2 Introduction

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Chapter Contents

Strategies for protecting climate-sensitive ecosystems will be increasingly important for management, because impacts resulting from a changing climate system are already evident and will persist into the future regardless of emissions mitigation. Climate is a dominant factor influencing the distributions, structures, functions, and services of ecosystems. Changes in climate can interact with other environmental changes to affect biodiversity and the future condition of ecosystems (*e.g.*, McCarty, 2001; IPCC, 2001; Parmesan and Yohe, 2003). The extent to which ecosystem condition may be affected will depend on the amount of climate change, the degree of sensitivity of the ecosystem to the climate change, and the availability of adaptation options for effective management responses. This Synthesis and Assessment Product (SAP), SAP 4.4, is charged with reviewing adaptation options for ecosystems that are likely to be sensitive to continuing changes in climate. SAP 4.4 is one of 21 SAPs commissioned by the U.S. government's Climate Change Science Program, seven of which examine the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.

Adaptation is defined as an adjustment in natural or human systems to a new or changing environment. Adaptation to climate change refers to adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2001). In biological disciplines, adaptation refers to the process of genetic change within a population due to natural selection, whereby the average state of a character becomes better suited to some feature of the environment (Groom, Meffe, and Carroll, 2006). This type of adaptation, also referred to as autonomous adaptation (IPCC, 2001), is a reactive biological response to climate stimuli and does not involve intervention by society. Planned adaptation, on the other hand, refers to strategies adopted by society to manage systems based on an awareness that conditions are about to change or have changed, such that action is required to meet management goals (adapted from IPCC, 2001). This report focuses on the latter form of adaptation, with all subsequent uses of the term "adaptation" referring to strategies for management of ecosystems in the context of climate variability and change.

The purpose of adaptation strategies is to reduce the risk of adverse outcomes through activities that increase the resilience of ecological systems to climate change stressors (Scheffer *et al.*, 2001; Turner, II *et al.*, 2003; Tompkins and Adger, 2004). A stressor is defined as any physical, chemical, or biological entity that can induce an adverse response (U.S. Environmental Protection Agency, 2000). Resilience refers to the amount of change or disturbance that can be absorbed by a system before the system is redefined by a different set of processes and structures (Holling, 1973; Gunderson, 2000; Bennett, Cumming, and Peterson, 2005). Potential adverse outcomes of climate change may vary for different ecosystems, depending on their sensitivity to climate stressors and their intrinsic resilience to climate change. The "effectiveness" of an adaptation option that is designed to boost ecosystem resilience will thus be case-dependent, and can be measured only against a desired ecosystem condition or natural resource management goal. This report evaluates the effectiveness of potential adaptation options for supporting natural resource management goals.

Adaptation options for enhancing ecosystem resilience include changes in management processes, practices, or structures to reduce anticipated damages or enhance beneficial responses associated with climate variability and change. In some cases, opportunities for adaptation offer stakeholders outcomes with multiple benefits, such as the addition of riparian buffer strips that (1) manage pollution loadings from agricultural land into rivers designated as "wild and scenic" today *and* (2) establish a protective barrier to increases in both pollution and sediment loadings associated with future climate change. Where there are multiple benefits to implementing specific adaptation options, this report seeks to identify those benefits.

A range of adaptation options may be possible for many ecosystems, but a lack of information or resources may impede successful implementation. In some cases, managers may not have the knowledge or information available to address climate change impacts. In other instances, managers may understand the issues and have the relevant information but lack resources to implement adaptation options. Furthermore, even with improvement in the knowledge and communication of available and emerging adaptation strategies, the feasibility and effectiveness of adaptation will depend on the adaptive capacity of the ecological system or social entity. Adaptive capacity is defined as the potential or ability of a system, region, or community to counteract, adjust for, or take advantage of the effects of climate change (IPCC, 2001). Depending on the management goals, there may be biological, physical, economic, social, cultural, institutional, or technological conditions that enhance or hinder adaptation. To the extent possible, this report will address those factors that affect managers' ability to implement adaptation options.

2.1 Goal and Audience

The goal of SAP 4.4 is to provide useful information on the state of knowledge regarding adaptation options for key, representative ecosystems and resources that may be sensitive to climate variability and change. To provide such useful information, it is necessary to examine adaptation options in the context of a desired ecosystem condition or natural resource management goal. Therefore, this report explores potential adaptation options for supporting natural resource management goals in the context of management systems such as the National Park System or the National Wildlife Refuge System. Management systems such as these provide a framework of processes and procedures used to ensure that an organization's objectives are fulfilled.

