9 Synthesis and Conclusions

Authors

Lead Author
Peter Kareiva, The Nature Conservancy

Contributing Authors
Carolyn Enquist, The Nature Conservancy
Ayana Johnson, University of California, San Diego
Susan Herrod Julius, U.S. Environmental Protection Agency
Joshua Lawler, Oregon State University
Brian Petersen, University of California, Santa Cruz
Louis Pitelka, University of Maryland
Rebecca Shaw, The Nature Conservancy
Jordan M. West, U.S. Environmental Protection Agency

NOTE: This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the U.S. Environmental Protection Agency. It does not represent and should not be construed to represent any agency determination or policy.

Chapter Contents

9.1 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 towards 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 (Chapter 3; 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 limiting constraint is 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 and discuss how managers can: (1) assess the impacts of climate change on their systems and goals (Section 9.2); (2) identify best practice approaches for adaptation (Section 9.3); and (3) evaluate barriers and opportunities associated with implementation (Section 9.4). It may be the case that certain management goals are unattainable in the future and no adaptation options exist. The final sections of this report address these circumstances and conclude with observations about how to advance our capability to adapt (Sections 9.5 and 9.6), along with approaches for making fundamental shifts in how ecosystems are managed to anticipate potential future ecosystem states. These discussions are based on the expert opinion of the authors of this report and feedback from the stakeholder workshops.

9.2 Assessing Impacts to Support Adaptation

9.2.1 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 (Houghton *et al.*, 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 Figure 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 Figure 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.

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

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

9.2.2 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 project (3) 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). 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.

9.2.2.1 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, In Press) 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.

A number of other frameworks have been developed as well. For example, within the international conservation arena, an extremely successful framework for managers is the one developed by (The Nature Conservancy, 2007). The steps include: (1) identifying the management goal and climate threat to that goal, (2) selecting measurable indicators; (3) determining the limits of acceptable variation in the indicators; (4) assessing the current status of the system with respect to meeting management goals, as well as with respect to the indicators; and (5) analyzing data on indicators to decide whether a change in management is required. These five steps were agreed upon by the Conservation Measures Partnership (2007), 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.

9.2.2.2 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 the Appendix, Section 9.8), although characterization of uncertainty could be improved, along with "user friendliness" and the ability to frame management endpoints in a manner that more closely meshes with the needs of federal agencies. 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.

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 and Hewistson, 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).

Impact Models to Assess Endpoints of Concern

In addition to projections of changes in climate, managers will also require projections of changes in hydrology, sea level rise, vegetation, and species distributions that result from climate change (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).

A detailed sea level rise assessment was undertaken by the USGS for the lower 48 states and specifically for coastal national parks (U.S. Geological Survey, 2007a). 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 (U.S. Climate Change Science Program; in review), 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).

Projected shifts in individual species distributions are also 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 need to be organized, catalogued, and standardized. 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). Recent analyses indicate that some models perform better than others. For example, with regard to range shifts, 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 (UCS; Union of Concerned Scientists, 2007). The UCS study used a statistically downscaled version of two global circulation models 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 kill 165–330 additional people each year in Los Angeles, a shorter ski season, annual losses of $266–836 million 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. California policy makers listened (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 a decision support model that allows 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.

9.2.2.3 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 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 climate trends have a reasonable likelihood of influencing any of these defining features of Mediterranean plant communities, then there will be a need for deeper analysis. Sensitivity to current or past climate variability may be a good indicator of potential future sensitivity.

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 a 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 can be politically infeasible, socially unpalatable, and ecologically irresponsible. Where available, paleoecological records could 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 only useful 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 baselines could be misleading. On the other hand, if baselines are to be developed using changing reference points or conditions, this approach also requires caution. The goal would be to realistically consider how conditions may change without allowing our definition of baseline conditions to rationalize acceptance of lower levels of “healthy” conditions, potentially risking 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. Although some monitoring may be designed to detect general ecological trends in poorly understood systems, the majority of the monitoring that is needed is hypothesis-based and specifically targeted to either determine vulnerabilities or to assess the effects of management as part of an adaptive management strategy. In many cases, the first step in developing a monitoring system will involve establishing baseline data, as described above. 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. However, other lands, such as the national wildlife refuges, lack even species inventories, much less records of population trends or disease prevalence (Chapter 5, National Wildlife Refuges).

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 (University of Wisconsin-Milwaukee, 2007).

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). 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.

9.2.3 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. Importantly, 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 rising greenhouse gases. Fortunately, there are approaches for dealing with uncertainty that allow progress.

9.2.3.1 Examples of Sources of Uncertainty

To project climate change in the future, 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. Global mean temperature projections range 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, Borchers, and Chaney, 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 is not just about the magnitude of change—but the direction of change as well (Chapter 6, Wild and Scenic Rivers).

Changes in temperature and precipitation will drive changes in species interactions, species distributions and ranges, community assemblages, ecological processes, and, therefore, ecosystem services. To understand the implications of the projected temperature and precipitation 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); 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) or 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, and the models do not address this.

9.2.3.2 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 what *range* of changes is 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, Section 9.8, 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 allows 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. This is exactly 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. 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).

9.3 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 function to lessen the impacts. As defined in this report, the goal of adaptation strategies 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 of management 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.

9.3.1 Resilience

Resilience is a highly desired attribute in the face of 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 re-growth) after a disturbance.

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. Furthermore, and 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 re-introduction) 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 several 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 in national parks).

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 underlying 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.

