1 Executive Summary

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Chapter Contents

1.1 Introduction

The United States government's Climate Change Science Program (CCSP) is responsible for providing the best science-based knowledge possible to inform management of the risks and opportunities associated with changes in the climate and related environmental systems (U.S. Climate Change Science Program, 2007). The CCSP has commissioned 21 "synthesis and assessment products" (SAPs) to advance decision-making on climate change-related decisions by providing current evaluations of climate change science and identifying priorities for research, observation, and decision support. This Report—SAP 4.4—focuses on federally owned and managed lands and waters to provide a "Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources." It is one of seven reports that support Goal 4 of the CCSP Strategic Plan to understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes.

1.2 Background

Climate variables such as temperature, precipitation, and wind play a fundamental role in determining the geographic distributions and biophysical characteristics of ecosystems, communities, and species. Climate *change* can therefore have profound effects on species attributes (*e.g.*, changes in flowering times, range shifts), ecological interactions (*e.g.*, decoupling of plants and pollinators, non-native invasions) and ecosystem processes (*e.g.*, nutrient cycling, carbon uptake). Because changes in the climate system are likely to persist into the future regardless of emissions mitigation, strategies for protecting climate-sensitive ecosystems through management will be increasingly important.

Thus, the primary audience for this report is resource managers, and the goal is to provide useful information on potential adaptation options for key, representative ecosystems and resources that may be sensitive to climate variability and change. Adaptation is defined as an adjustment in ecological, social, or economic systems in response to climate stimuli and their effects. The chosen context for reviewing adaptation options is federally protected and managed lands and waters, because they have management challenges that are representative of the range of challenges faced by other ecosystem management organizations across the United States. The six types of federally managed systems that are considered include national forests, national parks, national wildlife refuges, wild and scenic rivers, national estuaries, and marine protected areas.

For each of the above management systems, the approach in this report is to examine (1) the combined effects on ecosystems of climate changes and non-climate stressors, and consequent implications for achieving specific management goals; (2) existing management options or new adaptation approaches that reduce the risk of negative outcomes; and (3) opportunities and barriers that could affect successful implementation of adaptation strategies. Case studies are used to discuss specific adaptation options and their potential application in specific places (Fig. 1.1).

Figure 1.1. Map showing the geographic distribution in the United States of SAP 4.4 case studies.

In order to ensure that the proposed structure and content of each chapter was assessed for technical rigor and feasibility from a management perspective, an array of stakeholders was engaged during the earliest stages of the report. Stakeholders from the management and adaptation research communities were selected from across federal and state governments, territories, non-governmental organizations, and academia to participate in a series of workshops to advise the authors of the report on its content. A major finding of the workshops was that for many of the management systems, management plans are only beginning to consider climate impacts, with few adaptation strategies yet being enumerated or implemented in the field; however, the stakeholders had considerable experience with management of “weather” and were able to contribute key insights into how best to convert current management practices—or create new ones—to achieve effective adaptation to climate change. These stakeholder contributions inform the content throughout each of the chapters described below.

1.3 National Forests

1.3.1 Background and Current Status of Management

Today there are 155 national forests and 20 national grasslands, the result of public and private interest in the conservation of natural resources within the United States. These lands encompass a wide range of ecosystems, harbor a large proportion of the nation’s biodiversity, and provide myriad goods and services. The U.S. Forest Service’s (USFS) mission has broadened from water and timber to sustaining the health, diversity, and productivity of forests and grasslands to meet the needs of present and future generations.

Climate change will affect the USFS’s ability to restore, sustain, and enhance forest and grassland ecosystems. Wildfires, nuisance species, extreme events, and air pollution are the most critical stressors within national forest (NF) boundaries, and climate change will amplify them further. Reduced snowpack, earlier snowmelt, and altered hydrology associated with warmer temperatures and altered precipitation patterns are expected to complicate western water management. Ozone exposure and deposition of mercury, sulfur, and nitrogen already affect watershed condition, and their impact will likely be exacerbated by climate change. While major USFS programs aim to manage these stressors, these programs are only beginning to consider climate change.

1.3.2 Adapting to Climate Change

Four adaptation options could be implemented immediately:

1) *Develop an information and educational outreach program for USFS employees*. Resource managers need to be much better informed about short- and long-term climate change effects and adaptation options within their forests.

