4 National Parks

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Chapter Contents

Chapter Structure

4.1 Background and History

The U.S. National Parks trace their distinctive origins to the early 19th century. The artist George Catlin is credited with initiating the uniquely American idea of protected national parks. While traveling through the Dakota territories in 1832, he expressed concern over the impact of westward expansion on wildlife, wilderness, and Indian civilization; he suggested they might be preserved "*by some great protecting policy of government... in a magnificent park...A nation's park, containing man and beast, in all the wild and freshness of their nature's beauty*" (Pitcaithley, 2001). In 1872, the United States Congress created the world's first national park, Yellowstone, in Wyoming and Montana territories "*as a public park or pleasuring ground for the benefit and enjoyment of the people*" (U.S. Congress, 1871). Other spectacular natural areas soon followed as Congress designated Sequoia, Yosemite, Mount Rainier, Crater Lake, and Glacier as national parks in an idealistic impulse to preserve nature (Baron, 2004).

The U.S. National Park System today includes a diverse set of ecological landscapes that form an ecological and cultural bridge between the past and the future. Covering about 4% of the United States, the 338,000 km² of protected areas in the park system contain representative landscapes of many of the world's biomes and ecosystems. U.S. national parks are found across a temperature gradient from the tropics to the tundra, and across an elevational gradient from the sea to the mountains. These parklands are dynamic systems, containing features that reflect processes operating over time scales from seconds to millennia. For example, over millions of years, seasonal variation in flows and sediment in the Colorado River, which flows through Grand Canyon National Park, produced an unusual river ecosystem surrounded by rock walls that demonstrate countless annual cycles of snowmelt and erosion (Fig. 4.1). At the other end of the geologic spectrum are 'new' park ecosystems such as the Everglades that is less than 10,000 years old. Seasonal patterns of water coursing through the sloughs in the Everglades, as in the Grand Canyon, produced an ecosystem with plants and animals that requires the ebb and flow of water to persist (Fig. 4.2).

Figure 4.1. Photograph looking up from the Colorado River at the Grand Canyon, courtesy of Jeffrey Lovich, USGS.

Figure 4.2. Everglades National Park, Photo courtesy of National Park Service; photo by Rodney Cammauf.

National park managers are confronting recent issues of climate change in the larger context of the many temporal and spatial scales at which geological and biological changes occur. For example, globally, 11 of the last 12 years (1995–2006) rank among the 12 warmest years since 1850, mountain glaciers have diminished all over the world, global average sea level is rising, and the maximum area covered by seasonally frozen ground has decreased, while the upper levels of permafrost have warmed (IPCC, 2007). Documented biological responses in North America include the northward range expansion of butterflies, birds, some shrub species, marine zooplankton, and fish. Long-term data for at least one species, Edith's Checkerspot butterfly, demonstrate that its range has shifted nearly 100 km north and 125 m higher in elevation since the beginning of the 20th century (Walther *et al.*, 2002). Parmesan (2006) summarized 866 studies that revealed changes in the phenology and distribution of representative species in all well-known groups of plants and animals in terrestrial, freshwater, and marine systems that were consistent with predictions on the basis of global increases in temperature. Changes in phenology, such as earlier dates of spring appearance of birds and butterflies and a lengthening of the vegetative growing season in the Northern Hemisphere, accounted for the majority of observed responses to climate change. Interactions between carnivorous and herbivorous predators and their prey also have been affected when the responses of predators and prey to climate change have varied. Disruption of coevolved species interactions, such as interdependence of flowering plants and their pollinators, can occur if one species responds to temperature while the other responds to day length. Some populations, especially those at interiors of species' ranges, have adapted genetically to higher temperatures during the past several decades. Examples from the literature include genetic adaptations in algal symbionts of coral reefs, wild populations of fruit flies, and the pitcher plant mosquito that so far have allowed the populations to remain in the same location (Parmesan, 2006). At the edges of species' ranges, by contrast, evolution seems to favor greater dispersal of individuals to locations where temperature patterns more closely resemble historic conditions. Contractions in geographic range have been most pronounced in species restricted to montane or polar environments because these species cannot disperse to higher elevations or more northern latitudes.

As greenhouse gases continue to accumulate in the atmosphere, the effects of climate change on the environment will only increase. Ecological changes will range from the emergence of new ecosystems to the disappearance of others. Few natural ecosystems remain in the United States; the National Park Service (NPS) is steward of some of the most intact representatives of these systems. However, changes in climate that are now being driven by human activities are likely to profoundly alter national parks as we know them. Some iconic species are at high risk of extinction. For example, the Joshua tree is likely to disappear from both Joshua Tree National Monument and the southern two thirds of its range, where it is already restricted to isolated areas that meet its fairly narrow winter minimum temperature requirements (Cole *et al.*, 2005) (Fig. 4.3). The distributions of many other species of plants and animals will likely shift across the American landscape, independent of the borders of protected areas. National Parks that have special places in the American psyche will remain parks, but their look and feel may change dramatically. For example, the glaciers in Glacier National Park are expected to melt by 2030 (Hall and Fagre, 2003). Therefore, the time is ripe for the NPS, the Department of the Interior, and the American public to revisit our collective vision of the purpose of parks.

Figure 4.3. Photograph of Joshua tree in Joshua Tree National Park. Photo courtesy of National Park Service.

Now is also the time to evaluate what can and should be done to minimize the effects of climate change on park resources, and to maximize opportunities for wildlife, vegetation, and the processes that support them to survive in the face of climate change. National parks increasingly are isolated by developed lands, and climate change is inseparable from the many other phenomena that degrade natural resources in national parks. Using climate change scenarios, we can realistically reevaluate current management efforts to reduce habitat fragmentation, remove or manage invasive species, maintain or restore natural disturbance regimes, and maximize air and water quality. Positive and negative feedbacks between contemporary changes in climate and resource management priorities must be carefully considered.

This chapter is directed specifically at the 270 national park areas with natural resource responsibilities, as opposed to cultural or historical parks. In this chapter, we suggest how national park managers might increase the probability that their resources and operations will adapt successfully to climate change. Successful adaptation begins by moving away from traditional ways of managing resources. We discuss strategies to stimulate proactive modes of thinking and acting in the face of climate change and other environmental changes. These strategies 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 at which species and processes function. Strategies also include catalyzing ecoregional coordination among federal, state, and private entities, valuing human resources, and understanding what climate change means for interpreting the language of the NPS Organic Act. By modifying and expanding its current monitoring systems, NPS can expand its capacity to (1) document and understand ecological responses to climate change and management interventions, and (2) increase natural resilience by minimizing the negative effects from other current stressors. The primary message of this document is that the onset and continuance of climate change over the next century requires NPS managers to think differently about park ecosystems than they have in the past. Preparing for and adapting to climate change is as much a cultural and intellectual challenge as it is an ecological one.

4.1.1 Legal History

The U.S. NPS Organic Act established the National Park System in 1916 "*to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations*" (U.S. Congress, 1916). This visionary legislation set aside lands in the public trust and created "a splendid system of parks for all Americans (Albright and Schenck, 1999)." The U.S. National Park System today includes more than 390 natural and cultural units and has been emulated worldwide. The National Park System has the warm support of the American people, and parks are often the embodiment of widespread public sentiment for conservation and protection of the environment (Winks, 1997).

The intent of Congress for management of national parks was initially set out in the Organic Act (see Fig. 4.4). The 1970 General Authorities Act and the 1978 "Redwood Amendment" to the Organic Act strengthened the Service's mission of conservation by clarifying that the "fundamental purpose" of the national park system is the mandate to conserve park resources and values. This mandate is independent of the separate prohibition on impairment. Park managers have the authority to allow and manage human uses, provided that those uses will not cause impairment, which is an unacceptable impact. Enabling legislation and park strategic and general management plans are used to guide decisions about whether specific activities will cause impairment (National Park Service, 2006a).

Figure 4.4. Historical timeline of the National Park Service. Adapted from the National Park Service (2007b).

Other acts passed by Congress have extended the roles and responsibilities of national parks. National parks are included in the Wilderness Act of 1964 (for parks that include wilderness or proposed wilderness), the Wild and Scenic Rivers Act of 1968, the Clean Water Act of 1972, the Endangered Species Act of 1973, and the Clean Air Act of 1990. These acts, along with the Organic Act, are translated into management guidelines and policies in the 2006 Management Policies guide. Historian Robin Winks identified three additional acts that help to define the role of NPS in natural resource protection: the National Environmental Policy Act (NEPA) of 1972, the National Forest Management Act of 1976, and the Federal Land Policy and Management Act of 1976 (Winks, 1997).

Although its overarching mission has remained mostly unchanged, the NPS has undergone substantial evolution in management philosophy since 1916. For instance, national park status is not necessarily conferred in perpetuity. Twenty-four units of the national park system were either deauthorized or transferred to other management custody for a number of reasons, demonstrating that designation of national park status is not necessarily permanent (NPS Bureau Historian, 2006). While fifteen areas were transferred to other agencies because their national significance was marginal, others were deauthorized because their location was inaccessible to the public, and the management of five reservoirs was handed over to the Bureau of Reclamation (National Park Service, 2003). Fossil Cycad National Monument in South Dakota, however, was deauthorized by Congress in 1957 due to near-complete loss of the fossil resource to collectors (National Park Service, 1998).

Prior to the 1960s the NPS "practiced a curious combination of active management and passive acceptance of natural systems and processes, while becoming a superb visitor services agency (National Park Service, 1999)." The parks actively practiced fire suppression, aggressive wildlife management (which included culling some species and providing supplemental food to others), and spraying with pesticides to prevent irruptions of native insects. Development of ski slopes and golf courses within park boundaries was congruent with visitor enjoyment. During the 1960s, the Leopold Report on Wildlife

Management in National Parks, the 1964 Wilderness Act, and the growth of the environmental movement ushered in a different management philosophy (Leopold, 1963). Managers began to consider natural controls on the size of wildlife populations. Some park managers decided skiing and golf were not congruent with their mission, and closed ski lifts and golf courses. The Wilderness Act of 1964 restricted mechanized and many other activities in designated or proposed wilderness areas within parks. Throughout its history, NPS has changed its priorities and management strategies in response to increased scientific understanding of ecological systems, public opinion, and new laws and administrative directives. Today, confronted not only with climate change but with many other threats to natural resources from within and outside park boundaries, the Park Service again has the opportunity to revisit resource management practices and policies.

4.1.2 Interpretation of Goals

The aggregate federal laws described above strongly suggest that the intent of Congress is not only to "conserve unimpaired" but also to minimize human-caused disturbances, and to restore and maintain the ecological integrity of the National Parks. The NPS mission remains much as it was in 1916 (Box 4.1). In general, the Secretary of the Interior, and by extension, the Director of the NPS, have been given broad discretion in management and regulation provided that the fundamental purpose of conservation of park resources and values is met. Although individual park-enabling legislation may differ somewhat from park to park, all parks are bound by the NPS Organic Act, the Redwood National Park Expansion Act, and other legislation described above. The enabling language of the Organic Act creates a dilemma that complicates the Park Service's ability to define key ecosystem characteristics upon which the goals depend: for example, what is the definition of "unimpaired?" Interpretations of how to manage to maintain unimpaired conditions have changed over time, from benign neglect early in the history of the national parks to restoring vignettes of primitive America and enhancing visitor enjoyment through much of the 20th century. The definition of "unimpaired" is central to how well NPS confronts and adapts its resources to climate change.

To accomplish its mission, NPS employs more than 14,000 permanent personnel and some 4,000 temporary seasonal personnel (Fig. 4.5). Parks receive more than 270 million visitors each year. Operations and management occur at three levels of organization: national, regional, and individual park. Service-wide policy is issued by the Director of the NPS, and may also be issued by the President, Congress, the Secretary of the Interior, or the Assistant Secretary for Fish, Wildlife, and Parks. Many of the programs that make up or are supplemented by the Natural Resource Challenge, described below, are administered from the national headquarters, called the Washington Office. Seven regional offices divide the National Park System by geography (Northeast, National Capital, Southeast, Midwest, Intermountain, Pacific West, and Alaska Regions). Regional offices provide administrative services and oversight to parks and serve as conduits for information between the Washington Office and parks. Two national-level offices, the Denver (Colorado) Service Center and the Interpretive Design Center at Harpers Ferry, West Virginia, provide professional architectural and engineering services, and media products (*e.g.*, publications, exhibits, interactive presentations, and audio-visual displays) to individual parks.

Figure 4.5. Organizational chart of National Park Service. Adapted from the National Park Service (2007d).

There are more than 14 different categories of park units within the National Park System, including national parks, national scenic rivers, lakeshores, seashores, historic sites, and recreation areas (Fig. 4.6). The parks in each category offer different experiences for visitors. In addition to the overarching NPS mission, certain activities can take place within individual park units depending on specific Congressional enabling legislation at the time of establishment. For example, public hunting is recognized as a legitimate recreational activity within the boundaries of many national lakeshores, seashores, recreation areas, and preserves because of the legislation that established those specific park units.

Figure 4.6. Map of the National Park System. Data courtesy of National Park Service, Harpers Ferry Center (2007).

Approximately 270 national park system areas contain significant natural resources. The Natural Resource Challenge, an action plan for preserving natural resources in national parks, was established in 2000 in the recognition that knowledge of the condition and trends of NPS natural resources was insufficient to effectively manage them (National Park Service, 1999). The Natural Resource Challenge has already enabled a significant advancement in inventory, monitoring, and understanding of resources. There are four natural resource action plan goals (Box 4.2). These goals are aligned with the NPS Strategic Plan, which emphasizes the role of natural resource stewardship and has as its first goal the preservation of park resources. Central to the Natural Resource Challenge is the application of scientific knowledge to resource management.

The Natural Resource Challenge includes the Inventory and Monitoring Program (including NPS Resource Inventories and Vital Signs Monitoring Networks), the Biological Resources Management Program, and the Air Quality, Water Resources, and Geologic Resources Programs. Natural Resource Challenge programs mostly provide *information, management guidance, and expertise,* to parks, as opposed to active management, although an exception is the Invasive Plant Management Teams. Individual parks set their own resource management agendas, which they carry out with permanent and seasonal staff and money from the park, the Natural Resource Preservation Program (a competitive research fund), and the Park Oriented Biological Support, (a joint USGS/NPS program). Many parks also encourage or invite researchers to study specific issues facilitated by two NPS entities—the Cooperative Ecosystem Studies Units and the Research Learning Centers.

