CHAPTER 9

Synthesis and Conclusions

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9.1 SUMMARY

The Nation's public lands and waters traditionally have been managed using frameworks and objectives that were established under an implicit assumption of stable climate and the potential of achieving specific desirable conditions. Climate change implies that past experience may not apply and that the assumption of a stable climate is in some regions untenable. Previous chapters in this report examine a selected group of management systems (National Forests, National Parks, National Wildlife Refuges, Wild and Scenic Rivers, National Estuaries, and Marine Protected Areas) and assess how these management systems can adapt to climate change. Using these chapters and their case studies, as well as more general scientific literature concerning adaptive management and climate change, this chapter presents a synthesis of suggested principles and management approaches for federal management agencies as well as other resource managers.

KEY FINDINGS

A useful starting point for adaptation is to analyze management goals, assess impacts, and characterize uncertainty. To inform adaptation decisions, the first step is to clarify the management goals that have been established for the system being studied. This information may then be used to define the boundaries of the impact assessment, including geographic scope, focal species, and other parameters. Within these boundaries, components of the assessment may then include developing conceptual models, assessing available ecological data and establishing current baseline information on system functioning, assessing available climate data, selecting impacts models, conducting scenario and sensitivity analyses that depict alternative futures, and characterizing uncertainty. Information from impact assessments helps determine whether existing monitoring programs need to be adjusted, or new ones established, to track changes in variables that represent triggers for threshold changes in ecosystems or that reflect overall resilience. Such monitoring programs can inform the location and timing of needed adaptation actions as well as the effectiveness of such actions once they are implemented. However, because of the high degree of uncertainty about the magnitude and temporal/spatial scale of climate change impacts, managers may find it difficult to translate results from impact assessments into practical management actions. The solution is not to view a scenario result as a "prediction" that supports planning for "most likely" outcomes. Rather, it is to select a range of future scenarios that capture the breadth of plausible outcomes and develop robust adaptation responses that address this full range.

A variety of adaptation approaches can be used to apply existing and new practices to promote resilience to climate change. Resilience may be defined as the amount of change or disturbance that an ecosystem can absorb without undergoing a fundamental shift to a different set of processes and structures. Many adaptation approaches suggested below are already being used to address a variety of other environmental stressors; however, their application may need to be adjusted to ensure their effectiveness for climate adaptation. These approaches include (1) protecting key ecosystem features that form the underpinnings of a system; (2) reducing anthropogenic stresses that erode resilience; (3) increasing representation of different genotypes, species, and communities under protection; (4) increasing the number of replicate units of each ecosystem type or population under protection; (5) restoring ecosystems that have been compromised or lost; (6) identifying and using areas that are "refuges" from climate change; and (7) relocating organisms to appropriate habitats as conditions change.

Reducing anthropogenic stresses is an approach for which there is considerable scientific confidence in its ability to promote resilience for virtually any situation. The effectiveness of the other approaches—including *protecting key ecosystem features, representation, replication, restoration, identifying refuges,* and especially *relocation*—is much more uncertain and will depend on a clear understanding of how the ecosystem in question functions, the extent and type of climate change that will occur, and the resulting ecosystem impacts. One method to implement adaptation approaches under such conditions of uncertainty is adaptive management. Adaptive management is a process that promotes flexible decision making, such that adjustments are made in decisions as outcomes from management actions and other events are better understood. This method requires careful monitoring of management results to advance scientific understanding and to help adjust policies or operations as part of an iterative learning process.

Barriers to implementing existing and new adaptation practices may be used as opportunities for strategic thinking. Providing information on adaptation approaches and specific strategies may not be enough to assist managers in addressing climate change impacts. Actual or perceived barriers may inhibit or prevent implementation of some types of adaptation. Identifying and understanding those barriers could facilitate critical adjustments to increase successful implementation and adaptive capacity of organizations. Four main types of barriers that affect implementation are (1) interpretation of legislative goals, (2) restrictive management procedures, (3) limitations on human and financial capital, and (4) gaps in information. Identifying a potential barrier, such as gaps in information or expertise necessary for implementing adaptation strategies, provides the basis for finding a solution, such as linking with other managers to coordinate training and research activities or sharing data and monitoring strategies to test scientific hypotheses. The challenge of turning barriers into opportunities may vary in the amount and degree of effort required, the levels of management necessary to engage, and the length of time needed. For example, re-evaluating management capabilities in light of existing authorities and legislation to expand their breadth may require more time, effort, and involvement of high level decision makers compared with altering the timing of management activities to take advantage of seasonal changes. Nevertheless, it should be possible to undertake strategic thinking and reshape priorities to convert barriers into opportunities to successfully implement adaptation.

Beyond the adaptation options reviewed in this report, key activities to ensure the Nation's capability to adapt include applying triage, determining appropriate scales of response, and reassessing management goals. Our capability to respond appropriately to climate change impacts will depend on (1) developing systematic approaches for triage (*i.e.*, a form of prioritizing adaptation actions), (2) determining the appropriate geographic and temporal scales of response to climate change, and (3) assessing whether current management goals will continue to be relevant in the future, or whether they need to be adjusted. Triage involves maximizing the effectiveness of existing resources by re-evaluating current goals and management targets in light of observed and projected ecological changes. The goal is to determine those management actions that are worthwhile to continue and those that may need to be abandoned.

To assess the appropriate scales of response, consideration of observed and projected ecological changes are again needed. In the event that impacts are broader than single management units or occur at predictable periods through time, the spatial, temporal, and biological scope of management plans may need to be systematically broadened and integrated to increase the capacity to adapt beyond that of any given unit.

Over time, some ecosystems may undergo state changes such that managing for resilience will no longer be feasible. In these cases, adapting to climate change would require more than simply changing management practices—it could require changing management goals. In other words, when climate change has such strong impacts that original management goals are untenable, the prudent course may be to alter the goals. At such a point, it will be necessary to manage for and embrace change. Climate change requires new patterns of thinking and greater agility in management planning and activities in order to respond to the inherent uncertainty of the challenge.

9.2 INTRODUCTION

Today's natural resource planning and management practices were developed under relatively stable climatic conditions in the last century, and under a theoretical notion that ecological systems tend toward a natural equilibrium state for which one could manage. Most natural resource planning, management, and monitoring methodologies that are in place today are still based on the assumption that climate, species distributions, and ecological processes will remain stable, save for the direct impacts of management actions and historical interannual variability. Indeed, many government entities identify a "reference condition" based on historical ranges of variability as a guide to future desired conditions (Dixon, 2003).

Although mainstream management practices typically follow these traditional assumptions, in recent years resource managers have recognized that climatic influences on ecosystems in the future will be increasingly complex and often outside the range of historical variability and, accordingly, more sophisticated management plans are needed to ensure that goals can continue to be met. By transforming management and goal-setting approaches from a static, equilibrium view of the natural world to a highly dynamic, uncertain, and variable framework, major advances in managing for change can be made, and thus adaptation is possible.

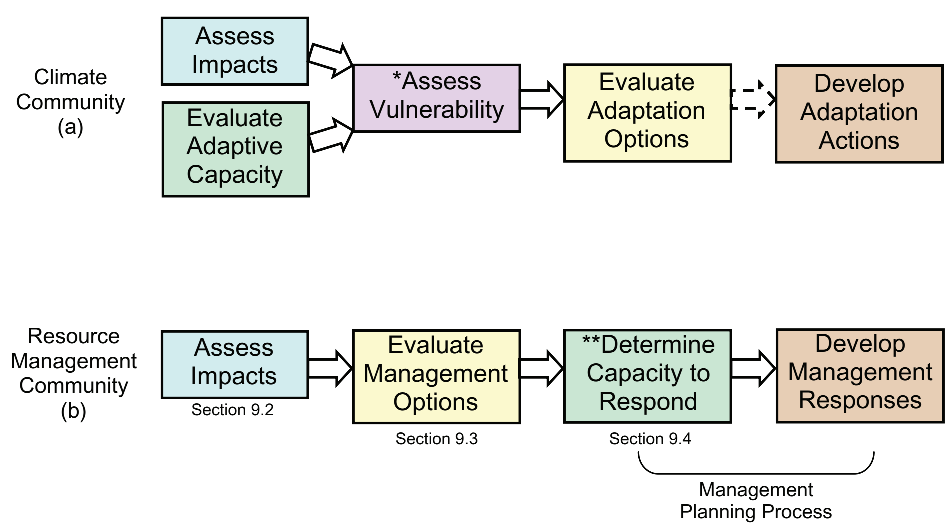
As resource managers become aware of climate change and the challenges it poses, a major limitation is lack of guidance on what steps to take, especially guidance that is commensurate with agency cultures and the practical experiences that managers have accumulated from years of dealing with other stresses such as droughts, fires, and pest and pathogen outbreaks. Thus, it is the intent in this chapter to synthesize the lessons learned from across the previous chapters together with recent theoretical work concerning adaptive management and resource management under uncertainty, and discuss how managers can (1) assess the impacts of climate change on their systems and goals (Section 9.3), (2) identify best practice approaches for adaptation (Section 9.4), and (3) evaluate barriers and opportunities associated with implementation (Section 9.5). When it comes to management, the institutional mandates and objectives determine the management constraints and in turn the response to changing climate. As a result, this discussion and synthesis are framed around the institutions that manage lands and waters, as opposed to the ecosystems themselves. It may be the case that certain management goals are unattainable in the future and no adaptation options exist. In that case the adaption that takes place would be an alteration of institutional objectives. The final sections of this chapter address these circumstances and conclude with observations about how to advance our capability to adapt (Sections 9.6 and 9.7), including suggested approaches for making fundamental shifts in how ecosystems are managed to anticipate potential future ecosystem states. These discussions build on the other chapters of this report, and have benefited from helpful comments received during the public and and expert review periods.

9.3 ASSESSING IMPACTS TO SUPPORT ADAPTATION

9.3.1 Mental Models for Making Adaptation Decisions

Within the context of natural resource management, an impact assessment is a means of evaluating the sensitivity of a natural system to climate change. Sensitivity is defined by the IPCC (2001) as "the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli." An impact assessment is part of a larger process to understand the risks posed by climate change, including those social and economic factors that may contribute to or ameliorate potential impacts, in order to decide where and when to adapt. In the climate change community, this process is well established (see Fig. 9.1a). It begins with an assessment of impacts, followed by an evaluation of an entity's capacity to respond (adaptive capacity). The information on impacts is then combined with information on adaptive capacity to determine a system's overall vulnerability. This information becomes the basis for selecting adaptation options to implement. The resource managers' mental model for this larger decision making process (see Fig. 9.1b) contains similar elements to the climate community's model, but addresses them in a different sequence of evaluation to planning. The managers' process begins with estimating potential impacts, reviewing all possible management options, evaluating the human capacity to respond, and finally deciding on specific management responses. The resource management community implicitly combines the information on potential impacts with knowledge of their capacity to respond during their planning processes. Since the primary audience for this report is the resource management community, the remainder of this discussion will follow their conceptual approach to decision making.

The following sub-sections lay out in greater detail some of the key issues and elements of an impact assessment, which must necessarily



* Vulnerability is the sum of projected impacts and adaptive capacity; this step is done by managers when they evaluate the projected impacts and their capacity to respond during their planning process

** Assessing the capacity to respond in the management community is equivalent to assessing adaptive capacity in the climate community

Figure 9.1. Two conceptual models for describing different processes used by (a) the climate community and (b) the resource management community to support adaptation decision making. Colors are used to represent similar elements of the different processes.

begin with a clear articulation of the goals and objectives of the assessment and the decisions that will be informed. This specification largely determines the technical approach to be taken in an assessment, including its scope and scale, the focal ecosystem components and processes to be studied, the types of tools most appropriate to use, and the baseline data and monitoring needed. The final subsection discusses ways in which uncertainty inherent in assessments of climate change impacts may be explicitly addressed.

9.3.2 Elements of an Impact Assessment

Impact assessments combine (1) our understanding of the current state of the system and its processes and functions with (2) drivers of environmental change in order to (3) project potential responses to future changes in those drivers. Knowledge of the current state of the system, including its critical thresholds and coping ranges, provides the fundamental basis for understanding the implications of changes in future conditions. A coping range is the breadth of conditions under which a system continues to persist without significant, observable consequences, taking into account the system's natural resilience (Yohe and Tol, 2002). Change is not necessarily "bad," and the fact that a system responds by shifting to a new equilibrium or state may not necessarily be a negative outcome. Regardless of the change, it will behoove managers to adjust to or take advantage of the anticipated change. Several examples of approaches to conducting impact assessments are provided below along with a discussion of the types of tools needed and key issues related to conducting impact assessments.

9.3.2.1 A Guiding Framework for Impact Assessments

The aim of a framework to assess impacts is to provide a logical and consistent approach for eliciting the information needs of a decision maker, for conducting an assessment as efficiently as possible, and for producing credible and useful results. While impact assessments are routinely done to examine the ecological effects of various environmental stressors, the need to incorporate changes in climate variables adds significantly to the spatial and temporal scales of the assessment, and hence its complexity. One example framework, developed by Johnson and Weaver (2008) for natural resource managers, is responsive to these and other concerns that have been raised by those who work with climate data to conduct impact assessments. This framework is described in Box 9.1.

BOX 9.1. An example framework for incorporating climate change information into impact assessments.

Step 1 – Define decision context: Clarify management goals and endpoints of concern, as well as risk preferences and tradeoffs, time horizons for monitoring and management, and planning processes related to established endpoints.

Step 2 – Develop conceptual model: Develop a conceptual model linking the spatial and temporal scales of interaction between and among drivers and endpoints to determine the most important dependencies, sensitivities, and uncertainties in the system.

Step 3 – Assess available climate data: Determine whether available information about climate change is adequate for achieving the specified goals and endpoints. Data sources that may be used include historical weather observations, palaeoclimate data, and data from climate model experiments.

Step 4 – Downscale climate data: Where necessary, develop finer resolution datasets from coarser scale data, e.g., using statistical relationships ("statistical" downscaling) or computer models ("dynamical" downscaling), to drive impacts models. For guidance on downscaling techniques, see IPCC-TGICA (2007).

Step 5 – Select impact assessment models: Review and select impact assessment models that capture the processes and causal pathways represented in the conceptual model.

Step 6 – Conduct sensitivity analyses and scenario planning: Conduct analyses to evaluate the basic sensitivities in the system. Specify a number of climate scenarios that are consistent with associated global-scale scenarios, physically plausible, and sufficiently detailed to support an assessment of the specified endpoints of concern. Use these scenarios to learn the potential ranges of the system's response to changes in the climate drivers.

Step 7 – Manage risks through adaptation: Evaluate the information generated to determine potential management responses, recognizing that the consequences of decisions are generally not known and hence decisions are made to reduce the net negative effects of risk.

A number of other frameworks have been developed as well. For example, within the international conservation arena, a successful framework for managers was developed by The Nature Conservancy (Parrish, Braun, and Unnasch, 2003). The steps include (1) identifying the management goal, management targets, and threats (including climate change); (2) selecting measurable indicators; (3) determining the limits of acceptable variation in the indicators; and (4) assessing the current status of the system with respect to meeting management targets, as well as with respect to the indicators. An additional step would be to analyze data on indicators to decide whether a change in management is required. The steps were further refined by the Conservation Measures Partnership,[1] which includes the African Wildlife Foundation, Conservation International, The Nature Conservancy, the Wildlife Conservation Society, and the World Wide Fund for Nature/World Wildlife Fund. By melding these steps with an assessment of the costs of any management response (including "no response" as one option), it should be possible to offer practical guidance.

9.3.2.2 Tools to Assess Impacts

The example frameworks described in the previous section reference two key types of tools: models that represent the climate system as a driver of ecological change and models that embody the physical world to trace the effect of climate drivers through relevant pathways to impacts on management endpoints of concern. There are numerous tools that begin to help managers anticipate and manage for climate change (see Appendix), although characterization of uncertainty could be improved in these tools, along with "user friendliness" and the ability to frame management endpoints in a manner that more closely meshes with the needs of decision makers. Fortunately, tool development for impact analysis is one of the most active areas of climate research, and greatly improved tools can be expected within the next few years.

1 **Conservation Measures Partnership**, 2007: Open Standards for the Practice of Conservation, Version 2.0, http://conservationmeasures.org/CMP/Site_Docs/CMP_Open_Standards_Version_2.0.pdf, accessed on 4-11-2008.

