help to prevent increasing stream temperatures with climate change and prevent sediment movement downstream. Thinning in high-risk landslide-prone areas in headwaters may also help to accelerate the establishment of large trees that provide wood to streams, thus improving aquatic habitat quality.

[Insert Figs Box 7 a-e]

Box 8

Using Early Detection-Rapid Response to Reduce Exotic Species

Olympic National Forest aggressively attempts to remove and control exotic plant species to reduce impacts on native plant species and animal habitat. Monitoring is used to locate and report exotic species when populations are still small and isolated (**early detection**). A decision is then made on whether it is possible to eradicate or significantly reduce the distribution and abundance of the plant, and an appropriate action is implemented (**rapid response**). Reducing exotic plant species increases **resistance** of native vegetation to climate change by eliminating a stressor that increases competition. Many exotic species, especially annuals, are more competitive than native species in a warmer climate and especially following disturbance.

Olympic National Forest uses early detection-rapid response (EDRR) to reduce populations of Japanese knotweed (*Polygonum cuspidatum* Siebold & Zucc.) and other knotweeds (Polygonaceae) that spread along riparian corridors through prolific seed dispersal and dense root systems, rapidly displacing native species. Knotweed can be so competitive that it excludes regeneration of trees, thus reducing the potential for conifers and hardwoods to grow near streams. Lack of trees reduces the potential for woody debris to fall into streams, removing a critical habitat element for Pacific salmon populations. Multiple mechanical treatments and herbicide applications are typically needed to remove knotweed, but this level of effort is considered worthwhile to protect riparian habitat.

Over 200 exotic plant species currently exist on the Olympic Peninsula. Most of those species are widely distributed and are either mixed with native systems or considered relatively benign (e.g., they cannot survive in shade). It is not realistic to eliminate most of these species, so application of EDRR focuses on new arrivals on the landscape. Originally conceived as a tool for conserving native biological diversity, EDRR is improving **resistance** of native systems to a warming climate.

Box 9

Interagency Collaboration Ensures Conservation of Native Flora and Fauna

Olympic National Forest (ONF) and Olympic National Park (ONP) share borders on the Olympic Peninsula in the northwestern corner of Washington state. This region has a high degree of endemism in native plant and animal species due to its glacial history, ocean border, and isolation from other mountainous landscapes. Areas that were ice-free (above about 1200 m) during glaciations contain rare species and habitats and served as both refugia and sources of biological diversity following glacial recession, thus creating *resistance* to impacts during past variations in climate.

ONF and ONP both emphasize conservation of native flora and fauna in management policy. ONF has been restoring forest habitat for over 20 years, with an emphasis on accelerating late-successional structure in coniferous forests, following several decades of extensive timber harvest. ONP served as an "island" of late-successional forest amidst timber harvest on ONF and private lands, providing habitat for those species (e.g., northern spotted owl [*Strix occidentalis caurina* Merriam], marbled murrelet [*Brachyramphus marmoratus* Gmelin] that depend on habitat in old forests

Equally important, wilderness at higher elevations in ONF and ONP provides refugia for flora and fauna across a common landscape that has never been disturbed by logging. As climate continues to warm, these subalpine and alpine landscapes may change due to altered competitive relationships among species, with effects determined largely by the effects of warming on duration of snowpack. Survival of species and populations in these areas in a warmer climate should be maximized because most native biota are still present and may be able to resist future stress.

Box 10

Forest Thinning Increases Tree Vigor

Olympic National Forest (ONF) routinely thins young conifer stands to control stand density, improve the growth of residual trees, and accelerate late-successional structural characteristics. Thinning increases the vigor of trees in the stand by reducing competition, thereby increasing **resilience** to low soil moisture, insects, and fungal pathogens.

All these benefits also increase the **resilience** of coniferous forest to a warmer climate by reducing susceptibility to other stressors. Therefore, trees are more likely to tolerate chronic stress such as low soil moisture and periodic stress caused by insects and fire, both of which will be more common in a warmer climate. Although insects and fire are not as prevalent on ONF as in the drier eastern Cascade Range, the northeastern portion of the Olympic Peninsula is relatively dry and could experience higher potential for insects and fire in the future. ONP policy does not allow forest harvest, although they occasionally conduct prescribed fires to reduce stand density and allow fire to play its natural role in the northeastern portion of the park.

ONF explicitly includes climate change as a factor in decision making about current forest management projects. Residual stand density is a component of thinning prescriptions, and lower stand densities may be necessary in a warmer climate to achieve the same level of reduced inter-tree competition as was achieved in the past. This aspect of managing for **resilience** is one of several objectives (e.g., wildlife habitat quality) that need to be considered when planning for forest thinning.

Box 11

Managing Road Systems to Reduce Flooding Impacts

Olympic National Forest (ONF) contains 3,200 km of roads within its boundaries, many of which were built to support logging operations prior to 1990. Roads are a potential source of sediment that can be transported to streams, thereby damaging aquatic habitat. Damaged roads are very expensive to maintain and repair. ONF has an ongoing program of decommissioning roads to restore forest habitat, limit erosion, and reduce costs.

During the past decade, major winter storms on ONF caused flooding that damaged roads, campgrounds, and other infrastructure. Increased winter flooding is a certain outcome of a warmer climate in this region. Therefore, ONF is **responding** to climate change by evaluating road maintenance and decommissioning with an eye towards higher flood levels and more frequent flooding. This may lead to decommissioning of some roads, such as those parallel to large rivers, which will be frequently damaged and expensive to repair. It may also require different road standards, such as larger culverts to accommodate increased water flow.

This response by ONF to the effects of a warmer climate demonstrates that it is possible to address physical, biological, and economic factors within the single context of road management. Projections of future hydrographs of rivers on the Olympic Peninsula, including magnitude and frequency of peak flows, is helping to inform decisions about road maintenance and decommissioning. It is a good example of incorporating climate change thinking directly into resource management and engineering.

Box 12

Restoring Structure and Function of Late-Successional Forests

Following extensive forest harvest prior to 1990, Olympic National Forest (ONF) is now considered a “restoration forest” whose principal resource management objective is to restore forest habitat and conserve biological diversity. In most cases, creating and accelerating late-successional forest structure (large trees, high crowns, gaps between trees, multiple vegetation strata) is a priority that drives forest management. Late-successional structure provides several valuable ecological functions, such as habitat for certain species of plants and animals, protection of riparian systems, and carbon retention.

For many years, Olympic National Park provided a core area of late-successional forest surrounded by the more disturbed landscape of ONF and private commercial forest. The opportunity now exists to **restore and realign** large landscapes on the ONF and begin to erase the “hard” visual boundary between the national forest (very young forest) and national park (very old forest). A forest mosaic of different ages and structure across the Olympic Peninsula is an adaptation strategy that will provide functional diversity and a range of habitats at large spatial and temporal scales. This will ensure that the effects of a warmer climate will not have uniform effects across this landscape and increase resilience to stressors. One or more age or structure combinations is likely to survive fires, windstorms, or other large disturbances.

Box 13

Restoring and monitoring degraded streambanks along the Middle Fork of the San Joaquin River, Devils Postpile National Monument, California. Ecosystem services of river and riparian processes are important for aquatic and upland ecosystems, and are increasingly vulnerable to climate-aggravated cycles of severe flooding and low water. Park managers implemented science-based treatments to restore streambanks, and now are monitoring and learning from their initial efforts how to improve techniques for future applications. (Photo courtesy of the National Park Service, Devils Postpile National Monument)

Figure Captions

Figure 1—Conceptual diagram of the ability of different types of models to characterize land area (extent) and spatial resolution (grain). After Mladenoff (2004).

Figure 2—Conceptual diagram of the relative emphasis on spatial dynamics and mechanistic (process-based) detail in different types of models used to understand the effects of climate change. After Mladenoff (2004).

Figure 3—Conceptual diagram of educational and training efforts leading to increased complexity of adaptation planning and activities. These elements are integrated, but need not be taken consecutively. Distance learning can be incorporated into all activities.

Figure 4—Use of scenario analysis in the 2010 RPA assessment. Climate change scenarios will be a part of this analysis allowing the exploration of future climate and socio-economic variability as drivers of resource change.

Figure 5—Projected modal vegetation types in the Pacific Northwest for the 2070-2099 time period compared to modeled historical vegetation types. Projections are from the MC1 model for three general circulation models (GCMs) and the A2 IPCC SRES carbon dioxide emissions scenario. The CSIRO GCM projects a relatively cool and wet Pacific Northwest, while the MIROC model projects a hot and wet Pacific Northwest, and the Hadley model projects a hot and dry Pacific Northwest. Data courtesy of R. Neilson and the MAPSS Team, U.S. Forest Service and Oregon State University. Figure by Brendan Rogers.

Figure 6—The NFMA-NEPA-Monitoring planning triangle showing the number of processes that are used on the left side to gather information. From USDA FS (1999).

Figure 7—Steps for developing and implementing adaptation options.

Figure 8—Guidelines for setting priority to implement adaptation options. Source: Morelli et al. (in prep.) and Füssel (2007).

Figure 9—Categories for determining priorities under a triage system of ranking.

FIGURE CAPTIONS FOR FIGURES IN APPENDIX

Figure A1—Terminology and conceptual model used in the pilot watershed vulnerability assessment.

Figure A2—Points of water diversion on the Shasta-Trinity National Forest. Relative density of diversions is shown at the sub-basin (HUC-4), watershed (HUC-5), and sub-watershed (HUC-6) scales. Note how different scales result in different resolution of values. The best scale for resolving important values differs with different values, and depends strongly on available data.

Figure A3—Infrastructure value, expressed as number of road-stream crossings, on the Sawtooth National Recreation Area, Sawtooth National Forest.