Most parks operate under a General Management Plan, a broad planning document that creates a vision for the park for a 15- to 20-year period. The General Management Plan provides guidance for fulfilling the park's purpose and protecting the park's fundamental resources and values. As part of the General Management Plan, or sometimes developed as an addendum to the General Management Plan, Desired Conditions Plans articulate ideal future conditions that a park strives to attain. Individual parks may have up to 40 additional specific resource- or place-based management plans (an example is Rocky Mountain National Park's Elk and Vegetation Management Plan). These natural resource management plans are increasingly science driven. However, despite having guidance and policies for natural resource management planning, there are still many parks that have no planning documents identifying desired future conditions, and many of the General Management Plans are out of date.

Public input, review, and comment are encouraged, and increasingly required, in all park planning activities. Increasingly, park planning activities take place in regional contexts and in consultation with other federal, state, and private land and natural resource managers.

4.2 Current Status of Management Systems

4.2.1 Key Ecosystem Characteristics on Which Goals Depend

National parks are found in every major biome of the United States. Parks with managed natural resources range from large intact (or nearly intact) ecosystems with a full complement of native species—including top predators, such as some Alaskan parks, Yellowstone, and Glacier (Stanford and Ellis, 2002)—to those diminished by disturbances such as within-park or surrounding-area legacies of land use, invasive species, pollution, or regional manipulation of resources (*e.g.*, hydrologic flow regimes).

Current NPS policy calls for management to preserve fundamental physical and biological processes, as well as individual species, features, and plant and animal communities (National Park Service, 2006a). "The Service recognizes that natural processes and species are evolving, and NPS will allow this evolution to continue — minimally influenced by human actions" (National Park Service, 2006a). Resources, processes, systems, and values are defined in NPS Management Policies (National Park Service, 2006a) as:

- Physical resources such as water, air, soils, topographic features, geologic features, paleontological resources, and natural soundscapes and clear skies, both during the day and at night;
- Physical processes such as weather, erosion, cave formation, and wildland fire;
- Biological resources such as native plants, animals, and communities;
- Biological processes such as photosynthesis, succession, and evolution;
- Ecosystems; and
- Highly valued associated characteristics such as scenic views.

4.2.2 Stressors of Concern

Despite mandates to manage national parks to maintain their unimpaired condition, there are many contemporary human-caused disturbances (as opposed to natural disturbances) that create obstacles for restoring, maintaining, or approximating the natural conditions of ecosystems. The current condition of park resources can be a legacy of past human activities or can be caused by activities that take place outside park boundaries. We grouped the most widespread and influential of the disturbances that affect park condition into four broad classes: altered disturbance regimes, habitat fragmentation and loss, invasive species, and pollution.

These four classes of stressors interact. For example, alteration of the nitrogen cycle via atmospheric nitrogen deposition can facilitate invasion of non-native grasses. In terrestrial systems, invasion of nonnative grasses can alter fire regimes, ultimately leading to vegetation-type conversions and effective loss or fragmentation of wildlife habitat (Brooks, 1999; Brooks *et al.*, 2004). Climate change is expected to interact with these pressures, exacerbating their effects. Climate change is already contributing to increasing frequency and intensity of wildfires in the western United States, potentially accelerating the rate of vegetation-type conversions that are being driven by invasive species (Mckenzie *et al.*, 2004; Westerling *et al.*, 2006). Two illustrations are presented in Boxes 4.3 and 4.4 of complex stressor interactions: fire and climate interactions in western parks, and myriad stressor interactions in the Everglades.

4.2.2.1 Altered Disturbance Regimes

Natural disturbance processes such as fire, insect outbreaks, floods, avalanches, and forest blowdowns are essential drivers of ecosystem patterns (*e.g.*, species composition and age structure of forests) and processes (*e.g.*, nutrient cycling dynamics). Disturbance regimes are characterized by the spatial and temporal patterns of disturbance processes, such as the frequency, severity, and spatial extent of fire. Many natural disturbance regimes are strongly modulated by climate variability, particularly extreme climate events, as well as by human land uses. Thus, climate change is expected to alter disturbance regimes in ways that will profoundly change national park ecosystems. Three types of natural disturbances whose frequency and magnitude have been altered in the past century include fire, soil erosion, and natural flow regimes.

Fire

Historic fire exclusion in or around many national parks has sometimes increased the potential for higher severity fires and mortality of fire-resistant species. Fire-resistant tree species that may have had their natural fire frequencies suppressed include giant sequoias (*Sequoia sempervirens*) in Yosemite, Sequoia, and Kings Canyon National Parks; ponderosa pine (*Pinus ponderosa*) in Grand Canyon and other southwestern parks; and southwestern white pine (*Pinus stobiformis*) in Guadalupe Mountains National Park. In other areas, such as Yellowstone or the subalpine forests of Rocky Mountain National Park, fires are driven almost completely by historically infrequent weather events and post-fire forest regrowth (Romme and Despain, 1989). Recent land use or fire suppression have had little effect on fire regimes in the latter parks.

Soil Erosion

Soils provide a critical foundation for ecosystems, and soil development occurs in geologic time. Natural soil erosion can also occur slowly, over eons, but rapid soil loss can happen in response to extreme physical and climatic events. Many of the changes in soil erosion rates in the parks are a legacy of human land use. Soil erosion rates are also influenced by interacting stressors, such as fire and climate change. Historic land uses such as grazing by domestic livestock have accelerated water and wind erosion in some semiarid national parks when overgrazing has occurred. This erosion has had long-term effects on ecosystem productivity and sustainability (Sydoriak, Allen, and Jacobs, 2000). In Canyonlands National Park, soils at sites grazed from the late 1800s until the 1970s have lost much of their vegetative cover. These soils have lower soil fertility than soils that never were exposed to livestock grazing (Belnap, 2003). Erosion after fires also can lead to soil loss, which reduces options for revegetation, and contributes sediment loads to streams and lakes. Excessive sediment loading degrades aquatic habitat. Long-term erosion in a humid environment like that in Redwood National Park is a direct legacy of intensive logging and road development (National Park Service, 2006d).

Altered Flow Regimes

Freshwater ecosystems are already among the most imperiled of natural environments worldwide due to human appropriation of freshwater (Gleick, 2006). Few natural area national parks have rivers that are unaltered or unaffected by upstream manipulations. Reservoirs in several national parks have flooded valleys where rivers once existed. Examples of large impoundments include Hetch Hetchy Reservoir in Yosemite National Park, Lakes Powell and Mead on the Colorado River of Glen Canyon and Lake Mead National Recreation Areas, and Lake Fontana in Great Smoky Mountains National Park. There are many smaller dams and reservoirs in other national parks. Parks below dams and diversions, such as Big Bend National Park, are subject to flow regulation from many miles upstream. Irrigation structures, such as the Grand Ditch in Rocky Mountain National Park, divert annual runoff away from the Colorado River headwaters each year (National Park Service, 2007e). Volume, flow dynamics, temperature, and water quality are often highly altered below dams and diversions (Poff *et al.*, 2007). Everglades National Park now receives much less water than it did before upstream drainage canals and diversions were constructed to divert water for agriculture. Natural hydrologic cycles have been disrupted and the water that Everglades now receives is of lower quality due to agricultural runoff. Altered hydrologic regimes promote shifts in vegetation, facilitate the invasion of non-native species such as tamarisk, Russian olive, and watermilfoil, and promote colonization by native species like cattail.

Groundwater depletion, which influences replenishment of springs, has been suggested as a cause of decreased artesian flows at Chickasaw National Recreation Area and in desert parks such as Organ Pipe Cactus and Death Valley (*e.g.*, Knowles, 2003). Groundwater depletion also directly affects phreatophytes, or water-loving riparian and wetland species. Groundwater depletion increasingly is occurring throughout the United States, even in the southeastern parks such as Chattahoochee National River National Recreation Area (Lettenmaier *et al.*, 1999).

Land use, particularly urbanization, alters flow regimes through creation of impervious surfaces. Water that previously percolated through soils and was assimilated by native vegetation runs rapidly off paved surfaces, increasing the probability that streams and rivers will flood in response to storms. Flooding is a management concern in urban parks such as Rock Creek Park in Washington, DC. When Rock Creek was established in 1890, it was at the edge of the city; its watershed is now wholly urbanized.

4.2.2.2 Habitat Alteration: Fragmentation and Homogenization

"Wild life" is identified specifically in the NPS enabling legislation, and regardless of whether the framers of the Organic Act intended the words to mean only birds and mammals, or all wild living things, large mammals have long been a central focus of NPS management and public discourse. Many wildlife challenges within parks stem from past extirpation of predators and overexploitation of game species, such as elk, and furbearers, such as beaver and wolverine. Restoration of species that were extirpated, and control of species that in the absence of predators have greatly expanded their populations, are important issues in many of the 270 natural area parks (Tomback and Kendall, 2002).

National parks may be affected by landscape alterations occurring either within or beyond their boundaries. Both fragmentation and landscape homogenization pose serious challenges to maintaining biodiversity. Roads, trails, campsites and recreational use can lead to fragmentation of habitat for various species. Fragmentation can directly or indirectly deter or prevent animal species from accessing food sources or accessing mating or birthing grounds (*e.g.*, some species of birds will not return to their nests when humans are present nearby, *e.g.*, Rodgers, Jr. and Smith, 1995). Moreover, fragmentation can impede dispersal of plant seeds or other propagules and migration of plant and animal populations that live along boundaries of national parks. However, fragmentation can also increase the amount and quality of habitat for some species, such as white-tailed deer, which, while native, are now considered a nuisance because of high numbers in many parts of the eastern United States.

Causes of fragmentation include road building and resource extraction such as timber harvest, mines, oil and gas wells, water wells, power lines, and pipelines. In lands adjacent to parks, fragmentation increasingly is driven by exurban development—low-density rural home development within a landscape still dominated by native vegetation. Since 1950, exurban development has rapidly outpaced suburban and urban development in the conterminous United States, and now constitutes approximately 50% of total land cover (Brown *et al.*, 2005; Hansen *et al.*, 2005). The effects of fragmentation are highly dependent on the spatial scale of disturbance and the particular taxonomic group being affected. And while there have been many studies on the effects of fragmentation on biodiversity, results of empirical studies are often difficult to interpret because they were conducted at patch scales rather than landscape scales, and did not distinguish between fragmentation and habitat loss (Fahrig, 2003) However, some known ecological effects include shifts in the distribution and composition of species, altered mosaics of land cover, modified disturbance regimes, and perturbations of biogeochemical cycles. Roads, ornamental vegetation, domestic animals, and recreational use serve as conduits for non-native invasive species, and the effects of exurban and other development may extend for large distances from those features.

Management activities that homogenize landscapes have also contributed to changes in species composition and ecological processes. Landscape homogenization can select against local adaptation, reducing the ability of species to evolve in response to environmental change. For example, reductions in the naturally variable rates of freshwater inflows and increases in nutrients have converted much of the vegetation of Florida Bay in Everglades National Park from sea grasses to algae (Unger, 1999). Fire exclusion has created large tracts of even-aged forest and woodland in many western and midwestern parks, reducing heterogeneity of land cover and species richness (Keane *et al.*, 2002).

4.2.2.3 Invasive Species

The deliberate or inadvertent introduction of species with the capability to become nuisances or invaders is a major challenge to management throughout the national park system and is likely to be exacerbated by climate change. These types of organisms are defined as invasive, whether or not they are non-native. Invasive plants are present across some 2.6 million acres in the national parks. Invasive animals are present in 243 parks (National Park Service, 2004c). The NPS has identified control of invasive species as one of its most significant land management issues and has established a highly coordinated and aggressive invasive plant management program. Efforts to restore native plants also occur, but at much lower levels than control of invasive plants.

4.2.2.4 Air and Water Pollution

Air Pollution

Atmospheric processes link park ecosystems to sources of air and water pollution that may be hundreds of miles away. These pollutants diminish both the recreational experience for park visitors and the ecological status of many park and wilderness ecosystems.

Ozone pollution from airsheds upwind of parks compromises the productivity and viability of trees and other vegetation. Because not all species are equally affected, competitive relationships are changed, leading to winners as well as losers. Ozone is also a human health hazard: during 2006, ozone health advisories were posted once each in Acadia and Great Smoky Mountains National Parks; and multiple times each in Sequoia, Kings Canyon, and Rocky Mountain National Parks (National Park Service, 2006b). Ozone concentrations are increasing in Congaree Swamp and ten western park units, including Canyonlands, North Cascades, and Craters of the Moon (National Park Service, 2006c).

Acid precipitation is still a concern in many eastern parks. While sulfur dioxide emissions have decreased significantly in response to the Clean Air Act Amendments of 1990, the legacy of soil, lake, and stream acidification persists (Driscoll *et al.*, 2001). Acadia, Great Smoky Mountains, and Shenandoah National Parks have active monitoring programs that track stream acidity and biological responses. Acidic waters from air pollution in Shenandoah are responsible for the loss of native trout populations and decline in fish species richness (MacAvoy and Bulger, 1995; Bulger, Cosby, and Webb, 2000). Warmer future climate conditions, economic growth, and increasing populations will create more requirements for energy, and if the energy is derived from fossil fuels, there is the potential for increasing acid rain.

Atmospheric nitrogen deposition, which is attributable to motor vehicles, energy production, industrial activities, and agriculture, contributes to acidification and also to fertilization of ecosystems because nitrogen is an essential nutrient whose supply is often limited. Nitrogen saturation, or unnaturally high concentrations of nitrogen in lakes and streams, is of great concern to many national parks. Although nitrogen oxide emissions are decreasing in the eastern United States, nitrogen emissions and deposition are increasing in many western parks as human density increases. Gila Cliff Dwellings, Grand Canyon, Yellowstone, and Denali National Parks reported increased nitrogen deposition over the period 1995–2004 (National Park Service, 2006c). Some classes of plants, especially many weedy herbs, may benefit from N-fertilization (Stohlgren *et al.*, 2002). Effects of excess nitrogen in Rocky Mountain National Park include changes in the composition of alpine tundra plant communities, increases in nutrient cycling and the nitrogen content of forests, and increased algal productivity and changes to species assemblages in lakes (Baron *et al.*, 2000; Bowman *et al.*, 2006).

The heavy metal mercury impairs streams and lakes in parks across the United States. Mercury is a byproduct of coal-fired energy production, incineration, mining, and other industrial activities. Mercury concentrations in fish are so high that many national parks are under fish advisories that limit or prohibit fish consumption. Parks in which levels of mercury in fish are dangerous to human health include Everglades, Big Cypress, Acadia, Isle Royale, and Voyageurs. Managers at many other parks, including Shenandoah, Great Smoky Mountains, and Mammoth Cave, have found significant bioaccumulation of mercury in taxonomic groups other than fish, including amphibians, bats, raptors, and songbirds. In Everglades, elevated mercury has been linked to mortality of endangered Florida panthers (Barron, Duvall, and Barron, 2004).