Understanding of specific resilience factors for particular systems is sparse, making managing for resilience currently more an art than a science. Fortunately, two approaches 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 approach. 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 approach. Although resource managers may not explicitly use these terms, examples of both approaches may be found in their decision-making.

Biodiversity Approach

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 between each other and 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—appear 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, 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 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 Approach

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.

9.3.2 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 that are discussed below involve techniques that manipulate or take advantage of ecosystem properties to enhance their resilience to climatic changes. These are: protection of key ecosystem features, reduction of anthropogenic stresses, representation, replication, restoration, refugia, and relocation. 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 approaches found throughout this report.

9.3.2.1 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.

9.3.2.2 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 draws additional examples of this adaptation approach from across the chapters of this report.

9.3.2.3 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 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 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 draws additional examples of this adaptation approach from across the chapters of this report.

9.3.2.4 Replication

Replication is simply managing for the continued survival of more than one example of each ecosystem or species within a reserve system, 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 from chapters of this report.

9.3.2.5 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 draws additional examples of this adaptation approach from across the chapters of this report.

9.3.2.6 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). Transplantation of organisms 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 draw additional examples of these adaptation approaches from across the chapters of this report.

9.3.3 Confidence

Due to uncertainties associated with climate change projections and uncertainties surrounding 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. Based on the expert opinion of the author teams, who considered the literature and the application of each approach within their specific management systems, confidence estimates are presented in Table 9.4. Such confidence estimates should be a key consideration when deciding which adaptation approaches to implement for a given system.

Confidence levels are presented for each of the seven adaptation approaches, within each management system type. The goal of all 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). It is important to note at this point that promoting resilience may be a management strategy that is useful only on shorter time scales (*i.e.*, 10–30 years) because as climate change continues, various thresholds of resilience will eventually be exceeded. Therefore, each confidence estimate is 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. On longer time scales, 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 (9.5.3, *Manage for Change*), where adaptation strategies associated with planning for major shifts are presented.

9.3.4 Adaptive Management

Once adaptation approaches have been selected after taking into account confidence levels, adaptive management is likely to be the most attractive 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 at heart an experiment, with data on the effects of various management interventions collected to measure the effectiveness of those interventions and to determine the best way to move forward. 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.

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 (Figure 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.

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 determining which riparian plant species are best adapted to extreme variations in flow regime and flooding, observing how increased variability in climatic conditions affects population dynamics of target insect pests or focal wildlife species, and determining the effect of marine reserve size on recruitment and survival of key species. 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 9.5.1), 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 negative 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.

The idea of “adaptive management” has been widely advocated among natural resource managers for decades but is still not applied as widely as it should be. Yet, the prospect of uncertain, widespread, and severe climatic changes may represent a tipping point that spurs 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.

9.4 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 stakeholder workshops, and are associated with implementation of adaptation options today, assuming no significant changes in institutional frameworks and authority.

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 and/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 either narrowly interpret the goals and thus hinder adaptation, or could broadly interpret the goals and thereby facilitate adaptation.

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) (Kelly and Adger, 2000).

The growing need for more management resources is ubiquitous across federal agencies as the ramifications of a growing human population put new and expanding pressures on the manager's 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 respond to climate change.

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 9.5).

9.4.1 Legislation and Regulation

9.4.1.1 Barriers

While original organic acts represented progressive policy and management frameworks at the time they 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 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 (Levings, 2003). Even recently implemented legislation and management plans have not directly addressed climate change (Chapter 7, National Estuaries). In general, while coarse-filter or community-focused approaches are more adaptive, 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 have failed to provide sufficient capacity to effectively manage 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 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, existing legislation does not prohibit adaptive management. The obstacle to implementing adaptive management is rarely legal—but rather political—opposition both from within and from outside the agencies. Additionally, the uncertainty surrounding its use has led 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 (Levings, 2003). 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.

9.4.1.2 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.

9.4.2 Management Policies and Procedures

9.4.2.1 Barriers

Most management systems have a history of static policies and procedures that are counter to the dynamic and flexible management actions called for now (Table 9.6; Chapter 3, National Forests). Thus, although adaptive management is encouraged, its implementation is rarely fully embraced (Lee, 1999; Stankey *et al.*, 2003). Part of the problem is that some agency policies do not recognize climatic change as a significant problem or stressor (Chapter 3, National Forests). In many cases 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 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 with regularity, 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 should 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.

9.4.2.2 Opportunities

Each management system mandates the development of a management plan. Incorporating climate change adaptation could be made a requirement and could be accomplished at the level of individual units or 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 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.

9.4.3 Human and Financial Capital

9.4.3.1 Barriers

Consistent under-funding and lack of staff capacity (or regular staff turnover) 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 (Chapter 3, National Forests). This system provides few incentives for creative project development and implementation, instead creating a culture that prioritizes projects with easily attainable goals. This comes at the expense of adaptive, forward thinking approaches to management.

Budgetary constraints can also curtail adaptation efforts. National and regional budget policies constrain the ability to alter or supplement current management practices that would enable adaptation to climate change. Managers often lack sufficient resources to deal with routine needs. Chronic budget shortfalls have reduced the ability or restricted the implementation of monitoring programs (Chapter 5, National Wildlife Refuges). Managers have even fewer resources available to address unexpected events, which will likely increase as a result of climate change. Exacerbating the problem of limited budgetary support is the lack of adequate staff capacity. National and regional budget policies pose a significant barrier by constraining the potential for changing current management practices that would enable adaptation to climate change (Chapter 3, National Forests). 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. Even if time and sufficient resources exist, 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 related to climate change, something that staff education programs could serve to remedy (Chapter 3, National Forests). The legacy of past practices and long-term institutional status quo may also make it difficult to increase capacity to address climate change. When other threats have been seen as higher priorities by historical leadership, then it may be difficult to attract and train the most innovative managers for adaptation to climate change.