Figure A4—(A) July observed average daily temperatures for 1950-1999; (B) Projections for 2050. Observed data are from PRISM (DiLuzio et al. 2008). Projected changes are from the IPCC (CMIP3) 22-model average for the A1B emissions scenario (Solomon et al. 2007).

Figure A5—Trends in snow depths in two river basins of the Shasta-Trinity National Forest, 1945-2008 (red=minimum, blue=mean, green=maximum).

Figure A6—Classes of sub-watershed sensitivity to erosion and sedimentation for the Grand Mesa-Umcompahgre-Gunnison National Forest, Colorado. (Unpublished data available from Carol Howe, Grand Mesa, Uncompahgre, and Gunnison National Forest, 2250 Highway 50, Delta, CO 81416.

Figure A7—Proportion of catchments in the transient snow zone (1500 to 2200 m elevation), Shasta-Trinity National Forest, California.[1] Results are shown for sub-basins (HUC-4), watersheds (HUC-5), and sub-watersheds (HUC-6). Note how scale of the classified units affects how the display might inform priority setting for adaptive response.

Figure A8—Historic and projected changes in April 1 snow-water equivalent on watersheds (HUC-5), Umatilla National Forest, Oregon and Washington, derived from composite models developed by the University of Washington Climate Impacts Group[1]

Figure A9—Locations of mountain pine beetle outbreaks and large wildfires, Helena National Forest, Montana.

Figure A10—An example of composite mapped values, climatic exposure, watershed sensitivity, and overall vulnerability for sub-watersheds (HUC-6), Umatilla National Forest, Oregon and Washington. The components and analysis algorithms for these classifications are documented.[1]

Figure A11—Relative vulnerability of road infrastructure to climate change effects for sub-watersheds (HUC-6), White River National Forest, Colorado. (Unpublished data available from Mark Weinhold, White River National Forest, 900 Grand Ave., Glenwood Springs, CO 61602).

FIGURE CAPTIONS FOR FIGURES IN BOXES

Figure Box 2—Organizational options for climate-science technical advisory boards to advise resource managers and decision makers

Figure Box 3—Example of a facilitated workshop to assess adaptation options, involving public (day 1) and internal national forest staff (day 2).

Figure Box 5—Interaction of inputs and outputs to the template for assessing climate change impacts and management options (TACCIMO) process for incorporating climate considerations into forest planning.

Figure Box 6—Monthly average (solid black) and 10th and 90th percentiles values (dashed lines) are based on observation over 1950-99. Projected monthly climatologies (thin red lines) are from the multi-model ensemble for the 20-year period centered on 2050. Magnitude of projected temperature change is comparable to or greater than the year-to-year variations throughout the historical records; however, this is not the case for precipitation.

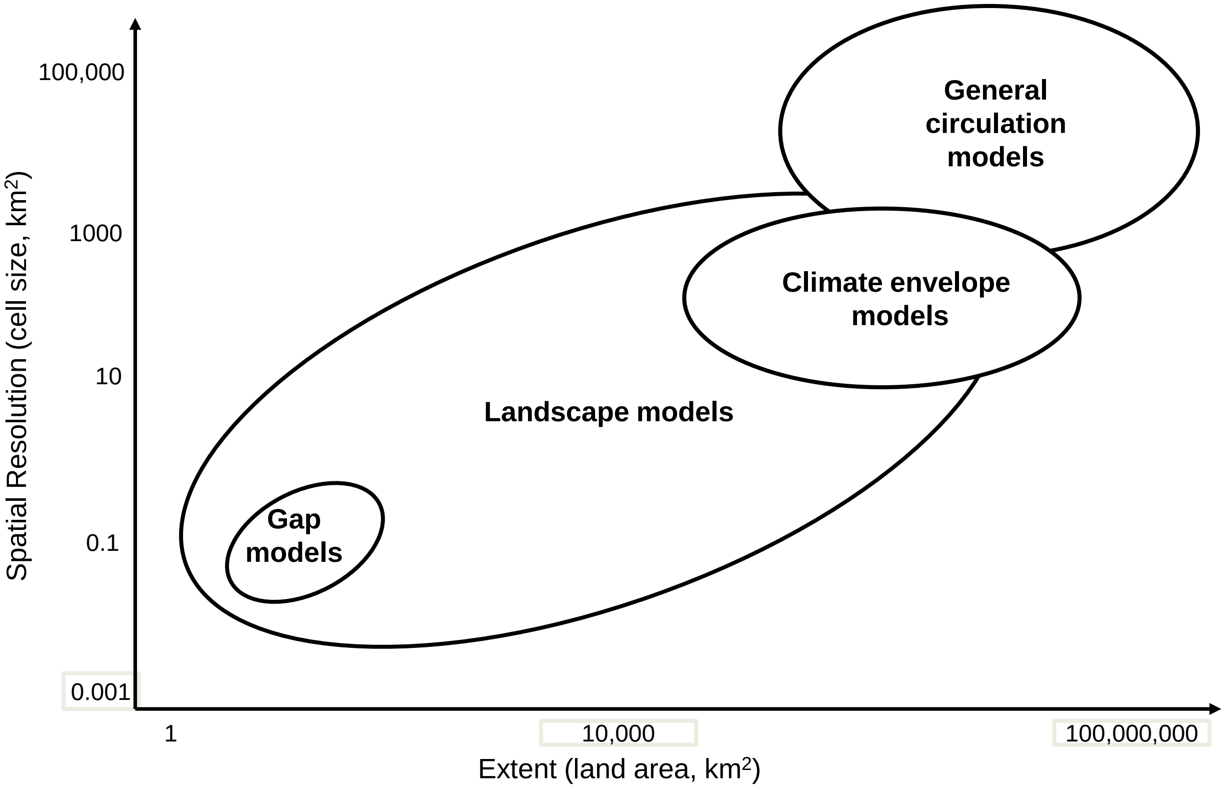
Figure Box 8—Resistance strategies. Early detection, rapid response to treatment to remove invasive weeds at Devils Postpile National Monument (California) is a key preventative measure in response to changing climatic conditions that favor the spread of these species. (Photos courtesy of the U.S. National Park Service, Devils Postpile National Monument)

Figure Box 9—Mountainous areas of the West provide heterogeneous habitat for alpine species, and afford opportunities to protect biodiversity in refugia under changing climates. In the Sierra Nevada of California, as in the Olympic Mountains of Washington, parts of the range were unglaciated during the last ice age, supporting a wide variety of species. (**A**) California golden trout (*Oncorhynchus mykiss aguabonita* Jordan 1892) California's state fish, is an endemic species that persisted in ice-free regions of the Sierra Nevada. (**B**) American pika (*Ochotona princeps* Richardson 1828), an alpine talus-dwelling rabbit relative, thrives in Sierra Nevada regions where continuous high-quality habitat exists. Management actions such as constructing trailside rock walls when erosion control is required can double as escape and dispersal corridors when thoughtfully designed. (Trout photo by Kathleen Matthews) (Pika photo by Andrey Shcherbina) (Other photos by Connie Millar)

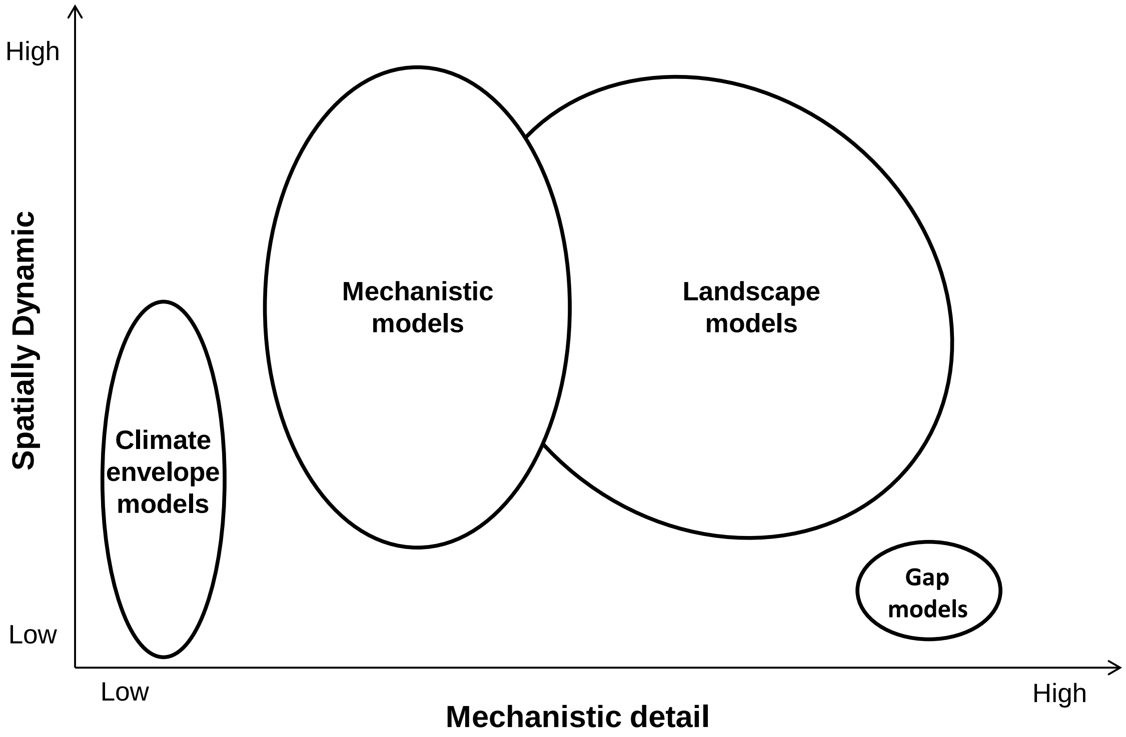
Figure Box 10—Promoting resilience through thinning. Fuel reduction can be an effective means to improve health of forest stands, improving resilience to changes in future climate. Here on the Tahoe National Forest (California), fire is a prescribed treatment to reduce understory fuels and remove small-diameter trees. (Photo courtesy of the U.S. Forest Service, Tahoe National Forest)

