

# 1 Executive Summary

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## 2 **1.1 Introduction**

3 The United States government’s Climate Change Science Program (CCSP) is responsible  
4 for providing the best science-based knowledge possible to inform management of the  
5 risks and opportunities associated with changes in the climate and related environmental  
6 systems (U.S. Climate Change Science Program, 2007). The CCSP has commissioned 21  
7 “synthesis and assessment products” (SAPs) to advance decision-making on climate  
8 change-related decisions by providing current evaluations of climate change science and  
9 identifying priorities for research, observation, and decision support. This Report—SAP  
10 4.4—focuses on federally owned and managed lands and waters to provide a  
11 “Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and  
12 Resources.” It is one of seven reports that support Goal 4 of the CCSP Strategic Plan to  
13 understand the sensitivity and adaptability of different natural and managed ecosystems  
14 and human systems to climate and related global changes.

## 15 **1.2 Background**

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

24

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

35

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

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**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.

- 1 2) *Integrate climate change into the existing USFS planning structure.* The USFS has a  
2 legislative mandate to address climate change. Integration would identify ecological,  
3 social, and institutional opportunities and barriers to adaptation. Research needs  
4 include development of a tool box for multi-scale analyses.
- 5 3) *Identify situations where management may forestall effects of climate change and*  
6 *where management may need to facilitate adaptation to climate change.* Existing  
7 management strategies can be reframed to identify ecosystem services and resources  
8 to manage for resistance to climate change (*e.g.*, management to suppress fire,  
9 insects), or for resilience (*e.g.*, expansion of seed transfer guidelines; encouraging  
10 landscape diversity of genetics, species, and structures). An adaptive strategy will  
11 involve integrating a suite of practices to address individual goals and evaluating  
12 various types of uncertainties (*e.g.*, present environmental conditions, information  
13 sources about the future, availability of staff, time, funds, and public and societal  
14 support). This evaluation would lead to a decision on whether it is best to develop  
15 reactive responses to changing disturbances and extreme events, or proactive  
16 responses anticipating climate change. Research needs include identifying the role of  
17 a changing climate in current management (*e.g.*, historical range of natural variability,  
18 “100 year flood” events) and in disturbances (*e.g.*, insect outbreaks, concept of  
19 “exotic versus native”).
- 20 4) *Manage for desired ecological processes using the changing structural conditions on*  
21 *forests and grasslands to restore, sustain, and enhance NF ecosystem services.*  
22 Working toward the goal of desired future functions (*e.g.*, processes, ecosystem  
23 services) would involve managing current and future conditions (*e.g.*, structure,  
24 outputs), which may be dynamic through a changing climate, to sustain those future  
25 functions as climate changes. This adaptation option builds upon the three activities  
26 above.

27  
28 Longer term adaptation options include:

- 29  
30 1) *Establish priorities for addressing potential changes in populations, species, and*  
31 *community abundances, structures, and ranges, including potential species*  
32 *extirpation and extinction under climate change.* The USFS could develop a common  
33 framework to prioritize management responses in situations where the magnitude and  
34 scope of anticipated needs, combined with diminishing available human resources,  
35 dictate that priorities be evaluated swiftly, strictly, and definitely.
- 36 2) *Develop early detection and rapid response systems for post-disturbance*  
37 *management.* Apply the proposed systems in the USFS invasive species strategy to a  
38 broader suite of climate-induced stressors (*e.g.*, fire, invasives, floods, wind). Large  
39 system-resetting disturbances offer opportunities to influence ecosystem structure and  
40 function and to consider post-disturbance management prior to disturbance.

### 41 **1.3.3 Insights from Case Studies**

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

44  
45 Identified barriers include limited resources such as staffing, expertise, and funds in light  
46 of the potential treatments needed to adapt to climate change; lack of a strong science-  
47 management partnership; and, policies or regulations that do not recognize climate or

1 climate change. One opportunity is to develop emerging carbon markets that are likely to  
2 promote biomass and biofuels industries, which in turn may provide economic incentives  
3 for active adaptive management. The collaboration and cooperation with other agencies,  
4 national networks, and the public required to manage NF lands could be an opportunity  
5 or a barrier. The ability of the USFS to adapt will be enhanced or hindered to the extent  
6 that these other groups recognize and address climate change. Adaptive management is  
7 also both an opportunity and a barrier. While it promotes learning how to project and  
8 mitigate the effects of climatic change, it may not be useful when the ability to act is  
9 constrained by policies or public opinion, or when actions must be taken quickly.