9.4.3.2 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 (Spittlehouse and Stewart, 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 and its effects 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. Additional human resources also would add new energy and passion that could lead to successful implementation of existing, new, and future adaptation strategies. In fact, it could be argued that by increasing funding, staff capacity, and access to new information and tools, the overall adaptive capacity of each management institution would be enhanced. Specifically creating new employment opportunities that include duties associated with or entirely focused on climate change could further build upon this capacity.

Conversely, it may also be argued that existing employees could be effectively trained 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.

9.4.4 Information and Science

9.4.4.1 Barriers

Adaptive management 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. However, in some agencies a disconnect exists between management and scientific personnel. 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 not only constrain the ability to monitor but also often preclude managers from analyzing data from the monitoring programs that do receive support. Without adequate monitoring, it remains impossible to move forward confidently with appropriate adaptation efforts (Chapter 6, Wild and Scenic Rivers).

Distinguishing the causes and effects of climate change from other natural phenomena has proven difficult, particularly at certain scales (Chapter 3, National Forests). In general the uncertainty associated with climate change at sub-regional and local levels has caused managers to take minimal action. Where agency managers are keen to apply adaptive management and are fully aware of the challenges posed by climate change, they are constrained by an absence of provisions for management experiments, by a lack of financial support, and by an absence of training in what to look for and how to respond.

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

9.4.4.2 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 combined with a shortage of funds 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 (*e.g.*, Hall and Fagre, 2003).

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.

9.5 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 some fundamental strategic foci are needed. Those foci are: 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, and 3) manage expecting change. In order to make progress on these foci, the authors believe greater collaboration and integration among federal agencies is a necessity.

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 and stakeholders 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 (Kerr, 2004; 2005). 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.

9.5.1 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 (Chapter 4, National Parks).

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 (Myers, 1979; Chapter 3). 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. 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.

9.5.2 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 9.4.2), 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 fundamental reconsideration of national lands and waters as a national network to be managed for climate disruption may be advantageous. To achieve this, the spatial and biological scope of management plans would have to be systematically broadened and integrated. 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 (Metzger, Leemans, and Schröter, 2005).

9.5.3 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 “best practices” and “standard protocols” need to be devised so 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 to systematically infuse into all resource planning 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), 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 9.2.3.2, 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 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. There is often intense post-flooding pressure for restoration 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. Scenario-based planning may be difficult to use at the regional level unless national-level policies are changed to permit this approach. One option may be to legislatively mandate a policy that calls for all agencies to address climate change in the development of their management plans. This approach has many advantages, one of them being to foster the use of scenario-based planning.

9.5.4 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. The need to better integrate research and management across agencies is not a new idea, but the current lack of extensive integration and collaboration indicates that it may be necessary to develop formal structures and policies that foster and even mandate extensive interagency cooperation.

To enhance the incorporation of climate information into management, each agency could designate two or more climate experts to advise agency scientists and managers on climate change related issues. At least one of the experts could be a high-level manager and at least one could be a PhD scientist with extensive expertise in climate change. The team 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 addition, the lead manager and scientist could be members of an interagency climate change advisory group.

A mechanism that might augment current collaboration across agencies could be to develop an interagency group or task force to coordinate climate change management efforts across agencies. Throughout the chapters of this Synthesis and Assessment Product, there has been an unequivocal call for the establishment of such an entity to strengthen the existing capability to address climate change. Several examples of interagency initiatives established to address universal threats to resources include the National Invasive Species Council and the Joint Fire Science Program and National Interagency Fire Center. The central responsibility of an interagency climate change council would be to advise managers and scientists in each of the agencies on both general and specific management issues. The council could help to interpret research findings, set priorities, and disseminate data and tools. The council could also help build collaborations among agencies.

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. As currently established, the CCSP would not entirely fulfill the needs called for in this report because few agency management program representatives participate, and consequently only a small number of direct management perspectives are voiced through the CCSP on climate change research. Without management representation, it would be difficult to bridge the gap between resource management needs and scientific research priorities. However, since one of the goals of the CCSP is to apply existing knowledge to decision-making, a natural step may be for the CCSP to expand its structure to explicitly incorporate management interests. One option for expanding the CCSP might be to include as representatives to the CCSP the management arms of each agency in addition to the research programs. Another option might be to add an interagency council focused on resource management that oversees and advises the CCSP on management-related research and decision support. Regardless of the form in which the CCSP might be expanded, a valuable change to the functioning of the CCSP would be to add the ability to evaluate research in light of the degree to which it supports resource management.

Further, collaborative interagency initiatives of all kinds would benefit greatly from the creation of a regional or national database with scientific and monitoring data that could increase the capacity to make informed decisions related to climate-induced changes. Such a system could support all federal resource agencies and be a shared financial responsibility. Pooling resources would allow for more effective data generation and sharing. Easily accessible databases housed in a single location that can readily provide comprehensive information would serve to better inform managers and decision-makers in their efforts to adapt to climate change. This information center also could serve as a central repository for climate-change projections and climate-change-related research. 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 (U.S. Geological Survey, 2007b) and EPA (U.S. Environmental Protection Agency, 2007). All maps, data, models, and papers could be easily downloaded and updated frequently as new information becomes available. To be most useful, the website would be constantly updated with new literature and model projections incorporating the latest climate-change projections from both GCMs and regional models.

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.