Climate Models

Across all types of federal lands, the most widely recognized need for information is the need for climate projections at useable scales—scales much finer than those associated with most general circulation model (GCM) projections (Chapter 6, Wild and Scenic Rivers). In particular, the resolution of current climate-change projections from GCMs is on the order of degrees of latitude and longitude (200–500 km^2). Projections from regional climate models are finer in resolution (*e.g.,* 10 km^2), but are not available for most regions. All climate projections can be downscaled using methods that take local topography and local climate patterns into account (Wilby *et al.*, 1998). Although relatively coarse climate projections may be useful for anticipating general trends, the effects of local topography, large water bodies, and specific ecological systems can make coarse predictions highly inaccurate. To be more useful to managers, projections will need to be downscaled using methods that account for local climate patterns. In addition, climate-change projections will need to be summarized in a way that takes their inherent uncertainty into account. That uncertainty arises from the basic model structure, the model parameters, and the path of global emissions into the future. Useful future projections will provide summaries that take this uncertainty into account and inform managers where the projections are more and less certain and, specifically, how confident we can be in a given level of change. Several different approaches exist for capturing the range of projected future climates (see comparison of approaches in Dettinger, 2005). It also will be important to work with climate modelers to ensure that they provide the biologically relevant output variables from the model results.

There are various methods of downscaling GCM data, including dynamical downscaling using regional climate models, statistical downscaling, and the change factor approach (a type of statistical downscaling). Dynamical downscaling uses physically based regional climate models that originate from numerical weather prediction and generate results at a scale of 50 km, although some generate results at 10km and finer scales (Georgi, Hewitson, and Christensen, 2001; Christensen *et al.*, 2007). As their name implies, they are typically run for a region of the globe, using GCM outputs as boundary conditions. Statistical downscaling uses various methods to estimate a relationship between large-scale climate variables ("predictors") and finer-scale regional or local variables ("predictands"). This relationship is derived from an observed period of climate and then applied to the output from GCMs for future projections. This method is also used for temporal downscaling to project daily or hourly variables, typically for hydrologic analyses (Wilby *et al*., 2004). Due to the complexity of determining a significant relationship between the "predictors" and "predictands," most studies that use statistical downscaling only use the results from one GCM (*e.g.*, Shongwe, Landman, and Mason, 2006; Spak *et al*., 2007; Benestad, Hanssen-Bauer, and Fairland, 2007). The change factor approach to downscaling involves subtracting the modeled future climate from the control run at the native coarse resolution of the GCM. These modeled climate "anomalies" are then interpolated to create a seamless surface of modeled change at a finer resolution. These interpolated data are then added to the current climate to provide an estimate of future climate. Researchers use the change factor approach when a rapid assessment of multiple GCMs and emissions scenarios is required (*e.g.*, Mitchell *et al*., 2004; Wilby *et al*., 2004; Scholze *et al*., 2006; Malcolm *et al*., 2006).

It is becoming increasingly possible to examine multiple GCMs and look for more robust results. As this approach becomes widespread, the consequences of choosing one particular GCM will become less important. Moreover, all GCMs are undergoing refinement in models and parameter estimates. At this point, the key to applying any climate modeling technique is understanding the sensitivity of results to model selection before results are used to conduct impact assessments.

Impact Models to Assess Endpoints of Concern

Climate change impacts may be defined by two factors, (1) the types and magnitude of climate changes that are likely to affect the target in a given location, and (2) the sensitivity of a given conservation target to climate change. Assessing the types and magnitude of climate changes that a population or system is likely to experience will require climate-change projections as well as projected changes in climate-driven processes such as fire, hydrology, vegetation, and sea level rise (Chapter 4, National Parks; Chapter 5, National Wildlife Refuges). For example, managing forests in a changing climate will require data on projected potential changes to vegetation, as well as detailed data on the current condition of vegetation (Chapter 3, National Forests).

As another example, to support managing coastlines, a detailed sea level rise assessment was undertaken by the USGS for the lower 48 states, and specifically for coastal national parks.[2] More accurate projections of coastal inundation and saltwater intrusion, such as those based on LIDAR conducted for the Blackwater National Wildlife Refuge, will require more detailed elevation data and targeted hydrological modeling (Chapter 5, National Wildlife Refuges). One report that provides information on ongoing mapping efforts by federal and non-federal researchers related to the implications of sea level rise is Synthesis and Assessment Product 4.1 (in press), produced by the U.S. Climate Change Science Program. Various data layers are overlaid to develop new results, focusing on a contiguous portion of the U.S. coastal zone (New York to North Carolina).

Sensitivity of target organisms to climate change depends on several aspects of the biology of a species or the ecological composition and functioning of a system. For example, species that are physiologically sensitive to changes in temperature or moisture; species that occupy climate-sensitive habitats such as shallow wetlands, perennial streams, and alpine areas; and species with limited dispersal abilities will all be more sensitive to climate change (Root and Schneider, 2002). Populations with slow growth rates and populations at a species range boundary are also likely to be more sensitive to climate change (Pianka, 1970; Lovejoy and Hannah, 2005). Species, communities,

[2] **U.S. Geological Survey**, 2007: Coastal vulnerability assessment of National Park units to sea-level rise. U.S. Geological Survey Website, http://woodshole.er.usgs.gov/project-pages/nps-cvi/, accessed on 6-11-2007.

or ecosystems that are highly dependant on specific climate-driven processes—such as fire regimes, sea level rise, and hydrology—will also be highly sensitive to climate change.

Projected shifts in individual species distributions are generally based on relatively coarse-scale data (*e.g.*, Pearson *et al.*, 2002; Thuiller *et al.*, 2005). Regional projections of species range shifts will require more detailed species distribution data. Some of these data already exist (*e.g.*, through the state Natural Heritage programs), but they need to be organized, catalogued and standardized. Even when built with finer-scale data, these species-distribution models have their limitations (Botkin *et al.*, 2007). They should not be seen as providing accurate projections of the future ranges of individual species, but instead should be viewed as assessments of the likely responses of plants and animals in general. They can be useful for identifying areas that are likely to experience more or less change in flora or fauna in a changing climate. In addition, as with the climate projections, all projections of climate-change impacts will need to include estimates of the inherent uncertainty and variability associated with the particular model that is used (*e.g.*, Araújo and New, 2007). For example, recent analyses of range shift models indicate that some models perform better than others. A model-averaging approach (*e.g.,* random forest models) was compared with five other modeling approaches and was found to have the greatest potential for accurately predicting range shifts in response to climate change (Lawler *et al.*, 2006).

An important consideration for impact analyses is to provide information on endpoints that are relevant to managers (*e.g.*, loss of valued species such as salmon) rather than those that might come naturally to ecologists (*e.g.*, changes in species composition or species richness). An exemplary impact analysis in this regard was a study of climate change impacts in California funded by the Union of Concerned Scientists.[3] The UCS study used a statistically downscaled version of two GCMs to consider future emissions conditions for the state. It produced compelling climate-related outputs. Projections of impacts, in the absence of aggressive emissions regulations, included heat waves that could cause two to three times more heat-related deaths by mid century than occur today in urban centers such as Los Angeles, a shorter ski season, declines in milk production by up to 20 percent by the end of the century for the dairy industry, and bad-tasting wine from the Napa Valley. Because the impacts chosen were relevant to management concerns, the study was covered extensively by national and California newspapers, radio stations, and TV stations (Tallis and Kareiva, 2006).

There are many new ecological models that would help managers address climate change, but the most important modeling tools will be those that integrate diverse information for decision making and prioritize areas for different management activities. Planners and managers need the capability to evaluate the vulnerability of each site to climate change and the social and economic costs of addressing those vulnerabilities. One could provide this help with models that allow the exploration of alternative future climate-change scenarios and different funding limitations that could be used for priority-setting and triage decisions. Comprehensive, dynamic, priority-setting tools have been developed for other management activities, such as watershed restoration (Lamy *et al.*, 2002). Developing a dynamic tool for priority-setting will be critical for effectively allocating limited resources.

9.3.2.3 Establishing Baseline Information

Collecting Information on Past and Current Condition

To estimate current and potential future impacts, a literature review of expected climate impacts may be conducted to provide a screening process that identifies "what trends to worry about." The next step beyond a literature review is a more focused elicitation of the ecological properties or components needed to reach management goals for lands and waters. For each of these properties or components, it will be important to determine the key to maintaining them (see Table 9.1 for examples). If the literature review reveals that any of the general climate trends may influence the ecological attributes or processes critical to meeting management goals, then the

[3] **Union of Concerned Scientists**, 2006: Union of Concerned Scientists homepage. Website, http://www.ucsusa.org/assets/documents/global_warming/Our-Changing-Climate-final.pdf, accessed on 6-11-2007.

Table 9.1. Examples of potential climate change-related effects on key ecosystem attributes upon which management goals depend.

Federal Lands	Ecosystem Attributes Critical to Management Goals	Potential Climate-Related Changes That Could Influence Management Goals
National forests	• Fire tolerance • Insect tolerance • Tolerance to invasives	• Altered fire regimes • Vegetation changes • Changes in species dominance
National wildlife refuges	• Persistence of threatened and endangered species • Wetland water replenishment • Coastal wetland habitat	• Threatened and endangered species decline or loss • Altered hydrology • Sea level rise
Marine protected areas	• Structural "foundation" species (*e.g.*, corals, kelp) • Biodiversity • Water quality	• Increased ocean temperatures and decreased pH • Increased bleaching and disease • Altered precipitation and runoff
National estuaries	• Sediment filtration • Elevation and slope • Community composition	• Altered stream flow • Sea level rise • Salt water intrusion/species shifts
Wild and scenic rivers	• Anadromous fish habitat • Water quality • "Natural" flow	• Increased water temperatures • Changes in runoff • Altered stream flow
National parks	• Fire tolerance • Snow pack • Community composition	• Vegetation shifts • Changes in snow pack amount • Temperature-related species shifts

next steps are to identify baselines, establish monitoring programs, and consider specific management tools and models. For example, suppose the management goal is to maintain a particular vegetation type, such as classical Mediterranean vegetation. Mediterranean vegetation is restricted to the following five conditions (Aschmann, 1973):

- at least 65% of the annual precipitation occurs in the winter half of the year (November–April in the northern hemisphere and May–September in the southern hemisphere);
- annual precipitation is greater than 275 mm;
- annual precipitation is less than 900 mm;
- the coldest month of the year is below 15°C; and
- the annual hours below 0°C account for less than 3% of the total.

If the general literature review indicates that climate trends have a reasonable likelihood of influencing any of these defining features of Mediterranean plant communities, there will be a need for deeper analysis. Sensitivity to current or past climate variability may be a good indicator of potential future sensitivity. In the event that these analyses indicate that it will be very unlikely that the region will be able to sustain Mediterranean plant communities in the future, it may be necessary to cease management at particular sites and to consider protecting or managing other areas where these communities could persist. Triage decisions like this will be very difficult, and should be based not only on future predictions but also on the outcome of targeted monitoring.

Once the important ecological attributes or processes are identified, a manager needs to have a clear idea of the baseline set of conditions for the system. Ecologists, especially marine ecologists, have drawn attention to the fact that the world has changed so much that it can be hard to determine an accurate historical baseline for any system (Pauly, 1995). The reason that an understanding of a system's long history can be so valuable is that the historical record may include information about how systems respond to extreme stresses and perturbations. When dealing with sensitive, endangered, or stressed systems, experimental perturbation is not feasible. Where available, paleoecological records should be used to examine past ranges of natural environmental variability and past organismal responses to climate change (Willis and Birks, 2006). Although in an experimental sense "uncontrolled," there is no lack of both historic and recent examples of perturbations (of various magnitudes) and recoveries through which to examine resilience.

Historic baselines have the potential to offer insights into how to manage for climate change. For example, while the authority to acquire land interests and water rights exists under the Wild and Scenic Rivers Act, lack of baseline data on flow regimes makes it difficult to determine how, when, and where to use this authority (Chapter 6, Wild and Scenic Rivers). Other examples of baseline data important for making management decisions and understanding potential effects of climate change include species composition and distribution of trees in forests; rates of freshwater discharge into estuaries; river flooding regimes; forest fire regimes; magnitude and timing of anadromous fish runs; and home ranges, migration patterns, and reproductive dynamics of sensitive organisms.

However, baselines also have the potential to be misleading. For example, in Chapter 3 (National Forests), it is noted that historic baselines are useful only if climate is incorporated into those past baselines and the relationship of vegetation to climate is explored. If a baseline is held up as a goal, and the baseline depends on historic climates that will never again be seen in a region, then the baseline could be misleading. Adjusting baselines to accommodate changing conditions is an approach that would require caution to avoid unnecessarily compromising ecosystem integrity for the future and losing valuable historical knowledge.

Monitoring to Inform Management Decisions

Monitoring is needed to support a manager's ability to detect changes in baseline conditions as well as to facilitate timely adaptation actions. Monitoring also provides a means to gauge whether management actions are effective. Some monitoring may be designed to detect general ecological trends in poorly understood systems. However, most monitoring programs should be designed with specific hypotheses in mind and trigger points that will initiate a policy or management re-evaluation (Gregory, Ohlson, and Arvai, 2006). For instance, using a combination of baseline and historical data, a monitoring program could be set up with pre-defined thresholds for a species' abundance or growth rate, or a river's flow rate, which, once exceeded, would cause a re-examination of management approaches and management objectives.

A second important feature of any monitoring program is the decision of what to monitor. Ideally several attributes should be monitored, and those that are selected should be chosen to represent the system in a tractable way and to give clear information about possible management options (Gregory and Failing, 2002). Otherwise there is a risk of collecting volumes of data but not really using it to alter management. Sometimes managers seek one aggregate indicator—the risk in this is that the indicator is harder to interpret because so many different processes could alter it.

Some systems will require site-specific monitoring programs, whereas others will be able to take advantage of more general monitoring programs (see Table 9.2 for examples of potential monitoring targets). For example, the analysis of National Forests (Chapter 3, National Forests) highlights the need for monitoring both native plant species and non-native and invasive species. In addition, the severity and frequency of forest fires are clearly linked to climate (Bessie and Johnson, 1995; Fried, Torn, and Mills, 2004; Westerling *et al.*, 2006). Thus, managing for changing fire regimes will require assessing fire risk by detecting changes in fuel loads and weather patterns. Detecting climate-driven changes in insect outbreaks and disease prevalence will require monitoring the occurrence and prevalence of key insects, pathogens, and disease vectors (Logan, Regniere, and Powell, 2003). Detecting early changes in forests will also require monitoring changes in hydrology and phenology, and in tree establishment, growth, and mortality. Some key monitoring efforts are already in place. For example, the Forest Service conducts an extensive inventory through its Forest Inventory and Analysis program, and the collaborative National Phenology Network collects data on the timing of ecological events across the country to inform climate change research.[4]

4 **University of Wisconsin-Milwaukee**, 2007: National phenological network. University of Wisconsin-Milwaukee Website, http://www.uwm.edu/Dept/Geography/npn/, accessed on 6-11-2007.

Table 9.2. Examples of hypothesis-driven monitoring for adaptive management in a changing climate.

Chapter	Monitoring Target	Hypothesis (Why Monitored)	Management Implications (How Used)
Forests (Chapter 3)	Invasive species	Climate change will alter species distributions, creating new invasive species (Lovejoy and Hannah, 2005).	• Inform proactive actions to remove and block invasions
Parks (Chapter 4)/ National Wildlife Refuges (Chapter 5)	Species composition	Species are shifting ranges in response to climate change (Parmesan, 1996).	• Manage for species lost from one park or refuge at a different site • Inform translocation efforts
Wild and Scenic Rivers (Chapter 6)	River flow	Increased temperatures will decrease snow pack and increase evaporation, changing the timing and amount of flows (Poff, Brinson, and Day, Jr., 2002).	• Manage flows • Increase connectivity
National Estuaries (Chapter 7)	Ecosystem functioning and species composition	As sea level rises, marshes will be lost and uplands will be converted to marshes (Moore *et al.*, 2003).	• Facilitate upland conversion, species translocation
Marine Protected Areas (Chapter 8)	Water quality	Changes in temperature and runoff will affect acidity, oxygen levels, turbidity, and pollutant concentrations (Behrenfeld *et al.*, 2006; Guinotte *et al.*, 2006; Portner and Knust, 2007).	• Address pollution sources • Inform coastal watershed policies

In the National Wildlife Refuge System, monitoring might include targets associated with sea level rise, hydrology, and the dynamics of sensitive species populations. Monitoring of marine protected areas should address coral bleaching and disease, as well as the composition of plankton, seagrass, and microbial communities. In the national estuaries, the most effective monitoring will be of salinity, sea level, stream flow, sediment loads, disease prevalence, and invasive species. Wild and scenic rivers should be monitored for changes in flow regimes and shifts in species composition. Finally, national parks, which encompass a diversity of ecosystem types, should be monitored for any number of the biotic and abiotic factors listed for the other federal lands.