Specifically, this report supports the stated goal by providing information on (1) the implications of the combined effects of climate changes and non-climate stressors on our ability to achieve specific resource management goals; (2) existing management options as well as new adaptation approaches that reduce the risk of negative outcomes; and (3) opportunities and barriers that affect successful implementation of management strategies to address climate change impacts. Through the provision of this information, the desired outcome of this report is an enhanced adaptive capacity to respond to future changes in climate.

The primary intended audience of this report is resource and ecosystem managers at federal, state, and local levels; tribes, nongovernmental organizations, and others involved in protected area management decisions. Additional audiences include scientists, engineers, and other technical specialists who will be able to use the information provided to set priorities for future research and to identify decision-support needs and opportunities. This information also may support tribes and government agencies at federal, state, and local levels in the development of policy decisions that promote adaptation and increase society's adaptive capacity for management of ecosystems and species within protected areas.

2.2 Stakeholder Interactions

Stakeholder interactions play a key role in maximizing the relevance, usefulness, and credibility of assessments and encouraging ownership of the results (National Research Council, 2007). This may be especially true in the adaptation arena, where managers are challenged by both the technical aspects of adaptation and the constraints imposed by legal mandates and resource limitations. In these cases, participation by an appropriate array of stakeholders is important in order to ensure that proposed adaptation options are analyzed in light of both technical rigor and feasibility. Given this, the appropriate composition of stakeholders for SAP 4.4 includes: (1) those who wish to consider options for reducing the risk of negative ecological outcomes associated with climate variability and change; (2) researchers who study climate change impacts on ecosystems and topics relevant for adaptation to impacts of climate variability and change (*e.g.*, ecosystem restoration, sustainability); (3) science managers from the physical and social sciences who develop long-term research plans based on the information needs and decisions at hand; and (4) tribes and government agencies at federal, state, and local levels who develop and evaluate policies, guidelines, procedures, technologies, and other mechanisms to improve adaptive capacity.

The initial planning of SAP 4.4 involved engaging a narrowly defined targeted group of expert stakeholders to review the substance of the report. Small groups of no more than 20 people from the fields of adaptation science and resource management were asked to provide comments to the authors of the report on its content through participation in a series of six workshops (one for each "management system" chapter; see below). Chapter lead and contributing authors presented draft information on their chapters and case studies, and incorporated the expert input into their revisions.

Beyond the narrowly defined group of expert stakeholders mentioned above, a broader array of relevant stakeholders were invited to contribute to the shaping of this document through a public review process. Feedback was received from non-governmental organizations, industry, academia, state organizations, and private citizens, as well as federal government representatives. That feedback resulted in significant changes to this report. Final input was received from a Federal Advisory Committee composed primarily of academicians.

2.3 Approach for Reviewing Adaptation Options for Climate-Sensitive Ecosystems and Resources

This report examines federally protected and managed lands and waters as a context for reviewing adaptation options for climate-sensitive ecosystems and resources. The focus on federal holdings was chosen because their protected status reflects the value placed on these ecosystems and resources by the American public; the management goals for federal ecosystems are also representative of the range of goals and challenges faced by other ecosystem management organizations across the United States; and adaptation options for federal ecosystems will require a variety of responses (equally applicable to non-federal lands) to ensure achievement of management goals over a range of time scales.

Approximately one-third of the nation's land base is managed by the federal government and administered by different agencies through a variety of "management systems." Since a comprehensive treatment of all federal holdings is beyond the scope of this report, the focus is on representative management systems that have clear management goals for which adaptation options can be discussed. Therefore, adaptation options are reviewed for six management systems: national forests, national parks, national wildlife refuges, wild and scenic rivers, national estuaries, and marine protected areas (especially national marine sanctuaries). By using a sample of management systems, the discussion of adaptation options can go beyond a general list to more specific options tailored to the management context and goals. This approach also allows exploration of any specific barriers and opportunities that may affect implementation. The array of adaptation options discussed should be useful to other resource managers, regardless of whether their management systems are represented in this report. Likewise, the types of barriers and suggested methods for addressing those barriers should be sufficiently broad to be useful to a wider audience of resource managers. Other federally protected systems—such as wilderness preservation areas, biosphere reserves, research natural areas, natural estuarine research reserves, and public lands—could not be examined in this report because of limitations on time and resources. As a result, certain important and extensive management systems (*e.g.*, Bureau of Land Management) were not reviewed in this report. Thus, the material in this report represents only the beginning of what should be an ongoing effort to inform and support resource management decision making. Other management systems not represented in this report would also benefit from specific examination of important impacts and adaptation options.