#### 10 **1.3.4 Conclusions**

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

17  
18 There is a clear need for the Forest Service as a whole to respond to the potential impacts  
19 of climate change. While this report focuses on the National Forest System and on  
20 research, climate change needs to be addressed across all functional lines and program  
21 areas (including state and private forestry, and international programs) of the Forest  
22 Service.

### 23 **1.4 National Parks**

#### 24 **1.4.1 Background, History, Current Status of Management**

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

1 **1.4.2 Adapting to Climate Change**

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

16 **1.4.3 Insights from Case Studies**

17 Rocky Mountain National Park is representative of a number of national parks that are  
18 just beginning to incorporate considerations of climate change into their planning efforts.  
19 Effective science-based management in Rocky Mountain National Park has enhanced the  
20 ability of park natural resource managers to adapt to climate change. Park managers are  
21 proactive in removing or preventing the spread of invasive and non-native species,  
22 managing fire risk through controlled burns and thinning, reducing regional air pollution  
23 through partnerships with regulatory agencies, acquiring the rights to most water in the  
24 park, and preparing a plan to control elk populations. However, climate change poses  
25 challenges to management that remain unaddressed: in particular, catastrophic wildfire,  
26 increasing insect infestations and outbreaks, damage from large storm events, and  
27 impacts on alpine tundra and the species that live above treeline. Scientific information  
28 on baseline conditions and projected changes in conditions (*e.g.*, temperature, CO<sub>2</sub>,  
29 ozone, drought, water quality and quantity) is needed in order to develop adaptation  
30 strategies to address these impacts. Recurrent workshops of experts and regional resource  
31 managers may prove useful for sharing information and identifying resources and  
32 processes susceptible to climate change, developing planning scenarios, proposing  
33 adaptive experiments and management opportunities, and keeping abreast of the state of  
34 knowledge regarding climate change and its effects. Rocky Mountain National Park also  
35 needs to develop baselines for species or processes of highest concern and establish  
36 monitoring programs to track changes over time. The “vital signs” that have been  
37 identified for the park should also be reviewed and possibly revised to capture effects that  
38 will occur with climate change. Greater collaboration with regional partners may also  
39 facilitate regional planning, especially for issues that cross park boundaries. Professional  
40 development programs for current resource managers, rangers, and park managers could  
41 be strengthened, so that all employees understand the natural resources that are under the  
42 protection of the NPS and the causes and consequences of threats to these resources.  
43 Finally, training of future natural resource managers needs to broaden beyond traditional  
44 training in fisheries, wildlife, or recreation management. University curricula should  
45 teach ecosystem concepts, interdisciplinary and collaborative ways of decision-making  
46 under uncertainty, and adaptive management tools.

1 **1.4.4 Conclusions**

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

19 **1.5 National Wildlife Refuges**

20 **1.5.1 Background and Current Status of Management**

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

33 **1.5.2 Adapting to Climate Change**

34 The most important existing adaptation option for the NWRS is the strategic growth of  
35 the system through increased representation, redundancy and resilience. Ensuring the  
36 representation and redundancy of different ecosystems, geophysical and biological  
37 features and habitats within the NWRS will help buffer against the uncertain effects of  
38 future climate change. Increased resilience could be achieved through restoration and  
39 expansion of the NWRS’s conservation role with conservation easements, and fee-simple  
40 acquisitions of in-holdings and adjacent land parcels from willing sellers. Strategic  
41 growth could be targeted toward those refuges, species, and ecosystems that are identified  
42 as most vulnerable to regime shifts, sea level rise, and other effects of climate change. In  
43 support of targeted growth, monitoring systems could be valuable for assessing species’



1 distributions and abundance, as well as for monitoring changes in phenology, arrival and  
2 departure times of migrants, flowering dates for plants, and emergence dates for insects.

3  
4 The most important future adaptation options include increased conservation partnerships  
5 with adjacent landowners, secured water rights for refuges, and the facilitation of state  
6 and federal agency cooperation and information sharing on issues of climate change.  
7 These options could be facilitated through establishment of a national interagency climate  
8 change council and a national interagency climate change information network.