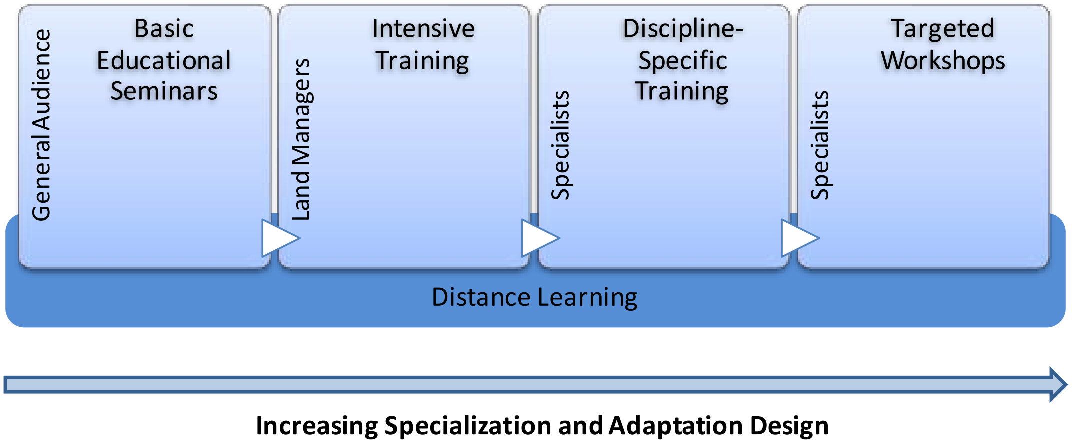
Figure Box 11—Promoting resistance to changing climates. The Olympic National Forest promotes resilience to extreme precipitation events, heavy erosion, and runoff by re-enforcing roads at stream crossings and promoting robust corridors for spawning salmon. (Photo by Kathy O’Halloran)

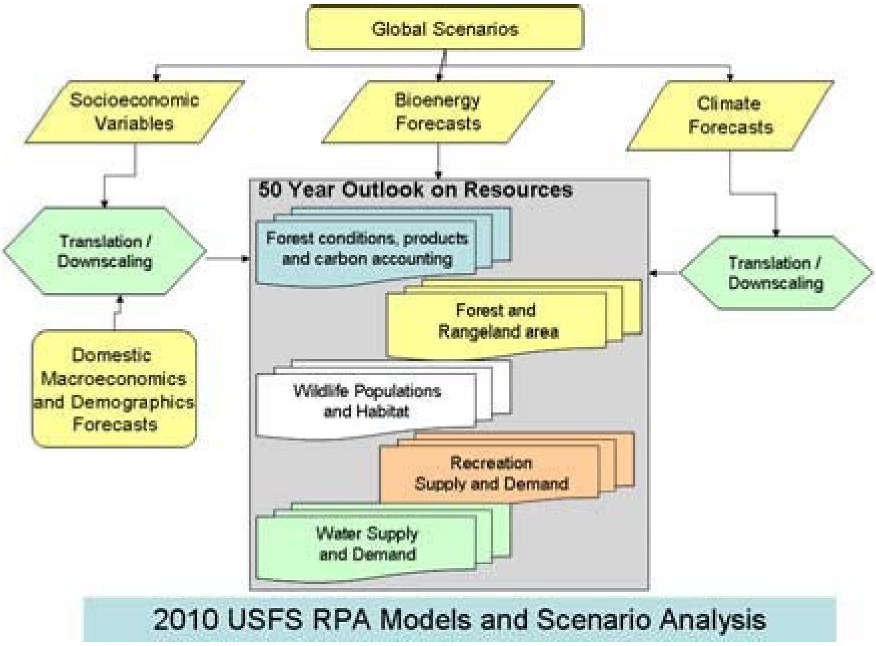
Figure Box 12a—(**A**) Restoring and realigning ecosystems. On the Tahoe and Plumas National Forests (California), as on the Olympic National Forest (Washington), a primary goal is to prescribe silvicultural treatments that restore diversity of stand composition, structure, and function, and align forests to conditions of future climates. (Photo by Connie Millar) (**B**) Restoring and monitoring degraded streambanks along the Middle Fork of the San Joaquin River in Devils Postpile National Monument (California). Ecosystem services of river and riparian processes are important for aquatic and upland ecosystems, and are increasingly vulnerable to climate-aggravated cycles of severe flooding and low water. Park managers implemented science-based treatments to restore streambanks, and now are monitoring and learning from their initial efforts how to improve techniques for future applications. (Photos courtesy of U.S. National Park Service, Devils Postpile National Monument)


General circulation models
Climate envelope models
Landscape models
Gap models
Spatial Resolution (cell size, km²)
100,000
1000
10
0.1
0.001
1
10,000
100,000,000
Extent (land area, km²)

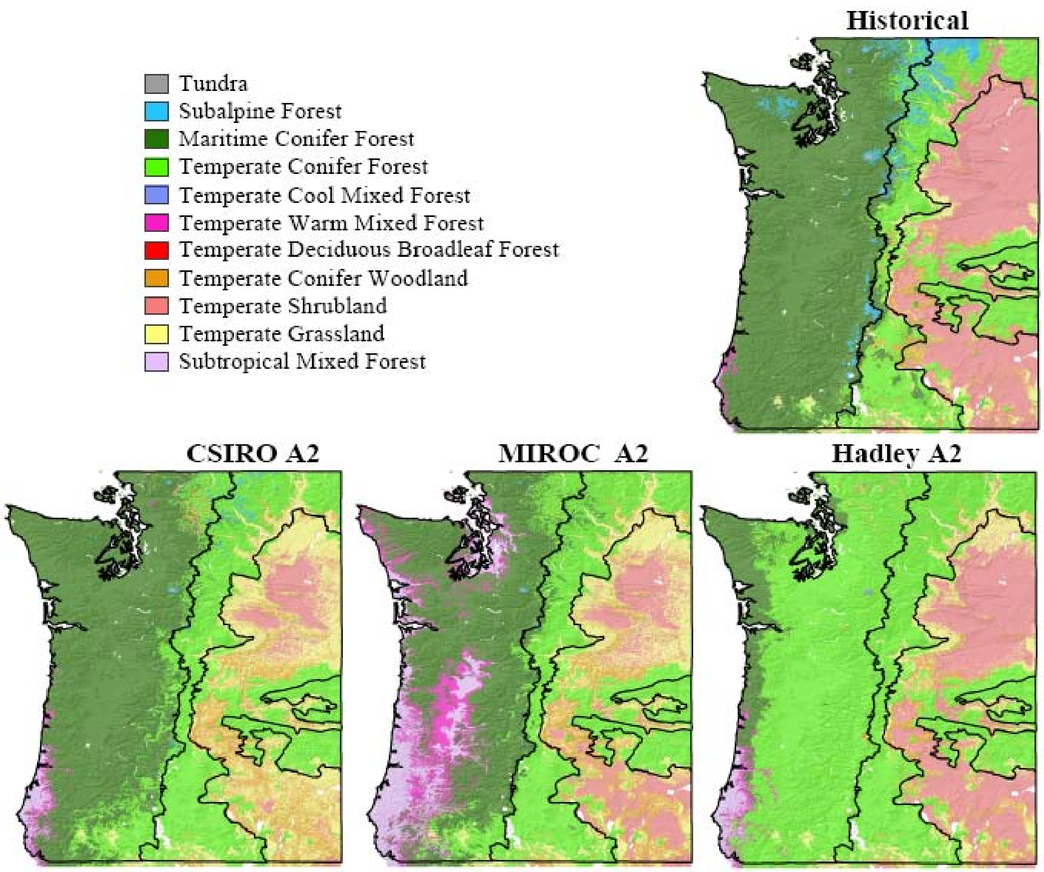
Peterson Figure 2

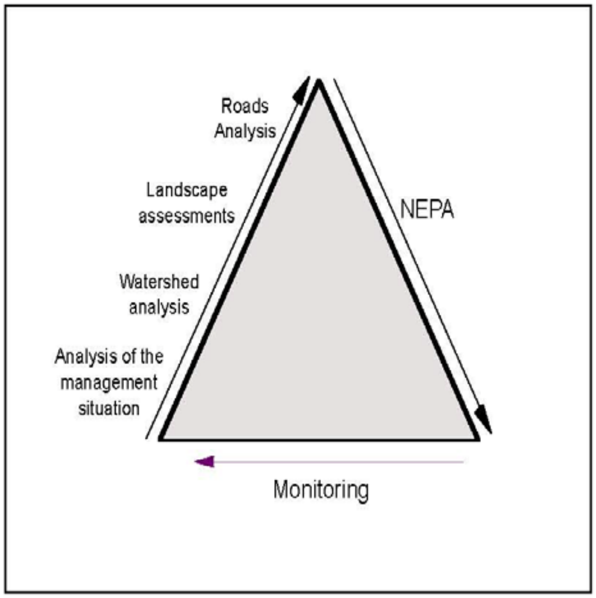



General Audience
Basic Educational Seminars
Land Managers
Intensive Training
Specialists
Discipline-Specific Training
Specialists
Targeted Workshops
Distance Learning
Increasing Specialization and Adaptation Design