Although developing directed, intensive monitoring programs may seem daunting, there are several opportunities to build on existing and developing efforts. In addition to the Forest Service's Forest Inventory and Analysis program and the National Phenology Network mentioned above, other opportunities include the National Science Foundation's National Ecological Observation Network and the Park Service's Vital Signs program (*e.g.*, Mau-Crimmins *et al.*, 2005). Some federal lands have detailed species inventories (*e.g.,* the national parks are developing extensive species inventories for the Natural Resource Challenge) or detailed stream flow measurements. Despite the importance of monitoring, it is critical to recognize that monitoring is only one step in the management process and that monitoring alone will not address the affects of climate change on federal lands.

9.3.3 Uncertainty and How to Incorporate It into Assessments

The high degree of uncertainty inherent in assessments of climate change impacts can make it difficult for a manager to translate results from those assessments into practical management action. However, uncertainty is not the same thing as ignorance or lack of information—it simply means that there is more than one outcome possible as a result of climate change. Fortunately, there are approaches for dealing with uncertainty that allow progress.

9.3.3.1 Examples of Sources of Uncertainty

To project future climate change, climate modelers have applied seven "families" of greenhouse gas emissions scenarios that encompass a range of energy futures to a suite of 23 GCMs (IPCC, 2007), all differing in their climatic projections. Based on a doubling of CO_2, global mean temperatures are projected to increase from 1.4–5.8˚C (2.5–10.5˚F) with considerable discrepancies in the distribution of the temperature and precipitation change. These direct outputs are typically not very useful to managers because they lack the resolution at local and regional scales where environmental impacts relevant for natural resource management can be evaluated. However, as mentioned above, GCM model outputs derived at the very coarse grid scales of 2.5˚ x 3.25˚ (roughly 200–500 km^2, depending on latitude) can be downscaled (Melillo *et al.*, 1995; Pan *et al.*, 2001; Leung *et al.*, 2003; Salathé, Jr., 2003; Wood *et al.*, 2004; IPCC, 2007). But when GCM output data are downscaled, uncertainties are amplified. In Region 6 of the Forest Service, the regional office recommended that the National Forest not model climatic change as a part of a management plan revision process after science reviewers acknowledged the high degree of uncertainty associated with the application of climate change models at the forest level (Chapter 3, National Forests). In the Northwest, management of rivers in the face of climate change is complicated by the fact that the uncertainty is so great that 67% of the modeled futures predict a decrease in runoff, while 33% predict an increase. Thus the uncertainty can be about the direction of change as well as the magnitude of change (Chapter 6, Wild and Scenic Rivers).

Changes in temperature, precipitation, and CO_2 will drive changes in species interactions, species distributions and ranges, community assemblages, ecological processes, and, therefore, ecosystem services. To understand the implications of these changes on species and/or vegetation distribution, models have been designed to assess the responses of biomes to climate change—but this of course introduces more uncertainty, and therefore management risk, into the final analysis. For terrestrial research, dynamic global vegetation models (DGVM) and Species Distributions Models (SDM) have been developed to help predict biological and species impacts. These models have weaknesses that make managers reluctant to use them. For example DGCM vegetation models, which should be useful to forest managers, are limited by the fact that they do not simulate actual vegetation (only potential natural vegetation), or the full suite of species migration patterns and dispersal capabilities, or the integration of the impacts of other global changes such as land use change (fragmentation and human barriers to dispersal) and invasive species (Field, 1999). Where vegetation cover is more natural and the impacts of other global changes are not prominent, the model simulations are likely to have a higher probability of providing useful information of future change. For regions where there is low percentage of natural cover, where fragmentation is great, and large areas are under some form of management, the models will provide limited insight into future vegetation distribution. It is unclear how climate change will interact with these other global and local changes, as well as unanticipated evolutionary changes and tolerance responses, and the models do not address this.

9.3.3.2 Using Scenarios as a Means of Managing Under Uncertainty

It is not possible to *predict* the changes that will occur, but managers can get an indication of the *range* of changes possible. By working with a range of possible changes rather than a single projection, managers can focus on developing the most appropriate responses based on that range rather than on a "most likely" outcome. To develop a set of scenarios—*e.g.*, internally consistent views of reasonably plausible futures in which decisions may be explored (adapted from Porter, 1985; Schwartz, 1996)—quantitative or qualitative visions of the future are developed or described. These scenarios explore current assumptions and serve to expand viewpoints of the future. In the climate change impacts area, approaches for developing scenarios may range from using a number of different realizations from climate models representing a range of emissions growths, to analog scenarios, to informal synthetic scenario exercises that, for example, perturbate temperature and precipitation changes by percentage increments (*e.g.*, -5% change from baseline conditions, 0, +5%, +10%).

Model-based scenarios explore plausible future conditions through direct representations of complex patterns of change. These scenarios have the advantage of helping to further our understanding of potential system responses to a range of changes in drivers. When using spatially downscaled climate models and a large number of emissions scenarios and climate model combinations (as many as 30 or more), a subset of "highly likely" climate expectations may be identifiable for a subset of regions and ecosystems. More typically, results among models will disagree for many places, precluding any unambiguous conclusions. Where there is a high level of agreement, statements may be made such as, "for 80% of the different model runs, peak daily summer temperatures are expected to rise by at least x degrees." When downscaled and multiple runs are available (see the Appendix for possible sources), managers can use them to explore the consequences of different management options. For instance, Battin *et al*. (2007) were able to identify specific places where habitat restoration was likely to be effective in the face of climate change if the goal was recovery of salmon populations, and in specific places where restoration efforts would be fruitless given anticipated climate change.

Analog scenarios use historical data and previously observed sensitivity to weather and climate variability. When developing analog scenarios, if historical data are incomplete or non-existent for one location, observations from a different region may used. Synthetic scenarios specify changes in particular variables and apply those changes to an observed time series. For example, an historic time series of annual mean precipitation for the northeastern United States would be increased by 2% to create a synthetic scenario, but no other characteristics of precipitation would change. Developing a synthetic scenario might start by simply stating that in the future, it is possible that summers will be hotter and drier. That scenario would be used to alter the sets of historic time series, and decision makers would explore how management might respond.

Along with developing multiple scenarios using the methods described above, it may be helpful to do sensitivity analyses to discover a system's response to a range of possible changes in drivers. In such analyses, the key attributes of the system are examined to see how they respond to systematic changes in the climate drivers. This approach may allow managers to identify thresholds beyond which key management goals become unattainable.

All of these scenario-building approaches and sensitivity analyses provide the foundation for "if/then" planning, or scenario planning. One of the most practical ways of dealing with uncertainty is scenario planning—that is, making plans for more than one potential future. If one were planning an outdoor event (picnic, wedding, family reunion), it is likely that an alternate plan would be prepared in case of rain. Scenario planning has become a scientific version of this common sense approach. It is appropriate and prudent when there are large uncertainties that cannot be reduced in the near future, as is the case with climate change. The key to scenario planning is limiting the scenarios to a set of possibilities, typically anywhere from two to five. If sensitivity analyses are performed, those results can be used to select the most relevant scenarios that both address managers' needs and represent the widest possible, but still plausible, futures. The strategy is to then design a variety of management strategies that are robust across the whole range of scenarios and associated impacts. Ideally scenarios represent clusters of future projections that fit together as one bundled storyline that is easy to communicate to managers (*e.g.*, warmer and wetter, warmer and drier, negligible change). When used deftly, scenario planning can alleviate decision-makers' and managers' frustration at facing so much uncertainty and allow them to proactively manage risks. For detailed guidance on using scenario data for climate impact assessments, see IPCC-TGICA (2007).

9.4 BEST PRACTICES FOR ADAPTATION

Another element essential to the process of adaptation decision making is to know the possible management options (*e.g.*, adaptation options) available to address the breadth of projected impacts, and how those options may function to lessen the impacts. As defined in this report, the goal of adaptation is to reduce the risk of adverse environmental outcomes through activities that *increase the resilience* of ecological systems to climate change (Scheffer *et al.*, 2001; Turner, II *et al.*, 2003; Tompkins and Adger, 2004). Here, resilience refers to the amount of change or disturbance that a system can absorb *before it undergoes a fundamental shift* to a different set of processes and structures (Holling, 1973; Gunderson, 2000; Bennett, Cumming, and Peterson, 2005). Therefore, all of the adaptation approaches reviewed below involve strategies for supporting the ability of ecosystems to persist at local or regional scales.

The suites of characteristics that distinguish different ecosystems and regions determine the potential for successful adaptation to support resilience. This section begins with a description of resilience theory, including examples of some types of biological and physical factors that may confer resilience to climate change. This is followed by a review of seven major adaptation approaches gleaned from across the chapters of this report, a discussion of the confidence levels associated with these approaches, and an examination of adaptive management as an effective means of implementing adaptation strategies.

9.4.1 Resilience

Management of ecosystems for any objective will be made easier if the systems are resilient to change—whether it is climate change or any other disturbance. Resilience is the ability of a system to return to its initial state and function in spite of some major perturbation. For example, a highly resilient coral reef might bleach but would be able to recover rapidly. Similarly, a resilient forest ecosystem would quickly re-establish plant cover following a major forest fire, with negligible loss of soils or fertility. An important contributing factor to overall resilience is *resistance*, which is the ability of an organism or a system to remain un-impacted by major disturbance or stress. "Un-impacted," in this sense, means that the species or system can continue to provide the desired ecosystem services. Resistance is derived from intrinsic biological characteristics at the level of species or genetic varieties. Resistance contributes to resilience since ecosystems that contain resistant individuals or communities will exhibit faster overall recovery (through recruitment and regrowth) after a disturbance. It is certainly possible that if systems are not resilient, the change that results could produce some benefits. However, from the perspective of a resource manager responsible for managing the ecosystems in question, a lack of resilience would mean that it would be difficult to establish clear objectives for that system and a consistent plan for achieving those objectives.

The science and theory of resilience may soon be sufficiently advanced to be able to confidently predict what confers resilience upon a system; the scientific literature is rapidly developing in this area and provides plausible hypotheses and likely resilience factors. Perhaps more importantly, common sense indicates that healthier ecosystems will generally be more resilient to disturbances. Activities that promote overall ecosystem health, whether they are restorative (*e.g.*, planting trees, captive breeding, and reintroduction) or protective (*e.g.,* restrictive of destructive uses) will tend to build resilience.

On the broadest level, working from the assumption that more intact and pristine ecosystems are more resilient to disturbances such as climate change, there are a number of ways to manage for resilience. The appropriate approach depends largely on the current state of the area being protected and the available resources with which to execute that protection. Options include (1) protecting intact systems (*e.g.*, Papahānaumokuākea Marine National Monument), (2) restoring systems to more pristine states (*e.g.,* restoring marshes and wetlands), and (3) preventing further degradation (*e.g.*, control of invasive species).

Beyond simply managing for pristine systems, which can be hard to identify, a quantifiable objective is to manage for biodiversity and key structural components or features. An important challenge associated with resilience is what might be called a "timescale mismatch." Resilience can be destroyed quickly, but often is "derived from things that can be restored only slowly, such as reservoirs of soil nutrients, heterogeneity of ecosystems on a landscape, or a variety of genotypes and species" (Folke *et al.*, 2002). This implies that while taking the necessary steps to prevent extinctions, management should worry most about species that have long generation times and low reproductive potential.

Our understanding of specific resilience factors for particular systems is sparse, making managing for resilience currently more an art than a science. Fortunately, two general concepts provide a simple framework for thinking about and managing for resilience. One is to ensure that ecosystems have all the components they need in order to recover from disturbances. This may be termed the biodiversity concept. The other is to support the species composing the structural foundation of the ecosystem, such as corals or large trees as habitat. This may be termed the structural concept. Although resource managers may not explicitly use these terms, examples of both concepts may be found in their decision-making.

Biodiversity Concept

Much academic research on managing for resilience invokes the precautionary principle. In this context, the precautionary principle calls for ensuring that ecosystems have all the biotic building blocks (functional groups, species, genes) that they need for recovery. These building blocks can also be thought of as *ecological memory*: the "network of species, their dynamic interactions among each other and with the environment, and the combination of structures that make reorganization after disturbance possible" (Bengtsson *et al.*, 2003).

A recent meta-analysis of ocean ecosystem services provides support for the biodiversity approach with its conclusion that in general, rates of resource collapse increased—and recovery rates decreased—exponentially with declining diversity. In contrast, with restoration of biodiversity, productivity increased fourfold and variability decreased by 21% on average (Worm *et al.*, 2006). Several other studies have concluded that diversity at numerous levels—*i.e.*, of functional groups, of species in functional groups, and within species and populations—appears to be critical for resilience and for the provision of ecosystem services (Chapin *et al.*, 1997; Luck, Daily, and Ehrlich, 2003; Folke *et al.*, 2004). National parks, national wildlife refuges, and marine protected areas all manage for maintaining as many native species as possible, and in so doing promote diversity as a resilience factor. The call for ecosystem-based management in the chapter on national estuaries represents a move toward a multi-species focus that could also enhance resilience. Although the detailed dynamics of the connection between biodiversity and resilience are not yet understood, evidence previously cited indicates that it is both practical and sensible as a precautionary act to protect biodiversity as a means of promoting resilience.

Biodiversity exists at multiple levels: genetic, species, function, and ecosystem. Table 9.3 briefly provides definitions and examples of management options for each of these four levels of biodiversity. It is worth noting that national parks, national wildlife refuges, and marine protected areas are all aimed at

Table 9.3. Levels of biodiversity and associated management options.

Levels of Biodiversity	Definition	Management Activities That Support Diversity
Genetic diversity	Allelic diversity and the presence/absence of rare alleles (foundation for all higher level diversity)	• Gene banks • Transplantation: re-introduction of lost genes (*e.g.*, transplanting and/or releasing hatchery-reared larvae/juveniles) • Protected areas and corridors
Species diversity	Quantity of species in a given area	• *Ex situ* conservation measures such as captive breeding programs • ESA listings • Protected areas
Functional diversity	Full representation of species within functional groups.	• Special protections for imperiled species within functional groups (*e.g.*, herbivorous fishes) • Protected areas
Ecosystem/landscape diversity	All important habitats represented as well as appropriately large scale of metapopulations	• Large protected areas • Networks of protected areas

supporting diversity to the extent that any "reserve" or "protected area" is. Wild and scenic rivers, national estuaries, and national forests have not traditionally had diversity as a core management goal. It is noteworthy, however, that the 2004–2008 USDA Forest Service Strategic plan does describe the Forest Service mission in terms of sustaining "diversity" (Chapter 3, National Forests).

Structural Concept

Organisms that provide ecosystem structure include trees in forests, corals on coral reefs, kelp in kelp forests, and grasses on prairies. These structure-providing groups represent the successional climax of their respective ecosystems—a climax that often takes a long time to reach. Logically, managers are concerned with loss of these species (whether due to disease, overharvesting, pollution, or natural disturbances) because of consequent cascading effects.

One approach to managing for resilience is to evaluate options in terms of what they mean for the recovery rate of fundamental structural aspects of an ecosystem. For example, the fishing technique of bottom trawling and the forestry technique of clear-cutting destroy biological structure, thus hindering recovery because the ecosystem is so degraded that either succession has to start from a more barren state or the community may even shift into an entirely new stable state. Thus, management plans should protect these structural species whose life histories dictate that if they are damaged, recovery time will increase.

It is important to note that while structural species are often representative of the ecosystem state most desirable to humans in terms of production of ecosystem services, they are still only representative of one of several states that are natural for that system. The expectation that these structural organisms will always dominate is unreasonable. In temperate forests, stand-replacing fires can be critical to resetting ecosystem dynamics; in kelp forests, kelp is periodically decimated by storms. Thus maintaining structural species does not mean management for permanence—it simply means managing for processes that will keep structural species in the system, albeit perhaps in a shifting mosaic of dominant trees in a forest, for example.