2) *Integrate climate change into the existing USFS planning structure.* The USFS has a legislative mandate to address climate change. Integration would identify ecological, social, and institutional opportunities and barriers to adaptation. Research needs include development of a tool box for multi-scale analyses.
3) *Identify situations where management may forestall effects of climate change and where management may need to facilitate adaptation to climate change.* Existing management strategies can be reframed to identify ecosystem services and resources to manage for resistance to climate change (*e.g.*, management to suppress fire, insects), or for resilience (*e.g.*, expansion of seed transfer guidelines; encouraging landscape diversity of genetics, species, and structures). An adaptive strategy will involve integrating a suite of practices to address individual goals and evaluating various types of uncertainties (*e.g.*, present environmental conditions, information sources about the future, availability of staff, time, funds, and public and societal support). This evaluation would lead to a decision on whether it is best to develop reactive responses to changing disturbances and extreme events, or proactive responses anticipating climate change. Research needs include identifying the role of a changing climate in current management (*e.g.*, historical range of natural variability, "100 year flood" events) and in disturbances (*e.g.*, insect outbreaks, concept of "exotic versus native").
4) *Manage for desired ecological processes using the changing structural conditions on forests and grasslands to restore, sustain, and enhance NF ecosystem services.* Working toward the goal of desired future functions (*e.g.*, processes, ecosystem services) would involve managing current and future conditions (*e.g.*, structure, outputs), which may be dynamic through a changing climate, to sustain those future functions as climate changes. This adaptation option builds upon the three activities above.

Longer term adaptation options include:

1) *Establish priorities for addressing potential changes in populations, species, and community abundances, structures, and ranges, including potential species extirpation and extinction under climate change.* The USFS could develop a common framework to prioritize management responses in situations where the magnitude and scope of anticipated needs, combined with diminishing available human resources, dictate that priorities be evaluated swiftly, strictly, and definitely.
2) *Develop early detection and rapid response systems for post-disturbance management.* Apply the proposed systems in the USFS invasive species strategy to a broader suite of climate-induced stressors (*e.g.*, fire, invasives, floods, wind). Large system-resetting disturbances offer opportunities to influence ecosystem structure and function and to consider post-disturbance management prior to disturbance.

1.3.3 Insights from Case Studies

The case studies (Tahoe NF, Olympic NF, and Uwharrie NF) represent a first attempt to consider adaptation to climate change within national forests.

Identified barriers include limited resources such as staffing, expertise, and funds in light of the potential treatments needed to adapt to climate change; lack of a strong science-management partnership; and, policies or regulations that do not recognize climate or climate change. One opportunity is to develop emerging carbon markets that are likely to promote biomass and biofuels industries, which in turn may provide economic incentives for active adaptive management. The collaboration and cooperation with other agencies, national networks, and the public required to manage NF lands could be an opportunity or a barrier. The ability of the USFS to adapt will be enhanced or hindered to the extent that these other groups recognize and address climate change. Adaptive management is also both an opportunity and a barrier. While it promotes learning how to project and mitigate the effects of climatic change, it may not be useful when the ability to act is constrained by policies or public opinion, or when actions must be taken quickly.

1.3.4 Conclusions

Over the near term, climatic-related disturbances will have the greatest impact on treatment of NF lands, given that active vegetation management treatments on NFs are limited. These disturbances—wildfire, insects, and invasive species expansion—offer an opportunity for the USFS to adapt to climate change because adjustments to management approaches could be best made during or after a major climatic event or disturbance event such as these.

There is a clear need for the Forest Service as a whole to respond to the potential impacts of climate change. While this report focuses on the National Forest System and on research, climate change needs to be addressed across all functional lines and program areas (including state and private forestry, and international programs) of the Forest Service.

1.4 National Parks

1.4.1 Background, History, Current Status of Management

The U.S. National Park Service (NPS) Organic Act established the National Park System in 1916 to conserve "unimpaired" select scenery, natural and historic objects, and wild life for the enjoyment of future generations. Although its overarching mission is mostly unchanged, the NPS has undergone substantial changes in management philosophy over time. Current guidance allows natural evolution of processes and species to continue, minimally influenced by human actions. Parklands are naturally dynamic systems. However, changes in climate are likely to profoundly alter national parks, with some iconic species facing a high risk of extinction and many other species shifting distributions across the American landscape without respect to protected area borders. Stressors of concern that will interact with and be exacerbated by climate change include altered disturbance regimes, habitat fragmentation and loss, invasive species, and pollution. Climate change will also directly affect park resources through increasing temperatures, changes in the timing and rate of precipitation events, storms and droughts, and changes in hydrologic processes. These impacts will affect the ability of the NPS to achieve its primary goal of conserving park resources and will create new challenges to scientific knowledge in support of resource management.