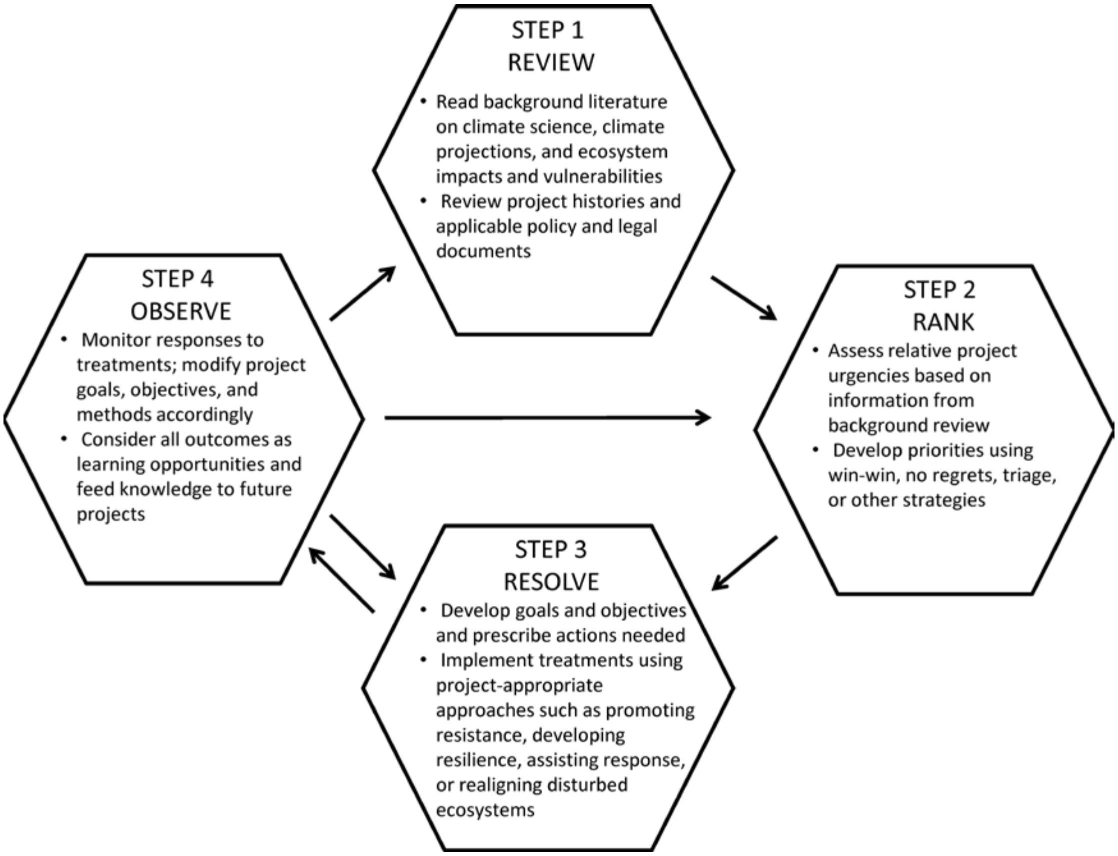

Global Scenarios
Socioeconomic Variables
Bioenergy Forecasts
Climate Forecasts
50 Year Outlook on Resources
Translation / Downscaling
Forest conditions, products and carbon accounting
Translation / Downscaling
Forest and Rangeland area
Domestic Macroeconomics and Demographics Forecasts
Wildlife Populations and Habitat
Recreation Supply and Demand
Water Supply and Demand
2010 USFS RPA Models and Scenario Analysis

Peterson Figure 5




Roads
Analysis
Landscape
assessments
Watershed
analysis
Analysis of the
management
situation
NEPA
Monitoring

Peterson Figure 7



Peterson Figure 8

Use adaptation if:	**Postpone adaptation if:**
OR climate-sensitive risks are already urgent, increasing risks are projected reliably, future impacts are potentially irreversible, decisions have long-term effects on ecological and/or social values, adaptation practices require a long time to implement.	OR current and anticipated future risks are moderate, adaptation is very costly, timely response options are readily available.
OR climate-sensitive risks are already urgent, increasing risks are projected reliably, future impacts are potentially irreversible, decisions have long-term effects on ecological and/or social values, adaptation practices require a long time to implement.	OR current and anticipated future risks are moderate, adaptation is very costly, timely response options are readily available.

TRIAGE Approach

Step 1: Assess condition; Sort into four categories:

Red Urgent condition, treatable: highest priority

Yellow Serious condition: will become urgent unless treated soon: high priority

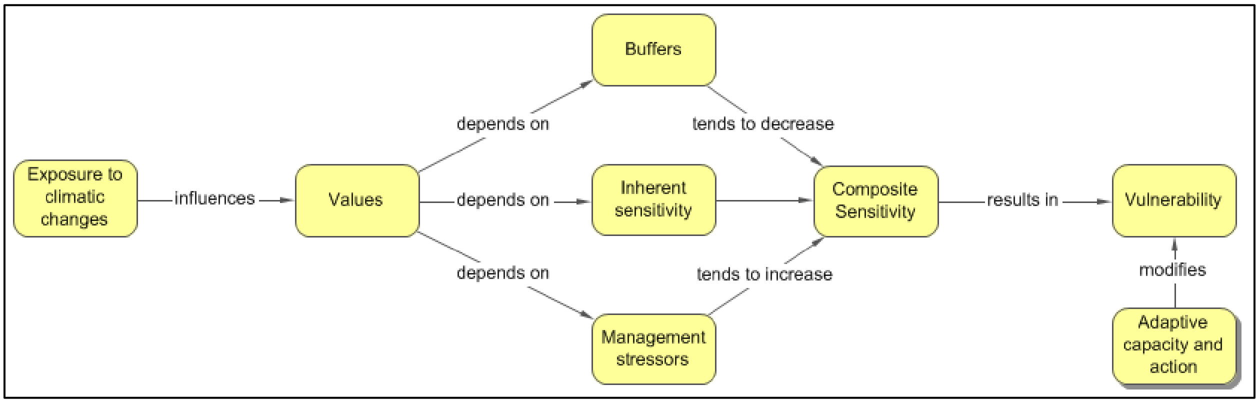
Green Stable condition: low priority

Black Urgent condition, untreatable with available resources: lowest priority, no action

Step 2: Treat according to determined priorities.

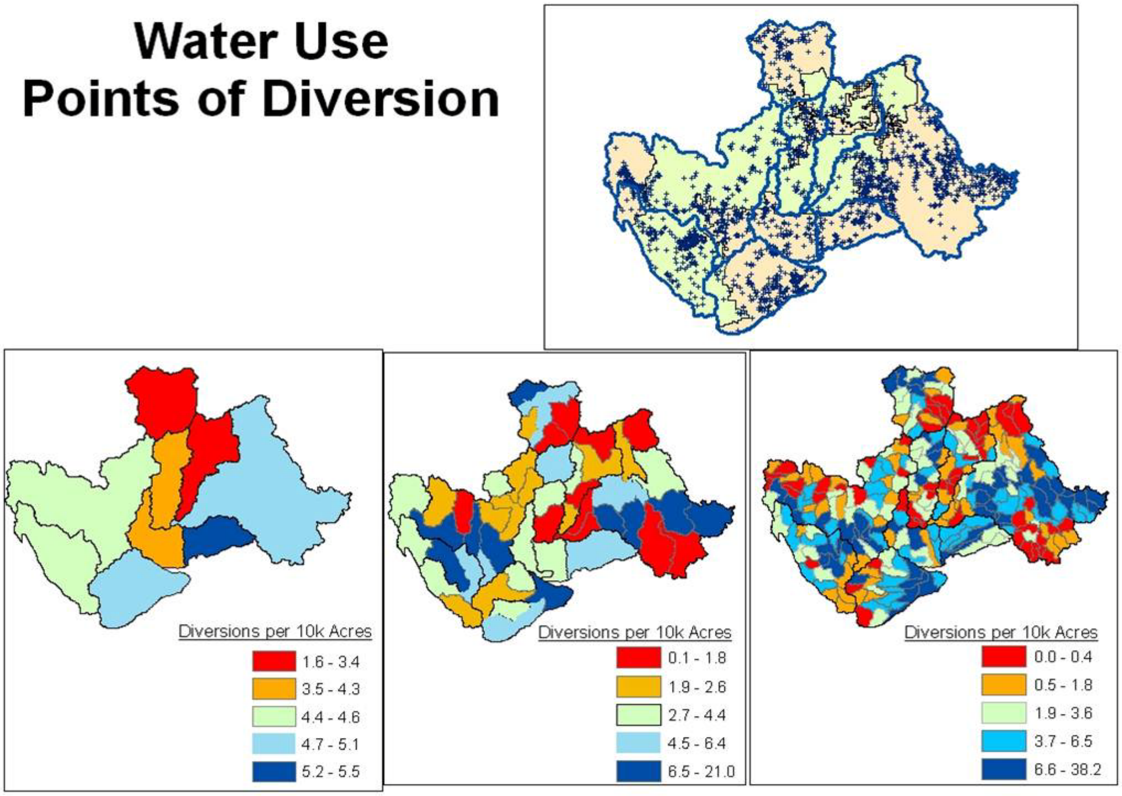
Step 3: Repeat Steps 1 & 2 routinely.