9.6 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 report authors’ and stakeholders’ expert opinion 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. The most effective course may be to manage the nation’s lands and waters as one large system, 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 a vulnerability analysis, agencies and the public can work together to bolster the resilience of those ecosystems and ecosystem services that are both valuable and, with apt management, 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 and institutional behavior. 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. So 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.

In addition, 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 this strategy also runs up against political and social constraints. In particular, protected areas are often associated with taking areas of land or ocean away from productive activities (such as ranching, farming, or fishing). In order to gain support for expanded networks of protected areas, it is essential that connections be made between the addition of protected areas and beneficial effects on the economy. 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 (Leeworthy and Wiley, 2003).

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 (IPCC, 2007). 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 will not be effective unless 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 provided fiscal resources, mandated new collaboration among agencies, extended existing authorities, and encouraged innovation. The report authors, consulted experts, and 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. More 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.

9.7 References

Araújo, M.B. and M. New, 2007: Ensemble forecasting of species distributions. *Trends in Ecology & Evolution*, **22**, 42-47.

Aschmann, H., 1973: Distribution and peculiarity of Mediterranean ecosystems, In: *Mediterranean Type Ecosystems: Origin and Structure*, [Castri, F.D. and H. Mooney (eds.)]. Springer-Verlag, New York, NY, pp. 11-19.

Battin, J., M.W. Wiley, M.H. Ruckelshaus, R.N. Palmer, E. Korb, K.K. Bartz, and H. Imaki, 2007: Projected impacts of climate change on salmon habitat restoration. *Proceedings of the National Academy of Sciences of the United States of America*, **104(16)**, 6720-6725.

Behrenfeld, M.J., R.T. O'Malley, D.A. Siegel, C.R. McClain, J.L. Sarmiento, G.C. Feldman, A.J. Milligan, P.G. Falkowski, R.M. Letelier, and E.S. Boss, 2006: Climate-driven trends in contemporary ocean productivity. *Nature*, **444(7120)**, 752-755.

Benestad, R.E., I. Hanssen-Bauer, and E.J. Fairland, 2007: An evaluation of statistical models for downscaling precipitation and their ability to capture long-term trends. *International Journal of Climatology*, **27(5)**, 649-665.

Bengtsson, J., P. Angelstam, T. Elmqvist, U. Emanuelsson, C. Folke, M. Ihse, F. Moberg, and M. Nystroem, 2003: Reserves, resilience and dynamic landscapes. *Ambio*, **32(6)**, 389-396.

Bennett, E.M., G.S. Cumming, and G.D. Peterson, 2005: A systems model approach to determining resilience surrogates for case studies. *Ecosystems*, **8**, 945-957.

Bessie, W.C. and E.A. Johnson, 1995: The relative importance of fuels and weather on fire behavior in subalpine forests. *Ecology*, **76(3)**, 747-762.

Chapin, F.S., B.H. Walker, R.J. Hobbs, D.U. Hooper, J.H. Lawton, O.E. Sala, and D. Tilman, 1997: Biotic control over the functioning of ecosystems. *Science*, **277(5325)**, 500-504.

Christensen, J. and B. C. Hewistson, 2007: Regional climate projections, In: *Climate Change 2007: the Physical Science Basis. Contribution of Working Group I to Fourth Assessment Report of IPCC*, [Solomon, S. (ed.)]. Cambridge University Press, Cambridge, UK, pp. 848-940.

Conservation Measures Partnership, 2007: Active initiatives. The Conservation Measures Partnership Website, http://conservationmeasures.org/CMP/Initiatives_Active.cfm, accessed on 6-11-2007.

Dettinger, M.D., 2005: From climate-change spaghetti to climate-change distributions for 21st century California. *San Francisco Estuary and Watershed Science*, **3(1)**.

Dixon, G.E., 2003: *Essential FVS: A User's Guide to the Forest Vegetation Simulator*. U.S. Department of Agriculture, Forest Service, Forest Management Service Center, Fort Collins, CO, pp.193p.

Field, C.B., 1999: Diverse controls on carbon storage under elevated CO_2: toward a synthesis, In: *Carbon Dioxide and Environmental Stress*, [Luo, Y. (ed.)]. Academic Press, San Diego, California, pp. 373-391.

Folke, C., S. Carpenter, T. Elmqvist, L. Gunderson, C. Holling, and B. Walker, 2002: Resilience and sustainable development: building adaptive capacity in a world of transformations. *Ambio*, **31(5)**, 437-440.

Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L.H. Gunderson, and C.S. Holling, 2004: Regime shifts, resilience, and biodiversity in ecosystem management. *Annual Review of Ecology and Systematics*, **35**, 557-581.

Fried, J.S., M.S. Torn, and E. Mills, 2004: The impact of climate change on wildfire severity: a regional forecast for Northern California. *Climatic Change*, **64(1)**, 169-191.

Georgi, F., B. Hewitson, and J. Christensen, 2001: Regional climate information - evaluation and predictions, In: *Climate Change 2001: the Scientific Basis. Contribution of Working Group I to Third Assessment Report of IPCC*, Cambridge University Press, Cambridge, UK, pp. 583-638.

Guinotte, J.M., J. Orr, S. Cairns, A. Freiwald, L. Morgan, and R. George, 2006: Will human-induced changes in seawater chemistry alter the distribution of deep-sea scleractinian corals? *Frontiers in Ecology and the Environment*, **4(3)**, 141-146.

Gunderson, L.H., 2000: Ecological resilience-in theory and application. *Annual Review of Ecology and Systematics*, **31**, 425-439.

