Chapter 4 Natural Resources

Contributing Authors: Melinda Koslow, Amanda Babson, and Courtney Schupp

Coastal natural resource managers are active leaders in the field of climate change adaptation, in part because climate change impacts to coastal natural resources are already apparent. Impacts from climate change are producing fundamental changes in ecosystem character, distribution, and function (Doney et al. 2012). These changes are exacerbated by stressors such as habitat destruction, pollution, and invasive species, further limiting the ability of coastal ecosystems to adapt. This chapter is not comprehensive on impacts and interacting stressors; rather, it focuses on the information and strategies necessary for getting started with adaptation for coastal natural resources. As our understanding of the breadth of coastal vulnerability develops and more examples of National Park Service (NPS) implementation of adaptation across a range of ecosystems and impacts become available, this guidance will be revised. Additional resources are available at http://www.nps.gov/subjects/climatechange/coastalhandbook.htm.

Expected Climate Change Impacts on Natural Resources

The major climate change impacts on coastal natural resources are changes in sea and lake level, air and water temperature, precipitation, storminess, and ocean acidification (see "Chapter 1 Introduction" for more information on each impact). Together and individually, these affect other ecological and geophysical processes and can have impacts to resources that can be cumulative and direct or indirect. Each habitat type may have differing susceptibility to particular impacts (table 4.1). Sea level rise is an often cited impact, but it does not act alone. Scientists and managers are working to better understand the combined impacts of multiple stressors on park resources. Combined impacts of sea level rise and storm surge, as they affect erosion both gradually and episodically, are beginning to be addressed together. Synergistic effects between sea level rise and nutrients, which influence eutrophication and thus hypoxia, have been found (Crain, Kroeker, and Halpern 2008). Hypoxia (low oxygen) can be exacerbated by warming water temperatures and increased stratification. Stratification is one of several factors influencing water quality that can be exacerbated by changes in precipitation patterns.

Changes in water level and air temperature can define which stretches of lakeshore are affected by ice cover and protect or expose stretches of lakeshore to coastal erosion. Warmer air temperatures are melting permafrost and causing an increase in erosion at northern latitudes when sea ice is not present along shores to prevent storm waves and currents from eroding the shores (see Schupp, Beavers, and Caffrey 2015, "Case Study 4: Cultural Resources Inventory and Vulnerability Assessment" and "Case Study 9: Collecting Baseline Biological and Geologic Data to Understand Coastal Change").

Ocean acidification is a result of rising atmospheric carbon dioxide absorbed into the ocean, which decreases pH. This change is harmful to calcifying species such as corals, oysters, mollusks, and calcareous plankton (Doney et al. 2009). In coastal areas (in contrast to open ocean areas), biological processes, nutrient loading, and freshwater inputs also influence acidity; the signal from these can be much larger and more variable than the open ocean signal of global changes in ocean pH driven by increased anthropogenic carbon dioxide alone (Wallace et al. 2014; Gledhill et al. 2015). Because of this variability and due to complexities of ocean carbonate chemistry, measuring pH and the associated variables (e.g., the partial pressure of CO_2 in seawater, total alkalinity, and dissolved inorganic carbon) is not a straightforward endeavor for parks, but it remains important to monitor and understand (Gledhill et al. 2015). Ocean acidification and increased hypoxia are being studied for their synergistic effects (Doney et al. 2009). Table 4.1 describes some of the ways in which coastal habitats are vulnerable to climate change.

Table 4.1. Climate Change Vulnerabilities of Coastal Habitats. Photographs by Tim Carruthers (seagrass & coral reef); NPS (all others).