### 9 **1.5.3 Insights from the Case Study**

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

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

### 31 **1.5.4 Conclusions**

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

## 37 **1.6 Wild and Scenic Rivers**

### 38 **1.6.1 Background, History, and Current Status of Management**

39 The Wild and Scenic Rivers Act of 1968 calls for the preservation of select “free-  
40 flowing” rivers with “outstandingly remarkable values.” The “outstandingly remarkable  
41 values” encompass a range of scenic, biological, and cultural characteristics that society

1 values while “free flowing” generally refers to river stretches with high water quality and  
2 with no major dams or obstructions within the stretch of river to be designated. Climate  
3 change will challenge river managers to explicitly consider not only climatic,  
4 hydrogeologic and ecological conditions, but also human-induced impacts. Current  
5 management practices related to water use and reuse, dam operations, and land-use are  
6 sensitive to the direct effects of climate change as well as indirect effects on river  
7 discharge and channel morphologies. These impacts will affect species and ecological  
8 processes of Wild and Scenic Rivers (WSRs) in ways that could threaten their ability to  
9 provide the ecosystem services for which they were designated.

## 10 **1.6.2 Adapting to Climate Change**

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

16  
17 *Proactive* management efforts can be taken to protect WSRs and are especially important  
18 for those in watersheds already affected by human activities. Specific management  
19 actions include restoration of flood plains and riparian buffers, land purchases, reductions  
20 in water withdrawals, and river flow augmentation using alternative water resources.  
21 These adaptations can be taken now to maintain or increase the resilience of WSRs in the  
22 face of expected impacts. Protecting species that reside in WSRs deemed the most  
23 vulnerable to the impacts of climate change (*e.g.*, because of their location or level of  
24 existing impacts) may require closure of these rivers to recreation. Land purchases and  
25 protection of nearby rivers that may serve as refugia for species are important actions.

26  
27 Without sufficient proactive management, managers will likely need to develop strategies  
28 once impacts are felt. Examples of reactive management include rescuing stranded  
29 canoeists caught by unexpected floods, moving Park Service buildings that are too close  
30 to eroding streambanks, restoring in-stream or riparian habitat that is lost to floods or  
31 drought, installing fish passages to allow stranded fish to move between isolated reaches  
32 during drought times, changing dam management to ensure adequate environmental and  
33 recreational flows during the summers or to ensure that dams are not breached in  
34 watersheds that are more flood-prone under future climates, and shifting access points for  
35 wildlife or river enthusiasts or moving existing trails. In general, reactive management  
36 approaches are not as desirable as proactive approaches because substantial ecosystem  
37 and infrastructure damage is likely to occur before reactive measures are taken. It is  
38 difficult to forecast the magnitude of such damages; minimizing uncertainty of outcomes  
39 requires a proactive approach. Some reactive strategies could become proactive  
40 adaptations if potential management responses are planned and implemented before the  
41 impacts are felt. For example, changes in dam management can be taken prospectively to  
42 ensure adequate environmental and recreational flows during summers under future  
43 climates.

1 **1.6.3 Insights from Case Studies**

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

30 **1.6.4 Conclusions**

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

## 1 **1.7 National Estuaries**

### 2 **1.7.1 Background and Current Status of Management**

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

### 22 **1.7.2 Adapting to Climate Change**

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

34  
35 Comprehensive planning could be initiated now to act opportunistically after major storm  
36 disasters. One example is to modify rules or change policies to restructure development  
37 along coastal barrier and estuarine shorelines, in order to avoid future loss of life and  
38 property and to protect environmental assets and ecosystem services in the interest of the  
39 public trust. Planning now to prevent rebuilding in hazardous areas of high flood risk and  
40 storm damage may be feasible (*e.g.*, modify local land use plans to direct post-storm  
41 redevelopment into less risky areas). However, such plans might result in financial losses  
42 to coastal property owners unless compensated through policy initiatives. Longer-term  
43 funding to purchase the most risky shorelines may be available from land trusts and  
44 programs to protect water quality, habitat, and fisheries.

1 **1.7.3 Insights from Case Studies**

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

7  
8 The greatest challenge to successful adaptation to climate change is preserving the  
9 integrity of the coastal barrier complex of the Outer Banks over time scales of a century  
10 and longer. These coastal barriers are responsible for creating this estuarine system, and a  
11 major breach in their integrity will ultimately convert the estuary into a coastal ocean  
12 embayment.