Peterson Figure A1

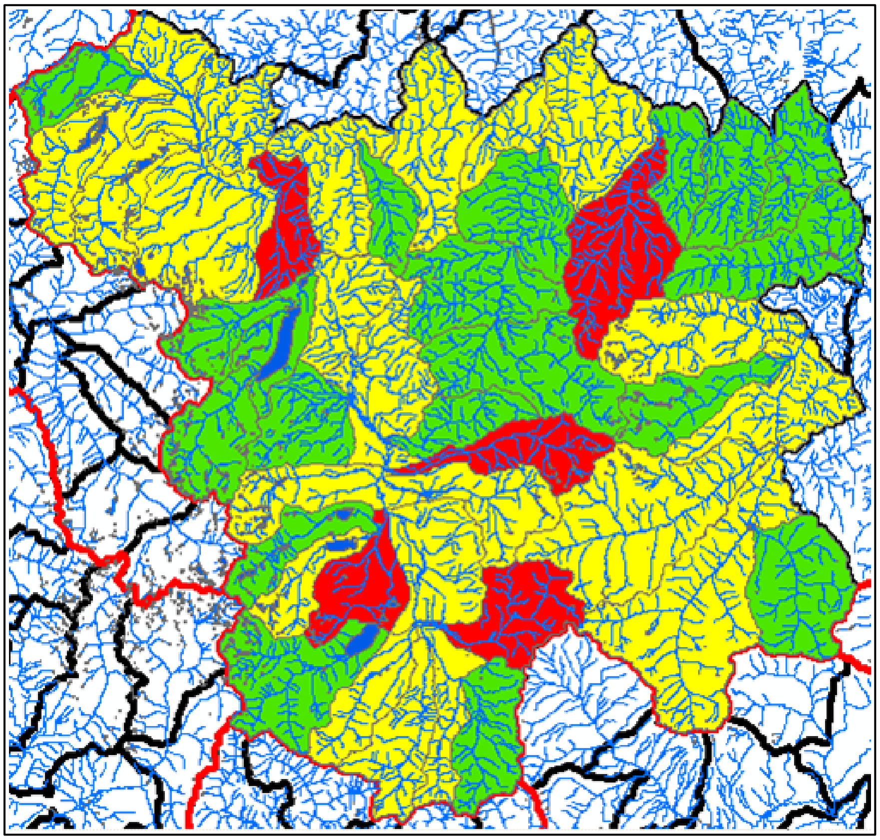


Peterson Figure A2

Water Use
Points of Diversion

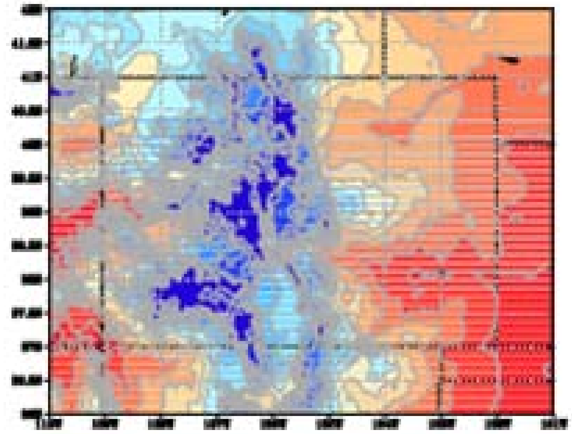


Peterson Figure A3

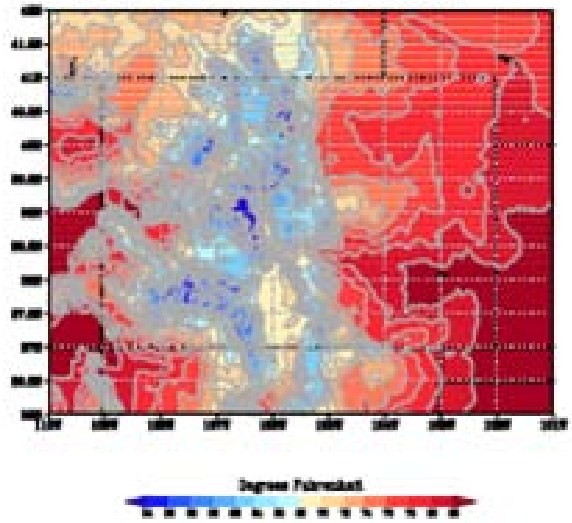


Peterson Figure A4

JULY CLIMATOLOGICAL TEMPERATURE (1950-99)