Habitat Type	Description
Beach 	Beaches are dynamic in nature, shaped by wind and waves. They accrete, erode, and develop dunes. Inlets open, migrate, and close. Both seasonal and long-term changes occur along beaches (Riggs and Ames 2007). Higher sea level causes increased coastal erosion and accelerates landward migration of barrier shorelines (Field et al. 2007). Impacts from sea level rise are amplified where sediment supply is disrupted or landward migration is impeded by built structures or steep topography (Field et al. 2007). Beaches provide vital nesting and feeding grounds for birds and sea turtles, as well as sunbathing and fishing spots for visitors. Lower lake levels allow vegetation encroachment on bare sand or sparsely vegetated beach areas that provide nesting habitat for birds.
Sand Dunes 	Sand dunes protect interior habitat from wind and wave damage. They protect the middle and inland facing sides of islands. While dunes are dynamic features, sea level rise and increased storm surge can lead to more frequent overwash events and increased erosion that will give less time for dune recovery and ecosystem recovery and subsequent restabilization. Dune grasses such as sea oats in the southeast Atlantic and American beach grass in the northeast Atlantic are essential to island health because they trap and hold sand, allowing the dunes to build. They are frequently used in coastal restoration programs following storm damage because they can stabilize dunes and reduce damage arising from erosion and wave action (Hodel and Gonzales 2013). On the Pacific mainland coast, non-native species that were historically used to stabilize dunes (e.g., iceplant and European beach grass) have led to monocultures. A number of federally and state protected species including shorebirds and beach mice use interdunal areas (overwash fans) for nesting, relying on the adjacent beaches for foraging.
Grasslands 	Grasslands are relatively flat sections of barrier islands. They make up the leeward side of the primary and secondary dunes. Although grasslands are somewhat protected by the dunes, large storms or heavy rains often bring salt water to this area, limiting the survival of woody vegetation. Terrestrial mammals, small birds, and reptiles inhabit the grasslands. If rainfall decreases and/or evaporative moisture loss increases with climate change, the likelihood of wildfires will increase (Twilley et al. 2001). While wildfires are an essential part of grassland ecosystems, in some sections of the United States (US), such as the Gulf Coast, increases in wildfires could threaten the ecosystem.
Salt Marsh 	Salt marshes are incredibly important nursery habitats for many estuarine fish and invertebrate species. They generally lie on the landward side of islands or in sheltered areas of a coastal system. Marsh grasses and dead plant material provide food for insects, crabs, shrimp, fish, and other bottom-dwelling organisms. Salt marshes also provide cover for offspring of many species of fish and crustaceans. Many species of birds feed on the insects, crabs, and other invertebrates that live in marshes and some nest in the high marsh. Salt marshes respond to sea level rise by landward marsh migration or conversion to mudflat if a marsh is not able to keep pace vertically. Warmer temperatures cause faster peat decomposition, which makes it harder for salt marshes to keep pace with sea level rise. Increases in storm frequency or intensity increase marsh edge erosion. Changes in seasonal freshwater input and drought will impact vegetation health and composition (Craft et al. 2009; Thorne, Takekawa, and Elliot-Fisk 2012). Peat bank erosion and conversion to mudflat releases sequestered carbon. Salt marshes are also susceptible to invasive species.