For each of the six management systems selected, this report reviews (1) the historical origins of the management system and the formative factors that shaped its mission and goals, (2) key ecosystem components and processes upon which those goals depend, (3) stressors of concern for the key ecosystem characteristics, (4) management methods currently in use to address those stressors, (5) ways in which climate variability and change may affect attainment of management goals, and (6) options for adjusting current management strategies or developing new strategies in response to climate change. All of these elements vary considerably depending on the history and organizational structure of the management systems and the locations and types of ecosystems that they manage.

Specific management goals for the ecosystems in the different management systems vary based on the management principles or frameworks employed to reach targeted goals. Natural resource management goals are commonly expressed in terms of maintaining ecosystem integrity, achieving restoration, preserving ecosystem services, and protecting wildlife and other ecosystem characteristics. The achievement of management goals is thus dependant on our ability to protect, support, and restore the structure and functioning of ecosystems.

Changes in climate may affect ecosystems such that management goals are not achieved. Thus, the identified management goals from the literature review are analyzed for their sensitivity to climate variability and change, as well as to other stressors present in the system that may interact with climate change. Adaptive responses to climate variability and change are meant to reduce the risk of failing to achieve management goals. Therefore, each management system chapter discusses adaptation theories and frameworks, as well as options for modifying existing management actions and developing new approaches to address climate change impacts.

For each chapter, the above analysis of climate sensitivities and management responses includes one or more place-based case studies that explore the current state of knowledge regarding management options that could be used to adapt to the potential impacts of climate variability and change. The case studies—which were selected using a range of criteria (Box 2.1)—cover a variety of ecosystem types such as forests, rivers and streams, wetlands, estuaries, and coral reefs (Fig. 2.1).

Figure 2.1. Map showing the geographic distribution in the United States of SAP 4.4 case studies.

Taken together, the six management system chapters of this report offer an array of issues, viewpoints, and case studies to inform managers as they consider adaptation options. As such, they are not only useful individually but also serve as rich sources of "data" to inform the cross-cutting themes and synthetic approaches that comprise the "results" of the Synthesis and Conclusions chapter.

2.4 Climate Variability and Change

Climate change is defined by the Intergovernmental Panel on Climate Change (IPCC) as any change in climate over time, whether due to natural variability or as a result of human activity (IPCC, 2007b). Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events (IPCC, 2007b). The motivation for developing responses to projected changes in the climate system stems from observations of changes that have already occurred, as well as projected climate changes. The discussion below provides background information on observed climatic and ecological changes that have implications for management of ecosystems in the United States. For more detailed information, the reader is referred to recent publications of the IPCC (IPCC, 2007a; 2007b).

2.4.1 Increases in Surface Temperature

Evidence from observations of the climate system has led to the conclusion that human activities are contributing to a warming of the earth's atmosphere. This evidence includes an increase of 0.74 ± 0.18°C in global average surface temperature over the last century, and an even greater warming trend over the last 50 years than over the last 100 years. Eleven of the last 12 years (1995–2006) are among the 12 warmest years since the instrumental record of global surface temperature was started in 1850 (IPCC, 2007b).

In the continental United States, temperatures rose linearly at a rate of 0.06°C per decade during the first half of the 20th century. That rate increased to 0.33°C per decade from 1976 to the present. The degree of warming has varied by region (Fig. 2.2) across the

United States, with the West and Alaska experiencing the greatest degree of warming (U.S. Environmental Protection Agency, 2007). These changes in temperature have led to an increase in the number of frost-free days. In the United States, the greatest increases have occurred in the West and Southwest (Tebaldi *et al.*, 2006).

Figure 2.2. Annual mean temperature anomalies 1901–2006. *Red shades indicate warming over the period and blue shades indicate cooling over the period. Data courtesy of NOAA's National Climatic Data Center.*

2.4.2 Changes in Precipitation

Changes in climate have also been manifested in altered precipitation patterns. Over the last century, the amount of precipitation has increased significantly across eastern parts of North America and several other regions of the world (IPCC, 2007b). In the contiguous United States, this increase in total annual precipitation over the last century has been 6.1%. When looked at by region (Fig. 2.3), however, the direction and magnitude of precipitation changes vary, with increases of more than 10% observed in the East North Central and South, and a decrease of more than 7% in Hawaii (U.S. Environmental Protection Agency, 2007). The form of precipitation has also changed in some areas. For example, in the western United States, more precipitation has been falling as rain than snow over the last 50 years (Knowles, Dettinger, and Cayan, 2006).