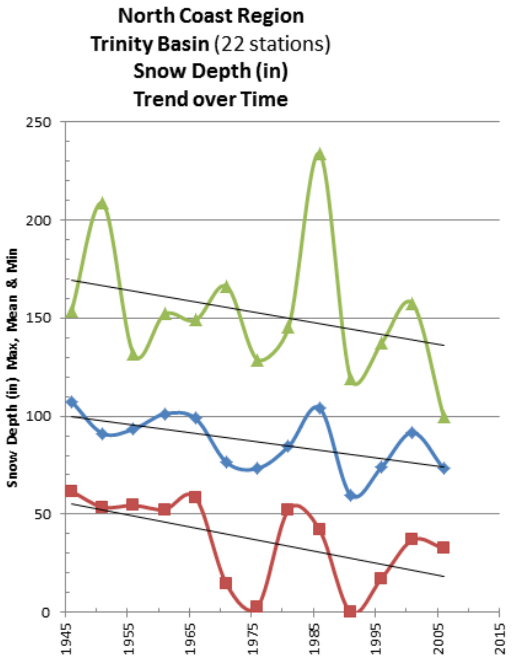


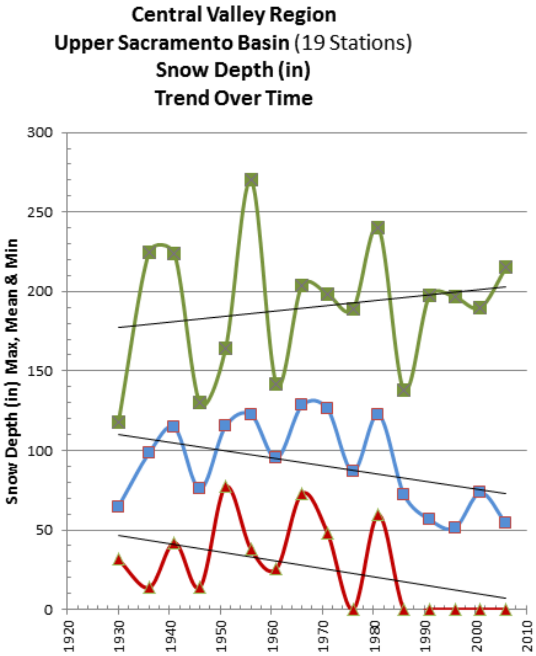
PROJECTED JULY CLIMATOLOGICAL TEMPERATURE 2050



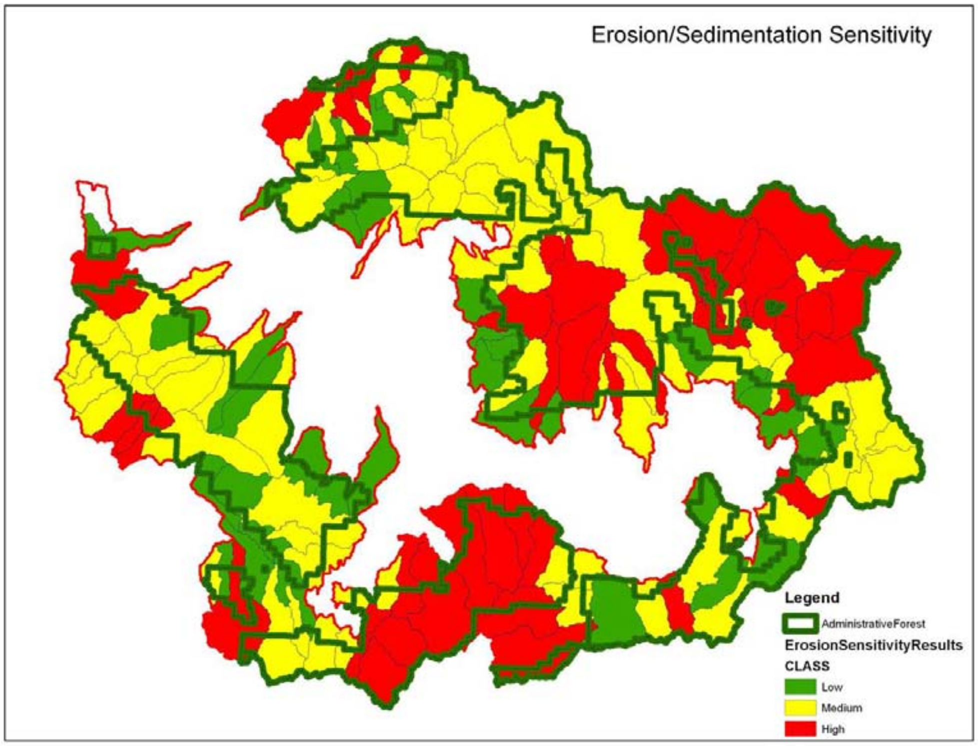
Peterson Figure A5

Snow Depth Trends on Shasta-Trinity National Forest

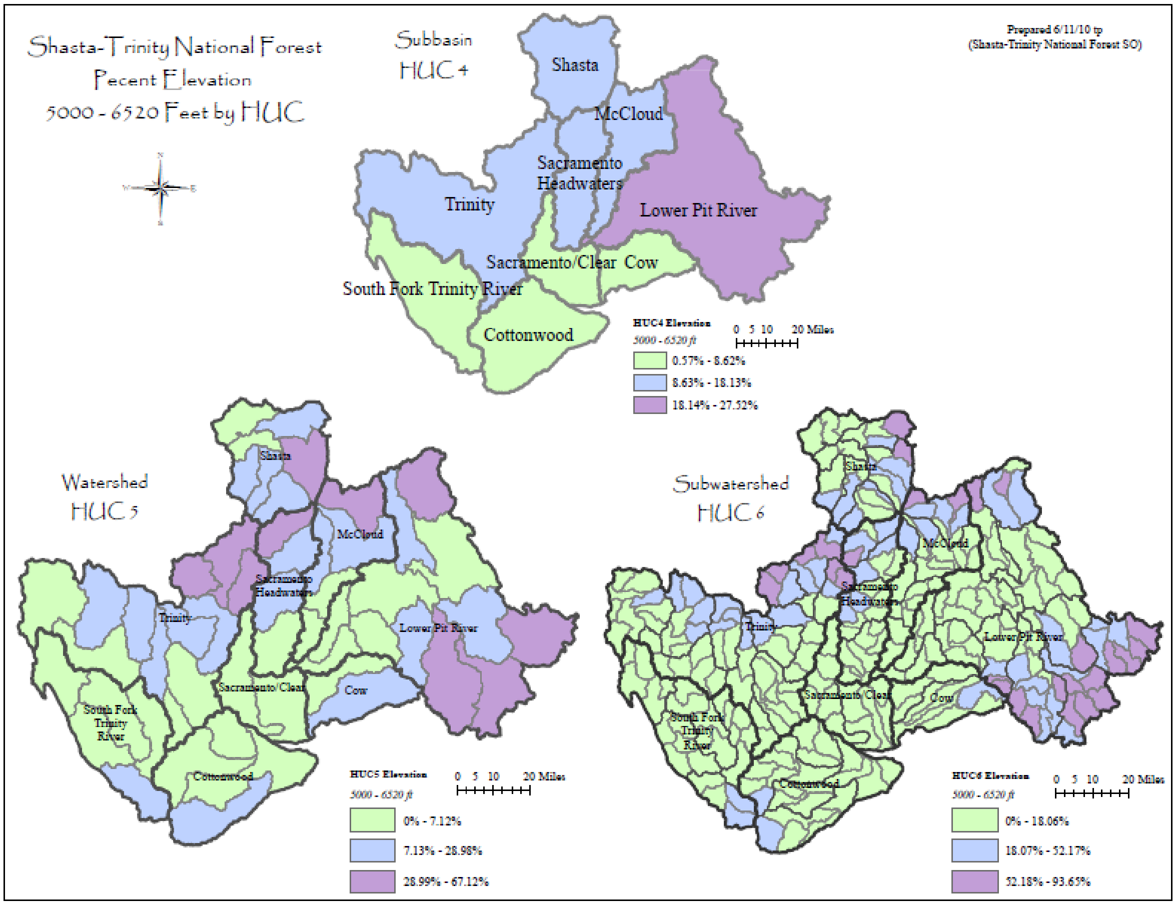




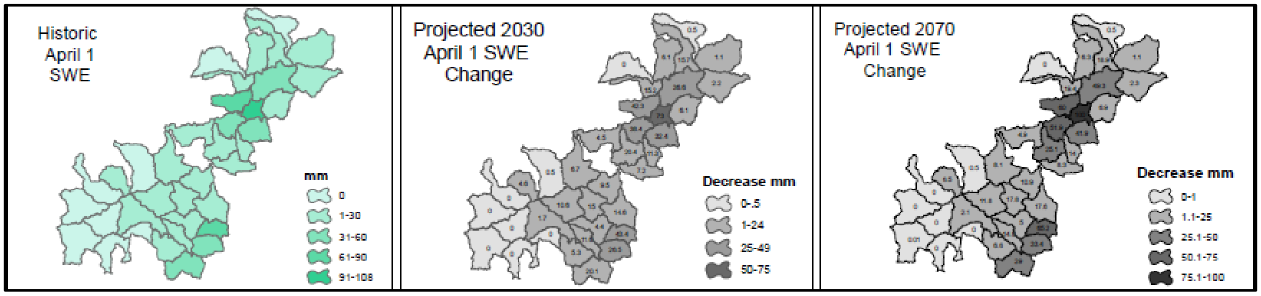
Peterson Figure A6



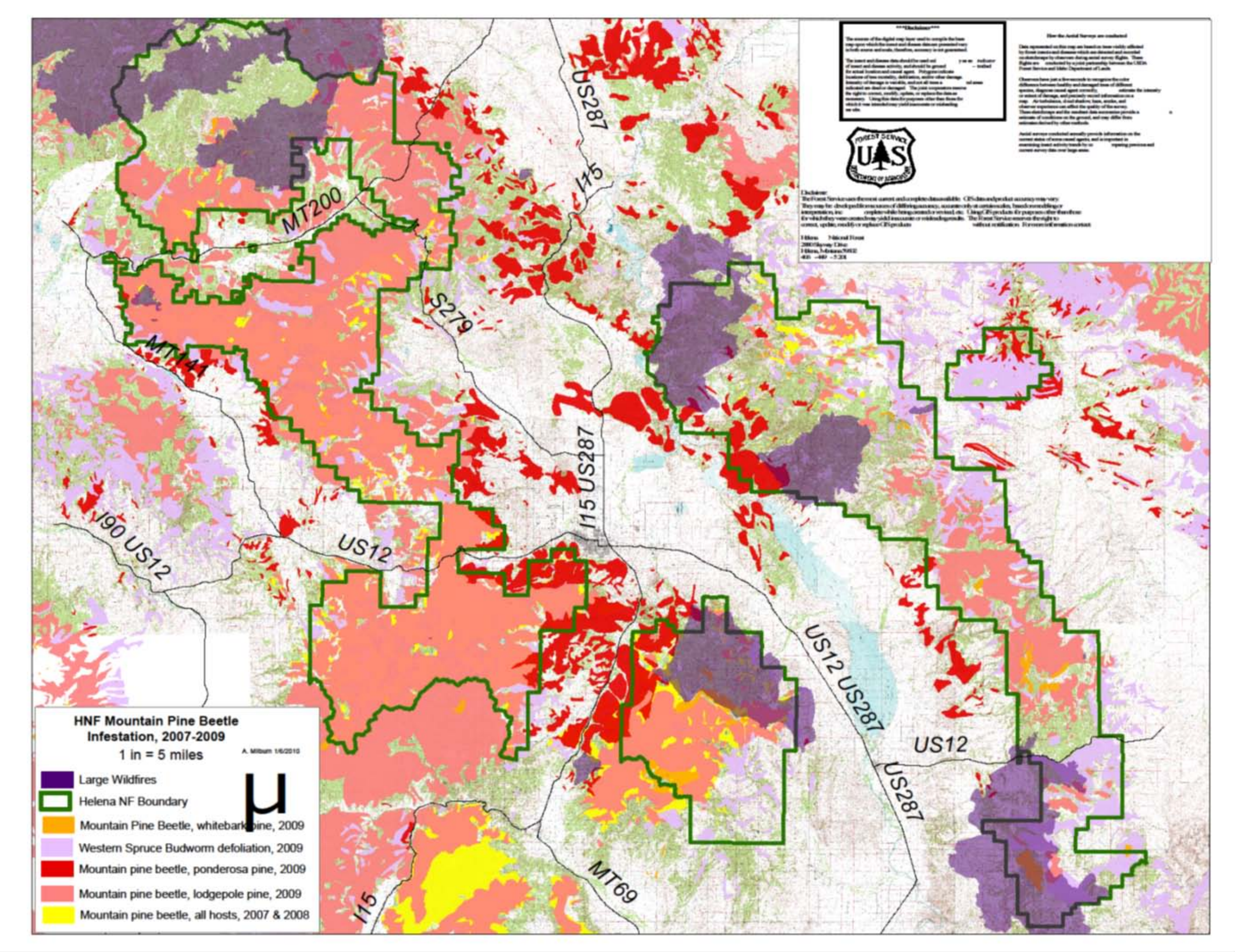