Water Quality

Water quality in national parks is influenced not only by air pollution, but also by current or past land use activities and pollution sources within the watersheds in which national parks are located. Currently, agricultural runoff that includes nutrients, manure and coliform bacteria, pesticides, and herbicides affects waters in nearly every park downstream from where agriculture or grazing is located. Discharges from other non-point sources of pollution—such as landfills, septic systems, and golf courses—also cause problems for park resources, as they have for Cape Cod National Seashore, which now has degraded surface and groundwater quality.

At least 10 parks, mostly in Alaska, are affected by past land-use activities and are designated as EPA Superfund sites. Severely polluted waters in Cuyahoga Valley National Park, in which surface oil and debris ignited in 1969, were an impetus for the

Clean Water Act of 1972. Although the Cuyahoga River has become cleaner in the past three decades, it still receives discharges of storm water combined-sewer overflows, and partially treated wastewater from urban areas upstream of the park. Beaches of lakes and seashores, such as Indiana Dunes National Lakeshore, are sometimes affected by high levels of bacteria from urban runoff and wastewater after heavy rainfall events.

4.2.2.5 Direct Impacts of Climate Change

There will be some direct effects of climate change, as well as many interactive effects of climate change with the other major disruptions of natural processes described above. In addition to warming trends, climate change will influence the timing and rate of precipitation events. Both storms and droughts are expected to become less predictable and more intense. There will be direct effects on glaciers and hydrologic processes. Because of warming, glaciers are predicted to disappear from Glacier National Park by 2030 (Hall and Fagre, 2003). In North Cascades National Park similar glacial attrition is being observed (Granshaw and Fountain, 2006). The retreating Van Trump glacier on Mount Rainier has produced four debris flows between 2001-2006, filling the Nisqually River with sediment and raising the river bed at least six feet. Future high flow events will spread farther from the river banks because of the raised bed (Halmon *et al.*, 2006). Data already show that climate change is modifying hydrologic patterns in seasonally snow-dominated systems (Mote, 2006). Snowmelt now occurs earlier throughout much of the United States (Huntington *et al.*, 2004; Stewart, Cayan, and Dettinger, 2005; Hodgkins and Dudley, 2006). Sea level rise has great potential to disturb coastal ecosystems.

Climatic changes will have both direct and indirect effects on vegetation. With rapidly warming temperatures, more productive species from lower elevations that are currently limited by short growing seasons and heavy snowpack may eventually replace upper-elevation tree species (Hessl and Baker, 1997). Similarly, alpine meadows will be subject to invasion by native tree species (Fagre, Peterson, and Hessl, 2003). Subalpine fir is already invading the Paradise flower fields at Mt. Rainier National Park, taking advantage of mild years to establish, and forming tree islands that buffer individual trees against cold and snow. In Tuolumne Meadows, at 2,900 m in Yosemite National Park, lodgepole pine is rapidly establishing, and indeed is colonizing other more remote meadows above 3,000 m (Yosemite National Park, 2006). Vegetation will be redistributed along north-south gradients, as well as along elevation gradients, facilitated by dieback in southern ranges and possible expansion to cooler latitudes. Piñon pine forests of the southwest are illustrative of how severe drought and unusual warmth exceeded species-specific physiological thresholds, causing piñon mortality across millions of hectares in recent years (Allen, In Press). Piñon pines are not dying in their northern range, according to the Forest Inventory Analysis (Shaw, Steed, and DeBlander, 2005), and model results suggest that their range could expand in Colorado over the next 100 years (Ironside *et al.*, 2007). Where vegetation dieback occurs, it can interact with wildfire activity, and both fires and plant mortality can enhance erosion (Allen, In Press).

Climate change will influence fire regimes throughout the country. Extended fire seasons and increased fire intensity have already been observed to correlate directly with climate in the western US, and these are projected to continue (Westerling *et al.*, 2006). Air quality is likely to be adversely affected by warmer climates, brought about by increased smoke from fires and ozone, whose production is enhanced with rising temperature (Langner, Bergström, and Foltescu, 2005; McKenzie *et al.*, 2006). Water quality is likely to decrease with climate change. Post-fire erosion will introduce sediment to rivers, lakes, and reservoirs; warmer temperatures will increase anoxia of eutrophic waters and enhance the bioaccumulation of contaminants and toxins (Murdoch, Baron, and Miller, 2000). Reduced flows, either from increased evapotranspiration or increased human consumptive uses, will reduce the dilution of pollutants in rivers and streams (Murdoch, Baron, and Miller, 2000).

4.2.3 Current Approaches to NPS Natural Resource Management

To date, only a few individual parks address climate change in their General Management Plans, Resource Management Plans, Strategic Plans, or Wilderness Plans. Dry Tortugas' General Management Plan lists climate change as an external force that is degrading park coral reefs and sea grass meadows, but considers climate change beyond the scope of park management authority. Sequoia and Kings Canyon National Park's Resource Management Plan specifically references climate change as a restraint to achieving desired future conditions and notes the need for inventory and monitoring to enable decision making.

NPS has made significant progress in recent years in gathering basic information, developing a rigorous structure for monitoring changes, and raising natural resource management to the highest level of importance. Decisions about the extent and degree of management actions that are taken to protect or restore park ecosystems are increasingly supported by management objectives and credible science (National Park Service, 2006a). NPS management approaches to altered disturbance regimes, habitat fragmentation, invasive species, and pollution are described below.

Fire management in the NPS, while conducted in close coordination with other agencies, is driven by five-year prescribed burn plans in individual parks and suppression responses to fire seasons that have become increasingly severe. The use of fire as an ecological management tool and the decision to let naturally ignited fires burn is highly constrained by human settlements and infrastructure. Park managers apply preemptive approaches including mechanical thinning and prescribed burns to reduce the risk of anomalously severe crown fires in forest ecosystems in which fires historically have been frequent low-severity events. These treatments appear to work in some systems, including the Rincon Wilderness in Saguaro National Park (Allen *et al.*, 2002; Finney, McHugh, and Grenfell, 2004).

Erosion is prevented or repaired by necessity on a site by site basis. Terrestrial ecosystem restoration often uses heavy machinery in an effort to repair severely damaged wetlands, stream banks, and coastal dunes, and to restore landforms and connectivity among landscapes disturbed by roads. Restoration treatments after severe fire can increase herbaceous ground cover and thus resistance to accelerated runoff and erosion, as exemplified by work at Bandelier National Monument in New Mexico (Sydoriak, Allen, and Jacobs, 2000).

There are no national summaries of the extent of hydrologic alteration in national parks. Technical assistance and research on flow regimes is supplied by the NPS Water Resource Division and the U.S. Geological Survey to individual parks. For downstream parks that have extensive upstream watershed development, there is no management of altered hydrology (*e.g.*, Cuyahoga Valley NRA, Big Bend National Park). In other locations, research is being conducted on hydrologic alterations and management options. For example, at Organ Pipe Cactus National Monument, scientists and managers are identifying groundwater source areas. Upper Delaware Scenic and Recreational River is quantifying minimum flows necessary for protecting endangered dwarf wedgemussels. Adaptive management using experimental flows in Grand Canyon National Park below Glen Canyon Dam is helping to develop a flow regime that supports endangered fish, sediment, recreation, and hydropower generation. Some park units are actively removing dams (*e.g.*, Glines Canyon and Elwha Dams in Olympic National Park), purchasing water rights from previous owners in order to protect water flows (*e.g.*, Zion National Park, Cedar Breaks National Monument, Craters of the Moon National Monument), and restoring wetlands, stream banks, and wildlife habitat in areas affected by logging (*e.g.*, Redwoods National Park, St Croix National Scenic Riverway) or road construction (*e.g.*, Klondike Gold Rush NHP).

Current wildlife management policies in national parks have been shaped by a combination of strong criticism of past wildlife management practices in Yellowstone and Rocky Mountain National Parks (Sellars, 1999) and by scientific research that has highlighted the role of parks as refuges for native wildlife. Individual parks manage their wildlife differently on the basis of history, current land use adjacent to the park, ecological feasibility, public sentiment, and legal directives. Large ungulates and carnivores attract much management attention, and there have been many studies on carrying capacity and the feasibility of reintroducing certain species in national parks. Reintroduction of gray wolves into Yellowstone National Park was accomplished in 1995 and 1996 after extensive study and environmental assessment. The number of packs and reproduction of individual wolves has increased substantially since the reintroductions. There have been remarkable effects to the entire trophic cascade and Yellowstone ecosystem as a result of the wolves’ hunting tactics and behavioral changes among ungulates. Changes have occurred in vegetation and habitat for many other species, including songbirds, beaver, and willows in response to restructuring the Yellowstone food chain (Ripple and Beschta, 2005).

Restoration of bighorn sheep illustrates another successful application of contemporary wildlife ecology to park management. A geospatial assessment of the existence and quality of habitat for bighorn sheep within 14 western national parks from which bighorn sheep had been extirpated found that only 32% of the available area could support reintroduced populations (Singer, Bleich, and Gudorf, 2000). By reintroducing bighorn sheep only to areas with adequate habitat quality and quantity, managers have facilitated establishment of stable reproducing populations.

Many other examples, from restoring nesting populations of Kemp's Ridley sea turtles at Padre Island National Seashore to directing more NPS funding toward protecting listed species whose need is most immediate, illustrate species-specific management activities that occur within park boundaries (Fig. 4.7). Management summaries have been completed for almost all of the 284 threatened and endangered species that occur in the national parks. The summaries that relate basic biological information to recovery goals for species are posted on a Web site in a form that is accessible to resource managers (National Park Service, 2004d).

Figure 4.7. Kemp's Ridley hatchlings heading for the water at a hatchling release. Photo courtesy National Park Service, Padre Island National Seashore.

At least two parks, Great Smoky Mountains and Point Reyes National Seashore, have embarked on All-Taxa Biodiversity Inventories (ATBIs) to catalog all living species of plants, vertebrates, invertebrates, bacteria, and fungi. Inventories are a critical first step toward tracking and understanding changes in species richness and composition. Through the Natural Resource Challenge, more than 1,750 park inventory data sets have recently been compiled. For all natural national parks, these sets of data include natural resource bibliographies, vertebrate and vascular plant species lists, base cartography, air and water quality measures, the location and type of water bodies, and meteorology. Additional inventories of geologic and vegetation maps, soils, land cover types, geographic distributions and status of vertebrates and vascular plants, and location of air quality monitoring stations are in progress.

Efforts to address regional landscape and hydrologic alteration occur in some park areas, and have been initiated either by individual parks or their regional partners. The Greater Yellowstone Coordinating Committee (Box 4.5), and the Comprehensive Everglades Restoration Plan—which includes Everglades, Big Cypress National Preserve, and Biscayne National Parks—are two examples of large multi-agency efforts targeting landscape and hydrologic rehabilitation or protection. Some management within park units has also attempted to alleviate fragmentation. For example, road underpasses have been constructed for desert tortoises in Joshua Tree National Monument.

As part of the NPS commitments within the National Invasive Species Management Plan, Seventeen Exotic Plant Management Teams operating under the principles of adaptive management serve more than 200 park units (National Invasive Species Council, 2001). Exotic Plant Management Teams identify, develop, conduct, and evaluate invasive species removal projects. Modeled after rapid response fire management teams, crews aggressively control unwanted plants. Mechanical, chemical, and cultural management methods and biological control techniques are all used in the effort to rapidly remove unwanted plant species. Exotic plant management teams work collaboratively with the U.S. Department of Agriculture, other bureaus in the Department of the Interior, state and local governments, and non-governmental organizations such as the Rocky Mountain Elk

Foundation to control invasive plants, many of which are common across extensive areas. In 2004, 6,782 acres with invasive plants were treated in national park units, and 387 were restored (National Park Service, 2004b).

If invasive insects, either native or alien, are considered a threat to structures or the survival of valued flora, they may be treated aggressively. Direct management interventions include use of biocides, biological control, and plant removal in "frontcountry" areas where safety and visitor perception are paramount. Non-native diseases are another major threat to native plants and animals. White pine blister rust (*Cronartium ribicola*), for instance, has caused die-offs of five-needled pines in western and Midwestern parks.

Because most sources of pollution are outside national park boundaries, NPS air and water managers work with state and federal regulatory agencies that have the authority to implement pollution control by requiring best management practices and adhering to air and water quality standards. Unlike many resource management programs that operate in individual parks, there is national oversight of air quality issues for all national parks. The Clean Air Act and the Wilderness Act set stringent standards for air quality in all 49 Class I Parks (those parks with the highest level of air quality protection), and the NPS Air Quality Program actively monitors and evaluates air quality in these parks, notifying the states and EPA when impairment or declining trends in air quality are observed. Rocky Mountain National Park provides an example of a successful program to reduce nitrogen deposition. A synthesis of published research found many environmental changes caused by increasing atmospheric nitrogen deposition. NPS used the information to convince the state of Colorado to take action, and NPS, Colorado, and EPA now have a plan in place to reverse deposition trends at the park. The Air Quality Program recently completed a risk assessment of the effects of increasing ozone concentrations to plants for all 270 natural resource parks (Kohut, 2007), and has planned a similar risk assessment of the potential for damage from atmospheric nitrogen deposition.

A baseline water quality inventory and assessment for all natural resource national parks is scheduled for completion in 2007, and 235 of 270 park reports were completed as of 2006. Reports are accessible online (National Park Service, 2004a), and electronic data are provided to individual parks for planning purposes. Measurement, evaluation of sources of water pollution, and assessment of biological effects currently are carried out by individual parks, with support from the NPS and USGS Water Resources Divisions. Most routine water quality monitoring is related to human health considerations.

A number of low-lying coastal areas and islands are at high risk of inundation as climate changes. The NPS Geologic Resources Division, in partnership with the USGS, conducted assessments of potential future changes in sea level. The two agencies used results of the assessments to create vulnerability maps to assist NPS in managing its nearly 7,500 miles of shoreline along oceans and lakes. Vulnerability was based on risk of inundation. For example, the USGS coastal vulnerability index has rated six of seven barrier islands at Gulf Islands National Seashore highly vulnerable to sea level rise; the seventh island was rated moderately vulnerable (Pendleton *et al.*, 2007).

4.2.4 Sensitivity of NPS Goals to Climate Change

Climate change will severely challenge NPS as it strives to protect natural processes and resources. The goals in the enabling language of the NPS, including the words "conserve" and "unimpaired," have a much better chance of being met when scientific principles are applied (Parsons, 2004). Science-based management principles will be even more important as park managers attempt to achieve these goals in the context of climate change.