Figure 2.3. Annual precipitation anomalies 1901–2006. *Green shades indicate a trend towards wetter conditions over the period, and brown shades indicate a trend towards dryer conditions. Data courtesy of NOAA's National Climatic Data Center..*

2.4.3 Warming of the Oceans

Another manifestation of changes in the climate system is a warming in the world's oceans. The global ocean temperature rose by 0.10°C from the surface to 700 m depth from 1961–2003 (IPCC, 2007b). Observations of sea-surface temperatures, based on a reconstruction of the long-term variability and change in global mean sea-surface temperature for the period 1880–2005, show that they have reached their highest levels during the past three decades over all latitudes (Fig. 2.4). Warming has occurred through most of the 20th century and appears to be independent of measured inter-decadal and short-term variability (Smith and Reynolds, 2005).

Figure 2.4. Annual global sea surface temperature anomaly, 1880–2005, compared with 1961–1990 climate normal (U.S. Environmental Protection Agency, 2007).

2.4.4 Sea Level Rise and Storm Intensity

Warming causes seawater to expand and thus contributes to sea level rise. This factor, referred to as thermal expansion, has contributed 1.6 ± 0.5 mm per year to global average sea level over the last decade (1993–2003). Other factors contributing to sea level rise over the last decade include a decline in mountain glaciers and ice caps (0.77 ± 0.22 mm per year), losses from the Greenland ice sheets (0.21 ± 0.07 mm per year), and losses from the Antarctic ice sheets (0.21 ± 0.35 mm per year) (IPCC, 2007c).

In the United States, relative sea levels have been rising along most of the coasts at rates of 1.5–3 mm per year (U.S. Environmental Protection Agency, 2007), which is consistent with the average rate globally for the 20th century (1.7±0.5 mm per year) (IPCC, 2007b). Relative sea level has risen 3–4 mm per year in the Mid-Atlantic states and 5–10 mm per year in the Gulf states, due to subsidence combined with accelerated global sea level rise (U.S. Environmental Protection Agency, 2007)**.** On Florida's Gulf coast, relative sea level rise has led to a rate of conversion of about 2 meters of forest to salt marsh annually (Williams *et al.*, 1999).

The effects of sea level rise in coastal areas would be compounded if tropical cyclones were to become more intense. For the North Atlantic, there is observational evidence since about 1970 of an increase in intense tropical cyclone activity which is correlated with increases in tropical sea surface temperatures (IPCC, 2007b). Various high resolution global models and regional hurricane models also indicate that it is likely that some increase in tropical cyclone intensity will occur if the climate continues to warm (IPCC, 2007b). This topic remains an area of intense debate and investigation, with many competing opinions as to the accuracy of detection methods, the quality of historical data, and the strength of various modeling results (*e.g.*, see Donnelly and Woodruff, 2007; Landsea, 2007; Vecchi and Soden, 2007). Nevertheless, if the prospect of increasingly intense tropical cyclone activity is one plausible scenario for the future, then the possibility of intensified storm surges and associated exacerbation of sea level rise impacts may merit consideration and planning by managers.

2.4.5 Changes in Ocean pH

Between 1750 and 1994, the oceans absorbed about 42% of all emitted carbon dioxide (CO_2) (IPCC, 2007b). As a result, the total inorganic carbon content of the oceans increased by 118 ±19 gigatons of carbon over this period and is continuing to increase. This increase in oceanic carbon content caused calcium carbonate ($CaCO_3$) to dissolve at greater depths and led to a 0.1 unit decrease in surface ocean pH from 1750–1994 (IPCC, 2007b). The rate of decrease in pH over the past 20 years accelerated to 0.02 units per decade (IPCC, 2007b). A decline in pH, along with the concomitant decreased depth at which calcium carbonate dissolves, will likely impair the ability of marine organisms to use carbonate ions to build their shells or other hard parts (The Royal Society, 2005; Caldeira and Wickett, 2005; Doney, 2006; Kleypas *et al.*, 2006).

2.4.6 Warming in the Arctic

Other observations at smaller geographic scales lend evidence that the climate system is warming. For example, in the Arctic, average temperatures have increased and sea ice extent has shrunk. Over the last 100 years, the rate of increase in average Arctic temperatures has been almost twice that of the global average rate, and since 1978 the annual average sea ice extent has shrunk by 2.7 ± 0.6% per decade. The permafrost layer has also been affected in the Arctic, to the degree that the maximum area of ground frozen seasonally has decreased by about 7% in the Northern Hemisphere since 1900, with the spring realizing the largest decrease (up to 15%) (IPCC, 2007b).

2.4.7 Changes in Extreme Events

Whether they have become drier or wetter, many land areas have likely experienced an increase in the number and intensity of heavy precipitation (5 cm of rain or more) events (IPCC, 2007b). About half of the increase in total precipitation observed nationally has been attributed to the increase in intensity of storms (Karl and Knight, 1998). Heavy precipitation events are the principal cause of flooding in most of the United States (Groisman *et al.*, 2005).