1.4.2 Adapting to Climate Change

The uncertainty associated with projecting changes to national parks poses clear challenges for NPS managers. Management practices that aim to “fix” problems work best when uncertainty about outcomes is low. Scenario-based strategic planning and adaptive environmental assessment and management are more flexible tools that help managers consider and learn how to manage when uncertainty is high. Strategies to stimulate proactive modes of thinking and acting in the face of climate change include broadening the portfolio of management approaches, increasing the capacity to learn from management successes and failures, and examining and responding to the multiple scales, including ecoregional, at which species and processes function. Strategies also include catalyzing ecoregional coordination, valuing human resources, and understanding what climate change means for interpreting the language of the NPS Organic Act. Central to successful adaptation is sound scientific information on the status and trends of ecosystems, biological resources, and important ecological processes identified by each park or region.

1.4.3 Insights from Case Studies

Rocky Mountain National Park is representative of a number of national parks that are just beginning to incorporate considerations of climate change into their planning efforts. Effective science-based management in Rocky Mountain National Park has enhanced the ability of park natural resource managers to adapt to climate change. Park managers are proactive in removing or preventing the spread of invasive and non-native species, managing fire risk through controlled burns and thinning, reducing regional air pollution through partnerships with regulatory agencies, acquiring the rights to most water in the park, and preparing a plan to control elk populations. However, climate change poses challenges to management that remain unaddressed: in particular, catastrophic wildfire, increasing insect infestations and outbreaks, damage from large storm events, and impacts on alpine tundra and the species that live above treeline. Scientific information on baseline conditions and projected changes in conditions (*e.g.*, temperature, CO_2, ozone, drought, water quality and quantity) is needed in order to develop adaptation strategies to address these impacts. Recurrent workshops of experts and regional resource managers may prove useful for sharing information and identifying resources and processes susceptible to climate change, developing planning scenarios, proposing adaptive experiments and management opportunities, and keeping abreast of the state of knowledge regarding climate change and its effects. Rocky Mountain National Park also needs to develop baselines for species or processes of highest concern and establish monitoring programs to track changes over time. The “vital signs” that have been identified for the park should also be reviewed and possibly revised to capture effects that will occur with climate change. Greater collaboration with regional partners may also facilitate regional planning, especially for issues that cross park boundaries. Professional development programs for current resource managers, rangers, and park managers could be strengthened, so that all employees understand the natural resources that are under the protection of the NPS and the causes and consequences of threats to these resources. Finally, training of future natural resource managers needs to broaden beyond traditional training in fisheries, wildlife, or recreation management. University curricula should teach ecosystem concepts, interdisciplinary and collaborative ways of decision-making under uncertainty, and adaptive management tools.

1.4.4 Conclusions

The insights that emerge from evaluating adaptation options of national parks to climate change are that *how* we think about natural resource management is at least as important than *what* we do to allow natural resources in national parks to adapt. The National Park System contains some of the least degraded ecosystems in the United States. However, all ecosystems are changing due to climate change and other human-caused disturbances, including those in national parks. All natural resource managers are challenged to evaluate the possible ramifications, both desirable and undesirable, to the resources under their protection, and to develop strategies for minimizing harm under changing global conditions. "Unimpaired" becomes a moving target as the baseline changes in response to human activities. Effective adaptations will go beyond policy evaluation, and include the need for collaborative evaluation of alternative scenarios of change at regional and local scales, specification of uncertainties, sensitivity analyses, and development of rigorous adaptive management plans in which collection of data is explicitly designed to evaluate the effects of alternative, feasible, management interventions. By adjusting NPS thinking to accept that future ecosystems in parks will be truly dynamic, management practices will evolve to maximize the potential for national park ecosystems to adapt as naturally as possible to changing climates.

1.5 National Wildlife Refuges

1.5.1 Background and Current Status of Management

The National Wildlife Refuge System (NWRS) includes 547 refuges and 30,000 waterfowl production areas managed by the U.S. Fish and Wildlife Service (USFWS). Its purpose is to conserve the diversity of plants, animals, and ecosystems in the United States, and to provide educational and recreational opportunities to the American public. Refuges that are most vulnerable to the effects of climate change include 161 coastal refuges that may be affected by sea level rise, and 16 refuges in Alaska (82% of the total area of the NWRS) that are projected to experience significant increases in temperature. All of the NWRS's conservation targets, including threatened and endangered species, ecosystems, and migratory species, could be affected directly by climate change through biome shifts, sea level rise, altered hydrological regimes, and increases in fire and storm intensity, as well as indirectly when climate change stressors affect existing threats to the NWRS such as non-native invasive species, diseases, habitat fragmentation, and drought.