One of the biggest challenges revolves around protection and restoration of native species. The Natural Resource Challenge distinguishes between native and nonnative plants, animals, and other organisms, and recommends non-natives are to be controlled where they jeopardize natural communities in parks. However, species distributions will change, and indeed are already changing, as the climate warms. Changing distributions are evident in observations of gradual migrations (*e.g.*, northward and higher elevation observations of many species; Edwards *et al.*, 2005; Parmesan, 2006) and in massive diebacks (*e.g.*, piñon mortality in Bandelier National Monument; Allen, In Press). A recent study suggests that by 2100 between 4% and 39% of the worlds land areas will experience combinations of climate variables that do not currently exist anywhere on Earth, and a biological response unprecedented in human history (Williams, Jackson, and Kutzbach, 2007). Individual species, constrained by different environmental factors, will respond differently, with the result that some species may vanish, others stay in place, and new arrivals appear (Saxon *et al.*, 2005). This type of ecosystem reshuffling will occur in national parks as well as other places, straining the ability of NPS to meet its goals.

Resistance to change in an attempt to maintain desired species assemblages is certainly being contemplated, if not actually practiced in many parks. Yet even if maintenance of representative current biotic communities is possible as climate changes, such maintenance may not be desirable. A community composition and structure that is maintained entirely by human intervention may be inherently unstable to novel environmental conditions and prone to sudden, complete loss, with potentially undesirable cascading effects (Harris *et al.*, 2006). For example, if active management maintains a certain vegetation association in a given location despite significant climatic changes, all vegetation cover might be lost if a precipitating event such as a drought, fire, or pathogen outbreak occurs.

NPS goals of providing visitor services such as interpretation and protection will not be directly altered by climate change, although programs will need to adapt. National parks will remain highly desirable places for people to visit, but climate change may cause visitation patterns to shift in season or location. Climate change will alter the length of visitor seasons in many parks; coastal and mountain parks may see increased visitation, while desert parks may see decreased visitation during summer months. Unpredictable weather may strain visitor safety services. Interpretation efforts can play an important role in educating park visitors about changes occurring in national parks and what the park is doing to manage or reduce the impacts of those changes. Interpretation may also be a good way to engage the public in meaningful discussions about what climate change means for ecosystems and valued species within them.

4.3 Adapting to Climate Change

4.3.1 Coming to Terms with Uncertainty

Predicting climate change and its effects poses a variety of challenges to park managers. What is likely to happen? What potentially could happen? Do we have any control over what happens? The answers to these questions are associated with substantial uncertainties, including uncertainties particular to management of natural resources (Rittel and Webber, 1973; Lee, 1993; Regan, Colyvan, and Burgman, 2002). Resource uncertainties can be separated into two categories (Lee, 1993): the first type, *technical and scientific* uncertainty, centers on what we do and do not know about future climate change effects and our ability to ameliorate them. The second type, *social uncertainty*, focuses on our cultural and organizational capability to respond.

There is considerable uncertainty in predictions, understanding, and interpretation of climate change and its effects. Managers must consider at least three different categories of climate change impacts, each associated with a different level of uncertainty: foreseeable or tractable changes, imagined or surprising changes, and unknown changes.

Predictions of climate change are generally accepted if changes are foreseeable; evidence already exists that many of these predictions are accurate. For instance, we can predict with high confidence that atmospheric carbon dioxide concentrations will increase, sea levels will rise, snow packs across most of North America will shrink, global temperature will increase, fire seasons will become longer and more severe, and the severity of storms will increase (IPCC, 2007). We refer to a given change as foreseeable if there is a fairly robust model (or models) describing relationships between system components and drivers, and sufficient theory, data, and understanding to develop credible projections over the appropriate scales. We cannot project precisely the magnitude of foreseeable changes, but we can quantify the distribution of probable outcomes. For example, a 40-year record shows that snow is melting increasingly earlier in the spring in the Sierra Nevada, Cascade Range, and New England (Stewart, Cayan, and Dettinger, 2005; Hodgkins and Dudley, 2006). We also have understanding from the physical sciences of why the timing of snowmelt is likely to change in regions with winter and spring temperatures between -3 and 0°C as the climate warms (Knowles, Dettinger, and Cayan, 2006). Foreseeable changes are sufficiently certain that park managers can begin planning now for effects of earlier snowmelt on river flow, fishes and other aquatic species, and fire potential. Such plans for aquatic organisms could include establishing refugia for valued species at risk, removing barriers for natural species migrations, or even conducting assisted migrations. As the risk of fire increases, planners might consider moving infrastructure out of fire-prone areas and restricting visitor access to fire-prone areas during fire seasons for safety reasons. Planners may also need to consider how to manage for increased smoke-related health alerts and possibly increased respiratory emergencies in parks.

The second category of climate change includes changes that are known or imaginable, but difficult to predict with high certainty and may include changes with which we have little or no past experience or history. It can also include effects of changes in systems for which there is a great deal of experience. For example, nonlinear interactions among system components and drivers could reduce the certainty of predictions and generate unexpected or surprising dynamics. Surprises may present crises when the ecological system abruptly changes into a qualitatively different state. For example, a November 2006 storm that caused severe flooding and damage in Mount Rainier National Park was surprising, because a storm of this magnitude had not been observed previously. An example of change that is known but difficult to project is rapid and extensive dieback of forests and woodlands from climate-induced physiological stress, and in some cases, associated insect outbreaks. Forest mortality in the Jemez Mountains of northern New Mexico had occurred before; the lower extent of the ponderosa pine zone in Bandelier National Monument retreated upslope by as much as 2 km in less than five years in response to severe drought and an associated outbreak of bark beetles in the 1950s (Allen and Breshears, 1998; Allen, In Press). Planning for these rare but major events requires that mechanisms be put in place to reduce the damage caused by those events. In some instances, minimizing the ecological effects of sudden changes in system state might require removing infrastructure or maintaining corridors for species migration.

The third category of climate change is unknown or unknowable changes. This group includes changes and associated effects that have not previously been experienced by humans. Perhaps the greatest uncertainties in predicting climate change and its effects are associated with the interaction of climate change and other human activities. The synergistic and cumulative interactions among multiple system components and stressors, such as new barriers or pathways to species movement, disruption of nutrient cycles, or the emergence of new diseases, will create emerging ecosystems unlike any ever seen before.

4.3.2 Approaches to Management Given Uncertainty

When confronting a complex issue, it is tempting to defer action until more information or understanding is gained. Continuing studies and evaluations almost always are warranted, but not all actions can or should be deferred until there is unequivocal scientific information. Scenario planning and knowledge gained from research and adaptive management practices can help with decision-making and point toward implementation of actions to manage natural resources in the face of substantial uncertainty. Ideally, actions should be taken that are robust to acknowledged uncertainty. It is critical to develop and implement frameworks that allow the NPS to learn from implementation of policies, regulations, and actions.

National parks are complex systems. John Muir wrote "*When we try to pick out anything by itself, we find it hitched to everything else in the universe*" (Muir, 1911). Species co-occur, influenced by physical, chemical, and biological conditions. Parks are surrounded by lands that are managed with different goals and objectives. Although few problems can be solved easily, the adoption of a systems approach to management, where living resources are evaluated in connection with the environment with which they interact, increases the probability of achieving park objectives. The two major factors that influence selection of strategies for managing complex resource systems are the degree (and type) of uncertainty and the extent to which key ecological processes can be controlled (Fig. 4.8). Uncertainty can be qualitatively evaluated as low or high. Ability to control an ecological process depends on the process itself, the responsible management organization or institution, and the available technology. For example, supply of surface water can be manipulated upstream from some national parks, such as Everglades or Grand Canyon.

Figure 4.8. Scenario planning is appropriate for systems in which there is a lot of uncertainty that is not controllable. In other cases optimal control, hedging, or adaptive management may be appropriate responses. Reprinted from Peterson, Cumming, and Carpenter (2003).

Optimal Control and Hedging

The strategic approaches in Fig. 4.8 provide a broad set of tools for resource management. Each tool is appropriate for certain types of management, and while not interchangeable, the lessons learned from application of one can and should inform the decisions on whether and how to employ the others. Most approaches toward current resource management in the NPS are appropriate when uncertainty is low. That is, most management is based on either an optimal control approach or a hedging approach. However, the attributes and effects of climate change present sufficient uncertainties to NPS managers that adaptive management or scenario development are much more appropriate than optimal control or hedging.

Fire and wildlife management as currently practiced are examples of optimal control. Many fire management plans are developed and implemented by controlling the timing—and hence the probable impact—of fire to achieve an optimal set of resource conditions. Control of wildlife populations through culling, birth control, or reintroduction of top predators is based on concepts about limits such as carrying capacity. Physical removal of invasive plants exemplifies optimal control. Hedging strategies involve management that may improve fitness or survival of species. For example, placing large woody debris in a stream to improve fish habitat is essentially a hedging strategy.

Scenario-Based Planning

Scenario-based planning is a qualitative, or sometimes quantitative process that involves exploration and articulation of a wide set of possible or alternative futures (Carpenter, 2002; Peterson, Cumming, and Carpenter, 2003; Raskin, 2005). Each of these alternative scenarios is developed through a discourse among knowledgeable persons, and is informed by data and either conceptual or simulation models. Scenarios are plausible—yet uncertain—stories or narratives about what might happen in the future. Scenario development is used routinely to assess a variety of environmental resource issues (National Research Council, 1999). Park Service managers, along with subject-matter experts, apply existing knowledge to conduct scenario planning related to climate change and resources of interest. Research into the rate, extent, or permanence of climate change-induced impacts on species and ecosystems of interest can inform the scenarios. Either passive or active contingency plans can be deployed for both (1) trends that are observed and have a high probability of continuing, and (2) events with low probability but high risk that result from any combination of climate change and other stressors.

Scenario planning and development of contingency plans can lead to several levels of preparedness. For example, plans can be constructed to trigger action if a threshold is crossed, similar to current air quality regulations for ozone. In addition to mandatory reductions in ozone precursor emissions, there are strong economic penalties imposed on the ozone-producing region by EPA when allowable ozone levels are exceeded. Plans could include management "drills" to prepare for low, but real, probabilities of an extreme event (fire drills are an example we are all familiar with). Scenarios should be built around consideration of how climate change will affect current resource management issues. If current habitat recovery plans for endangered species, for instance, do not take future climate change into account, recovery goals may not be met.

Adaptive Environmental Assessment and Management

Adaptive environmental assessment and management refers to a set of processes to integrate learning with management actions (Holling, 1978; Walters, 1986; Lee, 1993). The processes focus on developing hypotheses or explanations to describe 1) how specific ecological dynamics operate and 2) how human interventions may affect the ecosystem. Adaptive environmental assessment is substantially different from environmental assessments routinely conducted within frameworks such as NEPA. The NEPA process presumes certainty of impacts and outcomes, and generally minimizes or ignores uncertainties. Adaptive environmental assessment and management, by contrast, highlights uncertainty. Managers design actions that specifically test uncertainties about ecosystem dynamics and outcomes of proposed interventions. The objectives of management actions explicitly include learning (hence reduction of uncertainty). Adaptive management views policies as hypotheses and management actions as treatments that are structured to "test" desired outcomes.

Adaptive management can be either active or passive. Active adaptive management involves direct manipulation of key ecological processes to test understanding of relationships among system components and drivers and to examine the effects of policies or decisions, such as the flood release experiments of 1996 and 2004 in the Grand Canyon (Walters *et al.*, 2000). Passive adaptive management uses natural variability in ecological processes to evaluate how systems might respond to interventions such as an experimental water delivery program in the Everglades (Walters, Gunderson, and Holling, 1992; Light, Gunderson, and Holling, 1995). Whether active or passive, information gathered throughout the iterative adaptive management cycle is used to assess hypotheses, increase ecological understanding, and refine management (Walters and Holling, 1990).

Adaptive management has been successful in large-scale systems that meet both ecological and social criteria: sufficient ecological resilience to deterministic and stochastic change, and a willingness to experiment and participate in a formal structure for learning. Ecological resilience, or the capacity for renewal in a dynamic environment, buffers the system from the potential failure of management actions that unavoidably were based upon incomplete understanding. Resilience allows managers the latitude to learn and change. Trust, cooperation, and other forms of social capital are necessary for implementing management actions that are designed to meet learning and other social objectives.

Safe-to-Fail Strategies

Because the uncertainties associated with predictions of climate change and its effects are substantial, expected outcomes or targets of agency policies and actions have some probability of being incorrect. Accordingly, NPS could take the robust approach of designing actions that are "safe to fail." That is, even though managers intend to implement a "correct" action, they and their supervisors recognize that failure may occur. A safe-to-fail policy or action is one in which the system can recover without irreversible damage to either natural resources or human resources (*e.g.*, careers and livelihoods). This type of approach is employed in other fields, such as engineering systems (*e.g.*, air traffic control, or electric power distribution) where uncertainty is actively managed through flexible designs that adjust to changing conditions (Neufville, 2003). One low tech example of where safe to fail strategies are already used in NPS resource management is in attempting to control invasive feral hogs. Feral hogs are common to many parks in the southeastern United States, California, the Virgin Islands, and Hawaii. The hogs are opportunistic omnivores whose rooting profoundly disrupts natural communities and individual populations, and facilitates establishment of invasive plants. Hogs compete directly with native wildlife for mast, prey on nests of ground-nesting birds and sea turtles, and serve as reservoirs for a variety of serious wildlife diseases and parasites. Fencing, hunting, and trapping efforts to eliminate feral hog populations in national parks often fail; either removal operations are unsuccessful or native plant and animal populations do not recover. Yet control tactics and restoration activities can be modified and managed adaptively as information accrues on probabilities of success associated with different sets of ecological conditions and interventions.

Although not desired, failures provide tremendous opportunities for learning. Learning from mistakes and successes is a critical part of adaptation to climate change. As climate changes, even the most well-reasoned actions have some potential to go awry. The wisdom, experience, and empirical data of front line managers, resource management personnel, and scientific staff needs to be protected, preserved, and expanded.

Acceptance of a gradient between success and failure might foster greater creativity in resource management and remove the need to assign blame. Shifting attitudes about failure increases institutional capacity to capture and expand learning. Punishing managers whose proactive management efforts fail may create an environment in which managers are risk-averse and act only on the basis of what is known with certainty.