The general warming trend observed in most of the United States was also accompanied by more frequent hot days, hot nights, and heat waves (IPCC, 2007b). Furthermore, higher temperatures along with decreased precipitation have been associated with observations of more intense and longer droughts over wider areas since the 1970s. Within the United States, the western region has experienced longer and more intense droughts, but these appear also to be related to diminishing snow pack and consequent reductions in soil moisture. In addition to the factors above, changes in sea-surface temperatures and wind patterns have been linked to droughts (IPCC, 2007b).

2.4.8 Changes in Hydrology

During the 20th century, the changes in temperature and precipitation described above caused important changes in hydrology over the continental United States. One change was a decline in spring snow cover. This trend was observed throughout the Northern Hemisphere starting in the 1920s and accelerated in the late 1970s (IPCC, 2007b). Declining snow cover is a concern in the United States, because many western states rely on snowmelt for their water use (Mote *et al.*, 2005). Less snow generally translates to lower reservoir levels. The earlier onset of spring snowmelt exacerbates this problem. Snowmelt started 2–3 weeks earlier in 2000 than it did in 1948 (Stewart, Cayan, and Dettinger, 2004).

Another important change, described in the preceding section, was the increase in heavy precipitation events documented in the United States during the past few decades. These changes have affected the timing and magnitude of streamflow. In the eastern United States, high streamflow measurements were associated with heavy precipitation events (Groisman, Knight, and Karl, 2001). Because of this association, there is a high probability that high streamflow conditions have increased during the 20th century (Groisman, Knight, and Karl, 2001). Increases in peak streamflow have not been observed in the West, most likely because of the reduction in snow cover (Groisman, Knight, and Karl, 2001).

2.4.9 Observed Ecological Responses

An emerging but growing body of literature indicates that over the past three decades, the changes in the climate system described above—including the anthropogenic component of warming— have caused physical and biological changes in a variety of ecosystems (Root *et al.*, 2005; Parmesan, 2006; IPCC, 2007a) that are discernable at the global scale. These changes include shifts in genetics (Bradshaw and Holzapfel, 2006; Franks, Sim, and Weis, 2007), species' ranges, phenological patterns, and life cycles (reviewed in Parmesan, 2006). Most (85%) of these ecological responses have been in the expected direction (*e.g.*, poleward shifts in species distributions), and it is very unlikely that the observed responses are due to natural variability alone (IPCC, 2007a). The asynchronous responses of different species to climate change may alter species' interactions (*e.g.*, predator-prey relationships and competition) and have unforeseen consequences (Parmesan and Galbraith, 2004).

2.4.10 Future Anticipated Climate Change

Improvements in understanding of the anthropogenic influences on climate have led to greater confidence in most of the changes described in the previous section. This improved understanding, in combination with improvements in the models that simulate climate change processes, has also increased confidence in model projections of future climatic changes. The most recent models project future changes in the earth's climate system that are greater in magnitude and scope than those already observed. Based on annual average projections (from 21 global climate models), surface temperature increases by the end of the 21st century will range from 2°C near the coasts in the conterminous United States to at least 5°C in northern Alaska. Nationally, summertime temperatures are projected to increase by 3–5°C. Winter temperatures in Northern Alaska are projected to increase by 4.4–11°C. In addition, more extreme hot events and fewer extreme cold events are projected to occur (IPCC, 2007b).

On average, annual precipitation will likely increase in the northeastern United States and will likely decrease in the Southwest over the next 100 years (IPCC, 2007b). In the western United States, precipitation increases are projected during the winter, whereas decreases are projected for the summer (IPCC, 2007b). As temperatures warm, precipitation will increasingly fall as rain rather than snow, and snow season length and snow depth are very likely to decrease in most of the country (IPCC, 2007b). More extreme precipitation events are also projected (Diffenbaugh *et al.*, 2005; Diffenbaugh, 2005), which, coupled with an anticipated increase in rain-on-snow events, would contribute to more severe flooding due to increases in extreme runoff (IPCC, 2007b).

The interaction of climate change with other stressors, as well as direct stressors from climate change itself, may cause more complicated responses than have so far been observed. In general, during the next 100 years, it is likely that many ecosystems will not be able to resist or recover from the combination of climate change, associated disturbances, and other global change drivers. Ecological responses to future climate change are expected with high confidence to negatively affect most ecosystem services. Major changes in ecosystem structure, composition, and function, as well as interspecific interactions, are very likely to occur where temperature increases exceed 1.5–2.5°C (IPCC, 2007a).