13  
14 Opportunities for implementing adaptive management exist through the legislatively  
15 mandated Coastal Habitat Protection Plan, an ecosystem-based management plan for  
16 preserving and enhancing coastal fisheries. This plan is developed collaboratively by all  
17 necessary state agencies and thus overcomes the historic constraints that arise from  
18 compartmentalized management authorities. The State Commission on Effects of Climate  
19 Change, legislated in 2005, also provides an opportunity for education and participation  
20 by legislators in a forward-looking planning process that exceeds the typical political  
21 term. Finally, sparse human populations and low levels of development along much of  
22 the interior mainland shoreline of the Albemarle-Pamlico National Estuary Program  
23 complex provides an opportunity to implement policies that allow the salt marsh and  
24 other shallow-water estuarine habitats to retreat as sea level rises.

25 **1.7.4 Conclusions**

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

33  
34 Among the consequences of climate change that threaten estuarine ecosystem services,  
35 the most serious involve interactions between climate-dependent processes and human  
36 responses to climate change. In particular, conflicts arise between sustaining public trust  
37 values and private property rights, in that current policies protecting private shoreline  
38 property become increasingly injurious to public trust values as climate changes and sea  
39 level rises further.

40 **1.8 Marine Protected Areas**

41 **1.8.1 Background and Current Status of Management**

42 Marine protected areas (MPAs) such as national marine sanctuaries provide place-based  
43 management of marine ecosystems through various degrees and types of protective

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

## 10 **1.8.2 Adapting to Climate Change**

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

17  
18 Within sites, managers can increase resilience to climate change by managing other  
19 anthropogenic stressors that also degrade ecosystems, such as fishing and  
20 overexploitation; inputs of nutrients, sediments, and pollutants; and habitat damage and  
21 destruction. Resilience is also affected by trophic linkages, which are a key characteristic  
22 maintaining ecosystem integrity. Thus, a mechanism that has been identified to maintain  
23 resilience is the management of functional groups, specifically herbivores. In one  
24 instance on the Great Barrier Reef, recovery from an algae-dominated to a coral-  
25 dominated state was driven by a single batfish species, not grazing by dominant  
26 parrotfishes or surgeonfishes that normally keep algae in check on reefs. This finding  
27 highlights the need to protect the full range of species to maintain resilience and the need  
28 for further research on key species and ecological processes.

29  
30 The challenges of climate change require creative collaboration among a variety of  
31 stakeholders to generate the necessary finances and support to respond to climate change  
32 stress. Engagement of stakeholders to help adapt management practices to changing  
33 conditions will help MPA managers build the knowledge and collaborations needed to  
34 implement adaptive approaches.

## 35 **1.8.3 Insights from Case Studies**

36 The Great Barrier Reef Marine Park is an example of an MPA that has a relatively highly  
37 developed climate change program in place. A Coral Bleaching Response Plan is part of  
38 its Climate Change Response Program, which is linked to a Representative Areas  
39 Program and a Water Quality Protection Plan in a comprehensive approach to support the  
40 resilience of the coral reef ecosystem. In contrast, the Florida Keys National Marine  
41 Sanctuary is only now developing a bleaching response plan. The Florida Reef Resilience  
42 Program, under the leadership of The Nature Conservancy, is implementing a  
43 quantitative assessment of coral reefs before and after bleaching events. The recently  
44 established Papahānaumokuākea (Northwestern Hawaiian Islands) Marine National  
45 Monument is the largest MPA in the world and provides a unique opportunity to examine

1 the effects of climate change on a nearly intact large-scale marine ecosystem. These three  
2 MPA case studies are based on coral reef ecosystems, which have experienced coral  
3 bleaching events over the past two decades. A fourth case study covers the Channel  
4 Islands National Marine Sanctuary, off the coast of southern California. The Sanctuary  
5 Management Plan for the Channel Islands National Marine Sanctuary mentions, but does  
6 not fully address, the issue of climate change. The plan describes a strategy to identify,  
7 assess, and respond to emerging issues through consultation with the Sanctuary Advisory  
8 Council and local, state, or federal agencies. Emerging issues that are not yet addressed  
9 by the management plan include ocean warming, sea level rise, shifts in ocean  
10 circulation, ocean acidification, spread of disease, and shifts in species ranges.

11  
12 Barriers to implementation of adaptation options in MPAs include lack of resources,  
13 varying degrees of interest in and concern about climate change impacts, and a need for  
14 basic research on marine ecosystems and climate change impacts. The National Marine  
15 Sanctuary Program’s strategic plan does not address climate change, but the program  
16 recently formed a Climate Change Working Group that will be developing  
17 recommendations. Although there is considerable research on physical impacts of climate  
18 change in marine systems, research on biological effects and ecological consequences is  
19 not as well developed.