1.5.2 Adapting to Climate Change

The most important existing adaptation option for the NWRS is the strategic growth of the system through increased representation, redundancy and resilience. Ensuring the representation and redundancy of different ecosystems, geophysical and biological features and habitats within the NWRS will help buffer against the uncertain effects of future climate change. Increased resilience could be achieved through restoration and expansion of the NWRS's conservation role with conservation easements, and fee-simple acquisitions of in-holdings and adjacent land parcels from willing sellers. Strategic growth could be targeted toward those refuges, species, and ecosystems that are identified as most vulnerable to regime shifts, sea level rise, and other effects of climate change. In support of targeted growth, monitoring systems could be valuable for assessing species' distributions and abundance, as well as for monitoring changes in phenology, arrival and departure times of migrants, flowering dates for plants, and emergence dates for insects.

The most important future adaptation options include increased conservation partnerships with adjacent landowners, secured water rights for refuges, and the facilitation of state and federal agency cooperation and information sharing on issues of climate change. These options could be facilitated through establishment of a national interagency climate change council and a national interagency climate change information network.

1.5.3 Insights from the Case Study

The Alaska Region of the USFWS held a Climate Change Forum to enhance regional awareness of potential climate-induced changes in habitats and trust species populations, and to identify examples of management adaptations. Among other adaptations, (1) the timing of annual waterfowl surveys have been dynamically adjusted to accommodate climate-induced advancing phenology; (2) research projects that document regional heterogeneity in the rate, magnitude, and mechanisms associated with climate-induced lake drying have been initiated; (3) partnerships with native communities have been developed to monitor invasive species and contaminants potentially associated with newly opened northern shipping routes; and (4) range expansions of desirable species have been facilitated by changes in management focus (*e.g.*, waterfowl, ungulates).

The primary barriers to implementation of adaptation options include (1) an inadequate understanding of the effects of changing climate on seasonal habitats of trust species and their implications for populations, (2) insufficient resources and funding mechanisms to develop an increased understanding of climate change effects on trust species and resources, and (3) a lack of system-level proactive planning actions. The primary opportunities for enhancing implementation of adaptation options include (1) creating an institutional culture where employees are rewarded for being proactive catalysts for adaptation to climate change, (2) developing enhanced predictive models of climate-induced changes in habitats, and (3) implementing Comprehensive Plans and Biological Reviews to routinely address expected effects of climate change and to identify potential mechanisms for adaptation to these challenges.

1.5.4 Conclusions

Climate change is not the first crisis faced by the NWRS, but it is unprecedented in the scale of its impacts. The size and geographic distribution of refuges is insufficient to allow them to maintain conservation targets and to fulfill the goals of the NWRS by themselves. The goals of the NWRS can be better met with cooperative conservation partnerships with public and private land managers.

1.6 Wild and Scenic Rivers

1.6.1 Background, History, and Current Status of Management

The Wild and Scenic Rivers Act of 1968 calls for the preservation of select “free-flowing" rivers with “outstandingly remarkable values.” The “outstandingly remarkable values” encompass a range of scenic, biological, and cultural characteristics that society values while "free flowing" generally refers to river stretches with high water quality and with no major dams or obstructions within the stretch of river to be designated. Climate change will challenge river managers to explicitly consider not only climatic, hydrogeologic and ecological conditions, but also human-induced impacts. Current management practices related to water use and reuse, dam operations, and land-use are sensitive to the direct effects of climate change as well as indirect effects on river discharge and channel morphologies. These impacts will affect species and ecological processes of Wild and Scenic Rivers (WSRs) in ways that could threaten their ability to provide the ecosystem services for which they were designated.

1.6.2 Adapting to Climate Change

The ability of rivers to "absorb" disturbances such as climate-induced changes in discharge depends largely on the "wildness" of their watershed. Un-impounded rivers in fully forested watersheds will fare best—they should be able to provide the expected ecosystem services unless changes in the thermal and flow regimes deviate dramatically from recent regimes.

Proactive management efforts can be taken to protect WSRs and are especially important for those in watersheds already affected by human activities. Specific management actions include restoration of flood plains and riparian buffers, land purchases, reductions in water withdrawals, and river flow augmentation using alternative water resources. These adaptations can be taken now to maintain or increase the resilience of WSRs in the face of expected impacts. Protecting species that reside in WSRs deemed the most vulnerable to the impacts of climate change (*e.g.,* because of their location or level of existing impacts) may require closure of these rivers to recreation. Land purchases and protection of nearby rivers that may serve as refugia for species are important actions.