9.4.2 Adaptation Approaches

Managers' past experiences with unpredictable and extreme events such as hurricanes, floods, pest and disease outbreaks, invasions, and forest fires have already led to some existing approaches that can be used to adapt to climate change. Ecological studies combined with managers' expertise reveal several common themes for managing natural systems for resilience in the face of disturbance. A clear exposition of these themes is the starting point for developing best practices aimed at climate adaptation.

The seven approaches discussed below—(1) protection of key ecosystem features, (2) reduction of anthropogenic stresses, (3) representation, (4) replication, (5) restoration, (6) refugia, and (7) relocation—involve techniques that manipulate or take advantage of ecosystem properties to enhance their resilience to climatic changes. All of these adaptation approaches ultimately contribute to resilience as defined above, whether at the scale of individual protected area units, or at the scale of regional/national systems. While different chapters vary in their perspectives and terminologies regarding adaptation, the seven categories presented are inclusive of the range of adaptation options found throughout this report.

9.4.2.1 Protect Key Ecosystem Features

Within ecosystems, there may be particular structural characteristics (*e.g.*, three-dimensional complexity, growth patterns), organisms (*e.g.*, functional groups, native species), or areas (*e.g.*, buffer zones, migration corridors) that are particularly important for promoting the resilience of the overall system. Such key ecosystem features could be important focal points for special management protections or actions. For example, managers of national forests may proactively promote stand resilience to diseases and fires by using silviculture techniques such as widely spaced thinnings or shelterwood cuttings (Chapter 3, National Forests). Another example would be to aggressively prevent or reverse the establishment of invasive non-native species that threaten native species or impede current ecosystem function (Chapter 4, National Parks). Preserving the structural complexity of vegetation in tidal marshes, seagrass meadows, and mangroves may render estuaries more resilient (Chapter 7, National Estuaries). Finally, establishing and protecting corridors of connectivity that enable migrations can enhance resilience across landscapes in national wildlife refuges (Chapter 5, National Wildlife Refuges). Box 9.2 draws additional examples of this adaptation approach from across the chapters of this report.

BOX 9.2. Examples of adaptation actions that focus on protection of key ecosystem features as a means of supporting resilience.

Adaptation Approach: Protect Key Ecosystem Features

National Forests

- Facilitate natural (evolutionary) adaptation through management practices (e.g., prescribed fire and other silvicultural treatments) that shorten regeneration times and promote interspecific competition.
- Promote connected landscapes to facilitate species movements and gene flow, sustain key ecosystem processes (e.g., pollination and dispersal), and protect critical habitats for threatened and endangered species.

National Parks

- Remove barriers to upstream migration in rivers and streams.
- Reduce fragmentation and maintain or restore species migration corridors to facilitate natural flow of genes, species and populations.
- Use wildland fire, mechanical thinning, or prescribed burns where it is documented to reduce risk of anomalously severe fires.
- Minimize alteration of natural disturbance regimes, for example through protection of natural flow regimes in rivers or removal of infrastructure that prohibits the allowance of wildland fire.
- Aggressively prevent establishment of invasive non-native species or diseases where they are documented to threaten native species or current ecosystem function.

National Wildlife Refuges

- Manage risk of catastrophic fires through prescribed burns.
- Reduce or eliminate stressors on conservation target species.
- Improve the matrix surrounding the refuge by partnering with adjacent owners to improve/build new habitats.
- Install levees and other engineering works to alter water flows to benefit refuge species.
- Remove dispersal barriers and establish dispersal bridges for species.
- Use conservation easements around the refuge to allow species dispersal and maintain ecosystem function.
- Facilitate migration through the establishment and maintenance of wildlife corridors.

Wild & Scenic Rivers

- Maintain the natural flow regime through managing dam flow releases upstream of the wild and scenic river (through option agreements with willing partners) to protect flora and fauna in drier downstream river reaches, or to prevent losses from extreme flooding.
- Use drought-tolerant plant varieties to help protect riparian buffers.
- Create wetlands or off-channel storage basins to reduce erosion during high flow periods.
- Actively remove invasive species that threaten key native species.

National Estuaries

- Help protect tidal marshes from erosion with oyster breakwaters and rock sills and thus preserve their water filtration and fisheries enhancement functions.
- Preserve and restore the structural complexity and biodiversity of vegetation in tidal marshes, seagrass meadows, and mangroves.
- Adjust protections of important biogeochemical zones and critical habitats as the locations of these areas change with climate.
- Connect landscapes with corridors to enable migrations to sustain wildlife biodiversity across the landscape.
- Develop practical approaches to apply the principle of rolling easements to prevent engineered barriers from blocking landward retreat of coastal marshes and other shoreline habitats as sea level rises.

Marine Protected Areas

- Identify ecological connections among ecosystems and use them to inform the design of MPAs and management decisions such as protecting resistant areas to ensure sources of recruitment for recovery of populations in damaged areas.
- Manage functional species groups necessary to maintaining the health of reefs and other ecosystems.
- Design MPAs with dynamic boundaries and buffers to protect breeding and foraging habits of highly migratory and pelagic species.
- Monitor ecosystems and have rapid-response strategies prepared to assess ecological effects of extreme events as they occur.
- Identify and protect ecologically significant (“critical”) areas such as nursery grounds, spawning grounds, and areas of high species diversity.

9.4.2.2 Reduce Anthropogenic Stresses

Managing for resilience often implies minimizing anthropogenic stressors (*e.g.*, pollution, overfishing, development) that hinder the ability of species or ecosystems to withstand a stressful climatic event. For example, one way of enhancing resilience in wildlife refuges is to reduce other stresses on native vegetation such as erosion or altered hydrology caused by human activities (Chapter 5, National Wildlife Refuges). Marine protected area managers may focus on human stressors such as fishing and inputs of nutrients, sediments, and pollutants both inside the protected area and outside the protected area on adjacent land and waters (Chapter 8, Marine Protected Areas). The resilience of rivers could be enhanced by strategically shifting access points or moving existing trails for wildlife or river enthusiasts, in order to protect important riparian zones (Chapter 6, Wild and Scenic Rivers). Box 9.3 presents additional examples of this adaptation approach drawn from across the chapters of this report.

9.4.2.3 Representation

Representation is based on the idea that biological systems come in a variety of forms. Species include locally adapted populations as opposed to one monotypic taxon, and major

BOX 9.3. Examples of adaptation actions that focus on reduction of anthropogenic stresses as a means of supporting resilience.

Adaptation Approach: Reduce Anthropogenic Stresses

National Forests
- Reduce the impact of current anthropogenic stressors such as fragmentation (e.g., by creating larger management units and migration corridors) and uncharacteristically severe wildfires and insect outbreaks (e.g., by reducing stand densities and abating fuels).
- Identify and take early proactive action against non-native invasive species (e.g., by using early detection and rapid response approaches).

National Parks
- Remove structures that harden the coastlines, impede natural regeneration of sediments, and prevent natural inland migration of sand and vegetation after disturbances.
- Reduce or eliminate water pollution by working with watershed coalitions to reduce non-point sources and with local, state and federal agencies to reduce atmospheric deposition.
- Manage Park Service and visitor use practices to prevent people from inadvertently contributing to climate change.

National Wildlife Refuges
- Reduce human water withdrawals to restore natural hydrologic regimes.

Wild & Scenic Rivers
- Purchase or lease water rights to enhance flow management options.
- Manage water storage and withdrawals to smooth the supply of available water throughout the year.
- Develop more effective stormwater infrastructure to reduce future occurrences of severe erosion.
- Consider shifting access points or moving existing trails for wildlife or river enthusiasts.

National Estuaries
- Conduct integrated management of nutrient sources and wetland treatment of nutrients to limit hypoxia and eutrophication.
- Manage water resources to ensure sustainable use in the face of changing recharge rates and saltwater infiltration.
- Prohibit bulkheads and other engineered structures on estuarine shores to preserve or delay the loss of important shallow-water habitats by permitting their inland migration as sea levels rise.

Marine Protected Areas
- Manage human stressors such as overfishing and excessive inputs of nutrients, sediments, and pollutants within MPAs.
- Improve water quality by raising awareness of adverse effects of land-based activities on marine environments, implementing integrated coastal and watershed management, and developing options for advanced wastewater treatment.

BOX 9.4. Examples of adaptation actions that focus on representation as a means of supporting resilience.

Adaptation Approach: Representation

National Forests
- Modify genetic diversity guidelines to increase the range of species, maintain high effective population sizes, and favor genotypes known for broad tolerance ranges.
- Where ecosystems will very likely become more water limited, manage for drought- and heat-tolerant species and populations, and where climate trends are less certain, manage for a variety of species and genotypes with a range of tolerances to low soil moisture and higher temperatures.

National Parks
- Allow the establishment of species that are non-native locally, but which maintain native biodiversity or enhance ecosystem function in the overall region.
- Actively plant or introduce desired species after disturbances or in anticipation of the loss of some species.

National Wildlife Refuges
- Strategically expand the boundaries of NWRs to increase ecological, genetic, geographical, behavioral and morphological variation in species.
- Facilitate the growth of plant species more adapted to future climate conditions.

Wild & Scenic Rivers
- Increase genetic diversity through plantings or by stocking fish.
- Increase physical habitat heterogeneity in channels to support diverse biotic assemblages.

National Estuaries
- Maintain high genetic diversity through strategies such as the establishment of reserves specifically for this purpose.
- Maintain landscape complexity of salt marsh landscapes, especially preserving marsh edge environments.

Marine Protected Areas
- Maximize habitat heterogeneity within MPAs and consider protecting larger areas to preserve biodiversity, biological connections among habitats, and ecological functions.
- Include entire ecological units (e.g., coral reefs with their associated mangroves and seagrasses) in MPA design to maintain ecosystem function and resilience.
- Ensure that the full breadth of habitat types is protected (e.g., fringing reef, fore reef, back reef, patch reef).

habitat types or community types include variations on a theme with different species compositions, as opposed to one invariant community. The idea behind representation as a strategy for resilience is simply that a portfolio of several slightly different forms of a species or an ecosystem increases the likelihood that, among those variants, there will be one or more that are suited to the new climate. A management plan for a large ecosystem that includes representation of all possible combinations of physical environments and biological communities increases the chances that, regardless of the climatic change that occurs, somewhere in the system there will be areas that survive and provide a source for recovery. Employing this approach with wildlife refuges may be particularly important for migrating birds because they use a diverse array of habitats at different stages of their life cycles and along their migration routes, and all of these habitats will be affected by climate change (Chapter 5, National Wildlife Refuges). At the level of species, it may be possible to increase genetic diversity in river systems through plantings or via stocking fish (Chapter 6, Wild and Scenic Rivers), or maintain complexity of salt marsh landscapes by preserving marsh edge environments (Chapter 7, National Estuaries). Box 9.4 presents additional examples of this adaptation approach drawn from across the chapters of this report.

9.4.2.4 Replication

Replication is simply managing for the continued survival of more than one example of each ecosystem or species, even if the replicated examples are identical. When one recognizes that climate change stress includes unpredictable extreme events and storms, then replication represents a strategy of having multiple bets in a game of chance. With marine protected areas, replication is explicitly used as a way to spread risk: if one area is negatively affected by a disturbance, then species, genotypes, and habitats in another area provide both insurance against extinction and a larval supply that may facilitate recovery of affected areas (Chapter 8, Marine Protected Areas). The analogy for forests would be spreading risks by increasing ecosystem redundancy and buffers in both natural environments and plantations (Chapter 3, National Forests). It is prudent to use replication in all systems. In practice, most replication strategies also serve as representation strategies (since no two populations or ecosystems can ever be truly identical), and conversely most representation strategies provide some form of replication. Box 9.5 provides examples of this adaptation approach drawn from across the chapters of this report.

BOX 9.5. Examples of adaptation actions that focus on replication as a means of supporting resilience.

Adaptation Approach: Replication

National Forests
- Spread risks by increasing ecosystem redundancy and buffers in both natural environments and plantations.

National Parks
- Practice bet-hedging by replicating populations and gene pools of desired species.

National Wildlife Refuges
- Provide redundant refuge types to reduce risk to trust species.

Wild & Scenic Rivers
- Establish special protection for multiple headwater reaches that support keystone processes or sensitive species.

National Estuaries
- When restoring oyster reefs, replicate reefs along a depth gradient to allow fish and crustaceans to survive when depth-dependant environmental degradation occurs.
- Support migrating shorebirds by ensuring protection of replicated estuaries along the flyway.

Marine Protected Areas
- Replicate habitat types in multiple areas to spread risks associated with climate change.

9.4.2.5 Restoration

In many cases natural intact ecosystems confer resilience to extreme events such as floods and storms. One strategy for adapting to climate change thus entails restoring intact ecosystems. For example the restoration of wetlands and natural floodplains will often confer resilience to floods. Restoration of particular species complexes may also be key to managing for resilience—a good example of this would be fire-adapted vegetation in forests that are expected to see more fires as a result of hotter and drier summers (Chapter 3, National Forests). At Blackwater National Wildlife Refuge, the USFWS is planning to restore wetlands that may otherwise be inundated by 2100 (Chapter 5, National Wildlife Refuges). In the case of estuaries, restoring the vegetational layering and structure of tidal marshes, seagrass meadows, and mangroves can stabilize estuary function (Chapter 7, National Estuaries). Box 9.6 provides additional examples of this adaptation approach drawn from across the chapters of this report.

9.4.2.6 Refugia and Relocation

The term *refugia* refers to physical environments that are less affected by climate change than other areas (*e.g.,* due to local currents, geographic location, etc.) and are thus a "refuge" from climate change for organisms. *Relocation* refers to human-facilitated transplantation of organisms from one location to another in order to bypass a barrier (*e.g.,* an urban area). Refugia and relocation, while major concepts, are actually subsets of one or more of the approaches listed above. For example, if refugia can be identified locally, they can be considered sites for long-term retention of species (*e.g.,* for representation and to maintain resilience) in forests (Chapter 3, National Forests). Or, in national wildlife refuges, it may be possible to use restoration techniques to reforest riparian boundaries with native species to create shaded thermal refugia for fish species (Chapter 5, National Wildlife Refuges). In the case of relocation, an example would be transport of fish populations in the Southwest that become stranded as water levels drop to river reaches with appropriate flows (*e.g.,* to preserve system-wide resilience and species representation) (Chapter 6, Wild and Scenic Rivers). Similarly, transplantation of organisms

BOX 9.6. Examples of adaptation actions that focus on restoration as a means of supporting resilience.

Adaptation Approach: Restoration

National Forests
- Use the paleological record and historical ecological studies to revise and update restoration goals so that selected species will be tolerant of anticipated climate.
- Where appropriate after large-scale disturbances, reset succession and manage for asynchrony at the landscape scale by promoting diverse age classes and species mixes, a variety of successional stages, and spatially complex and heterogeneous vegetation structure.

National Parks
- Restore vegetation where it confers biophysical protection to increase resilience, including riparian areas that shade streams and coastal wetland vegetation that buffers shorelines.
- Minimize soil loss after fire or vegetation dieback using native vegetation and debris.

National Wildlife Refuges
- Restore and increase habitat availability and reduce stressors in order to capture the full geographical, geophysical, and ecological ranges of species on as many refuges as possible.

Wild & Scenic Rivers
- Conduct river restoration projects to stabilize eroding banks, repair in-stream habitat, or promote fish passages from areas with high temperatures and less precipitation.
- Restore the natural capacity of rivers to buffer climate-change impacts (*e.g.*, through land acquisition around rivers, levee setbacks to free the floodplain of infrastructure, riparian buffer repairs).

National Estuaries
- Restore important native species and remove invasive non-natives to improve marsh characteristics that promote propagation and production of fish and wildlife.
- Direct estuarine habitat restoration projects to places where the restored ecosystem has room to retreat as sea level rises.

Marine Protected Areas
- Following extreme events, consider whether actions should be taken to enhance natural recovery processes through active restoration.
- Consider mangrove restoration for potential benefits including shoreline protection, expansion of nursery habitat, and release of tannins and other dissolved organic compounds that may reduce photo-oxidative stress in corals.

among national parks could preserve system-wide representation of species that would not otherwise be able to overcome barriers to dispersal (Chapter 4, National Parks). Boxes 9.7 and 9.8 provide additional examples of these adaptation approaches drawn from across the chapters of this report.

9.4.3 Confidence

Due to uncertainties associated with climate change projections as well as uncertainties in species and ecosystem responses, there is also uncertainty as to how effective the different adaptation approaches listed above will be at supporting resilience. It is therefore essential to assess the level of confidence associated with each adaptation approach. For this report, the levels of confidence for each adaptation approach are based on the expert judgment of the authors, using a conceptual methodology developed by the IPCC (2007).