Hall, M.H.P. and D.B. Fagre, 2003: Modeled climate-induced glacier change in Glacier National Park, 1850-2100. *BioScience*, **53(2)**, 131-140.

Holling, C.S., 1973: Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, **4**, 1-23.

Houghton, J.T., Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson, 2001: *Climate Change 2001: the Scientific Basis*. Cambridge University Press, Cambridge.

IPCC, 2007: *Climate Change 2007: the Physical Science Basis. Summary for Policymakers*. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC-TGICA, 2007: *General Guidelines on the Use of Scenario Data for Climate Impact and Adaptation Assessment*. Version 2, Prepared by T.R. Carter on behalf of the Intergovernmental Panel on Climate Change, Task Group on Data and Scenario Support for Impact and Climate Assessment, pp.1-66.

Johnson, T. and C. Weaver, In Press: A framework for assessing climate change impacts on water resources. *Environmental Management*.

Kelly, P.M. and W.N. Adger, 2000: Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change*, **47(4)**, 325-352.

Kerr, R.A., 2004: Climate change: three degrees of consensus. *Science*, **305**, 932-934.

Kerr, R.A., 2005: How hot will the greenhouse world be? *Science*, **309(5731)**, 100-100.

Lamy, F., J. Bolte, M. Santelmann, and C. Smith, 2002: Development and evaluation of multiple-objective decision-making methods for watershed management planning. *Journal of the American Water Resources Association*, **38(2)**, 517-529.

Lawler, J.J., D. White, R.P. Neilson, and A.R. Blaustein, 2006: Predicting climate-induced range shifts: model differences and model reliability. *Global Change Biology*, **12**, 1568-1584.

Lee, K.N., 1999: Appraising adaptive management. *Conservation Ecology*, **3(2)**, 1-3. [online] http://www.consecol.org/vol3/iss2/art3/.

Leeworthy, V.R. and P.C. Wiley, 2003: *Profiles and Economic Contribution: General Visitors to Monroe County, Florida 2000-2001*. National Oceanic and Atmospheric Administration, Silver Spring, MD, pp.1-24.

Leung, L.R., L.O. Mearns, F. Giorgi, and R.L. Wilby, 2003: Regional climate research: needs and opportunities. *Bulletin of the American Meteorological Society*, **84**, 89-95.

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

Logan, J.A., J. Regniere, and J.A. Powell, 2003: Assessing the impacts of global warming on forest pest dynamics. *Frontiers in Ecology and the Environment*, **1(3)**, 130-137.

Lovejoy, T.E. and L. Hannah, 2005: *Climate Change and Biodiversity*. Yale University Press, New Haven.

Luck, G.W., G.C. Daily, and P.R. Ehrlich, 2003: Population diversity and ecosystem services. *Trends in Ecology & Evolution*, **18(7)**, 331-336.

Malcolm, J.R., C. Liu, R.P. Neilson, L. Hansen, and L. Hannah, 2006: Global warming and extinctions of endemic species from biodiversity hotspots. *Conservation Biology*, **20(2)**, 538-548.

Mau-Crimmins, T., A. Hubbard, D. Angell, C. Filippone, and N. Kline, 2005: *Sonoran Desert Network: Vitals Signs Monitoring Plan*. National Park Service, Intermountain Region, Denver, CO.

Mearns, L.O., F. Giorgi, P. Whetton, D. Pabon, M. Hulme, and M. Lal, 2003: *Guidelines for Use of Climate Scenarios Developed From Regional Climate Model Experiments*. Intergovernmental Panel on Climate Change, Task Group on Data and Scenarios Support for Impact and Climate Assessment, pp.1-38.

Melillo, J.M., J. Borchers, and J. Chaney, 1995: Vegetation/ecosystem modeling and analysis project: comparing biogeography and geochemistry models in a continental-scale study of terrestrial ecosystem responses to climate change and CO_2 doubling. *Global Biogeochemical Cycles*, **9(4)**, 407-437.

Metzger, M.J., R. Leemans, and D. Schröter, 2005: A multidisciplinary multi-scale framework for assessing vulnerability to global change. *International Journal of Applied Earth Observation and Geoinformation*, **7**, 253-267.

Mitchell, T.D., T.R. Carter, P.D. Jones, M. Hulme, and M. New, 2004: *A Comprehensive Set of High-Resolution Grids of Monthly Climate for Europe and the Globe: the Observed Record (1901-2000) and 16 Scenarios (2001-2100)*. Working Paper 55, Tyndall Centre for Climate Change Research.

Moore, J.L., A. Balmford, T. Brooks, N.D. Burgess, L.A. Hansen, C. Rahbek, and P.H. Williams, 2003: Performance of sub-Saharan vertebrates as indicator groups for identifying priority areas for conservation. *Conservation Biology*, **17(1)**, 207-218.

Myers, N., 1979: *The Sinking Arc*. Pergamon Press, New York, NY.

National Research Council, 1999: *Downstream: Adaptive Management of the Glen Canyon Dam and the Colorado River Ecosystem*. National Academies Press, Washington, DC.

Pan, Z., J.H. Christensen, R.W. Arritt, and W.J. Gutowski, 2001: Evaluation of uncertainties in regional climate change simulations. *Journal of Geophysical Research*, **106**, 17735-17751.

Parmesan, C., 1996: Climate and species' range. *Nature*, **382**, 765-766.

Pauly, D., 1995: Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology and Evolution*, **10(10)**, 430-430.