Without sufficient proactive management, managers will likely need to develop strategies once impacts are felt. Examples of reactive management include rescuing stranded canoeists caught by unexpected floods, moving Park Service buildings that are too close to eroding streambanks, restoring in-stream or riparian habitat that is lost to floods or drought, installing fish passages to allow stranded fish to move between isolated reaches during drought times, changing dam management to ensure adequate environmental and recreational flows during the summers or to ensure that dams are not breached in watersheds that are more flood-prone under future climates, and shifting access points for wildlife or river enthusiasts or moving existing trails. In general, reactive management approaches are not as desirable as proactive approaches because substantial ecosystem and infrastructure damage is likely to occur before reactive measures are taken. It is difficult to forecast the magnitude of such damages; minimizing uncertainty of outcomes requires a proactive approach. Some reactive strategies could become proactive adaptations if potential management responses are planned and implemented before the impacts are felt. For example, changes in dam management can be taken prospectively to ensure adequate environmental and recreational flows during summers under future climates.

1.6.3 Insights from Case Studies

Rivers across the United States have been designated as wild and scenic for diverse reasons and they exist in diverse settings; only a small subset of WSRs are free-flowing rivers in fully protected watersheds. For this reason, multiple case studies were chosen that spanned free-flowing pristine rivers to highly stressed rivers. The Upper Delaware WSR section is expected to experience more flooding, so the National Park Service has already begun to work with the National Weather Service to gather data on local precipitation, snowpack, and river ice cover to enable better forecasting of flood crests and times to provide advanced warning to valley residents. Further, NPS is working with local councils to encourage land use and zoning that are protective of the river and its resources, and they have already moved park infrastructure and re-routed some trails. The Wekiva River in Florida is a spring-fed system in a rapidly developing coastal region. This development pressure along with expected increases in temperatures will further stress the Floridan aquifer that currently provides water for people and agriculture and sustains the Wekiva springs. In response, the local water management district in concert with counties and cities in the watershed are working on local water resources plans and an integrated basin-wide water plan that will guide water use and conservation land use changes for the coming decades. The Rio Grande throughout New Mexico and Texas is likely to experience climate extremes in the form of higher temperatures and recurring droughts, on top of population growth and other existing stressors such as excessive water extractions and dams. Sustaining flows will depend on coordination between the U.S. Forest Service and the Bureau of Land Management, which manage this WSR stretch, and the Bureau of Reclamation, which manages upstream water projects (both groundwater and surface water) that influence downstream flows. Finally, the wild rivers of Alaska should be viewed as a laboratory for researching climate change impacts on riverine ecosystems and developing potential adaptation strategies. Given the location and pristine nature of these rivers, they can serve as an early warning to managers in regions further south years before they face similar changes that will necessitate similar adaptation responses.

1.6.4 Conclusions

Unlike many parks that exist entirely within federal lands, most WSRs are within watersheds in which substantial parcels of land are in private ownership. Further, many are within watersheds greatly affected by human activities including development, dams, and water extraction. Thus, climate change will interact with other stressors to potentially increase the overall impacts to many WSR ecosystems. Further, the complex ownership issue makes management a great challenge. Proactive management to minimize impacts to these systems will involve careful planning and forging partnerships between land owners and federal managers to initiate actions now. Without such proactive actions, management will require reactive responses as floods, droughts, elevated temperatures, and other impacts of climate change affect ecosystems and the services they provide for species and people.

1.7 National Estuaries

1.7.1 Background and Current Status of Management

There are 28 estuaries in the U.S. National Estuaries Program (NEP) that span the full spectrum of estuarine types from saline coastal lagoons to more traditional estuaries with salinity gradients. The NEP management goals at greatest risk to climate change include preserving valuable habitat, sustaining fish and wildlife production, and maintaining water quality. The authorities used to manage national estuaries are diffuse and include a combination of federal and state programs that have their own management goals. Estuaries have experienced dramatic declines in marsh and seagrass habitat, water quality, apex predators, and delivery of ecosystem services compared with historic baselines of the late 1800s. Ecosystems at risk from climate change include shallow coastal habitats such as salt marsh, intertidal flats, seagrass beds, and oyster reefs. The greatest threat to estuarine habitat, fish and wildlife, and water quality from climate change derives from the loss of tidal marsh and wetland buffers. These vegetated buffers are threatened by both sea level rise and increasingly intense storms interacting with estuarine shoreline hardening (*e.g.*, from installation of bulkheads, dikes, and other engineered structures). Although such structures protect private property and public infrastructure from erosion, they also prevent intertidal and shallow subtidal habitats from migrating inland as sea level rises. The result of this impeded retreat is loss of marsh habitat and associated water quality functions along extensive portions of estuarine shorelines.