Confidence levels are presented for each of the seven adaptation approaches for each management system (Table 9.4). The goal of these adaptation approaches is to support the resilience of ecosystems to persist *in their current form* (*i.e.*, without major shifts to entirely redefined systems) under changing climatic conditions. Thus it is important to note at this point that promoting resilience may be a management strategy that is useful only on shorter time scales of a few decades rather than centuries, because as climate change continues, various thresholds of resilience will eventually be exceeded. Therefore, each of the authors'

BOX 9.7. Examples of adaptation actions that focus on the use of refugia as a means of supporting resilience.

Adaptation Approach: Refugia

National Forests
- Use the paleological record and historical ecological studies to identify environments buffered against climate change, which would be good candidates for long-term conservation.

National Parks
- Create or protect refugia for valued aquatic species at risk to the effects of early snowmelt on river flow.

National Wildlife Refuges
- Reforest riparian boundaries with native species to create shaded thermal refugia for fish species in rivers and streams.
- Identify climate change refugia and acquire necessary land.

Wild & Scenic Rivers
- Plant riparian vegetation to provide fish and other organisms with refugia.
- Acquire additional river reaches for the wild and scenic river where they contain naturally occurring refugia from climate change stressors.
- Create side-channels and adjacent wetlands to provide refugia for species during droughts and floods.

National Estuaries
- Restore oyster reefs along a depth gradient to provide shallow water refugia for mobile species such as fish and crustaceans to retreat to in response to climate-induced deep water hypoxia/anoxia.

Marine Protected Areas
- Identify and protect areas observed to be resistant to climate change effects or to recover quickly from climate-induced disturbances.
- Establish dynamic MPAs defined by large-scale oceanographic features such as oceanic fronts where changes in types and abundances of organisms often occur.

BOX 9.8. Examples of adaptation actions that focus on relocation as a means of supporting resilience.

Adaptation Approach: Relocation

National Forests
- Establish or strengthen long-term seed banks to create the option of re-establishing extirpated populations in new/more appropriate locations.

National Parks
- Assist in species migrations.

National Wildlife Refuges
- Facilitate long-distance transport of threatened endemic species.
- Facilitate interim propagation and sheltering or feeding of mistimed migrants, holding them until suitable habitat becomes available.

Wild & Scenic Rivers
- Establish programs to move isolated populations of species of interest that become stranded when water levels drop.

National Estuaries – none
Marine Protected Areas – none

confidence estimates are based solely on how effectively—in the near term—the adaptation approach will be at achieving positive ecological outcomes with respect to increased resilience to climate change. Through time, as ecosystem thresholds are exceeded, these approaches will cease to be effective, at which point major shifts in ecosystem processes, structures and components will be unavoidable. This eventuality is discussed in a later section (9.6.3, *Manage for Change*), where adaptation strategies associated with planning for major shifts are presented. In addition to limiting their confidence assessments to the near term, the authors also excluded from consideration any non-ecological factor (such as confidence in the ability to put particular approaches into practice) and only evaluated those adaptation approaches for which they had adaptation strategies discussed in their chapter.

9.4.3.1 Approach to Estimating Levels of Confidence

The authors considered two separate but related elements of confidence (IPCC, 2007). The first element is the amount of evidence that is available to assess the effectiveness of a given adaptation approach to support resilience. The second is the level of agreement or consensus in the expert community regarding the different lines of evidence. From each chapter, specific adaptation options were grouped according to the seven categories of "adaptation approaches" described in the previous section (see Boxes 9.2–9.8). The authors then developed confidence estimates for each adaptation approach based on consideration of the specific adaptation options and the following questions:

High/low amount of evidence. Is this adaptation approach well-studied and understood, or instead is it mostly experimental or theoretical and not well-studied? Does your experience in the field, your analyses of data, and your understanding of the literature and performance of specific adaptation options under this type of adaptation approach indicate that there is a high or low amount of information on the effectiveness of this approach?

High/low amount of agreement. Do the studies, reports, and your experience in the field, analyzing data, or implementing the types

Table 9.4. Confidence levels associated with seven different adaptation approaches, examined across six management system types. Estimates reflect the expert opinions of the authors and are based on the literature and personal experience.

Confidence Estimates for SAP 4.4 Adaptation Approaches

Agreement ↑		
	LH Low evidence High agreement	HH High evidence High agreement
	LL Low evidence Low agreement	HL High evidence Low agreement
	Evidence →	

	Protecting key ecosystem features	Reducing anthropogenic stresses	Representation	Replication	Restoration	Refugia	Relocation
National Forests	HL	HH	LL	LL	HL	HL	HL
National Parks	HH	HH	LL	LL	HH	LL	LL
National Wildlife Refuges	HH	HH	HH	HH	LL	HL	LL
Wild and Scenic Rivers	LH	HH	HH	HH	LL	HH	LL
National Estuaries	LL	HH	LH	LH	HH	LL	N/A
Marine Protected Areas	LH	LH	LH	LH	LL	LH	N/A

of adaptation strategies that comprise this approach reflect a high degree of agreement on the effectiveness of this approach, or does it lead to competing interpretations?

Because of the qualitative nature of this confidence exercise, the author teams provided explanations of the basis for each of their estimates under each adaptation approach (see Annex B, Confidence Estimates). The evidence they considered in making their judgments included peer-reviewed and gray literature (journal articles, reports, working papers, management plans, workshop reports, other management literature, other gray literature), data and observations, model results, and the authors' own experience, including their experiences in the field, their analyses of data, and their knowledge of the performance of specific adaptation options under each type of adaptation approach.

Confidence estimates are presented in Table 9.4 by management system type for each of the seven adaptation approaches. Such confidence estimates should be a key consideration when deciding which adaptation approaches to implement for a given system.

9.4.3.2 Findings

To take action today using the best available information, *reducing anthropogenic stresses* is currently the adaptation approach that ranks highest in confidence, in terms of both evidence and agreement across all six management systems. This may be due partly to the fact that managers have been dealing with anthropogenic stresses for a long time, so there are a lot of data and good agreement among the experts that this approach is effective in increasing resilience to any kind of stress, including climate change.

Protecting key ecosystem features, representation, replication, restoration, and *refugia* all received variable confidence rankings across the management system chapters. This could be due to a number of factors related to both evidence and agreement. One explanation could be differences in the amount and nature of research and other information available on an approach depending on the management system. For example, one management system may have a great deal of evidence for the effectiveness of an approach at the species level, but little evidence that it would be effective in enhancing resilience at the ecosystem level; in contrast, another management system may have more evidence at the ecosystem as well as species level. Also, regardless of the amount of evidence, different groups can arrive at different interpretations of what constitutes agreement based on management goals, institutional perspectives, and experiences with particular ecosystem types. Even though the variability in confidence in these approaches suggests that caution is warranted, many of the individual adaptation options under these approaches may still be effective. In these cases, a more detailed assessment of confidence is needed for each specific adaptation option and ecosystem in which it would be applied.

Relocation stands out as being the weakest in terms of confidence *at the current time*, based on available information. There appears to be little information (evidence) about *relocation* or its implications for ecosystem resilience, and thus there is little agreement among experts that it is a robust approach. Future research may change this ranking (as well as the rankings for other approaches) at any time.

9.4.3.3 Improving Confidence Estimates

Management planning to select and prioritize adaptation approaches will always involve some assessment of confidence, whether implicitly or explicitly. Explicit estimations of confidence, while difficult, afford managers a better understanding of the nature, implications, and risks of different adaptation approaches. The confidence exercise in this report is a first attempt at evaluating a series of seven conceptual approaches to adaptation that each represents an aggregation of various adaptation options. The next level of refinement for confidence assessments may involve evaluating confidence in individual adaptation options within each approach. This will be especially important in those cases where levels of confidence in an approach are highly variable across management systems or across ecosystems.

There are a number of challenges associated with improving confidence estimates for adaptation. One challenge is removing the inherent subjectivity of judgments about evidence and agreement. This could be addressed by more clearly defining terminology (*e.g.*, evidence and agreement) and developing more systematic rules (*e.g.*, weighting criteria for different sources of evidence). The goal of such improvements would be to move from a qualitative to a more quantitative method of expressing confidence, thereby facilitating more effective use of scientific information for adaptation planning. Finally, any confidence exercise would benefit from the largest number of participants as possible to improve the robustness of the results.

9.4.4 Adaptive Management

Once adaptation approaches have been selected after taking into account confidence levels, adaptive management is likely to be an effective method for implementing those approaches. It emphasizes managing based on observation and continuous learning and provides a means for effectively addressing varying degrees of uncertainty in our knowledge of current and future climate change impacts. Adaptive management is typically divided into two types: passive and active (Arvai *et al.*, 2006; Gregory, Ohlson, and Arvai, 2006). Passive adaptive management refers to using historical data to develop hypotheses about the best management action, followed by action and monitoring. Often models are used to guide the decisions and the monitoring can improve the models. Active adaptive management refers to actually conducting a management experiment, ideally with several different management actions implemented at once as a means of testing competing hypotheses. Examples include flood release experiments in the Grand Canyon (Chapter 4, National Parks) and at the Glen Canyon dam (National Research Council, 1999). Releasing water from a dam allows for the application of highly regulated experimental treatments and assessments of effects. For more information on adaptive management, see the Technical Guide[5] released in the spring of 2007 by the Department of Interior. It provides a robust analytical framework that is based on the experience, in-depth consultation, and best practices of scientists and natural resource managers.

Adaptive management to address climate change is an iterative process that involves the consideration of potential climate impacts, the design of management actions and experiments that take those impacts into account, monitoring of climate-sensitive species and processes to measure management effectiveness, and the redesign and implementation of improved (or new) management actions (Fig. 9.2). To maximize the implementation of climate-sensitive adaptive management within federal systems, managers can focus on (1) previously established strategies that were designed for other management issues but have strong potential for application toward climate change impacts, and (2) new strategies that are not yet in place but appear to be feasible and within reasonable reach of current management structures. In other words, at a minimum, managers need to vigorously pursue changes that are relatively easily accomplished under existing programs and management cultures.

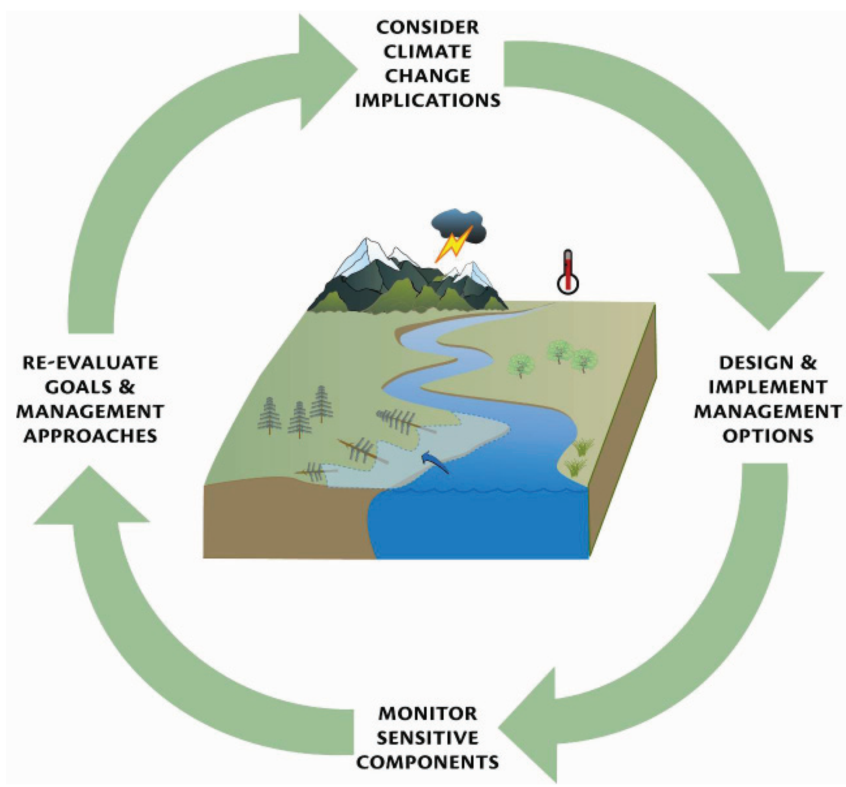


Figure 9.2. The process of adaptive management.

[5] **Williams**, B. K., R. C. Szaro, and C. D. Shapiro. 2007. Adaptive Management: The U.S. Department of the Interior Technical Guide. Adaptive Management Working Group, U.S. Department of the Interior, Washington, DC.

Recent examinations of the difficulty of actually using adaptive management have emphasized that the temporal and spatial scale, dimension of uncertainty, risks, and institutional support can create major difficulties with applying adaptive management. When one considers adaptive management (whether active or passive) in response to climate change, every one of these potential difficulties is at play (Arvai *et al.*, 2006; Gregory, Ohlson, and Arvai, 2006). The critical challenge will be stating explicit scientific hypotheses, establishing monitoring programs with predefined triggers that initiate a re-examination of management approaches, and a flexible policy or institutional framework (Gregory, Ohlson, and Arvai, 2006). These challenges do not mean adaptive management is impossible—only that attention to hypotheses, monitoring, periodic re-evaluations, and flexibility are necessary.

Even in the absence of an ability to experimentally manipulate systems, rapid, climate-induced ecological changes provide excellent opportunities to observe the effects of climate change in relatively short time frames. Managers and scientists can design studies to take advantage of increased climatic variability and climate trends to inform management. Some examples of such studies could include observing: which riparian plant species are best adapted to extreme variations in flow regime and flooding, how increased variability in climatic conditions affects population dynamics of target insect pests or focal wildlife species, and the effects of marine reserve size on recruitment and survival of key species. In order to make this approach effective, specific hypotheses should be proposed about which life history traits will predispose species to (biologically) adapt to climate change (Kelly and Adger, 2000). Otherwise the data collection will be less focused and efficient. Using climate-driven changes as treatments *per se* will be much less exact and less predictable than controlled experiments, so taking advantage of such situations for adaptive management studies will require increased flexibility, foresight, and creativity on the part of managers and scientists.

Another key element of adaptive management is monitoring of sensitive species and processes in order to measure the effectiveness of experimental management actions. In the case of adaptive management for climate change, this step is critical, not only for measuring the degree to which management actions result in positive outcomes on the ground, but also for supporting a better scientific understanding of how to characterize and measure ecological resilience. Most resource agencies already have monitoring programs and sets of indicators. As long as management goals are not changed (see Section 9.6.1), then these existing monitoring programs should reflect the outcomes of management actions on the ground. If management goals are altered because climate change is perceived to be so severe that historical goals are untenable, then entirely new indicators and monitoring programs may need to be designed. Whatever the case, monitoring is fundamental to supporting the reevaluation and refinement of management strategies as part of the adaptive process.

The same monitoring can also foster an improved understanding of how best to characterize and quantify resilience. For some systems, the ecology of climate stress (*e.g.,* coral bleaching) has been studied for decades, and resilience theory continues to develop rapidly. For other ecosystems, the impacts of climate change are less well understood, and understanding resilience is more difficult. In any event, while there may be some good conceptual models that describe resilience characteristics for species and ecosystems, there is generally a paucity of empirical data to confirm and resolve the relative importance of these characteristics. Such information is needed for the next generation of techniques and tools for quantification and prediction of resilience across species and ecosystems. If monitoring programs are designed with explicit hypotheses about resilience, they will be more likely to yield useful information.

The idea of "adaptive management" has been widely advocated among natural resource managers for decades and has been ascribed to many management decisions. However, due largely to the challenges cited above, it is not as widely or rigorously applied as it could be. Yet the prospect of uncertain, widespread, and severe climatic changes may galvanize managers to embrace adaptive management as an essential strategy. Climate change creates new situations of added complexity for which an adaptive management approach may be the only way to take management action today while allowing for increased understanding and refinement tomorrow.

9.5 BARRIERS AND OPPORTUNITIES FOR ADAPTATION

Although there may be many adaptation strategies that could be implemented, a very real consideration for managers is whether all of the possibilities are feasible. Factors limiting or enhancing managers' ability to implement options may be technical, economic, social, or political. As noted previously in this chapter, the climate community refers to such opportunities and constraints (or barriers) as adaptive capacity. It may be helpful to understand the types of barriers to implementation that exist in order to assess the feasibility of specific adaptation options, and even more so to identify corresponding ways in which barriers may be overcome. The barriers and opportunities discussed below are based on the expert opinions of the authors of this report and feedback from the expert workshops and are associated with implementation of adaptation options today, assuming no significant changes in institutional frameworks and authorities.