20  
21 Opportunities with regard to implementation of adaptation options in MPAs include a  
22 growing public concern about the marine environment, recommendations of two ocean  
23 commissions, and an increasing dedication of marine scientists to conduct research that is  
24 relevant to MPA management. References to climate change as well as MPAs permeate  
25 both the Pew Oceans Commission and U.S. Commission on Ocean Policy reports on the  
26 state of the oceans. Both commissions held extensive public meetings, and their findings  
27 reflect changing public attitudes about protecting marine resources and threats of climate  
28 change. The interests of the marine science community have also evolved, with a shift  
29 from basic to applied research over recent decades. Attitudes of MPA managers have  
30 changed as well, with a growing recognition of the need to better understand ecological  
31 processes in order to implement science-based adaptive management in the ocean.

#### 32 **1.8.4 Conclusions**

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

## 1 **1.9 Synthesis and Conclusions**

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

10  
11 The first question for managers is whether their ability to meet the management goals for  
12 their systems will be affected by climate change. This question may be addressed through  
13 examining the existing literature and comparing likely climate change impacts with key  
14 ecological properties or components needed to reach management goals. If management  
15 goals are vulnerable to climate change, a tool such as a decision support model may be  
16 used to conduct sensitivity analyses of ecological properties and components to a range  
17 of potential future climate changes. Such sensitivity analyses can provide the foundation  
18 for “if/then” planning. Managers will also need to develop or modify monitoring schemes  
19 to track and substantiate vulnerabilities to climate change and assess the effects of  
20 management adaptations.

21  
22 When the nature of a system’s vulnerability to climate change is understood well enough  
23 to determine that action should be taken in order to continue meeting management goals,  
24 there are a number of adaptation approaches that may be applied (Box 1.1). These  
25 approaches are relevant for most managed systems and can be operationalized in a  
26 variety of ways. In addition to these “ecological” adaptation approaches, there are other  
27 relevant approaches that focus on adapting social systems to anticipated ecological  
28 changes. Such approaches include adjusting management targets, policies, and  
29 procedures to reflect anticipated changes, and restricting activities or practices to allow  
30 ecological changes to occur (such as restricting development along the coast to allow  
31 tidal wetlands to migrate inland).

32  
33 Because of uncertainties in projected climate change and in our knowledge of the  
34 consequent effect on species and ecosystems, the ability of adaptation approaches to  
35 effectively accomplish their intended purpose is also uncertain. It is therefore essential to  
36 characterize for resource managers the level of confidence associated with the adaptation  
37 approaches listed in Box 1.1. Based on the literature and the expert opinion of the author  
38 teams who considered the application of each approach within their specific management  
39 systems, confidence estimates have been developed (see Table 1.1). It is important to  
40 consider these types of confidence estimates when deciding which adaptation approaches  
41 to implement for a given system.

42  
43 Adaptive management is likely to be the most attractive method for implementing these  
44 adaptation approaches since it is an iterative process that emphasizes (1) experiments to  
45 learn how management practices function, (2) monitoring and data collection to measure  
46 their effectiveness, and (3) adjustments in practices to incorporate new information and  
47 improve results. The prospect of widespread and uncertain ecological effects from



1 changes in the climate system may represent a tipping point that spurs managers to  
2 embrace adaptive management as an essential strategy—one that enables management  
3 action today while allowing for increased understanding and refinement tomorrow.  
4

5 Finally, there may be situations in which adaptation strategies will not enable a manager  
6 to meet specific goals. Promoting resilience may be a management strategy that is useful  
7 only on shorter time scales (*i.e.*, 10–30 years) because as climate change continues,  
8 various thresholds of resilience will eventually be exceeded. On longer time scales, as  
9 ecosystem thresholds are exceeded, these approaches will cease to be effective, at which  
10 point major shifts in ecosystem processes, structures and components will be  
11 unavoidable. Such circumstances may necessitate fundamental shifts in how ecosystems  
12 are managed, such as reformulating goals, managing cooperatively across landscapes,  
13 and looking forward to potential future ecosystem states and facilitating movement  
14 toward those preferred states. These sorts of fundamental shifts in management at local-  
15 to-regional scales may only be possible with coincident changes in organizations at the  
16 national level that empower managers to make the necessary shifts. Such fundamental  
17 shifts in national-level policies include establishing priorities across systems and species,  
18 and developing rules for triage; enabling management across jurisdictions and at larger  
19 scales; enabling management for projected ecological changes; and expanding  
20 interagency collaboration and access to expertise in climate change science and  
21 adaptation, data, and tools. Although many agencies have embraced subsets of these  
22 needed changes, there are no examples of the full suite of these changes being  
23 implemented as a best practices approach.  
24