1.7.2 Adapting to Climate Change

It may be possible to partially alleviate damage in the short term to tidal marshes on developed shores through management adaptations, such as installation of natural and artificial breakwaters and shoreline purchase programs. On undeveloped shores, programs prohibiting structural defense against erosion or requiring rolling easements could allow orderly retreat of shoreline habitats. As climate change leads to increases in storm intensity, proactive expansion and protection of riparian floodplains could help sustain wetland habitat functions and provide better flood protection for developed areas. Floodplains offer some of the last remaining undeveloped components of the coastal landscape over which flooding due to rising sea level might occur with minimal human impact. Expanding protected areas of floodplains helps build resilience of the ecological and socioeconomic system.

Comprehensive planning could be initiated now to act opportunistically after major storm disasters. One example is to modify rules or change policies to restructure development along coastal barrier and estuarine shorelines, in order to avoid future loss of life and property and to protect environmental assets and ecosystem services in the interest of the public trust. Planning now to prevent rebuilding in hazardous areas of high flood risk and storm damage may be feasible (*e.g.*, modify local land use plans to direct post-storm redevelopment into less risky areas). However, such plans might result in financial losses to coastal property owners unless compensated through policy initiatives. Longer-term funding to purchase the most risky shorelines may be available from land trusts and programs to protect water quality, habitat, and fisheries.

1.7.3 Insights from Case Studies

The 1994 Comprehensive Conservation and Management Plan for the Albemarle-Pamlico National Estuary Program presented objectives for plans in five areas: water quality, vital habitats, fisheries, stewardship, and implementation. Climate change was not explicitly considered. However, current efforts to identify ecosystem status indicators include several related to climate change.

The greatest challenge to successful adaptation to climate change is preserving the integrity of the coastal barrier complex of the Outer Banks over time scales of a century and longer. These coastal barriers are responsible for creating this estuarine system, and a major breach in their integrity will ultimately convert the estuary into a coastal ocean embayment.

Opportunities for implementing adaptive management exist through the legislatively mandated Coastal Habitat Protection Plan, an ecosystem-based management plan for preserving and enhancing coastal fisheries. This plan is developed collaboratively by all necessary state agencies and thus overcomes the historic constraints that arise from compartmentalized management authorities. The State Commission on Effects of Climate Change, legislated in 2005, also provides an opportunity for education and participation by legislators in a forward-looking planning process that exceeds the typical political term. Finally, sparse human populations and low levels of development along much of the interior mainland shoreline of the Albemarle-Pamlico National Estuary Program complex provides an opportunity to implement policies that allow the salt marsh and other shallow-water estuarine habitats to retreat as sea level rises.

1.7.4 Conclusions

Maintaining the status quo in management of estuarine ecosystems would insure substantial losses of ecosystem services as climate change progresses. In the absence of effective management adaptation, climate-related failures will appear in all of the most important management goals identified in the Comprehensive Conservation and Management Plans of national estuaries: maintaining water quality, sustaining fish and wildlife populations, preserving habitat, protecting human values and services, and fulfilling water quantity needs.

Among the consequences of climate change that threaten estuarine ecosystem services, the most serious involve interactions between climate-dependent processes and human responses to climate change. In particular, conflicts arise between sustaining public trust values and private property rights, in that current policies protecting private shoreline property become increasingly injurious to public trust values as climate changes and sea level rises further.

1.8 Marine Protected Areas

1.8.1 Background and Current Status of Management

Marine protected areas (MPAs) such as national marine sanctuaries provide place-based management of marine ecosystems through various degrees and types of protective actions. A goal of national marine sanctuaries is to maintain natural biological communities by protecting habitats, populations, and ecological processes using community-based approaches. Biodiversity and habitat complexity are key ecosystem characteristics that must be protected to achieve sanctuary goals, and biologically structured habitats (such as coral reefs and kelp forests) are especially susceptible to degradation resulting from climate change. Marine ecosystems are susceptible to the effects of ocean acidification on carbonate chemistry, as well as to direct and indirect effects of changing temperatures, circulation patterns, increasing severity of storms and other factors.

1.8.2 Adapting to Climate Change

Implementing networks of MPAs will help spread the risks posed by climate change by protecting multiple replicates of the full range of habitats and communities within an ecosystem. In designing networks, managers should consider information on areas that may represent potential refugia from climate change impacts as well as information on connectivity (current patterns that support larval replenishment and recovery) among sites that vary in their sensitivities to climate change.