Table 4.1. Continued

Habitat Type	Description
Mangroves 	Mangrove forests grow in tropical and subtropical intertidal zones, are highly adaptable to variability and disturbance, have historically kept pace with sea level by building elevation and have been expanding their range northward in Florida with warming. In addition to their important habitat functions, mangroves offer storm protection and carbon sequestration benefits. Mangroves may be vulnerable to increasing air temperatures, to changes in precipitation affecting salinity, and in some areas to high rates of sea level rise depending on sediment sources (Lugo, Medina, and McGinley 2014). Estimates of 10-15% future mangrove loss due to climate change, especially in areas with low-relief islands or carbonate settings with low sediment supply and upland migration potential, are secondary compared to the current rates of loss due to deforestation (Alongi 2008).
Maritime Forest 	Maritime forests are coastal wooded habitat found on higher ground than dune areas within range of salt spray. They are found along the Atlantic, Gulf of Mexico, and Pacific Northwest coasts and are composed of deciduous, coniferous, and broadleaf evergreen tree species. The composition and structure of these forests are likely to change with changes in air temperature, precipitation, and sea level. For example, 36% of tree species are projected to undergo major change in habitat suitability at Cumberland Island National Seashore and surrounding areas by 2100, based on changes in air temperature and precipitation (Fisichelli et al. 2014). At Fire Island National Seashore, one of the few remaining occurrences of maritime holly forest, 74% of tree species are projected to undergo major change in habitat suitability by 2100 (Fisichelli et al. 2014). Saltwater intrusion into the freshwater aquifer and increased incidence of overwash will also impact vegetation. Invasive species may cause further stress as milder winters reduce pest mortality and temperature changes increase the range of invasive species.
Seagrass 	Seagrasses are vitally important nursery habitat for many marine species, several of which are important economically and socially. Potential threats to seagrass from climate change include rising sea level, which can affect light availability; increases in sedimentation and turbidity due to increases in heavy precipitation events; sediment hypoxia and anoxia due to warmer water temperatures; and increased storm damage (Bjork et al. 2008). The ability of seagrasses to buffer against local acidification through uptake of carbon dioxide through photosynthesis and sequestration in their roots and rhizomes is an active research topic (Bjork et al. 2008; Manzello et al. 2012). Interactions with non-climate stressors including eutrophication may increase hypoxia and reduce light availability, further stressing seagrasses.
Freshwater / Great Lakes Coastal Wetlands 	Climate change impacts on Great Lakes wetlands include earlier spring runoff, larger floods, higher nutrient loading, and hotter summers. Changes in biodiversity and wetland structure could lead to a reduction of services provided by wetlands including flood storage, breeding habitats for birds and amphibians, and reduced water filtering and clean-up capacity. Wetlands exposed to lower Great Lakes water levels are likely to be under intense pressure for alteration through "beach grooming" (wetland removal) activities undertaken by lakeshore owners. Forested wetlands may be affected by more frequent droughts and fires, and the introduction of new forest pests in response to warmer temperatures and shifts in species composition as the forest biomes shifts northward (Christie and Bostwick 2012). Coastal freshwater wetlands are vulnerable to saltwater intrusion and migration of saltwater wetlands.

Table 4.1. Continued

Habitat Type	Description
Tundra 	Tundra is high latitude, generally treeless landscapes with low growth vegetation underlain by frozen subsurface soils (permafrost). This frozen layer contributes to the low growth characteristics of the habitat. Tundra includes numerous plant, lichen, and fungus genera and is found ranging from low coastal plains into mountainous areas. Tundra is susceptible to climate change impacts through the melting of the permafrost layer, leading to coastal erosion rates in the Arctic that are among the highest in the world (Jones, Mieszkowska and Wethey 2009). As permafrost melts, tundra elevation decreases, melt ponds form (thermokarst lakes), and rapid runoff can occur (Callaghan et. al 2005). Tundra elevation decreases can lead to tundra submergence into thermokarst lakes or through oceanic inundation, drowning the tundra. Rapid runoff on steep slopes can slough tundra into adjacent water bodies (thaw slumps) (Burn and Lewkowicz 1990). Uneven melting of coastal tundra cliffs causes catastrophic structural failure of the underlying soils, leading to cliff collapse and wave erosion (Mars and Houseknecht 2007).
Coral Reefs 	Coral reefs are extremely vulnerable to climate change, with projected loss globally between 30% and 90% depending on our ability to limit warming and coral thermal tolerances (Frieler et al. 2013). Warming increases bleaching events, leading to degradation and mortality. Ocean acidification reduces (and potentially reverses) coral calcification and growth (Hoegh-Guldberg et al. 2007). Identifying species resilient to bleaching and refugia from warming events is a growing research focus to better protect these species and places.
Coastal Waters 	Warming of coastal waters from the sub-tropics through the Great Lakes to Alaskan waters is affecting fisheries and nearshore and pelagic ecosystems. In Alaska, air and ocean warming and decreased sea ice cover is causing northward shifts in Alaskan fisheries and ecosystem reorganization (Grebmeier et al. 2006). While effects of warming are already becoming evident on Arctic coastal waters and marine ecosystems, the research documenting changes is limited (Wassmann et al. 2011). Tropical and subtropical sea surface temperatures increased by an average of 0.5°F between the 1950s and 1990s, and this trend is projected to continue (Florida Oceans and Coastal Council 2009). Several commercially important species now present off the New England coast, such as cod, haddock, winter flounder, and yellowtail flounder, are particularly vulnerable to temperature increases at the southern end of their ranges (Staudinger et al. 2013). Great Lakes nearshore waters are warming faster than air temperatures due to declining ice cover and changes in stratification; this influences the growth and distribution of a variety of aquatic species (Austin and Colman 2007; Dobiesz and Lester 2009).