Peterson Figure A7



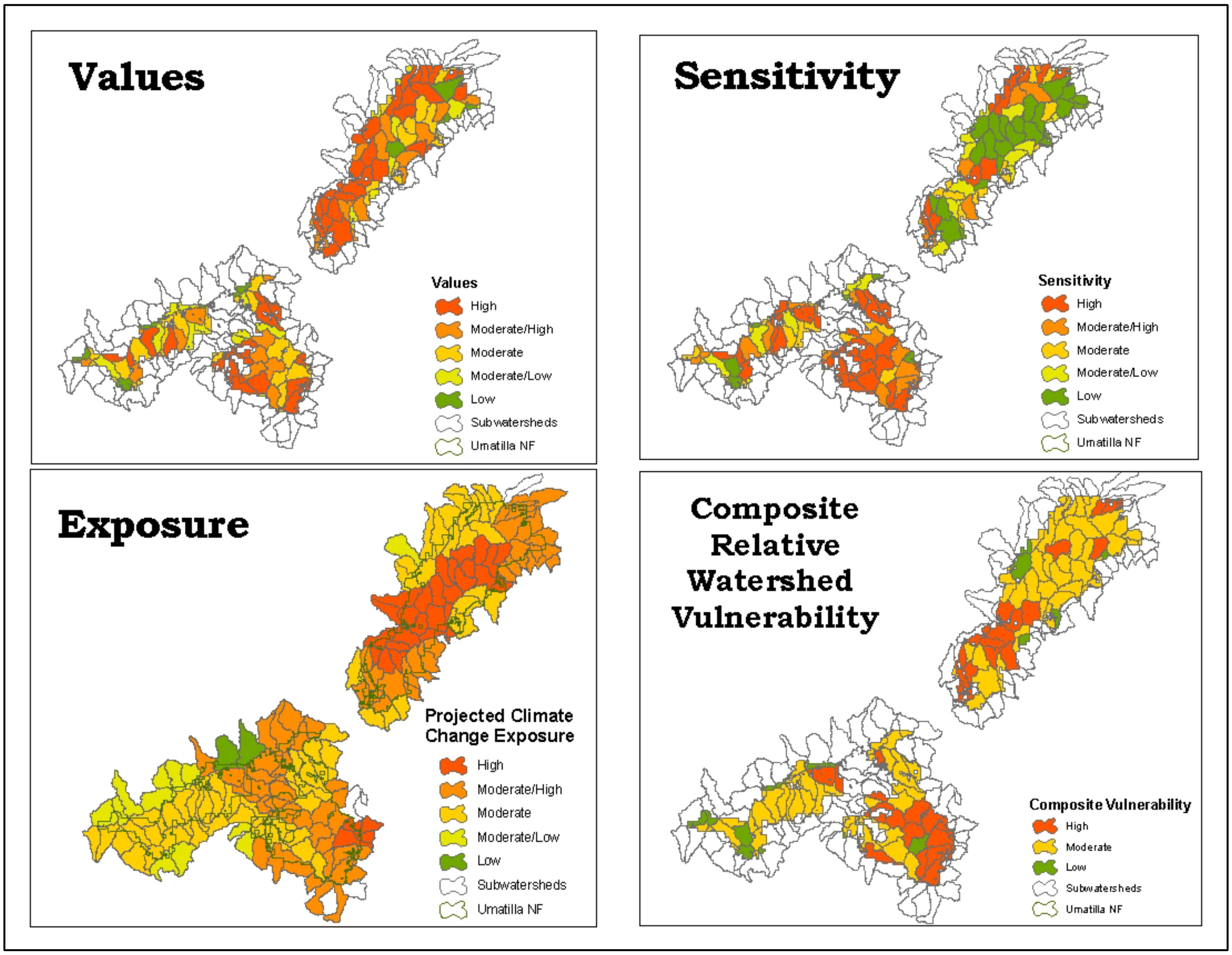
Peterson Figure A8



Peterson Figure A9



Peterson Figure A10



Peterson Figure A11

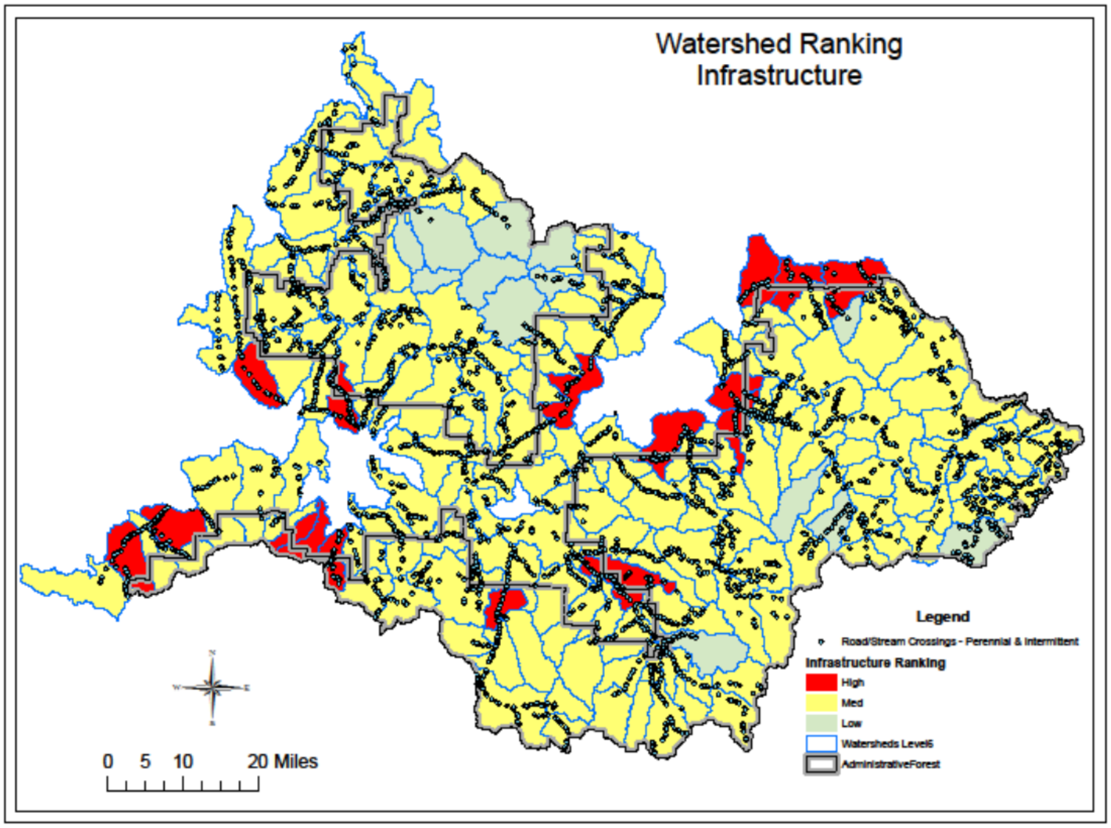


Figure for Box 2

INCORPORATING SCIENCE INTO NATIONAL FOREST PLANNING & PROJECT IMPLEMENTATION

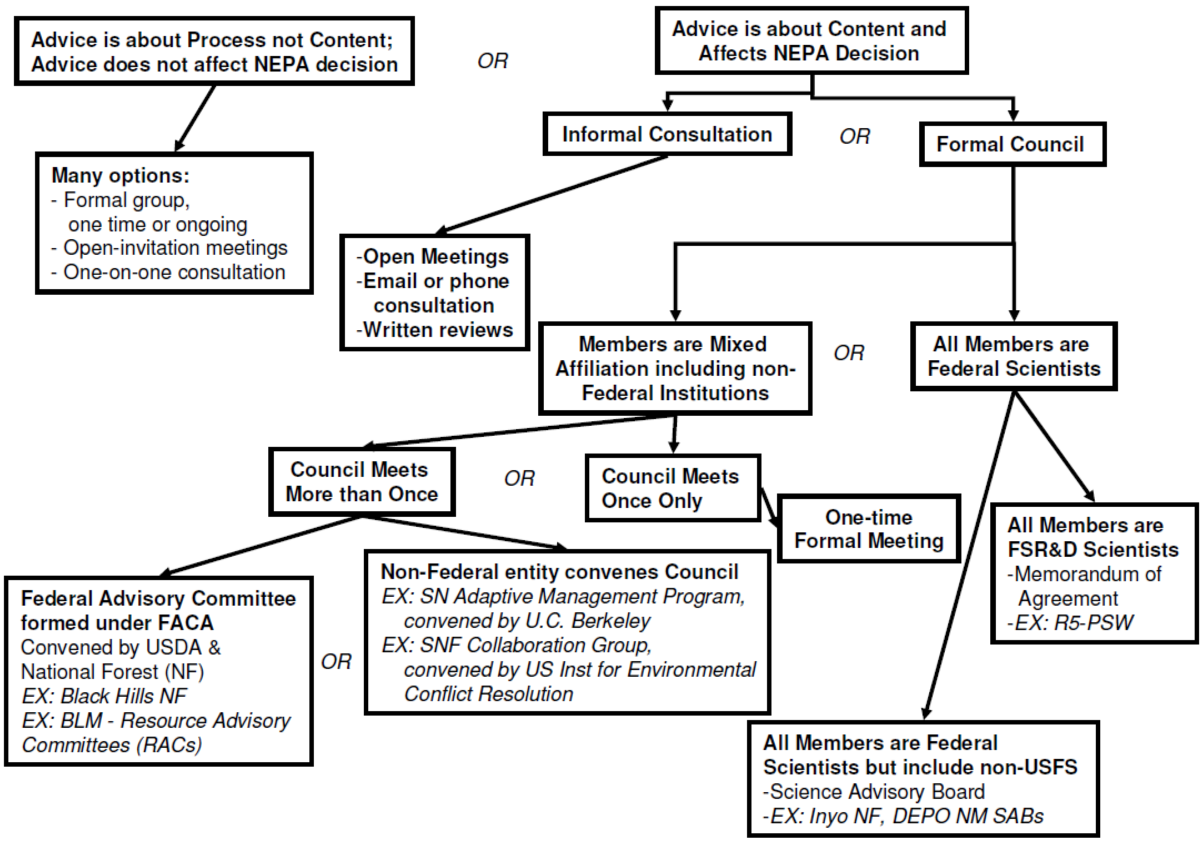
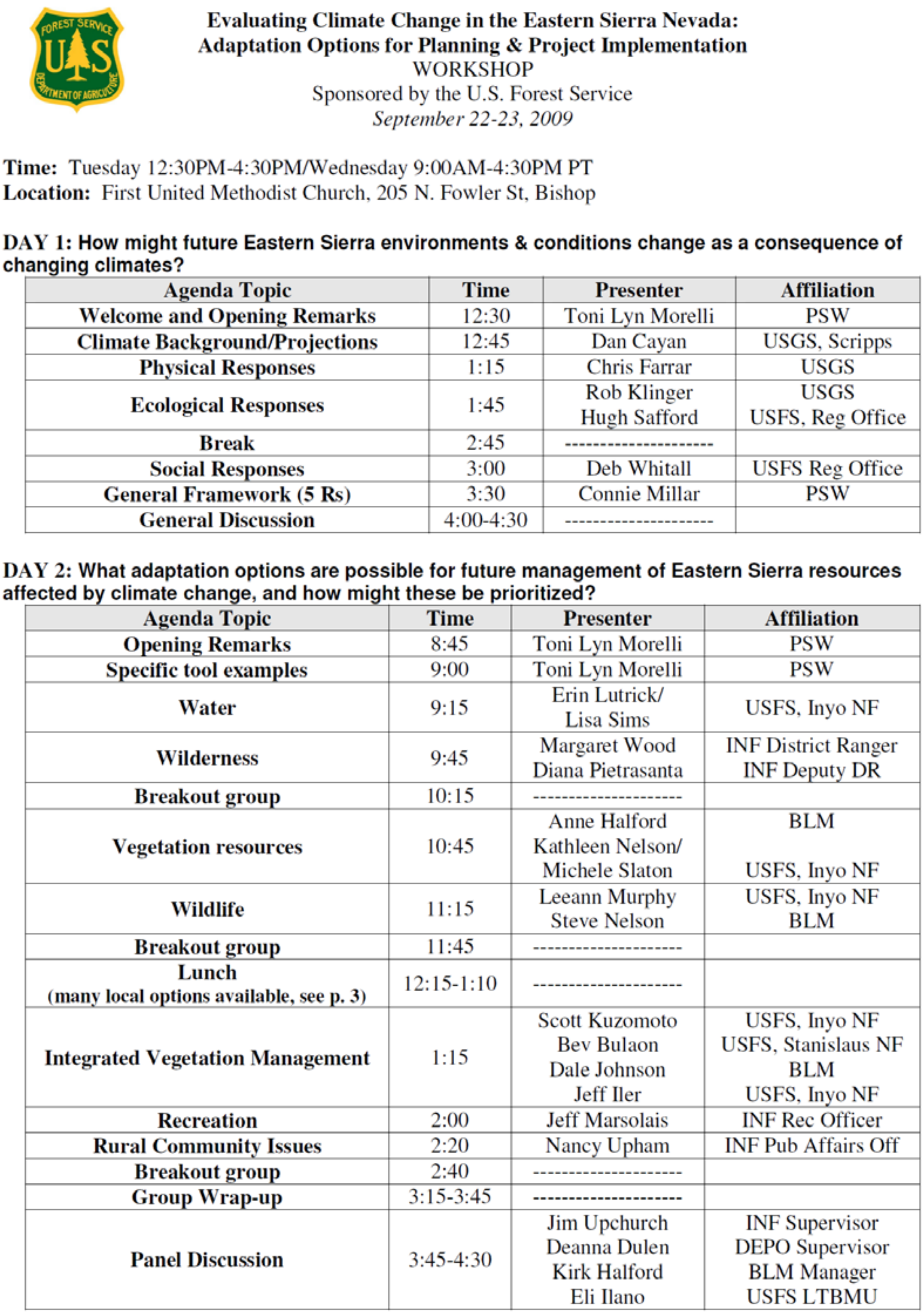