Within sites, managers can increase resilience to climate change by managing other anthropogenic stressors that also degrade ecosystems, such as fishing and overexploitation; inputs of nutrients, sediments, and pollutants; and habitat damage and destruction. Resilience is also affected by trophic linkages, which are a key characteristic maintaining ecosystem integrity. Thus, a mechanism that has been identified to maintain resilience is the management of functional groups, specifically herbivores. In one instance on the Great Barrier Reef, recovery from an algae-dominated to a coral-dominated state was driven by a single batfish species, not grazing by dominant parrotfishes or surgeonfishes that normally keep algae in check on reefs. This finding highlights the need to protect the full range of species to maintain resilience and the need for further research on key species and ecological processes.

The challenges of climate change require creative collaboration among a variety of stakeholders to generate the necessary finances and support to respond to climate change stress. Engagement of stakeholders to help adapt management practices to changing conditions will help MPA managers build the knowledge and collaborations needed to implement adaptive approaches.

1.8.3 Insights from Case Studies

The Great Barrier Reef Marine Park is an example of an MPA that has a relatively highly developed climate change program in place. A Coral Bleaching Response Plan is part of its Climate Change Response Program, which is linked to a Representative Areas Program and a Water Quality Protection Plan in a comprehensive approach to support the resilience of the coral reef ecosystem. In contrast, the Florida Keys National Marine Sanctuary is only now developing a bleaching response plan. The Florida Reef Resilience Program, under the leadership of The Nature Conservancy, is implementing a quantitative assessment of coral reefs before and after bleaching events. The recently established Papahānaumokuākea (Northwestern Hawaiian Islands) Marine National Monument is the largest MPA in the world and provides a unique opportunity to examine the effects of climate change on a nearly intact large-scale marine ecosystem. These three MPA case studies are based on coral reef ecosystems, which have experienced coral bleaching events over the past two decades. A fourth case study covers the Channel Islands National Marine Sanctuary, off the coast of southern California. The Sanctuary Management Plan for the Channel Islands National Marine Sanctuary mentions, but does not fully address, the issue of climate change. The plan describes a strategy to identify, assess, and respond to emerging issues through consultation with the Sanctuary Advisory Council and local, state, or federal agencies. Emerging issues that are not yet addressed by the management plan include ocean warming, sea level rise, shifts in ocean circulation, ocean acidification, spread of disease, and shifts in species ranges.

Barriers to implementation of adaptation options in MPAs include lack of resources, varying degrees of interest in and concern about climate change impacts, and a need for basic research on marine ecosystems and climate change impacts. The National Marine Sanctuary Program's strategic plan does not address climate change, but the program recently formed a Climate Change Working Group that will be developing recommendations. Although there is considerable research on physical impacts of climate change in marine systems, research on biological effects and ecological consequences is not as well developed.

Opportunities with regard to implementation of adaptation options in MPAs include a growing public concern about the marine environment, recommendations of two ocean commissions, and an increasing dedication of marine scientists to conduct research that is relevant to MPA management. References to climate change as well as MPAs permeate both the Pew Oceans Commission and U.S. Commission on Ocean Policy reports on the state of the oceans. Both commissions held extensive public meetings, and their findings reflect changing public attitudes about protecting marine resources and threats of climate change. The interests of the marine science community have also evolved, with a shift from basic to applied research over recent decades. Attitudes of MPA managers have changed as well, with a growing recognition of the need to better understand ecological processes in order to implement science-based adaptive management in the ocean.

1.8.4 Conclusions

The most effective configuration of MPAs would be a network of highly protected areas nested within a broader management framework. As part of this configuration, areas that are ecologically and physically significant and connected by currents, larval dispersal, and adult movements should be identified and included as a way of enhancing resilience in the context of climate change. Critical areas to consider include nursery grounds, spawning grounds, areas of high species diversity, areas that contain a variety of habitat types in close proximity, and potential climate refugia. At the site level, managers can build resilience to climate change by protecting marine habitats from direct anthropogenic threats such as pollution, sedimentation, destructive fishing, and overfishing. The healthier the marine habitat, the greater the potential will be for resistance to—and recovery from—climate-related disturbances. Finally, effective implementation of the above strategies in support of ecological resilience will only be possible in the presence of human social resilience.

1.9 Synthesis and Conclusions

A synthesis of ideas and lessons learned from across this report provides an approach to climate adaptation that may be useful to the larger community of non-federal as well as federal resource managers. Any manager may apply the thought processes outlined below to determine whether the management goals for a system are vulnerable to climate change and how he or she can respond. Responses may range from relatively simple changes in existing practices that fit within current programs and management policies, to wholly new adaptation practices that require a transformation in management and goal-setting from a static approach to one that is dynamic.