2.5 Treatment of Uncertainty: Confidence

In SAPs such as this report, evaluations of uncertainty are communicated for judgments, findings, and conclusions made in the text. Treatment of uncertainty involves characterization and communication of two distinct concepts: uncertainty in terms of *likelihood* or in terms of *confidence* in the science (IPCC, 2007b). Likelihood is relevant when assessing the chance of a specific future occurrence or outcome, and is often quantified as a probability. However, in this report, judgments and conclusions about adaptation will be associated with qualitative expressions of confidence rather than quantitative statements of likelihood.

Confidence is composed of two separate but related elements (IPCC, 2007b). The first element is the amount of evidence available to support the determination that the effectiveness of a given adaptation approach is well-studied and understood. The second element is the level of agreement or consensus within the scientific community about the different lines of evidence on the effectiveness of that adaptation approach. Thus, each of the synthetic adaptation approaches drawn from across the chapters of this report is assessed and given a ranking of “high” or “low” for each element (amount of evidence and amount of agreement). These assessments of confidence are presented and discussed in the Synthesis and Conclusions chapter.

2.6 The Adaptation Challenge: The Purpose of This Report

Understanding how to incorporate adaptation into strategic planning activities is an important challenge because: (1) the climate system is always changing and will continue to change; (2) those changes will affect attainment of management goals for ecosystems; and (3) there are varying levels of uncertainty associated with both the magnitude of climatic changes and the magnitude and direction of ecosystem responses. This report addresses where, when, and how adaptation strategies may be used to address climate change impacts on managed ecosystems, the barriers and opportunities that may be encountered while trying to implement those strategies, and potential long-term strategic shifts in management approaches that may be made to broaden the scope of adaptation strategies available to resource managers.

Different approaches are discussed to address adaptation in the planning process. These approaches generally fall into broad categories that may be distinguished by (1) timing of the management response: whether the response takes place prior to (proactively) or after (reactively) a climate event has occurred; and (2) intention of the managing agency: whether climate-induced changes are formally acknowledged and addressed in management plans (Box 2.2).

Given that management agencies’ resources are likely to fluctuate over time, a key to the planning process will be to determine an approach that maximizes attainment of established short- and long-term goals, especially in light of the effect that climate change may have on those goals. This report provides a discussion of key questions, factors, and potential approaches to consider when setting priorities during the planning process, as well as examples of adaptation strategies that may be employed across different types of ecosystems and geographic regions of the country.

Addressing future changes is an imprecise exercise, fraught with uncertainties and unanticipated changes. Managers have to anticipate the interaction of multiple stressors, the interdependencies of organisms within an ecosystem, and the potential intertwined, cascading effects. Thus the ability to measure effectiveness of management options, *i.e.*, ecological outcomes of specific actions on the ground, is essential in order to continuously refine and improve adaptation. This report raises issues to consider when measuring management effectiveness for increasing the resilience of ecosystems to climate variability and change.

Another requirement for management effectiveness is successful implementation. Challenges to implementation may be associated with different organizational scales, operational tradeoffs, cost/benefit considerations, social/cultural factors, and planning requirements. The information in this report provides an improved understanding of barriers and opportunities associated with these challenges, including priority information gaps and technical needs.

Finally, some challenges to implementation of adaptation options and their ultimate success may require fundamental shifts in management approaches. This report will seek to identify and discuss possible short- and long-term shifts in management structures, approaches, and policies that increase the likelihood of effectiveness and success in implementation, and that may open the door to a greater array of adaptation options in the future.

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2.8 Boxes

Box 2.1. Case Study Selection Criteria

The authors of this report, in consultation with agency representatives and stakeholders, used the following criteria for evaluation and selection of candidate case studies:

- Contains one or more ecosystem services or features that are protected by management goals;
- Management goals are sensitive to climate variability and change, and the potential impacts of climate variability and change are significant relative to the impacts of other changes;
- Adaptation options are available or possible for preserving a service or a physical or biological feature; and
- Adaptation options have potential for application in other geographic regions or for other ecosystem types.

In order to ensure that the entire collection of case studies would include broad representation across geographic areas, ecosystem types, and management goals and methods, the following characteristics were required of the group as a whole:

- Addresses a reasonable cross section of important, climate-sensitive ecosystems and/or ecosystem services and features;
- Addresses a range of adaptation responses (*e.g.*, structural, policy, permitting);
- Distributed across the United States and valued by a national constituency; and
- Attributes allow for comparison of adaptation approaches and their effectiveness across the case studies (*e.g.*, lessons learned about research gaps and about factors that enhance or impede implementation).