A useful way of thinking about both barriers and opportunities is in terms of the following four categories: (1) legislation and regulations, (2) management policies and procedures, (3) human and financial capital, and (4) information and science (see Tables 9.5–9.8). All of the federal land and water management systems reviewed in the preceding chapters are mandated by law to preserve and protect the nation's natural resources. Specific management goals vary across systems, however, due to the unique mission statements articulated in their founding legislation, or organic acts. Organic acts are fundamental pieces of legislation that either signify the organization of an agency or provide a charter for a network of public lands, such as the National Park Service Organic Act that established the National Park System. Accordingly, goals are manifested through management principles that could interpret those goals in ways that may inhibit or enhance the capability to adapt.

No matter how management goals are approached, achievement of goals may be difficult even without climate change. For example, in the case of the National Forest System, managers are asked to provide high-quality recreational opportunities and to develop means of meeting the nation's energy needs through biofuel production while reducing the risk of wildfire and invasive species and protecting both watersheds and biodiversity. Successful management requires not only significant resources (*e.g.*, staff capacity and access to information), but also the ability of managers to apply resources strategically and effectively (*e.g.*, for monitoring and management experiments) (Spittlehouse and Stewart, 2003).

Resources are managed carefully across federal agencies to deal with a growing human population that puts new and expanding pressures on managers' ability to meet management goals. Examples of these existing pressures include economic development near management unit boundaries (Chapter 5, National Wildlife Refuges), air pollution (Chapter 4, National Parks), increased wildfire-related costs and risks (Chapter 3, National Forests), habitat degradation and destruction (Chapter 8, Marine Protected Areas), pollutant loading (Chapter 7, National Estuaries), and excessive water withdrawals (Chapter 6, Wild and Scenic Rivers). The added threat of climate change may exceed the capacity of the federal management systems to protect the species and ecological systems that each is mandated to protect. However, as many of the previous chapters point out, this threat also represents an opportunity to undertake strategic thinking, reshape priorities, and use carefully considered actions to initiate the development of management adaptations to more effectively protect resources.

Adaptation responses to climate change are meant to reduce the risk of failing to achieve management goals. A better understanding of the barriers and opportunities that affect implementation of adaptation strategies could facilitate the identification of critical adjustments within the constraints of management structures and policies, and subsequently could foster increased adaptive capacity within and across federal management systems as those constraints are addressed in the longer term (see Section 9.6).

9.5.1 Legislation and Regulation

9.5.1.1 Perceived Barriers

In general, existing agency experience and law, taken together, provide the flexibility needed to adapt to climate change. However, an individual organic act or other enabling legislation, or its interpretation may sometimes be perceived as a barrier to adaptation. While original organic acts represented progressive policy and management frameworks at the time were written, many reflect a past era (Table 9.5). For example, the first unit of the National Wildlife Refuge System, Pelican Island, was designated in 1903 to protect waterfowl from being over-hunted when that was the greatest threat. At that time, the U.S. population was half of what it is now, and the interstate highway system was decades away from establishment (Chapter 5, National Wildlife Refuges). In addition, ambiguous language in enabling legislation poses challenges to addressing issues related to climate change, such as determining what "impaired" means (Chapter 4, National Parks). It also has been recognized that specific environmental policies such as the Endangered Species Act, National Environmental Policy Act, and the National Forest Management Act are highly static, making dynamic planning difficult and potentially impeding adaptive responses.[6] Even recently implemented legislation and management plans have not directly addressed climate change (Chapter 7, National Estuaries). In general, while community-focused approaches are more flexible, many existing laws force a species-specific approach to management (Chapter 3, National Forests), limiting agency action to address issues related to climate change.

Furthermore, organic acts and pursuant enabling legislation may limit the capacity to effectively manage some resources. For example, the chief legal limitation on intensive management to adapt to climate change for the National Wildlife Refuge System is the limited jurisdiction of many refuges over their water (Chapter 5, National Wildlife Refuges). Both the timing of water flows as well as the quantity of water flowing through refuges are often subject to state permitting and control by other federal agencies. Similarly, legal frameworks such as the Colorado River Compact establish water rights, compacts, and property rights that all serve to constrain the ability to use adaptive strategies to address climate change (Chapter 6, Wild and Scenic Rivers).

Protected areas have political rather than ecological boundaries as an artifact of legislation. These boundaries may pose a barrier to effectively addressing climate change. Climate change will likely lead to shifts in species and habitat distribution (Chapter 3, National Forests; Chapter 4, National Parks; Chapter 7, National Estuaries; Chapter 8, Marine Protected Areas), potentially moving them outside the bounds of federal jurisdiction or introducing new species that cause changes

6 **Levings**, W., 2003: *Economics of Delay*. Unpublished report on file at the Tahoe National Forest, pp.1-6.

Table 9.5. Examples of legislation and regulation as barriers to and opportunities for adaptation.

LEGISLATION AND REGULATION		
Perceived Barrier	**Opportunity**	**Examples**
Legislation and agency policies may be highly static, inhibit dynamic planning, impede flexible adaptive responses and force a fine-filter approach to management.	Re-evaluate capabilities of, or authorities under, existing legislation to determine how climate change can be addressed within the legislative boundaries.	• Use state wildlife action plans to manage lands adjacent to national wildlife refuges to enable climate-induced species emigration. • Re-evaluate specific ecosystem- and species-related legislation to use all capabilities within the legislation to address climate change. • Incorporate climate change impacts into priority setting for designation of new wild and scenic rivers (see Chapter 6 section 6.4.4).

in animal communities, such as changing predation and competition (Chapter 5, National Wildlife Refuges). Agencies often do not have the capacity or authority to address issues outside their jurisdiction, which could hamper efforts to adapt to climate change. This could affect smaller holdings more acutely than others (Chapter 5, National Wildlife Refuges).

Despite historical interpretations and organizational and geographic boundaries, existing legislation does not prohibit adaptation. Yet uncertainty surrounding application of certain management techniques can lead to costly and time-consuming challenges from particular stakeholders or the public (Chapter 3, National Forests). Fuel treatments and other adaptive projects that have ground-disturbing elements, such as salvage harvest after disturbance and use of herbicides before revegetation, have been strongly opposed by the public.[7] While using adaptation approaches in management poses the risk of spurring costly litigation from stakeholders, every chapter in this volume concludes that inaction with regard to climate change may prove more damaging and costly than acting with insufficient knowledge of the outcomes.

9.5.1.2 Opportunities

Federal land and water managers can use existing legislative tools in opportunistic ways (Table 9.5). Managers can strategically apply existing legislation or regulations at the national or state level by applying traditional features or levers in non-traditional ways. For example, while still operating within the legislative framework, features of existing legislation can be effectively used to coordinate management outside of jurisdictional boundaries. Generally, the USFWS has ample proprietary authority to engage in transplantation-relocation, habitat engineering (including irrigation-hydrologic management), and captive breeding to support conservation (Chapter 5, National Wildlife Refuges). These activities are especially applicable to managing shifts in species distributions and in potentially preventing species extirpations likely to result from climate change. Portions of existing legislation could also be used to influence dam operations at the state level as a means of providing adaptive flow controls under future climate changes (*e.g.*, using the Clean Water Act to prevent low flows in vulnerable stream reaches, adjusting thermal properties of flows). As these examples suggest, managers can influence change within the legislative framework to address climate change impacts.

9.5.2 Management Policies and Procedures

9.5.2.1 Perceived Barriers

Some management systems have a history of static policies that are counter to the dynamic management actions called for today (Table 9.6) and do not recognize climatic change as a significant problem or stressor. These agency policies do not allow for sufficient flexibility under uncertainty and change. Without flexibility, existing management goals and priorities—though potentially unrealistic given climate change—may have to be pursued without adjustments. Yet, with limited resources and staff time, priorities need to be established and adaptation efforts focused to make best use of limited resources. There are several specific hindrances to such management changes that are worth mentioning in detail.

First, addressing climate change will require flexible and long-term planning horizons. Existing issues on public lands, coupled with insufficient resources (described below), force many agencies and managers to operate under crisis conditions, focusing on short-term and narrow objectives (Chapter 4, National Parks). Agencies often put priority on maintaining, retaining, and restoring historic conditions. These imperatives can lead to static as opposed to dynamic management (Chapter 3, National Forests) and may not be possible to achieve as a result of climate change. Additionally, place-based management paradigms may direct management at inappropriate spatial and temporal scales for climate change. Managing on a landscape scale, as opposed to smaller-scale piecemeal planning, would enable greater adaptability to climate-related changes (Chapter 3, National Forests).

A number of factors may limit the usefulness of management plans. The extent to which plans are followed and updated is highly variable across management systems. Further, plans may

7 **Levings**, W., 2003: *Economics of Delay*. Unpublished report on file at the Tahoe National Forest, pp.1-6.

not always adequately address evolving issues or directly identify actions necessary to address climate change (Chapter 3, National Forests; Chapter 8, Marine Protected Areas). If a plan is not updated regularly, or a planning horizon is too short-sighted in view of climate change, a plan's management goals may become outdated or inappropriate. To date, few management plans address or incorporate climate change directly. Fortunately, many agencies recognize the need for management plans to identify the risks posed by climate change and to have the ability to adapt in response (Chapter 6, Wild and Scenic Rivers). Some proactive steps to address climate change will likely cost very little and could be included in policy and management plans (Chapter 7, National Estuaries). These include documenting baseline conditions to aid in identifying future changes and threats, identifying protection options, and developing techniques and methods to help predict climate related changes at various scales (Chapter 3, National Forests; Chapter 6, Wild and Scenic Rivers).

Last, even if the plan for a particular management system addresses climate change appropriately, many federal lands and waters are affected by neighboring lands for which they have limited or no control (Chapter 4, National Parks). National wildlife refuges and wild and scenic rivers are subject to water regulation by other agencies or entities. This fragmented jurisdiction means that collaboration among agencies is required so that they are all working toward common goals using common management approaches. Although such collaboration does occur, formal co-management remains the exception, not the rule. Despite this lack of collaboration, there is widespread recognition that managing surrounding lands and waters is important to meeting management objectives (Chapter 5, National Wildlife Refuges; Chapter 8, Marine Protected Areas), which may lead to more effective management across borders in the future.

9.5.2.2 Opportunities

Each management system mandates the development of a management plan. Incorporating climate change adaptation could be made a part of all planning exercises, both at the level of individual units and collaboratively with other management units. This might encourage more units in the same broad geographical areas to look for opportunities to coordinate and collaborate on the development of regional management plans (Table 9.6). A natural next step would then be to prioritize actions within the management plan. Different approaches may be used at different scales to decide on management activities across the public lands network or at specific sites. If planning and prioritizing occurs across a network of sites, then not only does this approach facilitate sharing of information between units, but this broader landscape approach also lends itself well to climate change planning. This has already occurred in the National Forest System, where the Olympic, Mt. Baker, and Gifford Pinchot National Forests have combined resources to produce coordinated plans. The Olympic National Forest's approach to its strategic planning process is also exemplary of an entity already possessing the capacity to incorporate climate change through its specific guidance on prioritization.

In some cases, existing management plans may already set the stage for climate adaptation. A good example is the Forest Service's adoption of an early detection/rapid response strategy for invasive species. This same type of thinking could easily be translated to an early detection/rapid response management approach to climate impacts. Even destructive extreme climate events can be viewed as management opportunities by providing valuable post-disturbance data. For example, reforestation techniques following a fire or windfall event can be better honed and implemented with such data (*e.g.*, use of genotypes that are better adjusted to the new or unfolding regional climate, use of nursery stock tolerant to low soil moisture and high temperature, or use of a variety of genotypes in the nursery stocks) (see Chapter 3, National Forests).

Management plans that are allowed to incorporate climate change adaptation strategies but that have not yet done so provide a blank canvas of opportunity. In the near term, state wildlife action plans are an example of this type of leveraging opportunity. Another example is the Forest Service's involvement with the Puget Sound Coalition and the National Estuary Program's involvement in Coastal Habitat Protection Plans for fish, an ecosystem-based fisheries management approach at the state

Table 9.6. Examples of management policies and procedures as barriers to and opportunities for adaptation.

MANAGEMENT POLICIES AND PROCEDURES		
Perceived Barrier	**Opportunity**	**Examples**
Seasonal management activities may be affected by changes in timing and duration of seasons.	Review timing of management activities and take advantage of seasonal changes that provide more opportunities to implement beneficial adaptation actions.	• Take advantage of shorter winter seasons (longer prescribed fire seasons) to do fuel treatments on more national forest acres (see the Tahoe National Forest Case Study, Annex A1.1).
Agency policies do not recognize climatic change as a significant problem or stressor.	Take advantage of flexibility in the planning guidelines and processes to develop management actions that address climate change impacts.	• Where guidelines are flexible for meeting strategic planning goals (e.g., maintain biodiversity), re-prioritize management actions to address effect of climate change on achievement of goals (see the Olympic National Forest Case Study, Annex A1.2).
Political boundaries do not necessarily align with ecological processes; some resources cross boundaries; checkerboard ownership pattern with lands alternating between public and private ownership at odds with landscape-scale management (see Chapter 3 section 3.4.5).	Identify management authorities/agencies with similar goals and adjacent lands; share information and create coalitions and partnerships that extend beyond political boundaries to coordinate management; acquire property for system expansion.	• Develop management plans that encompass multiple forest units such as the Pacific Northwest Forest Plan that includes Olympic National Forest-Mt. Baker-Gifford Pinchot National Forest (see the Olympic National Forest Case Study, Annex A1.2). • Implement active management at broader landscape scales through existing multi-agency management processes such as (1) the Herger-Feinstein Quincy Library Group Pilot and the FPA Adaptive Management project on Tahoe National Forest (see the Tahoe National Forest Case Study, Annex A1.1), (2) the Greater Yellowstone Coordinating Committee, and the Southern Appalachian Man and the Biosphere Program with relationships across jurisdictional boundaries (see Chapter 4 section 4.4.3), (3) The Delaware River, managed cooperatively as a partnership river (see the Upper Delaware River Case Study, Annex A4.3). • Coordinate dam management at the landscape level for species that cross political boundaries by using dam operations prospectively as thermal controls under future climate changes (see Chapter 6 section 6.4.4.2). • Coordinate habitat and thermal needs for fish species with entities that control the timing and amount of up-stream water releases (see Chapter 6 section 6.4.4.2).

level. Stakeholder processes, described above as a barrier, might be an opportunity to move forward with new management approaches if public education campaigns precede the stakeholder involvement. The issue of climate change has received sufficient attention that many people in the public have begun to demand actions by the agencies to address it.

As suggested by the many themes identified by the federal land and water management systems, the key to successful adaptation is to turn barriers into opportunities. This should be possible with increased availability of practical information, corresponding flexibility in management goals, and strong leadership. At the very least, managers (and corresponding management plans) may need to recognize climate change and its synergistic effects as an overarching threat to their resources.

9.5.3 Human and Financial Capital

9.5.3.1 Perceived Barriers

Level of funding and staff capacity (or regular staff turnover) may pose significant barriers to adaptation to climate change (Table 9.7). Agencies may also lack adaptive capacity due to the reward systems in place. Currently, in some agencies a reward system exists that focuses primarily on achieving narrowly prescribed targets, and funding is directed at achieving these specific activities. This system provides few incentives for creative project development and implementation, instead creating a culture that prioritizes projects with easily attainable goals.

Budgets may also curtail adaptation efforts. Managers may lack sufficient resources to deal with routine needs. Managers may have even fewer resources available to address unexpected events, which will likely increase as a result of climate change. In addition, staff capacity may not be sufficient to address climate change. While climate change stands to increase the scope of management by increasing both the area of land requiring active management and the planning burden per unit area (because of adaptive management techniques), agencies such as the USFWS face decreasing personnel in some regions. Additionally, minimal institutional capacity exists to capture experience and expand learning (Chapter 4, National Parks). As a result, many agency personnel do not have adequate training, expertise, or understanding to effectively address emerging issues (Chapter 3, National Forests). All of these factors work to constrain the ability of managers to alter or supplement practices that would enable adaptation to climate change.