Pearson, R.G., T.P. Dawson, P.M. Berry, and P.A. Harrison, 2002: SPECIES: A Spatial Evaluation of Climate Impact on the Envelope of Species. *Ecological Modelling*, **154(3)**, 289-300.

Poff, N.L., M.M. Brinson, and J.W. Day, Jr., 2002: *Aquatic Ecosystems & Global Climate Change: Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States*. Pew Center on Global Climate Change, pp.1-56.

Porter, M.E., 1985: *The Competitive Advantage*. Free Press, New York, NY.

Portner, H.O. and R. Knust, 2007: Climate change affects marine fishes through the oxygen limitation of thermal tolerance. *Science*, **315(5808)**, 95-97.

Salathé, E.P., Jr., 2003: Comparison of various precipitation downscaling methods for the simulation of streamflow in a rainshadow river basin. *International Journal of Climatology*, **23(8)**, 887-901.

Scheffer, M., S. Carpenter, J.A. Foley, C. Folke, and B.H. Walker, 2001: Catastrophic shifts in ecosystems. *Nature*, **413**, 591-596.

Scholze, M., W. Knorr, N.W. Arnell, and I.C. Prentice, 2006: A climate-change risk analysis for world ecosystems. *Proceedings of the National Academy of Sciences of the United States of America*, **103(35)**, 13116-13120.

Schwartz, P., 1996: *Art of the Long View: Planning for the Future in an Uncertain World*. Currency Doubleday, New York, NY, pp. 1-258.

Shongwe, M.E., W.A. Landman, and S.J. Mason, 2006: Performance of recalibration systems for GCM forecasts for southern Africa. *International Journal of Climatology*, **26(12)**, 1567-1585.

Spak, S., T. Holloway, B. Lynn, and R. Goldberg, 2007: A comparison of statistical and dynamical downscaling for surface temperature in North America. *Journal of Geophysical Research*, **112**, 1029-1034.

Spittlehouse, D.L. and R.B. Stewart, 2003: Adaptation to climate change in forest management. *BC Journal of Ecosystems and Management*, **4(1)**, 7-17.

Stankey, G.H., B.T. Bormann, C. Ryan, B. Shindler, V. Sturtevant, R.N. Clark, and C. Philpot, 2003: Adaptive management and the Northwest Forest Plan: rhetoric and reality. *Journal of Forestry*, **101(1)**, 40-46.

Tallis, H.M. and P. Kareiva, 2006: Shaping global environmental decisions using socio-ecological models. *Trends in Ecology and Evolution*, **21**, 562-568.

The Nature Conservancy, 2007: Conservation action planning. The Nature Conservancy, http://conserveonline.org/workspaces/cbdgateway/cap, accessed on 6-11-2007.

Thuiller, W., S. Lavorel, M.B. Araujo, M.T. Sykes, and I.C. Prentice, 2005: Climate change threats to plant diversity in Europe. *Proceedings of the National Academy of Sciences of the United States of America*, **102(23)**, 8245-8250.

Tompkins, E.L. and N.W. Adger, 2004: Does adaptive management of natural resources enhance resilience to climate change? *Ecology and Society*, **19(2)**.

Turner, B.L., II, R.E. Kasperson, P.A. Matsone, J.J. McCarthy, R.W. Corell, L. Christensene, N. Eckley, J.X. Kasperson, A. Luerse, M.L. Martello, C. Polsky, A. Pulsipher, and A. Schiller, 2003: A framework for vulnerability analysis in sustainability science. *PNAS Early Edition*, **100(14)**.

U.S. Climate Change Science Program, 2007: *Synthesis and Assessment Product 4.1: Coastal Elevation and Sensitivity to Sea Level Rise*. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, U.S. Environmental Protection Agency.

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

U.S. Geological Survey, 2007a: 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 6-11-2007a.

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

Union of Concerned Scientists, 2007: Union of concerned scientists homepage. Website, http://www.ucsusa.org/, accessed on 6-11-2007.

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.

Westerling, A.L., H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam, 2006: Warming and earlier spring increase western U.S. forest wildfire activity. *Science*, **313(5789)**, 940-943.

Wilby, R.L., S.P. Charles, E. Zorita, B. Timbal, P. Whetton, and L.O. Mearns, 2004: *Guidelines for Use of Climate Scenarios Developed From Statistical Downscaling Methods*. Intergovernmental Panel on Climate Change, Task Group on Data and Scenarios Support for Impact and Climate Assessment, pp.1-27.

Wilby, R.L., T.M.L. Wigley, D. Conway, P.D. Jones, B.C. Hewitson, J. Main, and D.S. Wilks, 1998: Statistical downscaling of general circulation model output: a comparison of methods. *Water Resources Research*, **34(11)**, 2995-3008.

Willis, K.J. and H.J.B. Birks, 2006: What is natural? The need for a long-term perspective in biodiversity conservation. *Science*, **314(5803)**, 1261.

Wood, A.W., L.R. Leung, V. Sridhar, and D.P. Lettenmaier, 2004: Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs. *Climatic Change*, **62(1)**, 189-216.

Worm, B., E.B. Barbier, N. Beaumont, J.E. Duffy, C. Folke, B.S. Halpern, J.B.C. Jackson, H.K. Lotze, F. Micheli, S.R. Palumbi, E. Sala, K.A. Selkoe, J.J. Stachowicz, and R. Watson, 2006: Impacts of biodiversity loss on ocean ecosystem services. *Science*, **314(5800)**, 787.

Yohe, G.W. and R.S.J. Tol, 2002: Indicators for social and economic coping capacity--moving toward a working definition of adaptive capacity. *Global Environmental Change-Human Policy Dimensions*, **12**, 25-40.