25 The spatial scale and ecological scope of climate change necessitates that we broaden our  
26 thinking to view the natural resources of the United States as one large interlocking and  
27 interacting system, including state, federal, and private lands. The most effective course  
28 may be to manage the nation’s lands and waters as one large system, with resilience  
29 emerging from coordinated stewardship of all of the parts. Only through collaboration  
30 and cooperation among institutions will this approach be feasible. Effective leadership at  
31 the highest levels of government is needed to enable agencies at all levels and the public  
32 to work together to maintain those ecosystems and ecosystem services that are both  
33 valuable and likely to be viable in the future despite the effects of climate change.

1 **1.10 References**

2

3 **McCarthy, J., O. Canziani, N. Leary, D. Dokken, and K. White, 2001: *Climate Change***  
4 ***2001: Impacts, Adaptation, and Vulnerability***. GRID-Arendal.

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

8

9

1 **1.11 Boxes**

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

4  
5 *Protect Key Ecosystem Features* – key ecosystem features (*e.g.*, structural habitat,  
6 keystone species, corridors, processes) upon which biodiversity (and hence resilience)  
7 depend are strategically targeted for special protections

8  
9 *Reduce Anthropogenic Stresses* – reduce or eliminate all direct (non-climate)  
10 anthropogenic stresses that can be managed locally, in order to preserve or enhance  
11 the resilience of ecosystems to regional, uncontrollable climate stresses

12  
13 *Refugia* – use physical environments that are less affected by climate change than  
14 other areas (*e.g.*, due to local currents, geographic location) as a “refuge” from climate  
15 change for organisms

16  
17 *Relocation* – use human-facilitated transplantation of organisms from one location to  
18 another in order to bypass a barrier (*e.g.*, an urban area)

19  
20 *Replication* – protect multiple replicates of a habitat type (*e.g.*, multiple fore reef areas  
21 throughout the reef system) as a “bet hedging” strategy against loss of the habitat type  
22 due to a localized disaster

23  
24 *Representation* – ensure that both (1) the full breadth of habitat types is protected (*e.g.*,  
25 fringing reef, fore reef, back reef, patch reef) and (2) the full breadth of species  
26 diversity is included within sites; both concepts relate to maximizing overall  
27 biodiversity of the larger system

28  
29 *Restoration* – manipulate the physical and biological environment in order to restore a  
30 desired ecological state or set of ecological processes

1 **1.12 Tables**

2 **Table 1.1.** Chapter authors’ confidence estimates on the effectiveness of various adaptation approaches for each management system  
 3 type. Estimates are based on an approach developed by the Intergovernmental Panel on Climate Change (McCarthy *et al.*, 2001).  
 4

<b>Adaptation Approach</b>	<b>National Forests</b>	<b>National Parks</b>	<b>National Wildlife Refuges</b>	<b>Wild &amp; Scenic Rivers</b>	<b>National Estuaries</b>	<b>Marine Protected Areas</b>
<b>Protect Key Ecosystem Features</b> Is strategic protection of key ecosystem features an effective way to preserve or enhance resilience to climate change?	Medium	Medium	High	High	High	High
<b>Reduce Anthropogenic Stresses</b> Is reduction of anthropogenic stresses effective at increasing resilience to climate change?	High	High	Very High	High	Medium	High
<b>Representation</b> Is representation effective in supporting resilience through preservation of overall biodiversity?	High	High	Very High	Low	Medium	High
<b>Replication</b> Is replication effective in supporting resilience by spreading the risks posed by climate change?	High	NA	Very High	Low	NA	High
<b>Restoration</b> Is restoration of desired ecological states or ecological processes effective in supporting resilience to climate change?	Medium	Medium	Medium	Medium	Medium	Low

<b>Refugia</b>						
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
<b>Relocation</b>						
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
<b>Confidence Levels</b>						
<b>Very High</b> = 95% or greater						
<b>High</b> = 67-95%						
<b>Medium</b> = 33-67%						
<b>Low</b> = 5-33%						
<b>Very Low</b> = 5% or less						

1

1 **1.13 Figures**

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

4

5