9.5.3.2 Opportunities

Agency employees play important roles as crafters and ultimate implementers of management plans and strategies. In fact, with respect to whether the implementation of adaptation strategies is successful or unsuccessful, the management of people can be as—or more—important than managing the natural resource. A lack of risk-taking coupled with the uncertainty surrounding climate change could lead to a situation where managers opt for the no-action approach (*e.g.*, Hall and Fagre, 2003). On the other hand, climate change could cause the opposite response if managers perceive that risks must be taken because of the uncertainties surrounding climate change. Implementation of human resource policies that minimize risk for action and protect people when mistakes are made will be critical to enabling managers to make difficult choices under climate change (Table 9.7). A "safe-to-fail" policy would be exemplary of this approach (Chapter 4, National Parks). A safe-to-fail policy or action is one in which the system can recover without irreversible damage to either natural or human resources (*e.g.,* careers and livelihoods). Because the uncertainties associated with projections of climate change are substantial, expected outcomes or targets of agency policies and actions may be equally likely to be correct or incorrect. Although managers aim to implement a "correct" action, it must be expected that when the behavior of drivers and system responses is uncertain, failures are likely to occur when attempting to manage for impacts of climate change (Chapter 4, National Parks).

Tackling the challenge of managing natural resources in the face of climate change may require that staff members not only feel valued but also empowered by their institutions. Scores of federal land management employees began their careers as passionate stewards of the nation's natural resources. With the threat of climate change further compounding management challenges, it is important that this passion be reinvigorated and fully cultivated. Existing employees could be effectively trained (or specialist positions designated) for tackling climate change issues within the context of their current job descriptions and management frameworks (Chapter 3, National Forests). For example, the National Park Service has recently implemented a program to educate park staff on climate change issues, in addition to offering training for presenting this information to park visitors in 11 national parks. Called the "Climate Friendly Parks" program, it includes guidelines for inventorying a park's greenhouse gas emissions, park-specific suggestions to reduce greenhouse gas emissions, and help for setting realistic emissions reduction goals. Additionally, the Park Service's Pacific West Regional Office has been proactive in educating western park managers on issues related to climate change as well as promoting messages to communicate to the public and actions to address the challenge of climate change (Chapter 4, National Parks). Such "no regrets" activities offer a cost-effective mechanism for empowering existing employees with both knowledge and public outreach skills.

Table 9.7. Examples of human and financial capital as barriers to and opportunities for adaptation.

HUMAN AND FINANCIAL CAPITAL		
Perceived Barrier	**Opportunity**	**Examples**
Lack of incentive to take risks, develop creative projects; reward system focuses on achieving narrowly prescribed targets; funds allocated to achieve targets encourage routine, easily accomplished activities.	Shift from a culture of punishing failure to one that values creative thinking and supports incremental learning and gradual achievement of management goals.	• Develop incentives that reward risk taking and innovative thinking. • Build into performance expectations of a gradient between success and failure. • Set up a systematic method for (1) learning from mistakes and successes, and (2) eliciting the experience and empirical data of front line managers, resource management personnel, and scientific staff. (Drawn from Chapter 4 section 4.4.2).
Little to no climate expertise within many management units at the regional and local level; disconnect between science and management that impedes access to information.	Use newly created positions or staff openings as opportunities to add climate change expertise; train resource managers and other personnel in climate change science.	• Use incremental changes in staff to "reinvent and redefine" organizations' institutional ability to better respond to climate change impacts (see the Tahoe National Forest Case Study, Annex A1.1). • Develop expertise through incorporation into existing Forest Service training programs like the silvicultural certification program, regional integrated resource training workshops, and regional training sessions for resource staffs (see Chapter 3 section 3.5). • Develop managers' guides, climate primers, management toolkits, a Web clearinghouse, and video presentations (see Chapter 3 section 3.5).
National and regional budget policies/processes constrain the potential for altering or supplementing current management practices to enable adaptation to climate change (see Chapter 3 section 3.5; general decline in staff resources and capacity (see Chapter 3 section 3.4.5).	Look for creative ways to augment the workforce and stretch budgets to institute adaptation practices (e.g., individuals or parties with mutual interests in learning about or addressing climate change that may be engaged at no additional cost).	• Augment budget and workforce through volunteers from the public or other sources such as institutions with compatible educational requirements, neighborhood groups, environmental associations, etc., such as the Reef Check Program that help collect coral reef monitoring data (see Chapter 8 sections 8.3.3, 8.4.4.1 and 8.4.4.2). • Identify organizations or private citizens that benefit from adaptation actions to share implementation costs in order to avoid more costly impacts/damages. • Use emerging carbon markets to promote (re-) development of regional biomass and biofuels industries, providing economic incentives for active adaptive management; funds from these industries could be used to promote thinning and fuel-reduction projects (see Tahoe National Forest Case Study, Annex A1.1).

9.5.4 Information and Science

9.5.4.1 Perceived Barriers

Adaptation is predicated upon research and scientific information. Addressing emerging issues that arise as a result of climate change will require new research and information to use in developing strategic management plans. Critical gaps in scientific information, such as understanding of ecosystem function and structure, coupled with the high degree of uncertainty surrounding potential impacts of climate change, hinder the potential for effective implementation of adaptation (Table 9.8; Chapter 8, Marine Protected Areas). A lack of climate-related data from monitoring precludes managers from assessing the extent to which climate has affected their systems. Staff and budget limitations may not only constrain the ability to monitor but may also preclude managers from analyzing data from the monitoring programs that do receive support. Without adequate monitoring, it remains difficult to move forward confidently with appropriate adaptation efforts (Chapter 6, Wild and Scenic Rivers).

Even if managers had sufficient information, decision-making would still prove problematic. Managers often lack sufficient tools to help guide them in selecting appropriate management

Table 9.8. Examples of information and science as barriers to and opportunities for adaptation.

INFORMATION AND SCIENCE		
Perceived Barrier	**Opportunity**	**Examples**
Often no inventory or baseline information on condition exists, and nothing is in place to detect climate change impacts.	Identify existing monitoring programs for management; develop a suite of climate change indicators and incorporate them into existing programs.	• Use monitoring programs such as the NPS vital signs for the Inventory and Monitoring Program, Global Fiducial Program, LTER networks, and NEON to monitor for climate change impacts and effectiveness of adaptation options (see Chapter 4 section 4.4.3).
Historic conditions may no longer sufficiently inform future planning (*e.g.*, "100-year" flood events may occur more often and dams need to be constructed accordingly).	Evaluate policies that use historic conditions and determine how to better reflect accurate baselines in the face of climate change; modify design assumptions to account for changing climate conditions.	• Change emphasis from maintenance of "minimum flows" to the more sophisticated and scientifically based "natural flow paradigm," as is happening in some places (see Chapter 6 section 6.3.4.2).
Lack of decision support tools and models, uncertainty in climate change science, and critical gaps in scientific information that limit assessment of risks and efficacy and sustainability of actions.	Identify and use all available tools/mechanisms currently in place to deal with existing problems to apply to climate-change related impacts.	• Use early detection/rapid response approaches (such as that used to manage invasive species) to respond quickly to the impacts of extreme events (*e.g.*, disturbances, floods, windstorms) with an eye towards adaptation (see Chapter 3 section 3.3.3). • Diversify existing portfolio of management approaches to address high levels of uncertainty. • Hedge bets and optimize practices in situations where system dynamics and responses are fairly certain. • Use adaptive management in situations with greater uncertainty (see Chapter 4 section 4.4.3).
Occurrence of extreme climate events outside historical experience.	Use disturbed landscapes as templates for "management experiments" that provide data to improve adaptive management of natural resources.	• After fire, reforest with genotypes of species that are better adjusted to the new or unfolding regional climate with nursery stock tolerant to low soil moisture and high temperature, or with a variety of genotypes in the nursery stock (see Chapter 3 section 3.4.1.2).
Stakeholders/public may have insufficient information to properly evaluate adaptation actions, and thus may oppose/prevent implementation of adaptive projects (*e.g.*, such as those that have ground-disturbing elements like salvaging harvests after disturbance and using herbicides before revegetating). Appeals and litigation from external public often results in the default of no action (See Chapter 3 section 3.4.5).	Inform public and promote consensus-building on tough decisions; invite input from a broad range of sources to generate buy-in across stakeholder interests.	• Conduct public outreach activities with information on climate impacts and adaptation options—including demonstration projects with concrete results—through workshops, scoping meetings, face-to-face dialog, and informal disposition processes to raise public awareness and buy-in for specific management actions (*e.g.*, like Tahoe NF, Annex A1.1 and Partnership for the Sounds (the Estuarium) and North Carolina Aquariums, Annex A5.1). • Use state and local stakeholders to develop management plans to gain support and participation in implementation and oversight of planning activities, as the National Estuary CCMPs do (see Chapter 7 section 7.2.2), the Coastal Habitat Protection Plans do for fisheries management (see Chapter 7 section 7.5), and some National Forests do (Chapter 3 section 3.5).

approaches that address climate change. The complexity of climate models poses a barrier to adequately understanding future scenarios and how to react to them, and gaps in tools and resource availability limit the ability of managers to prioritize actions to address climate change (Chapter 3, National Forests). Of particular importance is the need to establish tools to help identify tradeoffs in different management decisions and understand how those tradeoffs would affect particular variables of interest (*e.g.,* air quality levels from prescribed fires versus high-intensity natural fires).

Another gap exists between stakeholder information and expertise compared with that held by resource managers and scientists. Stakeholders often do not have full information, sufficient expertise, or a long-term perspective that allow them to evaluate the relative merit of adaptation options. Therefore, they may act to inhibit or even block the use of adaptation in management planning. Strong local preferences can contradict broader agency goals and drive non-optimal decision-making, all of which act to limit or preclude acceptance of proactive management (Chapter 3, National Forests).

9.5.4.2 Opportunities

Although barriers exist, effective collaboration and linkages among managers and resource scientists are possible (Table 9.8). Scientists can support management by targeting their research to provide managers with information relevant to major management challenges, which would enable managers to make better-informed decisions as new resource issues emerge. Resource scientists have monitoring data and research results that are often underused or ignored. Monitoring efforts that have specific objectives and are conducted with information use in mind would make the data more useful for managers. The need for monitoring efforts may provide impetus for a more unified approach across agencies or management regions. This would serve to not only provide more comprehensive information but would also serve to minimize costs associated with monitoring efforts.

A unified effort is also needed to invest resources and training into the promotion of agile approaches to adaptation management across all federal resource agencies and land or water managers. This would include producing general guidance in terms of the likely impacts of concern, and the implications of these impacts for ecosystem services and management. It would also mean expending efforts to develop "climate science translators" who are capable of translating the projections of climate models to managers and planners who are not trained in the highly specialized field of GCMs. These translators would be scientists adept at responding to climate change who help design adaptive responses. They would also function as outreach staff who would explain to the public what climate change might mean to long-standing recreational opportunities or management goals.

Many federal lands and waters provide excellent opportunities for educating the public about climate change. The national parks and wildlife refuges already put extensive resources into education and outreach for environmental, ecological, and cultural subjects. There are several ways in which the agencies can inform the public about climate change and climate-change impacts. The first of these uses traditional communication venues such as information kiosks and signs, documentaries, and brochures. Interactive video displays are well suited to demonstrating the potential effects of climate change. Such displays could demonstrate the effects of different climate-change scenarios on specific places or systems, making use, for example, of photos or video documenting coral bleaching and retreating glaciers, or modeling studies projecting changes in specific lands or waters (Kerr, 2004; 2005).

The second major way that agencies can inform the public is to provide examples of sustainable practices that reduce greenhouse gas emissions. The National Park Service's Climate Friendly Parks program is a good example of such an outreach effort. The program involves a baseline inventory of park emissions using Environmental Protection Agency models and then uses that inventory to develop methods for reducing emissions, including coordinating transportation, implementing energy-saving technology, and reducing solid waste. Similar programs could easily be developed for other agencies.

9.6 ADVANCING THE NATION'S CAPABILITY TO ADAPT

Until now, we have discussed specific details and concepts for managers to consider relating to adapting to climate change. When all of these details and case studies are pulled together it is the opinion of the authors of this report that the following fundamental strategic foci will aid in achieving adaptation to climate change: (1) have a rational approach for establishing priorities and triage; (2) make sure the management is done at appropriate scales, and not necessarily simply the scales of convenience or tradition; (3) manage expecting change; and (4) increase collaboration among agencies in research and management activities.

In order to understand how these conclusions were reached, one needs only to appreciate that for virtually every category of federal land and water management, one is likely to find situations that exist in which currently available adaptation strategies will not enable a manager to meet specific goals, especially where those goals are related to keeping ecosystems unchanged or species where they are. The expert opinion of the report authors is that these circumstances may require fundamental shifts in how ecosystems are managed. Such shifts may entail reformulating goals, managing cooperatively across landscapes, and looking forward to potential future ecosystem states and facilitating movement toward those preferred states. These sorts of fundamental shifts in management at local-to-regional scales may only be possible with coincident changes in organizations at the national level that empower managers to make the necessary shifts. Thus, fundamental shifts in national-level policies may also be needed.

Even with actions taken to limit greenhouse gas emissions in the future, such shifts in management and policies may be necessary since concentrations resident in the atmosphere are significant enough to require planning for adaptation actions today (Myers, 1979). Ecosystem responses to the consequences of increasing concentrations are likely to be unusually fast, large, and non-linear in character. More areas are becoming vulnerable to climate change because of anthropogenic constraints compounding natural barriers to biological adaptations.

The types of changes that may be needed at the national level include modification of priorities across systems and species and use of new rules for triage; enabling management to occur at larger scales and for projected ecological changes; and expansion of interagency collaboration and access to expertise in climate change science and adaptation, data, and tools. Although many agencies have embraced subsets of these needed changes, there are no examples of the full suite of these changes being implemented as a best practices approach.

9.6.1 Re-Evaluate Priorities and Consider Triage

Climate change not only requires consideration of how to adapt management approaches, it also requires reconsideration of management objectives. In a world with unlimited resources and staff time, climate adaptation would simply be a matter of management innovation, monitoring, and more accessible and useable science. In reality, priorities may need to be re-examined and re-established to focus adaptation efforts appropriately and make the best use of limited resources. At the regional scale, one example of the type of change that may be needed is in selected estuaries where freshwater runoff is expected to increase and salt water is expected to penetrate further upstream. Given this scenario, combined with the goal of protecting anadromous fishes, models could be used to project shifts in critical propagation habitats and management efforts could be refocused to those sites (Chapter 7, National Estuaries). In Rocky Mountain National Park, because warmer winters are expected to result in greatly increased elk populations, a plan to reduce elk populations to appropriate numbers is being prepared with the goal of population control (Annex A2).

In the situations above, the goals are still attainable with some modifications. However, in general, resource managers could face significant constraints on their authority to re-prioritize and make decisions about which goals to modify and how to accomplish those modifications. National-level policies may have to be re-examined with thought toward how to accommodate and even enable such changes in management at the regional level. This re-examination of policies at the national level is another form of priority-setting. Similar to regional-level prioritization, prioritization at the national level would require information at larger scales about the distribution of natural resources and conservation targets, the vulnerability of those targets to climate change, and costs of different management actions in different systems. Prioritization schemes may weight these three factors in different ways, depending on goals and needs. Knowing where resources and conservation targets are is relatively straightforward, although even baseline information on species distributions is often lacking (Chapter 5, National Wildlife Refuges; Chapter 6, Wild and Scenic Rivers). Prioritization schemes that weight rare species or systems heavily would likely target lands with more threatened and endangered species and unique ecosystems.

Because climate-driven changes in some ecological systems are likely to be extreme, priority-setting may, in some instances, involve triage (Metzger, Leemans, and Schröter, 2005). Some goals may have to be abandoned and new goals established if climate change effects are severe enough. Even with substantial focused and creative management efforts, some systems may not be able to maintain the ecological properties and services that they provide in today's climate. In other systems, the cost of adaptation may far outweigh the ecological, social, or economic returns it would provide. In such cases, resources may be better invested in other systems. One simple example of triage would be the decision to abandon habitat management efforts for a population of an endangered species on land at the "trailing" edge of its shifting range. If the refuge or park that currently provides habitat for the species will be unsuitable for the species in the next 50 years, it might be best to actively manage for habitat elsewhere and, depending on the species and the circumstances, investigate the potential for relocation. Such decisions will have to be made with extreme care. In addition to evaluating projected trends in climate and habitat suitability, it will be necessary to monitor the species or habitats in question to determine whether the projected trends are being realized. All of the changes in management approaches discussed throughout the rest of this section would likely require fundamental changes in policy and engagement in triage at the national level.