Figure for Box 3



Evaluating Climate Change in the Eastern Sierra Nevada:
Adaptation Options for Planning & Project Implementation
WORKSHOP
Sponsored by the U.S. Forest Service
September 22-23, 2009

Time: Tuesday 12:30PM-4:30PM/Wednesday 9:00AM-4:30PM PT
Location: First United Methodist Church, 205 N. Fowler St, Bishop

DAY 1: How might future Eastern Sierra environments & conditions change as a consequence of changing climates?

Agenda Topic	Time	Presenter	Affiliation
Welcome and Opening Remarks	12:30	Toni Lyn Morelli	PSW
Climate Background/Projections	12:45	Dan Cayan	USGS, Scripps
Physical Responses	1:15	Chris Farrar	USGS
Ecological Responses	1:45	Rob Klinger Hugh Safford	USGS USFS, Reg Office
Break	2:45	---------------------	
Social Responses	3:00	Deb Whitall	USFS Reg Office
General Framework (5 Rs)	3:30	Connie Millar	PSW
General Discussion	4:00-4:30	---------------------	

DAY 2: What adaptation options are possible for future management of Eastern Sierra resources affected by climate change, and how might these be prioritized?

Agenda Topic	Time	Presenter	Affiliation
Opening Remarks	8:45	Toni Lyn Morelli	PSW
Specific tool examples	9:00	Toni Lyn Morelli	PSW
Water	9:15	Erin Lutrick/ Lisa Sims	USFS, Inyo NF
Wilderness	9:45	Margaret Wood Diana Pietrasanta	INF District Ranger INF Deputy DR
Breakout group	10:15	---------------------	
Vegetation resources	10:45	Anne Halford Kathleen Nelson/ Michele Slaton	BLM USFS, Inyo NF
Wildlife	11:15	Leeann Murphy Steve Nelson	USFS, Inyo NF BLM
Breakout group	11:45	---------------------	
Lunch **(many local options available, see p. 3)**	12:15-1:10	---------------------	
Integrated Vegetation Management	1:15	Scott Kuzomoto Bev Bulaon Dale Johnson Jeff Iler	USFS, Inyo NF USFS, Stanislaus NF BLM USFS, Inyo NF
Recreation	2:00	Jeff Marsolais	INF Rec Officer
Rural Community Issues	2:20	Nancy Upham	INF Pub Affairs Off
Breakout group	2:40	---------------------	
Group Wrap-up	3:15-3:45	---------------------	
Panel Discussion	3:45-4:30	Jim Upchurch Deanna Dulen Kirk Halford Eli Ilano	INF Supervisor DEPO Supervisor BLM Manager USFS LTBMU

Figure for Box 5

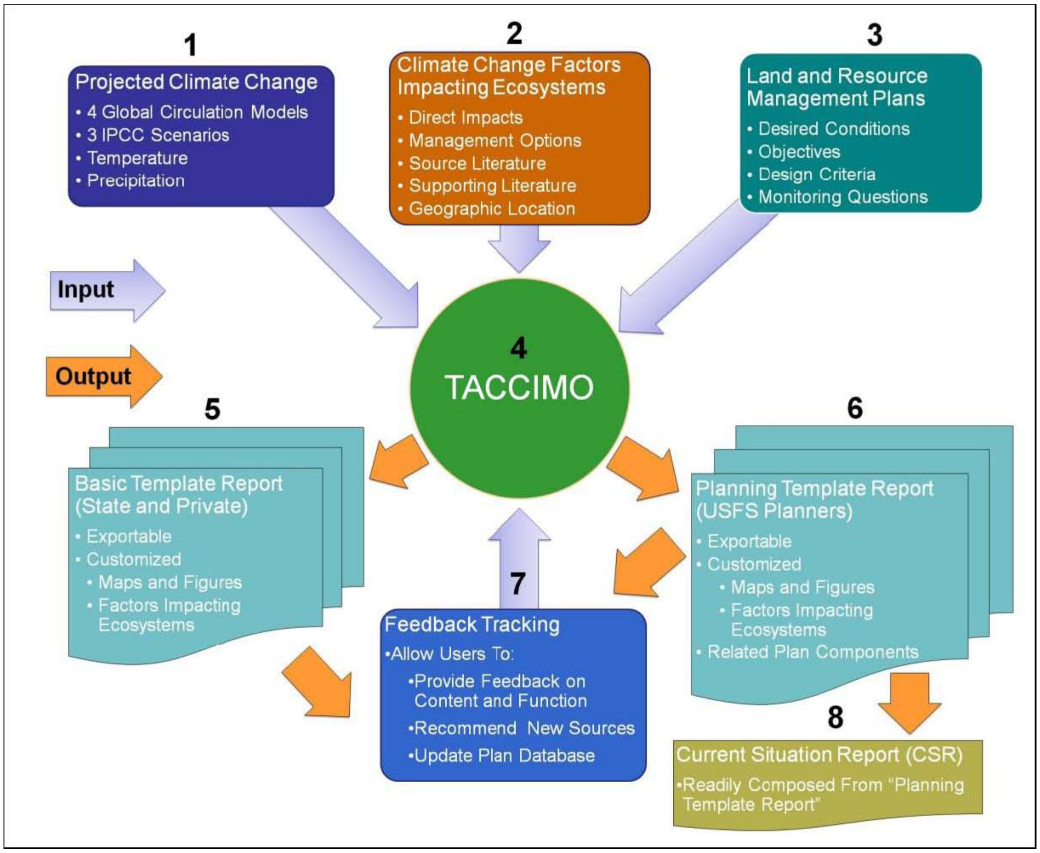
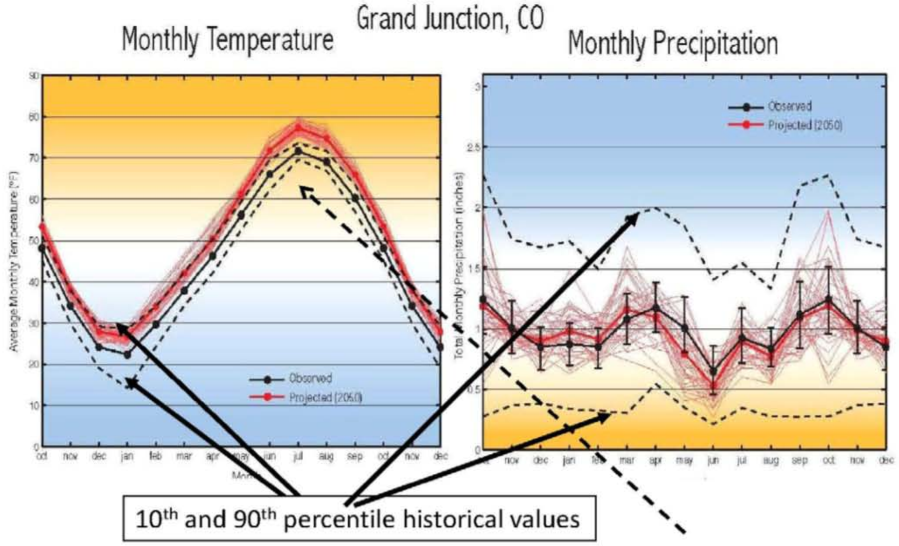


Figure for Box 6

Box 6.1 Use past climate to place projected temperatures in context of management experience.

Projected temperatures are outside of the historical temperatures for summer but precipitation remains within the historical range.



Grand Junction, CO

Monthly Temperature

Monthly Precipitation

10th and 90th percentile historical values

Figure for Box 8

Figure for Box 9

Figure for Box 10

Figure for box 11

Figure for Box 12

Figure for Box 13