4.3.3 Incorporating Climate Change Considerations into Natural Resource Management

Given that recent climate changes and climate variations are already beginning to have effects on natural systems, and warming trends are projected into the next century (IPCC, 2007), it is prudent to begin to implement adaptation strategies as soon as possible. The importance of action in national parks extends well beyond the parks themselves. The value of national parks as minimally disturbed refugia for natural processes and biodiversity becomes more important with increasing alteration of other lands and waters. Many parks have received international recognition as Biosphere Reserves or World Heritage sites because of their transcendent value worldwide. If protection of natural resources and processes is to be achieved during the coming decades of climate change, Park Service managers need to first identify what is at risk, define the baselines, or reference conditions, that constitute “unimpaired” in a changing world, decide the appropriate scales at which to manage the processes and resources of national parks, and finally set measurable targets of protection by which to measure success or failure over time (Box 4.6). All of these actions require intimate and iterative connection between scientific research and resource management. Managers define research needs in consultation with scientists; researchers evaluate the trends and the range of possible outcomes from climate change using long-term data, regional surveys, experiments, and models. Continuous dialog between scientists and managers will build the greatest possible understanding of the threats, consequences, and possible actions related to climate change (Box 4.7).

Identify Resources and Processes at Risk from Climate Change

The first activity is to identify the important park processes and resources that are likely to change as a result of climate change. This should take place within each park, but the exercise should occur at the network, regional, and national scale as well, in order to prioritize which resources will respond most rapidly, thus warranting immediate attention. It begins with characterizing potential future climate changes, and systematically considering resources susceptible to change under future climates. This can be accomplished through summaries of the literature, guided research, gatherings of experts, and workshops where scientists and managers engage in discussing risks to resources. Some of this may have already been done during the process of identifying vital signs for the Inventory and Monitoring Program. Park managers may wish to rank resources and processes according to how susceptible they are to changes in climate based on the rapidity of expected response, the potential for adaptation opportunities (or conversely, the threat of endangerment), the “keystone” effect (*i.e.*, species or processes that have disproportionate effects on other resources), and the importance of the species or resources to meeting the park’s management goals.

Develop Monitoring and Assessment Programs for Resources at Risk from Climate Change

In periods of accelerated change, it is critical to understand and evaluate the nature of change. As part of the NPS Inventory and Monitoring Program, every national park has established a number of vital signs for monitoring change over time; these vital signs lists should be reviewed in order to ensure they are adequate to capture climate-caused changes. If they are not, the list of vital signs and the frequency with which they are measured may need to be amended. Increasingly, ground-based monitoring can and should be augmented with new technologies and remote sensing. NPS maintains 64 sites as part of the Global Fiducial Program, which collects high-resolution geospatial data for predetermined sites over a period of years to decades (National Park Service, 2007c). Global Fiducial represents an important, and underutilized, type of information that has much to offer to national parks. Collaborations with universities and other agencies can accelerate the ability of NPS to obtain useful data that can be incorporated into adaptive management. Collaborations with other information gathering and assessment programs—such as programs of the USGS and National Science Foundation, including the NEON and the LTER networks—present benefits to all partners by developing broad integrated analyses.

Assessment involves tracking the vital signs and their major drivers of change to evaluate the presence of trends or thresholds. While it is important to look at the data that show what happened in the past, it is critically important to use monitored information to forecast potential future trends or events. Forecasting allows management intervention in advance of some undesired change, and can be conducted with simple extrapolations of monitored data. Simulation and statistical models are invaluable tools for forecasting future events, but they need to be parameterized with physical and biological information, and validated against existing records. The data requirements for models, therefore, need to be considered when choosing which environmental attributes to monitor.

Define Baselines or Reference Conditions for Protection or Restoration

As the change in biological assemblages plays out in our national parks, certain common sense actions should be undertaken, among them establishment of quantifiable and measurable baseline conditions that describe current or unimpaired (not necessarily the same thing) conditions, and routine monitoring of select indicators that can be used to measure change. Philosophical discussions will need to take place regarding the legitimacy of novel ecosystems made up of previously unrepresented species (Hobbs *et al.*, 2006). Natural migrations of plants and animals from outside park boundaries will occur, indeed will need to occur, as individual species seek favorable climatic conditions. The distinction between “welcome” and “unwelcome” new arrivals will need to be addressed.

As part of this exercise, national park managers may need to address whether protecting or recovering certain processes or resources will be possible and what the ramifications are if such ends are not attainable. Individual species, such as the pika—a small-bodied mammal related to rabbits and hares that lives on isolated mountains in the Great Basin, Rocky Mountains, and Sierra Nevada—or features, such as glaciers in Glacier National Park, are extremely vulnerable to climate change (Beever, Brussard, and Berger, 2003; Hall and Fagre, 2003; Grayson, 2005). Ramifications are economic as well as ecological. With limited resources, NPS will have hard decisions in the coming years over how to manage most effectively.

Develop and Implement Management Strategies for Adaptation

Developing and implementing strategies for adaptation to climate change will require NPS managers to adopt a broad array of tools well beyond control and hedging strategies. Current management practices may not be effective under future climates. Some strategies include:

- *Diversify the portfolio of management approaches.* Because climate change is complex and predictions often have high levels of uncertainty, diverse management strategies and actions will be needed. It is important to think broadly about potential environmental changes and management responses and not be constrained by history, existing policies and their interpretation, current practices, and traditions. Initial assessments of effective approaches in general or specific environmental circumstances can be informed by the degree of uncertainty in management outcomes and the potential for control through human intervention. Managers can hedge bets and optimize practices in situations where system dynamics and responses are fairly certain. In situations with greater uncertainty, adaptive management can be undertaken if key ecosystem processes can be manipulated. In all situations, capacity to project changes and manage adaptively will be enhanced by scenario development, planning, and clear goals. Scenario development can rely primarily on qualitative conceptual models, but is more likely to be effective when data are available to characterize key system components, drivers, and mechanisms of responses.

- *Plan, and manage, for inevitable changes.* New climate conditions and assemblages are likely to favor opportunistic species such as non-native grasses, pests, and diseases (Lovejoy, 2007). It is possible that invasive species cannot be controlled before native species are extirpated (Box 4.8). Potential responses may include aggressive efforts to prevent invasion of non-native species in specific locations at which they currently are absent and future conditions may remain favorable for native species. Managers might “help” individuals of a favored species through transplanting them, or perhaps consider conceding the loss of the species.

  Although in many cases restoration and maintenance of natural biotic communities may become impossible or undesirable, useful efforts might be directed toward maintenance of ecosystem function and regional native species assemblages. For example, even if a particular vegetation community on a landscape is “unnatural” in the sense that it had no past analog (and may even contain some non-native species and “displaced natives,” species native to nearby bioregions that for the first time have migrated into a particular protected area in response to climatic changes), it may serve to maintain regional native biodiversity. Of at least equal importance, the “unnatural” vegetation maintains ecosystem functions such as providing food and habitat for wildlife, preserving soil, and regulating hydrologic processes.

- *Accelerate the capacity for learning.* Given the magnitude of potential climate changes and the degree of uncertainties about specific changes and their effects on national parks, park managers, decision makers, scientists, and the public will need to learn quickly. Some amount of uncertainty should not be an excuse for inaction, since inaction can sometimes lead to greater harm than actions based on incomplete knowledge. Adaptive management—the integration of ongoing research, monitoring, and management in a framework of testing and evaluation—will facilitate that learning. Bringing together experts at issue-specific workshops can rapidly build understanding. Application of safe-to-fail approaches also will increase capacity for learning and effective management.

- *Assess, plan, and manage at multiple scales*. Complex ecological systems in national parks operate and change at multiple spatial and temporal scales. As climate changes, for example, the ranges of some species will shrink, whereas the ranges of others will expand beyond park borders. The scales at which ecological processes operate often will dictate the scales at which management institutions must be developed. Migratory bird management, for instance, requires international collaboration; large ungulates and carnivores require regional collaboration; both are examples of where park managers cannot be effective working solely within park boundaries. Similarly, preparation for rapid events such as floods will be managed very differently than responses to climate impacts that occur over decades. Species may be able to move to favorable climates and habitats over time if there is appropriate habitat and connectivity. There are several examples of management of park resources within larger regional or ecosystem contexts. The Greater Yellowstone Coordinating Committee, and the Southern Appalachian Man and the Biosphere (SAMAB) Program are building relationships across jurisdictional boundaries that will allow effective planning for species and processes to adapt to climate change. These ecoregional consortia should serve as models for other park areas as they begin to address the multiple challenges that emanate from outside park boundaries (Box 4.9).

- *Reduce other human-caused stressors to park ecosystems*. In addition to the direct consequences of climate change to park resources, we know that interactions of climate with other stressors will have major influences on national park resources (McKenzie *et al.*, 2006). Therefore, one of the most basic actions park managers can take to slow or mitigate some effects of climatic change is to reduce the magnitude of other disturbances to park ecosystems (*e.g.*, Hansen, Biringer, and Hoffman, 2003; Welch, 2005). Minimizing sources of pollution, competition between non-native and native species, spread of disease, and alteration of natural disturbance regimes should increase ecosystem resilience to changing climate. Some combination of these stressors affects every one of the 270 natural national parks either directly or indirectly. Reducing threats and repairing damage to natural resources is the major purpose of the Natural Resource Challenge, among other NPS programs; the synergistic effect of other disturbances with climate change increases the urgency for getting other threats under control. The interactions between these drivers and climate change can lead to nonlinear ecological dynamics, sometimes causing unexpected or undesired changes in populations or processes (Burkett *et al.*, 2005). Once an ecosystem shifts from one state to another, it may be very difficult to return it to its prior desirable state (Gunderson and Holling, 2002). Strategies that enable natural processes and species to adapt naturally to climate change should be pursued to the greatest extent possible.

- *Nurture and cultivate human resources*. The NPS is endowed with a wealth of human resources in terms of the wisdom, experience, dedication and understanding of its staff and affiliated personnel (such as advisory groups, research scientists, and volunteers). That human capital should be protected and preserved concurrent with natural resources. Promote training, continuous inquiry, an atmosphere of respect, allowance for periodic failure, and personal initiative. Allow time, also, for managers and resource practitioners to step back from their daily routines once or twice a year to take in broad strategic views of national park resources, their stressors, and management approaches.

Use Parks to Demonstrate Responses to Climate Change

The goodwill of Americans toward national parks means that they can be used as examples for appropriate behavior, including mitigation strategies, education, and adaptive natural resource management. The NPS is well aware of its ability to serve as an example, and is rapidly becoming a “green” leader through its Climate Friendly Parks Program, a partnership between NPS and EPA (Box 4.10). There is an initial cost to change operations in response to climate change, but the tradeoff between that cost and a high certainty of long-term tangible benefits makes decisions easier to make and implement. It is also fairly easy to incorporate information about the causes and effects of climate change into park education and interpretation activities. National parks offer tremendous opportunities for increasing ecological literacy, and park staff rely on sound science in their public education efforts.

No-regrets activities for national park operations, education, and outreach have already begun. The Climate Friendly Parks program is visionary in its efforts to inventory greenhouse gas emissions from parks, provide park-specific suggestions to reduce greenhouse gas emissions, and help parks set realistic emissions reduction goals. Education and outreach are addressed in the Climate Friendly Parks program with materials for educating staff and visitors about climate change. NPS’s Pacific West Regional Office has been proactive in educating western park managers on the issues related to climate change, as well as promoting messages for communication to the public and actions for addressing the challenge of climate change. Expansion of this type of proactive leadership is needed.

4.4 Case Study: Rocky Mountain National Park

Rocky Mountain National Park (RMNP), Colorado, is just beginning to consider how to meet its mission in a rapidly changing climate. Park managers know RMNP has some highly vulnerable, and visible, resources, including glaciers and alpine tundra communities, but there is high uncertainty regarding just how vulnerable they are, how rapidly change might occur, or what to do. As such, RMNP is a good example of the state at which most parks find themselves as they confront resource management in the face of climate change. The following case study describes RMNP's first attempt to take stock of the park with respect to climate change, and begin to think about management.

4.4.1 Park Description and Management Goals

RMNP was established in 1915 and "is dedicated and set apart as a public park for the benefit and enjoyment of the people of the United States …with regulations primarily aimed at the freest use of the said park and for the preservation of natural conditions and scenic beauties…" (U.S. Congress, 1915). The park is located in the Front Range of the Rocky Mountains, the first mountain range west of the Great Plains. RMNP's wide elevation gradient—from 8,000 to more than 14,000 feet—includes montane forests and grasslands, old-growth subalpine forests, and the largest expanse of alpine tundra in the lower 48 states. More than 150 lakes and 450 miles of streams form the headwaters of the Colorado River to the west, and the South Platte River to the east. Rich wetlands and riparian areas are regional hotspots of native biodiversity. Several small glaciers and rock glaciers persist in east-facing cirque basins along the Continental Divide. The snow that accumulates in these basins each winter provides water that supports downstream cities and agricultural activities in Colorado and neighboring states. The park is home to populations of migratory elk, mule deer, and bighorn sheep; many plant and animal species that live in the alpine, including white-tailed ptarmigan, pika, and yellow-bellied marmot; and several endangered species, including the boreal toad and the greenback cutthroat trout.

Rocky Mountain National Park is not large compared with other western national parks; it is slightly larger than 415 square miles. Yellowstone, for comparison, is 3,432 square miles. RMNP is bordered on all four sides by national forests. The Roosevelt National Forest surrounds the park on the north and east, the Routt National Forest is found to the northwest, and the Arapahoe National Forest surrounds the southwest, southern, and eastern park boundaries. Approximately half of the adjacent Forest Service land is in wilderness designation (Comanche Peak Wilderness, Neota Wilderness, Never Summer Wilderness, and Indian Peaks Wilderness), and 95% of Rocky Mountain National Park is managed as if it was wilderness. A primary goal for RMNP, therefore, is to protect and manage the park in its natural condition (see Box 4.11). Wilderness status has been proposed since 1974, and legislation is pending. RMNP is also designated a Clean Air Act Class I Area, meaning the superintendent has a responsibility to protect air-quality related values, including vegetation, visibility, water quality, wildlife, historic and prehistoric structures and objects, cultural landscapes, and most other elements of a park environment that are sensitive to air pollution. Several endangered species, such as the boreal toad and the greenback cutthroat trout, have management plans for enhancement and recovery. Other current management issues include fire, elk, and invasive exotic species. All told, there are more than 30 planning documents (Acts, Executive Orders, Plans, and Recommendations) that guide RMNP operations.

The towns of Estes Park and Grand Lake form gateway communities, and are connected by Trail Ridge Road, which is open for traffic during the summer and fall months. The park receives more than three million visitors each year, 25% of whom come from Colorado. Most visitor use is in the summer, when hiking, camping, mountain climbing, and sightseeing are common. Fall visitation is also popular to view aspen leaves and watch and listen to elk go through their mating rituals.