The first question for managers is whether their ability to meet the management goals for their systems will be affected by climate change. This question may be addressed through examining the existing literature and comparing likely climate change impacts with key ecological properties or components needed to reach management goals. If management goals are vulnerable to climate change, a tool such as a decision support model may be used to conduct sensitivity analyses of ecological properties and components to a range of potential future climate changes. Such sensitivity analyses can provide the foundation for "if/then" planning. Managers will also need to develop or modify monitoring schemes to track and substantiate vulnerabilities to climate change and assess the effects of management adaptations.

When the nature of a system's vulnerability to climate change is understood well enough to determine that action should be taken in order to continue meeting management goals, there are a number of adaptation approaches that may be applied (Box 1.1). These approaches are relevant for most managed systems and can be operationalized in a variety of ways. In addition to these "ecological" adaptation approaches, there are other relevant approaches that focus on adapting social systems to anticipated ecological changes. Such approaches include adjusting management targets, policies, and procedures to reflect anticipated changes, and restricting activities or practices to allow ecological changes to occur (such as restricting development along the coast to allow tidal wetlands to migrate inland).

Because of uncertainties in projected climate change and in our knowledge of the consequent effect on species and ecosystems, the ability of adaptation approaches to effectively accomplish their intended purpose is also uncertain. It is therefore essential to characterize for resource managers the level of confidence associated with the adaptation approaches listed in Box 1.1. Based on the literature and the expert opinion of the author teams who considered the application of each approach within their specific management systems, confidence estimates have been developed (see Table 1.1). It is important to consider these types of confidence estimates when deciding which adaptation approaches to implement for a given system.

Adaptive management is likely to be the most attractive method for implementing these adaptation approaches since it is an iterative process that emphasizes (1) experiments to learn how management practices function, (2) monitoring and data collection to measure their effectiveness, and (3) adjustments in practices to incorporate new information and improve results. The prospect of widespread and uncertain ecological effects from changes in the climate system may represent a tipping point that spurs managers to embrace adaptive management as an essential strategy—one that enables management action today while allowing for increased understanding and refinement tomorrow.

Finally, there may be situations in which adaptation strategies will not enable a manager to meet specific goals. 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. 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. Such circumstances may necessitate fundamental shifts in how ecosystems are managed, such as 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. Such fundamental shifts in national-level policies include establishing priorities across systems and species, and developing rules for triage; enabling management across jurisdictions and at larger scales; enabling management for projected ecological changes; and expanding 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.

The spatial scale and ecological scope of climate change necessitates 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. Only through collaboration and cooperation among institutions will this approach be feasible. Effective leadership at the highest levels of government is needed to enable agencies at all levels and the public to work together to maintain those ecosystems and ecosystem services that are both valuable and likely to be viable in the future despite the effects of climate change.

1.10 References

McCarthy, J., O. Canziani, N. Leary, D. Dokken, and K. White, 2001: *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. GRID-Arendal.

U.S. Climate Change Science Program, 2007: US Climate Change Science Program website homepage. Climate Change Science Program Website, http://www.climatescience.gov/, accessed on 7-27-2007.

1.11 Boxes

Box 1.1. Categories of adaptation approaches drawn from across the chapters of this report.

Protect Key Ecosystem Features **–** key ecosystem features (*e.g.*, structural habitat, keystone species, corridors, processes) upon which biodiversity (and hence resilience) depend are strategically targeted for special protections

Reduce Anthropogenic Stresses **–** reduce or eliminate all direct (non-climate) anthropogenic stresses that can be managed locally, in order to preserve or enhance the resilience of ecosystems to regional, uncontrollable climate stresses

Refugia – use physical environments that are less affected by climate change than other areas (*e.g.*, due to local currents, geographic location) as a "refuge" from climate change for organisms

Relocation – use human-facilitated transplantation of organisms from one location to another in order to bypass a barrier (*e.g.*, an urban area)

Replication – protect multiple replicates of a habitat type (*e.g.*, multiple fore reef areas throughout the reef system) as a "bet hedging" strategy against loss of the habitat type due to a localized disaster

Representation – ensure that both (1) the full breadth of habitat types is protected (*e.g.*, fringing reef, fore reef, back reef, patch reef) and (2) the full breadth of species diversity is included within sites; both concepts relate to maximizing overall biodiversity of the larger system

Restoration – manipulate the physical and biological environment in order to restore a desired ecological state or set of ecological processes

1.12 Tables

Table 1.1. Chapter authors' confidence estimates on the effectiveness of various adaptation approaches for each management system type**.** Estimates are based on an approach developed by the Intergovernmental Panel on Climate Change (McCarthy *et al.*, 2001).

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

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1.13 Figures

Figure 1.1. Map showing the geographic distribution in the United States of SAP 4.4 case studies.