9.6.2 Manage at Appropriate Scales

Experience gained from natural resource management programs and other activities may offer insights into the application of integrated ecosystem management under changing climatic conditions. Integrated ecosystems management seeks to optimize the positive ecological and socioeconomic benefits of activities aimed at maintaining ecosystem services under a multitude of existing stressors. One lesson learned from this approach is that it may be necessary to define the management scale beyond the boundaries of a single habitat type, conservation area, or political or administrative unit to encompass an entire ecosystem or region. Currently, management plans for forests, rivers, marine protected areas, estuaries, national parks, and wildlife refuges are often developed for discrete geographies with specific attributes (species, ecosystems, commodities), without recognition that they may be nested within other systems. For example, marine protected areas are often within national estuaries; wild and scenic rivers are often within national parks. With few exceptions (see Section 9.5.2), plans are not developed with the ability to fully consider the matrix in which they are embedded and the extent to which those attributes may vary over time in response to drivers external to the management system. Climate change adaptation opportunities may be missed if land and water resources are thought of as distinct, static, or out of context of a regional and even continental arena. A better approach would be to systematically broaden and integrate management plans, where possible. Although a single national park or national forest may have limited capacity for adaptation, the entire system of parks and forests and refuges in a region may have the capacity for adaptation. When spatial scales of consideration are larger, federal agencies often have mutually reinforcing goals that may result in the enhancement of their ability to manage cooperatively across landscapes (Leeworthy and Wiley, 2003).

9.6.3 Manage for Change

Agencies have established best practices based on many years of past experience. Unfortunately, dramatic climate change may change the rules of the game, rendering yesterday's best practices tomorrow's bad practices. Experienced managers have begun to realize that they can anticipate changes in conditions, especially conditions that might alter the impacts of grazing, fire, logging, harvesting, park visitation, and so forth. Such anticipatory thinking will be critical, as climate change will likely exceed ecosystem thresholds over time such that strategies to increase ecosystem resilience will no longer be effective. At this point, major shifts in ecosystem processes, structures, and components will be unavoidable, and adaptation will require planning for management of major ecosystem shifts.

For example, some existing management plans identify a desired state (based on structural, ecosystem service, or ecosystem process attributes of the past) and then prescribe practices to achieve that state. While there is clarity and accountability in such fixed management objectives, these objectives may be unrealistic in light of dramatic environmental change. A desirable alternative management approach may be to "manage for change." For example, when revegetation and silviculture are used for post-disturbance rehabilitation, species properly suited to the expected future climate could be used. In Tahoe National Forest, white fir could be favored over red fir, pines could be preferentially harvested at high elevations over fir, and species could be shifted upslope within expanded seed transfer guides (Chapter 3, National Forests). It is also possible that, after accounting for change, restoration may cease to be an appropriate undertaking. Again, in Tahoe National Forest, warming waters may render selected river reaches no longer suitable for salmon, so restoration of those reaches may not be a realistic management activity (Chapter 3, National Forests). The same applies to meadows in Tahoe National Forest, where restoration efforts may be abandoned due to possible succession to non-meadow conditions. Management will not be able to prevent change, so it may also be important to manage the public's expectations. For example, the goal of the Park Service is to maintain a park exactly as it always has been, composed of the same tree species (Chapter 4, National Parks),

BOX 9.9. Adaptation options for managing in the context of major climatic and ecological changes.

Adaptation Options for Managing for Change

- Assist transitions, population adjustments, and range shifts through manipulation of species mixes, altered genotype selections, modified age structures, and novel silivicultural techniques.
- Rather than focusing only on historic distributions, spread species over a range of environments according to modeled future conditions.
- Proactively manage early successional stages that follow widespread climate-related mortality by promoting diverse age classes, species mixes, stand diversities, genetic diversity, etc., at landscape scales.
- Identify areas that supported species in the past under similar conditions to those projected for the future and consider these sites for establishment of "neo-native" plantations or restoration sites.
- Favor the natural regeneration of species better adapted to projected future conditions.
- Realign management targets to recognize significantly disrupted conditions, rather than continuing to manage for restoration to a "reference" condition that is no longer realistic given climate change.
- Manage the public's expectations as to what ecological states will be possible (or impossible) given the discrepancy between historical climate conditions and current/future climate conditions.
- Develop guidelines for scenarios under which restoration projects or rebuilding of human structures should occur after climate disturbances.

and the public may not recognize the potential impossibility of this goal. Some additional examples of adaptation options for managing for change are presented in Box 9.9.

Scenario-based planning can be a useful approach in efforts to manage for change. As discussed in Section 9.3.3.2, this is a qualitative process that involves exploration of a broad set of scenarios, which are plausible—yet very uncertain—stories or narratives about what might happen in the future. Protected-area managers, along with subject matter experts, can engage in scenario planning related to climate change and resources of interest and put into place plans for both high-probability and low-probability, high-risk events. Development of realistic plans may require a philosophical shift concerning when restoration is an appropriate post-disturbance response. It is impractical to attempt to keep ecosystem boundaries static. Estuaries display this poignantly. After a flood, there is often intense pressure to restore to the pre-flooding state (Chapter 7, National Estuaries). To ensure sound management responses, guidelines for the scenarios under which restoration and rebuilding should occur could be established in advance of disturbances. In this sense, disturbances could become opportunities for managing toward a distribution of human population and infrastructure that is more realistic given changing climate.

9.6.4 Expand Interagency Collaboration, Integration, and Lesson-Sharing

The scale of the challenge posed by climate disruption and the uncertainty surrounding future changes demand coordinated, collaborative responses that go far beyond traditional "agency-by-agency" responses to stressors and threats. Every chapter in this volume has noted the need for a structured, interagency effort and for partnerships and collaboration in everything from research to management and land acquisition. Scientists and mangers across agencies and management systems would benefit from greater sharing of data, models, and experiences. It may be necessary to develop formal structures and policies that foster extensive interagency cooperation.

One example of how to enhance the incorporation of climate information into management could be to designate climate experts to advise agency scientists and managers on climate change related issues. They could advise agency scientists and managers both at the national and at the site level, providing guidance, translating climate-impact projections, and coordinating interagency collaborations.

In the area of climate change science, one interagency program established specifically to address climate change research is the U.S. Climate Change Science Program (CCSP). The goals of this program are to develop scientific knowledge of the climate system; the causes of changes in this system; and the effects of such changes on ecosystems, society, and the economy; and also to determine how best to apply that knowledge to decision-making. Climate change research conducted across 13 U.S. government departments and agencies is coordinated through the CCSP. The CCSP could be expanded to include management research and coordination to bridge the gap between resource management needs and scientific research priorities. This may enhance the goal of the CCSP to apply existing knowledge to decision-making.

There are also other examples of existing collaborations across agencies that could be used as models. Several examples of interagency initiatives established to address universal threats to resources include the National Invasive Species Council, the Joint Fire Science Program, and National Interagency Fire Center. The analogy for climate change adaptation would be a group that would coordinate management activities, interpret research findings, inform on priority-setting, and disseminate data and tools.

Any collaborative interagency effort would benefit from coordinating regional and national databases with scientific and monitoring data to increase the capacity to make informed decisions related to climate-induced changes. Pooling resources would allow for more effective data generation and sharing. Coordination could be done through easily accessible databases that can access and readily provide comprehensive information and serve to better inform managers and decision-makers in their efforts to adapt to climate change. Information on climate-change projections and climate-change-related research could also be included. Ideally, this would be a web-based clearinghouse with maps, a literature database, and pertinent models (*e.g.,* sea level projection models such as the Sea Level Affecting Marshes Model [SLAMM] and hydrology models such as those developed and used by the USGS[8] and EPA.[9] All maps, data, models, and papers could be easily downloaded and updated frequently as new information becomes available.

Collaborations through national councils or interagency efforts may gain the greatest momentum and credibility when they address on-the-ground management challenges. There are several nascent collaborative networks that may provide models for success, such as the Greater Yellowstone Coalition and some collaborative research and management coalitions built around marine protected areas and wild and scenic rivers. These sorts of networks are critical to illustrating how to overcome the challenges posed by lack of funding, and how to create critical ecological and sociological connectivity. With strong leadership, a systematic national network of such coalitions could lead to increased adaptive capacity across agencies and may set precedents for coordinating approaches among regional, state, and local-level management agencies.

9.7 CONCLUSIONS

Information on climate trends and climate impacts has increased dramatically within the last few years. The public, business leaders, and political leaders now widely recognize the risks of climate change and are beginning to take action. While a great deal of discussion has focused on emissions reductions and policies to limit climate change, many may not realize that—no matter which policy path is taken—some substantial climate change, uncertainty, and risk are inevitable. Moreover, the climate change that is already occurring will be here for years to come. Adaptation to climate change will therefore be necessary. Although there are constraints and limits to adaptation, some adaptation measures can go a long way toward reducing the loss of ecosystem services and limiting the economic or social burden of climate disruption. However, if the management cultures and planning approaches of agencies continue with a business-as-usual approach, it is likely that ecosystem services will suffer major degradation. It is the opinion of this report's authors and expert stakeholders that we may be seeing a tipping point in terms of the need to plan and take appropriate action on climate adaptation.

These experts believe that the current mindset toward management of natural resources and ecosystems may have to change. The spatial scale and ecological scope of climate change may necessitate that we broaden our thinking to view the natural resources of the United States as one large interlocking and interacting system, including state, federal, and private lands, with resilience emerging from coordinated stewardship of all of the parts. To achieve this, institutions may have to collaborate and cooperate more. Under conditions of uncertain climatic changes combined with uncertain ecosystem responses, agile management may have to become the rule rather than the exception. While energy corporations, insurance firms, and coastal developers are beginning to adapt to climate change, it is essential that federal agencies responsible for managing the nation's land and water resources also develop management agility and deftness in dealing with climate disruptions. Maladaptation—adaptation that does not succeed in reducing vulnerability but increases it instead—must be avoided. Finally, to adapt to climate change, managers need to know in advance where the greatest vulnerabilities lie. In response to vulnerability analyses, agencies and the public can work together to bolster the resilience of those ecosystems and ecosystem services that are both valuable and capable of remaining viable into the future.

It is crucial to emphasize that adaptation is not simply a matter of managers figuring out what to do, and then setting about to change their practices. All management is conducted within a broader context of socioeconomic incentives

8 **U.S. Geological Survey**, 1-4-2007: USGS water resources National Research Program (NRP) models. USGS Website, http://water.usgs.gov/nrp/models.html, accessed on 6-12-2007.

9 **U.S. Environmental Protection Agency**, 4-27-2007: Better assessment science integrating point & non-point sources. U.S.Environmental Protection Agency Website, http://www.epa.gov/waterscience/basins, accessed on 6-12-2007.

and institutional behaviors. This means it is essential to make sure that polices that seem external to the federal land and water resource management agencies do not undermine adaptation to climate change. One of the best examples of this danger is private, federal, and state insurance for coastal properties that are at risk of repeated storm damage or flooding. As long as insurance and mortgages are available for coastal building, coasts will be developed with seawalls and other hardened structures that ultimately interfere with beach replenishment, rollback of marshes, and natural floodplains. At first glance one would not think that mortgages and insurance had anything to do with the adaptation of national estuaries to climate change, but in fact these economic incentives and constraints largely dictate the pattern of coastal development.

Federal lands and waters do not function in isolation from human systems or from private land or water uses. For this reason, mechanisms for reducing conflict among private property uses and federal lands and waters are essential. For example, the National Park Service is working cooperatively with landowners bordering the Rio Grande in Texas to establish binding agreements that offer them technical assistance with measures to alleviate potentially adverse impacts on the river resulting from their land-use activities. In addition, landowners may voluntarily donate or sell lands or interests in lands (*i.e.*, easements) as part of a cooperative agreement. In the absence of agreements with private landowners, withdrawals from rivers and loss of riparian vegetation could foreclose opportunities for adaptation, potentially exacerbating the impacts of climate change.

One adaptive response is large protected areas and replicated protected areas, but they are often associated with taking areas of land or ocean away from productive activities such as ranching, farming, or fishing. However, protected areas have multiple beneficial effects on the economy that are also important to consider. For example, in the Florida Keys it has been shown that total annual spending by recreating visitors to the Florida Keys was $1.2 billion between June 2000 and May 2001 (IPCC, 2007).

Society can adapt to climate change through technological solutions and infrastructure, through behavioral choices (altered food and recreational choices), through land management practices, and through planning responses (Johnson and Weaver, 2008). Although federal resource management agencies will tend to adapt by altering management policies, the effectiveness of those policies will be constrained by or enhanced by all of the other societal responses. In general, the federal government's authority over national parks, national forests, and other public resources is most likely to remain effective if management is aligned with the public's well-being and perception of well-being. Experienced resource managers recognize this and regularly invest in public education. This means that education and communication regarding managing for adaptation needs just as much attention as does the science of adaptation.

Repeatedly, in response to crises and national challenges, the nation's executive and congressional leadership have mandated new collaboration among agencies, extended existing authorities, and encouraged innovation. The report authors and expert stakeholders conclude that this is exactly what is needed to adapt to climate change. The security of land and water resources and critical ecosystem services requires a national initiative and leadership. Greater agility will be required than has ever before been demanded from major land or water managers. The public has become accustomed to stakeholder involvement in major resource use decisions. This involvement cannot be sacrificed, but decision-making processes could be streamlined so that management approaches do not stand still while climate change proceeds rapidly. The specific recommendations for adaptation that emerge from studies of national forests, national parks, national wildlife refuges, wild and scenic rivers, national estuaries, and marine protected areas will not take root unless there is leadership at the highest level to address climate adaptation.

APPENDIX

Resources for Assessing Climate Vulnerability and Impacts

NCAR's MAGICC and SCENGEN
http://www.cgd.ucar.edu/cas/wigley/magicc/index.html
Coupled, user-friendly interactive software suites that allow users to investigate future climate change and its uncertainties at both the global-mean and regional levels.

WALTER
http://java.arid.arizona.edu/ahp/
Fire-Climate-Society (FCS-1) is an online, spatially explicit strategic wildfire planning model with an embedded multi-criteria decision process that facilitates the construction of user-designed risk assessment maps under alternative climate scenarios and varying perspectives of fire probability and values at risk.

North American Regional Climate Change Assessment Program
http://www.narccap.ucar.edu/

Regional Hydro-Ecologic Simulation Tool
http://geography.sdsu.edu/Research/Projects/RHESSYS

U.S. Climate Division Dataset Mapping Tool
http://www.cdc.noaa.gov/USclimate/USclimdivs.html
http://www.cdc.noaa.gov/cgi-bin/PublicData/getpage.pl
This tool can generate regional maps.

ISPE/Weiss/Overpeck climate change projections for West (based on IPCC)
http://www.geo.arizona.edu/dgesl/research/regional/projected_US_climate_change/projected_US_climate_change.htm

High Plains Regional Climate Center
http://www.hprcc.unl.edu/

Intergovernmental Panel On Climate Change
http://www.ipcc.ch/
Climate change reports, graphics, summaries.

The Hadley Centre
http://www.metoffice.gov.uk/research/hadleycentre/index.html
Coarse scale global temperature, soil moisture, sea level, and sea-ice volume and area projections.

National Center for Atmospheric Research (NCAR)
http://www.ucar.edu/research/climate/
Coarse resolution climate-change projections, regional climate model.

Pew Center on Global Climate Change
http://www.pewclimate.org/what_s_being_done/
Background on climate change, policy implications.

NOAA Earth System Research Lab (Climate Analysis Branch)
http://www.cdc.noaa.gov/
Current climate data and near-term forecasts.

The Climate Institute
http://www.climate.org/climate_main.shtml
Basic background information on climate change.

U.S. Global Change Research Information Office
http://www.gcrio.org/
Reports and information about climate change.

Real Climate
http://www.realclimate.org/
In-depth discussions with scientists about many different aspects of climate change.

EPA Sea Level Rise
http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsSeaLevelRiseIndex.html
Reports and impact projections.

CLIMAS, Climate Assessment for the Southwest
http://www.ispe.arizona.edu/climas/
A source for climate change related research, short-term forecasts and climate reconstructions for the southwestern United States.

Climate Impacts Group, University of Washington
http://www.cses.washington.edu/cig/
Climate-change research and projections for the Pacific Northwest.