4.4.2 Observed Climate Change in the Western U.S.

There have been many observed signals of climate warming in the western United States, but not all of them have been exhibited in the southern Rocky Mountains or in RMNP. Strong trends in winter warming, increased proportions of winter precipitation falling as rain instead of snow, and earlier snowmelt from mountains are found throughout the western United States (Stewart, Cayan, and Dettinger, 2005; Knowles, Dettinger, and Cayan, 2006; Mote, 2006). All of these trends are more pronounced in the Pacific Northwest and the Sierra Nevada than they are in the Colorado Front Range of the southern Rocky Mountains. The less pronounced evidence for RMNP compared with the rest of western U.S. mountains should not be interpreted as a lack of climate change potential within the park. The high (and thus cold) elevations and a shift over the past 40 years from more even annual distribution of precipitation into more winter precipitation have contributed to Front Range mountain weather going against the trend seen across much of the rest of the West (Knowles, Dettinger, and Cayan, 2006).

Summer warming has been observed in RMNP, where July temperatures increased approximately 3°C, as measured at three high elevation sites from 1991-2001 (Clow *et al.*, 2003). Rocky Mountain National Park, along with most of the rest of the western U.S. experienced record-breaking extreme March temperatures and coincident early melting of winter snowpack in 2004. While not directly attributed to climate change, extreme heat events are consistent with climate change theory that suggests a warmer atmosphere will engender more extreme events (Pagano *et al.*, 2004).

4.4.3 Observed and Projected Effects of Climate Change in Rocky Mountain National Park

Regional phenological trends and mountain glacier retreat are evidence that climate warming is occurring. A long-term study of the timing of marmot emergence from hibernation in central Colorado found marmots emerge on average 38 days earlier than they did in 1977 (Inouye *et al.*, 2000). The arrival of migratory robins two weeks earlier now than in 1977 to Crested Butte, Colorado, also signals biological changes in response to climate (Inouye *et al.*, 2000). Arapahoe Glacier, located 10 miles south of the park on the Continental Divide, has thinned by more than 40 m since 1960 (Fig. 4.9). Photograph pairs of Rowe Glacier in RMNP also show the loss of ice mass over time (Fig. 4.10).

Figure 4.9. Photos of Arapahoe Glacier in 1898 and 2004 (NSIDC/WDC for Glaciology, Boulder, Compiler, 2006).

Figure 4.10. Photo pair of Rowe Glacier, with permissions, NSIDC and leachfam website (Lee, 1916; Leach, 1994).

A number of species of plants and animals may be vulnerable to climate change. Dwarf larkspur (*Delphinium nuttalianum*) shows a strong positive correlation between snowpack and flower production (Saavedra *et al.*, 2003). Research findings suggest that reduced snowpacks that accompany global warming might reduce fitness of this flowering plant. Local weather, as opposed to regional patterns, exerts a strong influence on several species of birds found in the park, including white-tailed ptarmigan (*Lagopus leucarus*) and dippers (*Cinclus mexicanus*) (Saether *et al.*, 2000; Wang *et al.*, 2002b). The median hatch rates of ptarmigan advanced significantly from 1975–1999 in response to warmer April and May temperatures, but population numbers have been declining along Trail Ridge Road, where they are routinely monitored (Wang *et al.*, 2002a). Population growth rates were negatively correlated with warmer winter minimum temperatures for both ptarmigan and dippers.

Some studies of animal responses to climate change in the park reveal positive responses. Elk populations were projected to double under climate scenarios of warmer winters and possibly wetter summers, while model results for warmer winters with drier summers projected an increase in the elk population of 50% (Wang *et al.*, 2002c). Greenback cutthroat trout, an endangered species, have been translocated into streams and lakes in Rocky Mountain National Park as part of a recovery effort. Water temperatures in many of the translocation streams are colder than optimal for greenback cutthroat trout growth and reproduction. Of the ten streams where the fish were reintroduced by the Colorado Division of Wildlife, only three had temperatures within the range for successful growth and reproduction at the time of translocation. A modeling scenario that postulated warmer stream temperatures suggested that three additional streams would sustain sufficient temperature increases to raise the probability of translocation success to >70%. In at least one of these streams, however, temperatures are projected to also warm enough to allow the establishment of whirling disease, caused by *Myxobolus cerebralis*, a parasite that is fatal to young trout (Cooney, 2005).

Other studies suggest that climate warming will diminish opportunities for willow establishment along riparian areas in Rocky Mountain National Park (Cooper *et al.*, 2006), and the occurrence of longer and more severe fire seasons will increase throughout the western United States (Westerling *et al.*, 2006).

An analysis of recreation preferences under climate change scenarios projected a relatively small increase (10-15%) in visitation to Rocky Mountain National Park for climate-related reasons under climate warming scenarios (Richardson and Loomis, 2004). An economic study of whether such an increased visitation would affect the economy and employment outlook for Estes Park similarly did not find climate change to be very important (Weiler *et al.*, 2002). A more important driver of economic change for the Town of Estes Park was projected increases in human population numbers within the State of Colorado (Weiler *et al.*, 2002).

4.4.4 Adapting to Climate Change

Rocky Mountain National Park is relatively rich in information about its ecosystems and natural resources, and has benefited from long-term research and monitoring projects and climate change assessments. Examples include research and monitoring, in Loch Vale Watershed (Natural Resource Ecology Laboratory, 2007), and the focused assessment of the effects of climate change on Rocky Mountain National Park and its Gateway Community (Natural Resource Ecology Laboratory, 2002). Even so, planning and resource management in the park does not include considerations of climate change. A workshop in March 2007 provided the opportunity for park managers and community members to begin thinking about the steps to take to increase preparedness for a climate that will be warmer and less predictable. Results of the workshop are summarized below.

In many ways, effective science-based management in RMNP has enhanced the ability of park natural resources to adapt to climate change. Most of the water rights have been purchased, dams and ditches have been removed, and many streams and lakes have been restored to free-flowing status since 1980. An exception is the Grand River Ditch. Park managers have also been proactive in removing or preventing invasive species such as leafy spurge, and invasive non-native species such as mountain goats; managing fire through controlled burns and thinning; reducing regional air pollution through partnerships with regulatory agencies; and preparing a plan to reduce elk populations to appropriate numbers.

Despite the actions above, Rocky Mountain National Park managers are concerned over the potential for catastrophic wildfire, increasing insect infestations and outbreaks, and damage from large storm events with increasing climate change. A flooding event in the Grand River Ditch, while not necessarily caused by climate change, serves as an example of the potential effects from future storm-caused floods. The Grand Ditch diverts a significant percentage of annual Colorado River tributary streamflow into the east-flowing Poudre River. It was developed in 1894, and is privately owned and managed. A breach of the ditch during snowmelt in May 2003 caused significant erosion and damage to Kawuneechee Valley forests, wetlands, trails, bridges, and campsites.

Park managers are also concerned about the future of alpine tundra and species that live above treeline, but do not have much information about current alpine species populations and trends. Modest baseline data and monitoring programs are currently in place. While regional biogeographic models suggest that the treeline will rise and some alpine areas will diminish or disappear, the future for the alpine in Rocky Mountain National Park is unknown (Neilson and Drapek, 1998). Reduced tundra area, or the separation of continuous tundra by trees, could endanger many obligate tundra plants and animals. Species such as pika, white-tailed ptarmigan, and marmots are already known to be responsive to climate change (Inouye *et al.*, 2000; Wang *et al.*, 2002a; Beever, Brussard, and Berger, 2003).

RMNP managers have identified a strategy for increasing their ability to adapt to climate change built on their current activities, what they know, and what they do not know about upcoming challenges related to climate change. The strategy involves bringing teams of experts and regional resource managers together in a series of workshops to share information and help identify resources and processes that may be most susceptible to climate change. Support for high resolution models that project possible changes to species and processes can be used to establish scenarios of future ecological conditions. Regularly held workshops with scientific experts offer the opportunity to develop planning scenarios, propose adaptive experiments and management opportunities, and keep abreast of the state of knowledge regarding climate change and its effects.

Managers also propose establishing a Rocky Mountain National Park Science Advisory Board. A Science Advisory Board could serve as a springboard for thinking strategically and enabling the park to anticipate climate-related events. RMNP managers recognize the need to develop baselines for species or processes of highest concern (or of greatest indicator value) and plan to establish monitoring programs to track changes over time. The vital signs that have been identified for the park need to be reviewed and possibly revised in order to capture effects that will occur with climate change.

Park managers identified a critical need to develop a series of learning activities and opportunities for all park employees to increase their knowledge of climate change-related natural resource issues within RMNP. The Continental Divide Learning Center was recognized as an ideal venue for these activities. Managers have proposed that the Center be used as a hub for adaptive learning, articulating the value of natural resources better, and turning managers into consumers of science.

Finally, park mangers have recognized the importance of building greater collaborations with regional partners in order to facilitate regional planning, especially for issues that cross park boundaries. RMNP already has strong working relations with the Town of Estes Park, the Colorado Department of Public Health and Environment, the Colorado Division of Wildlife, the U.S. Fish and Wildlife Service, Larimer and Boulder Counties, and many local organizations and schools. Opportunities to work more closely with the Routt, Arapaho, and Roosevelt National Forest managers could be pursued with the objective of discussing shared management goals.

In summary, RMNP managers propose to continue current resource management activities to minimize damage from other threats, increase their knowledge of which species and ecosystems are subject to change from climate change, monitor rates of change for select species and processes, and work with experts to consider what management actions are appropriate to their protection. By developing working relations with neighboring and regional resource managers, the park keeps its options open for allowing species to migrate in and our of the park, considering assisted migrations, and promotes regional approaches toward fire management (Box 4.12).

4.4.5 Needed: A New Approach Toward Resource Management

RMNP, like other national parks, often operates in reactive mode, with limited opportunity for long-term planning. Reactive management has a number of causes, only some of which are related to tight budgets and restrictive funding mechanisms. Partly because national parks are so visible to the public, there are public expectations and political pressures that trigger short-term management activities (tree thinning in lodgepole pine forest is one example of an activity that is visible to many, but of questionable value in reducing the risk of catastrophic fire). Natural resource issues are increasingly complex, and climate change adds greatly to this complexity.

RMNP managers have been proactive in addressing many of the resource issues faced by the park. Yet they recognize there is still more to be done, particularly in human resource management. Complex issues require broad and flexible ways of thinking about them, and creative new tools for their management. 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, the causes and consequences of threats to these resources, and the various management options that are available.

The skill sets for new NPS employees should reflect broad systems training. University programs for natural resource management could shift from traditional training in fisheries, wildlife, or recreational management to providing more holistic ecosystems management training. Curricula at universities and colleges could also emphasize critical and strategic thinking that embraces science and scientific tools for managing adaptively, and recognizes the need for lifelong learning. Climate change can serve as the catalyst for this new way of managing national park resources. Indeed, if the natural resources entrusted to Rocky Mountain National Park—and other parks—are to persist and thrive under future climates, the Park Service will need managers that see the whole as well as the parts, and act accordingly.

4.5 Conclusions

The National Park System contains some of the least degraded ecosystems in the United States. Protecting national parks for their naturally functioning ecosystems becomes increasingly important as these systems become more rare (Baron, 2004). However, all ecosystems are changing due to climate change and other human-caused disturbances, including those in national parks. Climate changes that have already been documented, coupled with other threats to national parks—including invasive species, habitat fragmentation, pollution, and alteration of natural disturbance regimes—constitute true global change. 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.

The challenges to the National Park Service posed by climate change are daunting. This chapter has highlighted those challenges to both the natural resources within parks and the social system linked to those parks. NPS is the crucial linchpin in these linked ecological and social systems, and has the opportunity to respond and adapt to unprecedented changes in our global environment. The NPS has the capacity to adapt, but adaptation will require mobilization of already scarce resources. Adaptation may involve prioritizing which resources, and possibly which parks, should receive immediate attention, while recognizing that the physical and biological changes that will accompany warming trends and increasing occurrences of extreme events will affect every one of the 270 natural national parks in the coming century. Effective adaptations will go beyond policy evaluation, and include the need for collaborative evaluation of alternative scenarios of change. This will require working together with other land and resource management entities. Uncertainties about how ecosystems will change, as well as the organizational responses to climate change will need to be confronted, acknowledged, and incorporated into decision-making processes. Adaptation will be facilitated by development of rigorous adaptive management plans in which collection of data is explicitly designed to evaluate the effects of alternative, feasible, management interventions. These and other strategies are available to confront the complexities of climate change, but with climate change upon us, there is precious little time to wait.

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4.8 Boxes

Box 4.1. The National Park Service Mission

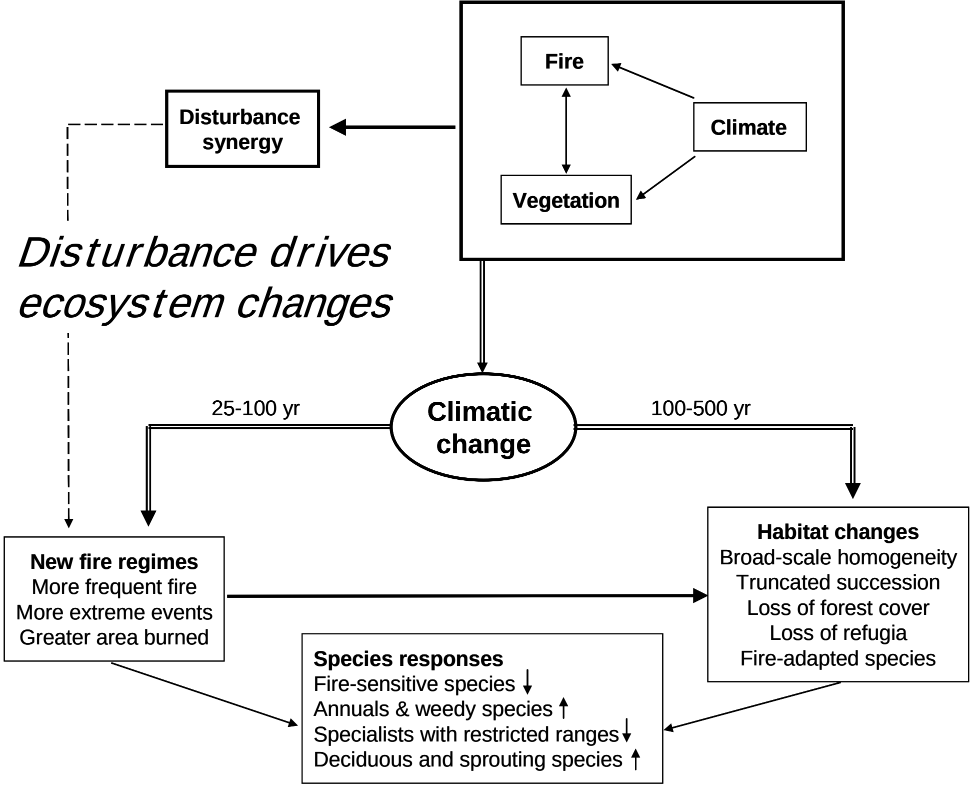
The National Park Service preserves unimpaired the natural and cultural resources and values of the national park system for the enjoyment, education, and inspiration of this and future generations. The Park Service cooperates with partners to extend the benefits of natural and cultural resource conservation and outdoor recreation throughout this country and the world.