Box 2.2. Approaches to Adaptation Planning

1. No adaptation: future climate change impacts are not planned for by the managing agency and are not acknowledged as likely to occur.
2. Reactive adaptation: climate change impacts are not planned for by the managing agency, and adaptation takes place after the impacts of climate change have been observed.
3. Anticipatory adaptation
   - Responsive: future climate change impacts are acknowledged as likely to occur by the managing agency, and responses to those changes are planned for when changes are observed.
   - Proactive: climate change impacts are acknowledged as likely to occur by the managing agency, and adaptation responses are planned for before the changes are observed.

2.9 Figures

Figure 2.1. Map showing the geographic distribution in the United States of SAP 4.4 case studies.

Figure 2.2. Annual mean temperature anomalies 1901–2006. *Red shades indicate warming over the period and blue shades indicate cooling over the period. Data courtesy of NOAA's National Climatic Data Center.*

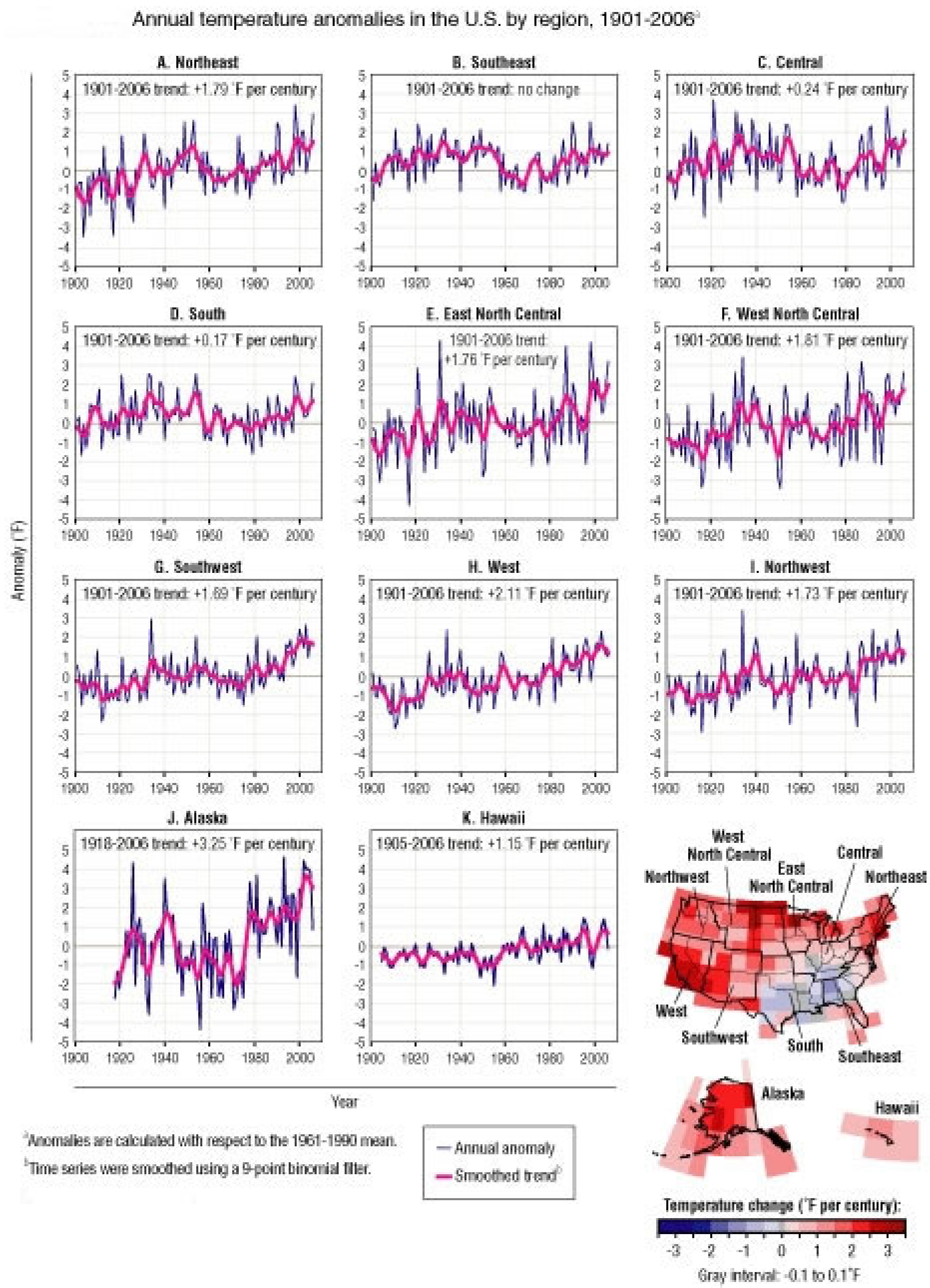

Figure 2.3. Annual precipitation anomalies 1901–2006. *Green shades indicate a trend towards wetter conditions over the period, and brown shades indicate a trend towards dryer conditions. Data courtesy of NOAA's National Climatic Data Center.*