9.8 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.

9.9 Boxes

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 the 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 climate data are 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 (the focus of this framework).

Step 4 – Downscale climate data: Develop finer resolution datasets from coarser scale data using statistical relationships ("statistical" downscaling) or computer models ("dynamical" downscaling) to drive impacts models. For guidance on downscaling techniques, see IPCC-TGICA reports (Mearns *et al.*, 2003; Wilby *et al.*, 2004) on http://www.ipcc-data.org/guidelines/index.html.

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

Step 6 – Conduct scenario and sensitivity analyses: 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. Use these scenarios to learn the potential ranges of the system's response to changes in the climate drivers.

Step 7 – Use risk management to make adaptation decisions: 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 effects of risk.

Source: Johnson and Weaver (In Press)

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

- ✓ Maintain species with strategies such as supplying needed nutrients and water, removing competing understory, fertilizing young plantations, and developing cover species.
- ✓ Conduct thinning and fuels abatement treatments to reduce crown fire potential and risk of insect epidemics.
- ✓ Identify high value areas and take special measures to protect them.
- ✓ Monitor non-native species to be able to take early, proactive, and aggressive action against them.
- ✓ Proactively promote stand resilience with silvicultural techniques (*e.g.*, widely spaced thinnings).
- ✓ Promote connected landscapes to facilitate migration.

National Parks

- ✓ Prevent establishment of invasive non-native species that threaten native species or current ecosystem function.
- ✓ Allow the persistence of non-native species that maintain or enhance ecosystem function.
- ✓ Minimize the spread of disease and alteration of natural disturbance regimes.
- ✓ Maintain species migration corridors.

National Wildlife Refuges

- ✓ Manage risk of catastrophic fires through prescribed burns.
- ✓ Reduce or eliminate stressors on conservation target species.
- ✓ Strictly preserve the core of a reserve, and have multiple use management reflect decreasing degrees of preservation in concentric buffer zones.
- ✓ 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

- ✓ Manage dam flow releases upstream of the WSR to save flora and fauna in drier downstream river reaches.
- ✓ Use drought-tolerant plant varieties to help protect riparian buffers.
- ✓ Establish agreements with private partners to ensure that flows during droughts remain sufficient to protect critical habitats and maintain water quality.
- ✓ Remove undesirable non-native species.

National Estuaries

- ✓ Protect the water quality of tidal marshes with oyster breakwaters and rock sills.
- ✓ Use “managed alignment” to reorient existing engineering structures affecting rivers, estuaries, and coastlines.
- ✓ Preserve the structural complexity of vegetation in tidal marshes, seagrass meadows, and mangroves.
- ✓ Adapt protections of important biogeochemical zones and critical habitats as the locations of these areas change.
- ✓ Prohibit engineered structures to delay the loss of shallow-water habitats by permitting their inland migration.
- ✓ Connect landscapes with corridors to enable migrations to sustain biodiversity across the landscape.

Marine Protected Areas

- ✓ Identify ecological connections among marine ecosystems and use them to inform management decisions.
- ✓ Manage functional species groups necessary to maintaining the health of reefs and other ecosystems.
- ✓ Protect resistant areas to ensure a secure source of recruitment to support recovery in damaged areas.
- ✓ Design dynamic boundaries and buffers to protect breeding and foraging habits, migratory and pelagic species.

- ✓ Create buffer zones to accommodate ecosystem shifts in response to sea level rise and temperature change.
- ✓ Monitor ecosystems and have rapid-response strategies prepared to deal with disturbances.

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 Parks

- ✓ Move or remove human infrastructure to minimize the ecological effects of sudden changes in system state.
- ✓ Minimize sources of pollution and the alteration of natural disturbance regimes.

National Wildlife Refuges

- ✓ Reduce human water withdrawals to restore natural hydrologic regimes.

Wild & Scenic Rivers

- ✓ Claim or purchase more water rights.
- ✓ Manage water storage and withdrawals to smooth the supply of available water throughout the year. Re-evaluate institutional mechanisms governing water use and management with an eye toward increasing flexibility (*e.g.*, apply forecasting to water management, improve water monitoring capabilities).
- ✓ 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.

Marine Protected Areas

- ✓ Manage human stressors such as fishing and inputs of nutrients, sediments, and pollutants within MPAs.
- ✓ Create buffer zones between intensive human activity and fully protected marine reserves.

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

Adaptation Approach: Representation

National Forests

✓ Hedge against change by modifying genetic diversity guidelines to increase the range of species, maintain high effective population sizes, and favor genotypes known for broad tolerance ranges in forest ecosystems.

✓ Use disturbances as opportunities (*e.g.*, reforest with species tolerant to low soil moisture and high temperatures, move species into the disturbed area from other seed zones).

National Parks

✓ Allow the establishment of species that are non-native locally, but maintain native biodiversity in the overall region.

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 via stocking fish.

✓ Increase physical habitat heterogeneity in channels to benefit aquatic fauna.

National Estuaries

✓ Maintain high genetic diversity through strategies such as the establishment of reserves specifically for this purpose.

✓ Maintain complexity of salt marsh landscapes, especially preserving marsh edge environments.

Marine Protected Areas

✓ Maximize habitat heterogeneity 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).

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.

Marine Protected Areas

✓ Replicate habitat types in multiple areas to spread risks associated with climate change.

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

Adaptation Approach: Restoration

National Forests

- ✓ Have ready deliberate and immediate plans to encourage the return of desired species to a site post-disturbance.