Box 4.2. Natural Resource Action Plan Goals

1. National parks are preserved so that this generation and future generations can enjoy, benefit, and learn from them.
2. Management of the national parks is improved through a greater reliance on scientific knowledge.
3. Techniques are developed and employed that protect the inherent qualities of national parks and restore natural systems that have been degraded; collaboration with the public and private sectors minimizes degrading influences.
4. Knowledge gained in national parks through scientific research is promulgated broadly by the National Park Service and others for the benefit of society.

Box 4.3. Interactions of fire with other stressors and resources

Future increases in the size and severity of wildland fires are likely not just in the western park areas, but across the United States (Dale *et al.*, 2001). Such increases would have direct impacts on infrastructure and air quality. There would also be short- and long-term consequences for conservation of valued species and their habitats. McKenzie *et al.* (2004) presented a conceptual model of how interactions between naturally functioning ecosystems with some recurrence interval of fire can be perturbed under conditions of climate change (see below). Warmer and drier summers are likely to produce more frequent and more extensive fires. Trees and other vegetation are also likely to be stressed by drought and increasing insect attacks, since stressed vegetation is predisposed toward other stressors (Paine, Tegner, and Johnson, 1998). Insect-caused mortality can lead to large areas with accumulations of woody fuels, enhancing the probability of large fires. More frequent and more extensive fires will lead to greater area burned. Over time this can alter existing forest structure. Depending on the location, homogeneous forest stands can regenerate. Savannahs or grasslands may replace trees in some areas. Increased erosion on slopes may affect forest fertility and stream or lake water quality. Increased fire frequency—indeed, any kind of land disturbance—favors opportunistic and weedy species. Annual weeds, such as cheatgrass and buffelgrass in the western United States, regenerate rapidly after fire and produce abundant fuel for future fires. The number of native fire-sensitive species decreases. Vegetation types that are at risk from either fire or the combination of fire and invasive species put obligate bird, mammal, and insect species at risk of local or regional extinction (Mckenzie *et al.*, 2004).



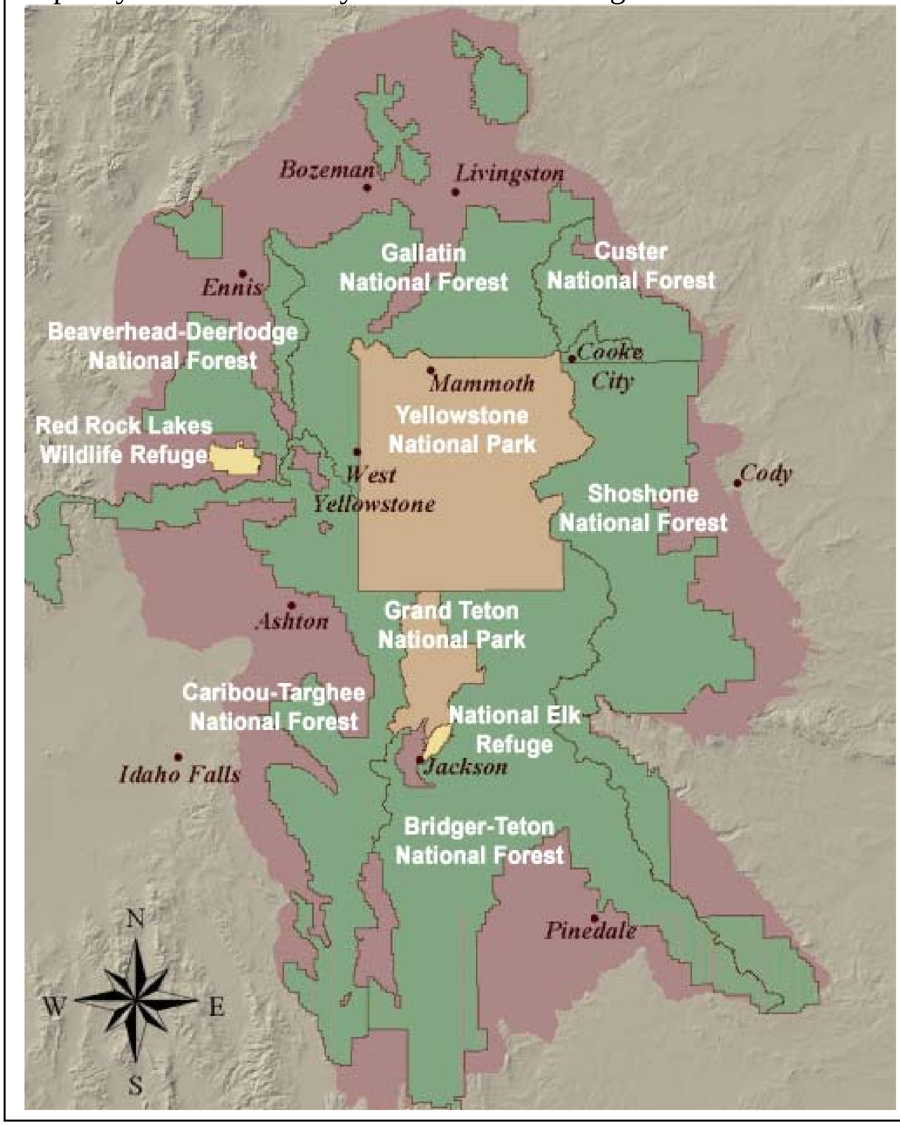
Box 4.4. Altered flow regimes, increased nutrients, loss of keystone species, and climate change

From the freshwater marshes of the Everglades to the shallow waters of Florida Bay, human alterations have resulted in dramatic ecosystem changes—changes that are likely to become exaggerated by climate change. Nutrient enrichment of freshwater sawgrass marshes have led to marshes now dominated by cattails (Unger, 1999). The soil phosphorous content defines these alternate sawgrass or cattail states, and several types of disturbances (fires, drought, or freezes) can trigger a switch between states (Gunderson, 2001). Downstream, the Florida Bay system has flipped from a clear-water, seagrass-dominated state to one of murky water, algal blooms, and recurrently stirred-up sediments. Hurricane frequency, reduced freshwater flow entering the Bay, higher nutrient concentrations, removal of large grazers such as sea turtles and manatees, sea-level rise, and construction activities that restrict circulation in the Bay have all contributed to the observed changes (Gunderson, 2001). A balance between freshwater inflows and sea levels maintains the salinity gradients necessary for mangrove ecosystems, which are important for mangrove fish populations, wood stork (*Mycteria americana*) and roseate spoonbill (*Platelea ajaja*) nesting colonies, and estuarine crocodiles.

Although there are intensive efforts to increase hydrologic flows to and through the Everglades, climate change is expected to increase the difficulty of meeting restoration goals. Interactions of fire, atmospheric CO_2, and hurricanes may favor certain tree species, possibly pushing open Everglades pine savannahs toward closed pine forests (Beckage, Gross, and Platt, 2006). Tree islands, which are hotspots of biodiversity, and peatlands that make up much of the Everglades landscape, may be additionally stressed by drought and peat fires. Animals that rely on these communities may see their habitat decrease (Smith *et al.*, 2003). Mangroves may be able to persist and move inland with climate change, but that will depend on the rates of sea level rise (Davis *et al.*, 2005).

Box 4.5. The Greater Yellowstone Coordinating Committee (2007)

The Greater Yellowstone Coordinating Committee, established in 1964, has been highly effective at working on public lands issues for the nearly 14 million acres of public lands that include Yellowstone and Grand Teton National Parks, John D. Rockefeller, Jr. Memorial Parkway, five national forests, and two national wildlife refuges (see map below). Subcommittees of managers from federal agencies as well as state and private entities work on a wide variety of cross-boundary issues, including land cover and land use patterns and fragmentation, watershed management, invasive species, conservation of whitebark pine and cutthroat trout, threatened and endangered species, recreation, and air quality. Shared data, information, and equipment have been effective in coordinating specific activities including acquiring and protecting private lands through deeds and conservation easements, raising public awareness, providing tools such as a vehicle washer, and increasing purchasing power. These activities have helped combat the spread of invasive plants, restore fish passageways, conserve energy, reduce waste streams, educate the public, and develop a collective capacity for sustainability across the federal agencies.



Box 4.6. Process for Adaptations of Parks and the Park Service to Climate Change

- Identify resources and processes at risk from climate change
    - Characterize potential future climate changes
    - Identify which resources are susceptible to change under future climates.
- Develop monitoring and assessment programs for resources and processes at risk from climate change
- Define baselines or reference conditions for protection or restoration
- Develop and implement management strategies for adaptation
    - Consider whether current management practices will be effective under future climates
    - Diversify the portfolio of management approaches
    - Accelerate the capacity for learning
    - Assess, plan, and manage at multiple scales
        - Let the issues define appropriate scales of time and space
        - Form partnerships with other resource management entities
    - Reduce other human-caused stressors to park ecosystems
    - Nurture and cultivate human and natural capital

Box 4.7. Adaptation Options for Resource Managers

National Parks: Adaptation Options for Resource Managers

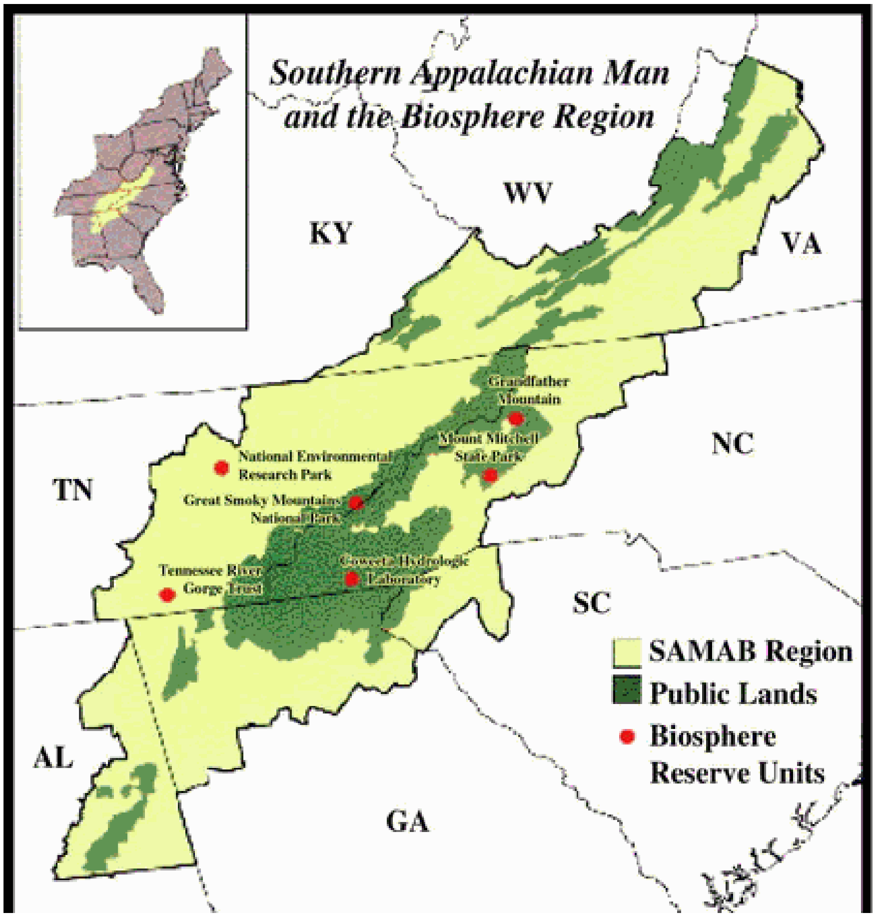
- ✓ Aggressively prevent establishment of invasive non-native species that threaten native species or current ecosystem function.
- ✓ Allow the persistence of non-native species that maintain or enhance ecosystem function.
- ✓ Minimize the spread of disease and alteration of natural disturbance regimes.
- ✓ Maintain species migration corridors.
- ✓ Move or remove human infrastructure to minimize the ecological effects of sudden changes in system state.
- ✓ Minimize sources of pollution and the alteration of natural disturbance regimes.
- ✓ Create refugia for valued aquatic species at risk to the effects of early snowmelt on river flow.
- ✓ Assist in species migrations and transplant species.
- ✓ Allow the establishment of species that are non-native locally, but maintain native biodiversity in the overall region.
- ✓ Restore ecosystems with vegetation that is no longer present locally, but is native to the overall region.

Box 4.8. Examples of Invasive Species Impacts

Buffelgrass (*Pennisetum ciliare*), an African bunchgrass, is spreading rapidly across the Sonoran Desert in southern and central Arizona. The Mojave Desert and Great Basin counterparts to buffelgrass, the brome grasses (*Bromus* spp.) and Arabian Schismus (*Schismus* spp.), cover millions of acres. Brome and Schismus grasses are highly flammable and spread rapidly after fires; their invasion into deserts that evolved with infrequent, low-intensity fires is hastening loss of native species. Among the many charismatic species at risk are saguaro cactuses, Joshua trees, and desert tortoises. Buffelgrass and the Mediterranean annual grasses thrive under most temperature regimes so they are likely to continue expanding (Weiss and Overpeck, 2005).

Box 4.9. Southern Appalachian Man and the Biosphere Program (2007)

The Southern Appalachian Man and the Biosphere (SAMAB) Program is a public/private partnership that focuses on the Southern Appalachian Biosphere Reserve. The program encourages the use of ecosystem and adaptive management principles. SAMAB's vision is *to foster a harmonious relationship between people and the Southern Appalachian environment.* Its mission is to promote the environmental health and stewardship of natural, economic, and cultural resources in the Southern Appalachians. It encourages community-based solutions to critical regional issues through cooperation among partners, information-gathering and sharing, integrated assessments, and demonstration projects. The SAMAB Reserve was designated by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in 1988 as a multi-unit regional biosphere reserve. Its "zone of cooperation" covers the Appalachian parts of six states: Tennessee, North Carolina, South Carolina, Georgia, Alabama, and Virginia, and includes Great Smoky Mountains National Park.