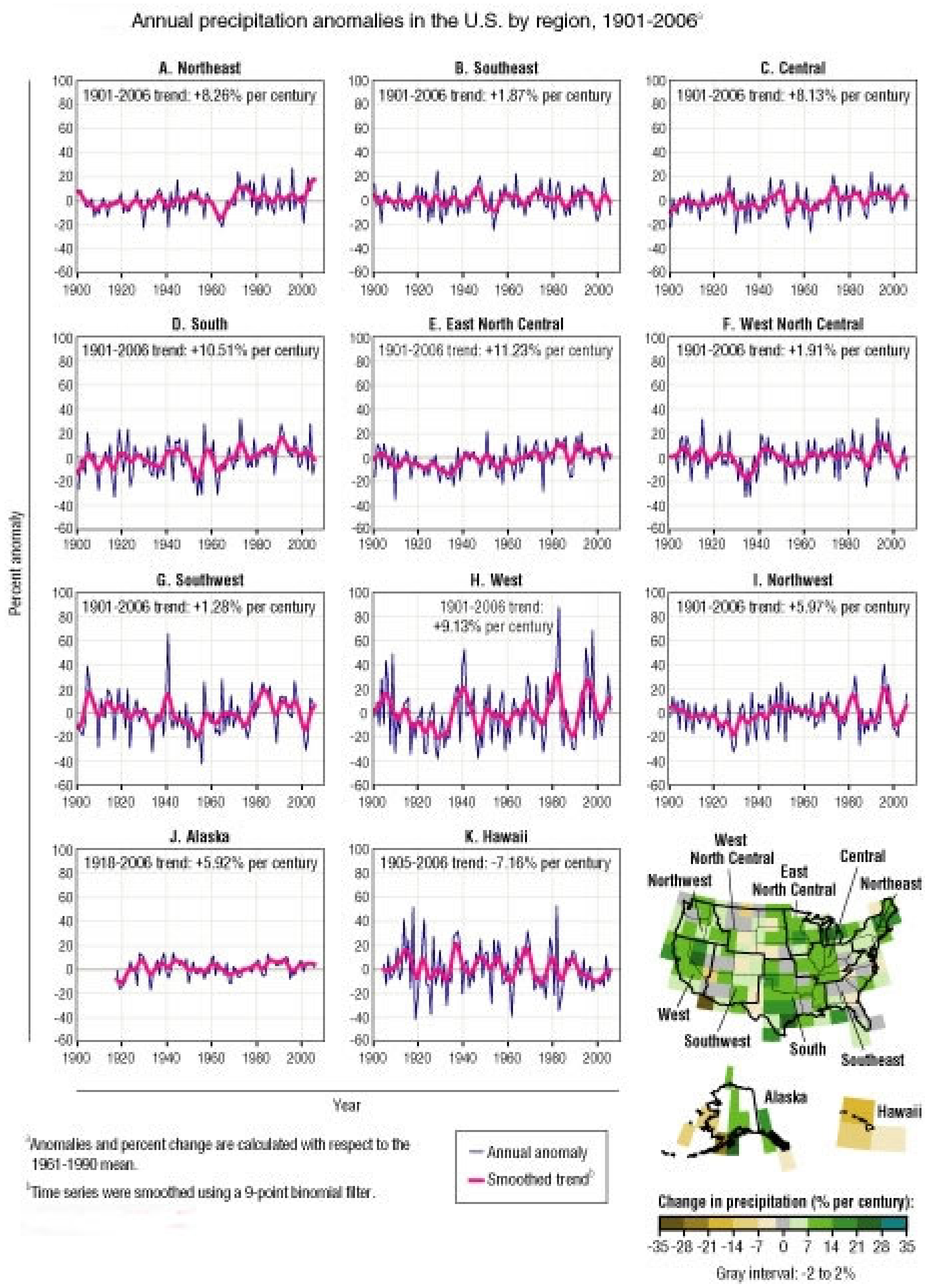

Figure 2.4. Annual global sea surface temperature anomaly, 1880–2005, compared with 1961–1990 climate normal (U.S. Environmental Protection Agency, 2007).