National Parks

- ✓ Restore ecosystems with vegetation that is no longer present locally, but is native to the overall region.

Wild & Scenic Rivers

- ✓ Replant native riparian vegetation with drought-resistant vegetation in areas with higher temperatures and less precipitation.
- ✓ Restore the natural capacity of rivers to buffer climate-change impacts (*e.g.*, stormwater management in developed basins, land acquisition around rivers, levee setbacks to free the floodplain of infrastructure, riparian buffer repairs).
- ✓ Conduct river restoration projects to stabilize eroding banks, repair in-stream habitat, or promote fish passages from areas with high temperatures and less precipitation.

National Estuaries

- ✓ Restore the vegetational layering and structure of tidal marshes, seagrass meadows, and mangroves to stabilize estuary function.
- ✓ Restore native species and remove invasive non-natives to improve marsh characteristics that promote propagation and production of fish and wildlife.
- ✓ Direct restoration programs to places where the restored ecosystem has room to retreat as sea level rises.

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

- ✓ Identify environments “buffered” against climate change and consider them as sites for new plantations or long-term conservation.
- ✓ Protect populations that currently exist in climatically buffered, cooler, or unusually mesic environments.

National Parks

- ✓ Create 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.

Marine Protected Areas

- ✓ Identify, protect, and restore areas observed to be resistant to climate change effects or to recover quickly from climate-induced disturbances.

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

Adaptation Approach: Relocation

National Parks

- ✓ Assist in species migrations and transplant species.

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.

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 the scenarios under which restoration projects or rebuilding of human structures should occur after climate disturbances.

9.10 Tables

Table 9.1. Examples of 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

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

Table 9.3. Levels of biodiversity and associated management options.

	Definition	*Management activities that support diversity*
Genetic Diversity	Allelic diversity and the presence/absence of rare alleles (foundation for all higher level diversity)	▪ 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	▪ 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

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, personal experience, and stakeholder discussions.

Adaptation Approach	**National Forests**	**National Parks**	**National Wildlife Refuges**	**Wild & Scenic Rivers**	**National Estuaries**	**Marine Protected Areas**
Protect Key Ecosystem Features Is strategic protection of key ecosystem features an effective way to preserve or enhance resilience to climate change?	Medium	Medium	High	High	High	High
Reduce Anthropogenic Stresses Is reduction of anthropogenic stresses effective at increasing resilience to climate change?	High	High	Very High	High	Medium	High

Representation Is representation effective in supporting resilience through preservation of overall biodiversity?	High	High	Very High	Low	Medium	High
Replication Is replication effective in supporting resilience by spreading the risks posed by climate change?	High	NA	Very High	Low	NA	High
Restoration						
Is restoration of desired ecological states or ecological processes effective in supporting resilience to climate change?	Medium	Medium	Medium	Medium	Medium	Low
Refugia						
Are refugia an effective way to preserve or enhance resilience to climate change at the scale of species, communities or regional networks?	High	NA	Low	Medium	NA	Medium
Relocation						
Is relocation an effective way to promote system-wide (regional) resilience by moving species that would not otherwise be able to emigrate in response to climate change?	Low	Medium	Low	Very Low	NA	Very Low
Confidence Levels						
Very High = 95% or greater						
High = 67-95%						
Medium = 33-						

67%						
Low = 5-33%						
Very Low = 5% or less						

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

LEGISLATION AND REGULATION		
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 6.3.4).

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

MANAGEMENT POLICIES AND PROCEDURES		
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 season) to do fuel treatments on more national forest acres (see Chapter 3 section 3.4.6.2, Tahoe National Forest).
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 Chapter 3 section 3.5.5, Olympic National Forest).
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 3.4.6.1).	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 Chapter 3 section 3.5.5). • 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 Chapter 3 section 3.4.6.2), (2) the Greater Yellowstone Coordinating Committee, and the Southern Appalachian Man and the Biosphere Program with relationships across jurisdictional boundaries (see Chapter 4 section 4.3.3), (3) The Delaware River, managed cooperatively as a partnership river (see Chapter 6 section 6.4.3). • Coordinate dam management at the landscape level for species that cross political boundaries using dam operations prospectively as thermal controls under future climate changes (see Chapter 6 section 6.3.4.2). • 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 6.3.4.2).

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

HUMAN AND FINANCIAL CAPITAL		
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 4.3.2.)
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 Chapter 3 section 3.4.6.2, Tahoe NF) • 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 3.7.2.3) • Develop managers’ guides, climate primers, management toolkits, a Web clearinghouse, and video presentations (see Chapter 3 section 3.7.2.3).
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 3.5.5; general decline in staff resources and capacity (see Chapter 3 section 3.4.6.1)	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 8.2.3, 8.3.4.1 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 Chapter 3 section 3.4.6.2).

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

INFORMATION AND SCIENCE		
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 4.3.3).
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 6.2.4.2).
Lack of decision support tools and models, uncertainty in climate change science, and critical gaps in scientific information that limits 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 3.5.4). • 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 4.3.3).
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 3.3.1.2).
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 publics often results in the default of	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, Chapter 3 section 3.4.6.2 and Partnership for the Sounds (the Estuarium) and North Carolina Aquariums, Chapter 7 sections 7.4.5). • 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 7.1.2), the Coastal Habitat Protection Plans do for fisheries

no action. (See Chapter 3 sections 3.4.4.2, 3.4.6.1, and 3.7.2.4).		management (see Chapter 7 section 7.4.4), and some National Forests do (Chapter 3 section 3.4.6.2).

9.11 Figures

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

*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 9.2. The process of adaptive management.