Box 4.10. Climate Friendly Parks

With support from EPA, the National Park Service began the Climate Friendly Parks initiative in 2002 (National Park Service, 2007a). The Climate Friendly Parks program provides tools for parks to mitigate their own contributions to climate change and increase energy efficiency. The program also aims to provide park visitors with examples of environmental excellence and leadership that can be emulated in communities, organizations, and corporations across the country. Parks begin with a baseline inventory of their own greenhouse gas emissions, using inventories and models developed by EPA. The baseline assessment is used to set management goals, prioritize activities, and demonstrate how to reduce emissions, both at the level of individual parks and service-wide. Solid waste reduction, environmental purchasing, management of transportation demands (*e.g.*, increasing vehicle efficiency, reducing motorized vehicle use and total miles traveled), and alternative energy and energy conservation measures are considered in developing action plans for emissions reductions by individual parks. In addition, the NPS will extend these efforts to air pollutants regulated under the Clean Air Act, including hydrocarbons, carbon monoxide, sulfur dioxide, nitrogen dioxide, and particulate matter. Education and outreach are strong components of the Climate Friendly Parks Program.

Box 4.11. Definition of Wilderness

A wilderness, in contrast with those areas where man and his own works dominate the landscape, is hereby recognized as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain. For the purposes of this chapter, an area of wilderness is further defined to mean an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation; (3) has at least five thousand acres of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and (4) may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value (U.S. Congress, 1964).

Box 4.12. Opportunities and Barriers for Rocky Mountain National Park in Adapting to Climate Change

Opportunities:
- Cadre of highly trained natural resource professionals
- Extensive scientifically grounded knowledge of many natural resources and processes
- Continental Divide Learning Center serves as hub of learning and training
- Plan to establish a Science Advisory Board
- Climate Friendly Parks Program has enhanced climate change awareness
- Good working relations with city, county, state, and federal land and resource managers
- RMNP is surrounded on nearly all sides by protected national forest lands, including wilderness.
- Regionally, mountain and high valley lands to the north, west, and south of RMNP are mostly publicly owned and protected, or sparsely populated ranch and second home developments.
- RMNP is a headwater park and controls most of the water rights within its boundaries. As such, it has direct control over its aquatic ecosystems and water quality.

Barriers:
- Insufficient knowledge about individual species’ status and trends
- Limited opportunity for long-term strategic planning
- Limited interagency coordination of management programs
- The large and growing urban, suburban, exurban Front Range urban corridor may hinder migration of species into or out of RMNP from the Great Plains and Foothills to the east.

4.9 Figures

Figure 4.1. Photograph looking up from the Colorado River at the Grand Canyon, courtesy of Jeffrey Lovich, USGS.

Figure 4.2. Everglades National Park, Photo courtesy of National Park Service; photo by Rodney Cammauf.

Figure 4.3. Photograph of Joshua tree in Joshua Tree National Park. Photo courtesy of National Park Service.

Figure 4.4. Historical timeline of the National Park Service. Adapted from the National Park Service (2007b).

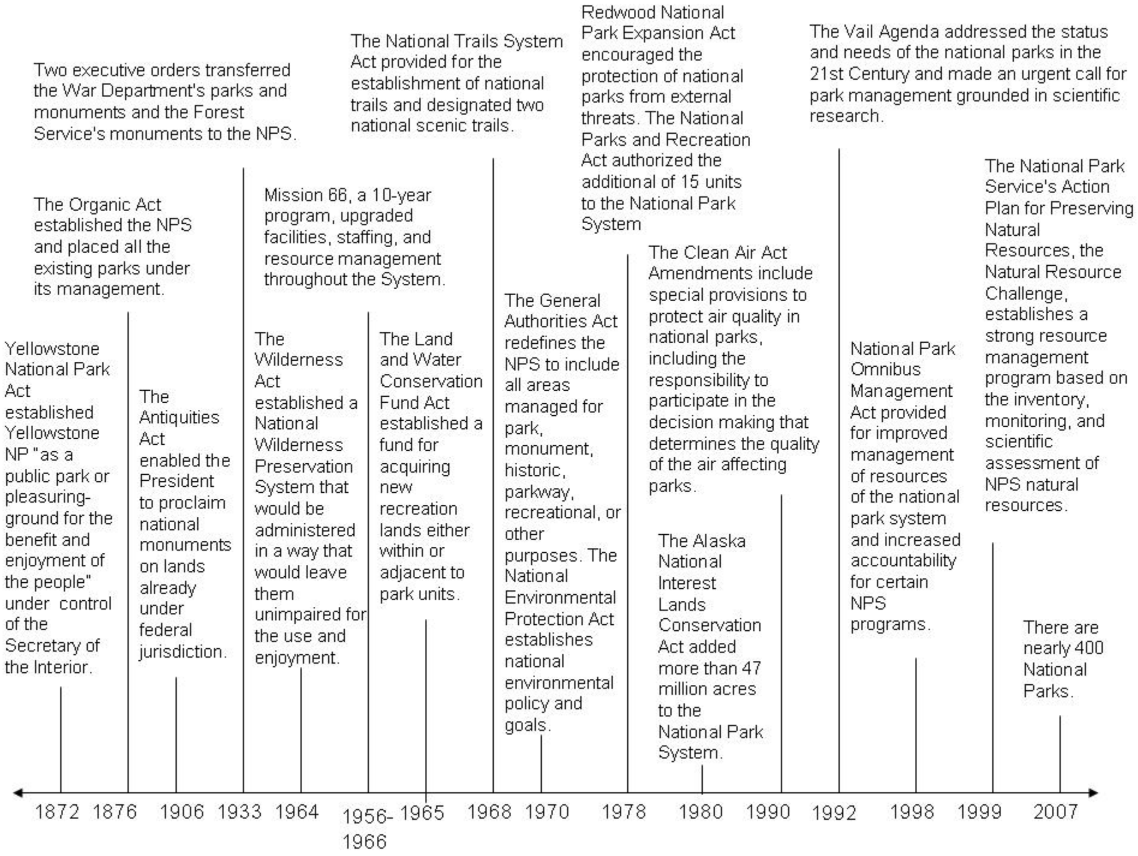
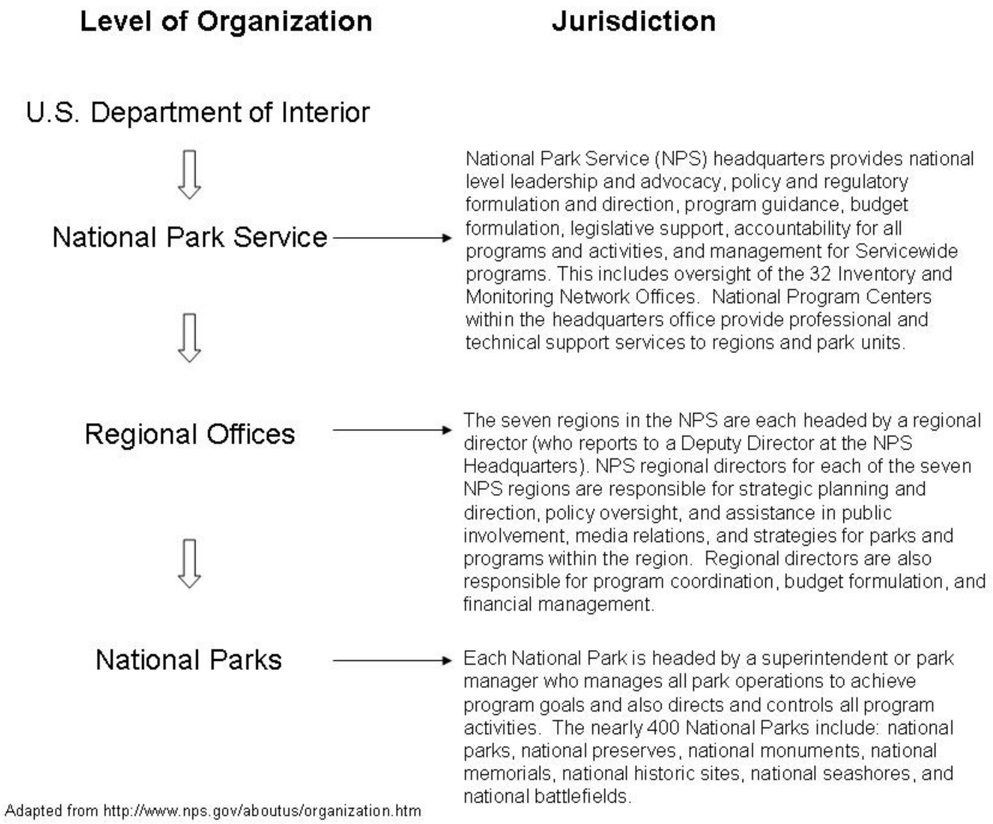


Figure 4.5. Organizational chart of National Park Service. Adapted from the National Park Service (2007d).



National Park Service (NPS) headquarters provides national level leadership and advocacy, policy and regulatory formulation and direction, program guidance, budget formulation, legislative support, accountability for all programs and activities, and management for Servicewide programs. This includes oversight of the 32 Inventory and Monitoring Network Offices. National Program Centers within the headquarters office provide professional and technical support services to regions and park units.

The seven regions in the NPS are each headed by a regional director (who reports to a Deputy Director at the NPS Headquarters). NPS regional directors for each of the seven NPS regions are responsible for strategic planning and direction, policy oversight, and assistance in public involvement, media relations, and strategies for parks and programs within the region. Regional directors are also responsible for program coordination, budget formulation, and financial management.

Each National Park is headed by a superintendent or park manager who manages all park operations to achieve program goals and also directs and controls all program activities. The nearly 400 National Parks include: national parks, national preserves, national monuments, national memorials, national historic sites, national seashores, and national battlefields.

Adapted from http://www.nps.gov/aboutus/organization.htm

Figure 4.6. Map of the National Park System. Data courtesy of National Park Service, Harpers Ferry Center (2007).

Figure 4.7. Kemp's Ridley hatchlings heading for the water at a hatchling release. Photo courtesy National Park Service, Padre Island National Seashore.

Figure 4.8. Scenario planning is appropriate for systems in which there is a lot of uncertainty that is not controllable. In other cases optimal control, hedging, or adaptive management may be appropriate responses. Reprinted from Peterson, Cumming, and Carpenter (2003).

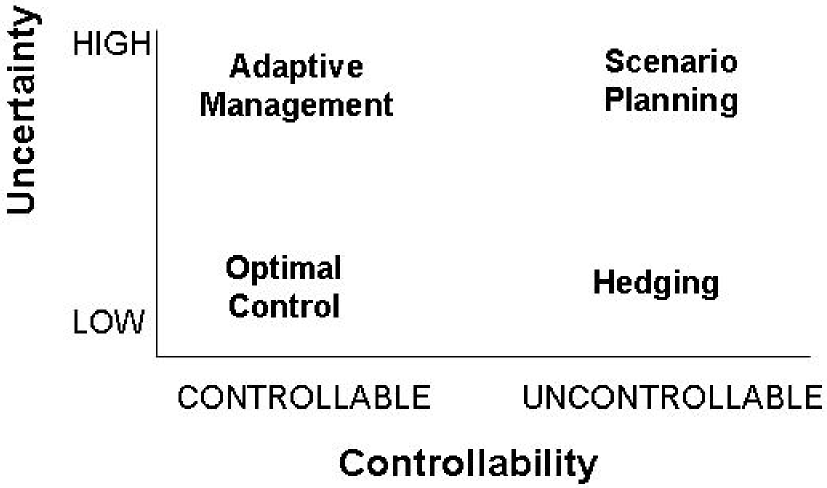


Figure 4.9. Photos of Arapahoe Glacier in 1898 and 2004 (NSIDC/WDC for Glaciology, Boulder, Compiler, 2006).

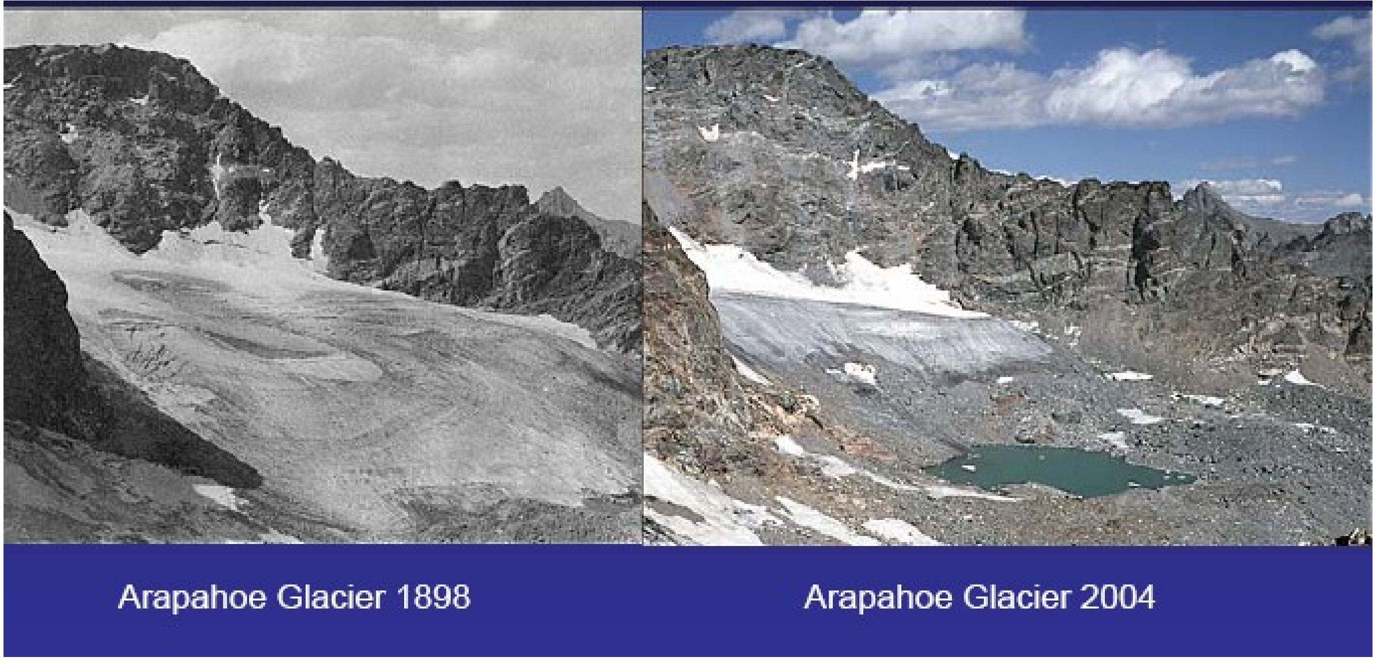


Figure 4.10. Photo pair of Rowe Glacier, with permissions, NSIDC and leachfam website (Lee, 1916; Leach, 1994).