Adaptation of Coastal Natural Resources

Effective adaptation strategies require an understanding of the effects of climate change on parks and a deliberate consideration of climate change within planning and management processes. Understanding ecosystem responses to those adaptation actions will require new research and monitoring that will provide an understanding of how resources are expected to change over time. Uncertainty of climate change effects and rapid development of climate change science make it imperative that we employ new, more flexible planning approaches. Science and management responses to ongoing and rapid changes must be developed concurrently, iteratively, and collaboratively in inclusive partnerships.

Adaptation options will be park- and resource-specific and are likely to evolve over time, but general strategies can be chosen from adaptation approaches for ecosystem management strategies that were outlined in Climate-Smart Conservation and the 2nd National Climate Assessment (Kareiva et al. 2008; West et al. 2009; West and Julius 2014). Definitions, applications, and issues for these seven strategies are highlighted in table 4.2 and parallel strategies for cultural resources are detailed in "Chapter 5 Cultural Resources."

Table 4.2. General adaptation strategies for ecosystem management (West and Julius 2014; Kareiva et al. 2008; West et al. 2009)

Strategy	Description
Reduce Non-climate Stresses	By reducing non-climate anthropogenic stressors (e.g., excess nutrient inputs, introduction of invasive species, overfishing), an ecosystem is thought to be more resilient to stressful climatic events. For coastal parks, this includes options working with state and local water management agencies to reduce land-based sources of nutrient pollution or removing hard structures (e.g., bulkheads, seawalls) that disrupt sediment transport and are impediments to shoreline migration. This approach has many benefits in the case of high uncertainty about climate impacts because it should be part of management goals without climate considerations. Marine reserves that reduce anthropogenic stressors such as fishing pressure can increase the resilience of coastal ecosystems to impacts of climate change such as increased harmful algal blooms or disease, when marine reserves are established within park boundaries (McLeod et al. 2009). Climate change may also indirectly increase risks from non-climate stressors, such as melting sea ice increasing shipping and the potential for oil drilling in new areas of the Arctic, which increase potential spill risk. Incident response plans need to be updated to protect ecosystems from increasing risks.
Protect Key Ecosystem Features	Keystone species such as ecosystem engineers (e.g., oysters, which build reefs or kelp forests that provide a physical substrate) have a disproportionate effect on the ecosystem and thus merit additional protection. Where key ecosystem features have already been identified as park fundamental resources, this is another approach that is an easy choice in the case of high uncertainty because it is already part of park goals. In cases such as historical parks where key ecosystem features may not be defined as fundamental resources, it will be important to identify the landscape characteristics (e.g., dunes), species, or areas that are key to other resources' resilience and then to protect those features.
Ensure Connectivity	Protecting and restoring landscape corridors and connections facilitates the movement of species that are able to respond to changing conditions. It also increases ecological resilience of species in their current ranges through increased gene flow across isolated populations. Coordination on a larger landscape scale by partnering with entities outside the park to maintain connectivity across park boundaries provides more diverse combinations of biological communities and environments.
Restore Structure and Function	A healthy functioning ecosystem is better able to adapt to climate change impacts. By restoring degraded ecosystems now, it is thought they will be better able to persist in future conditions. For example, by removing tidal restrictions to salt marshes and thus restoring hydrology, the marsh will be better able to keep pace with accelerated sea level rise by vertical accretion through sediment trapping and adding belowground biomass (Burdick and Roman 2012). See Schupp, Beavers, and Caffrey (2015), "Case Study 11: Restoring the Jamaica Bay Wetlands" and "Case Study 12: Restoring the Giacomini Wetlands from Agricultural Lands."
Support Evolutionary Potential Strategy	By protecting a diversity of species, populations, and ecosystems in multiple locations, we can support ecological adaptive capacity. The idea that biodiversity improves resilience (Worm et al. 2006; SCBD 2009) is the basis for this approach, and it applies to physical environments as well (Lenihan et al. 2001). When it is uncertain how systems will adapt, maintaining diversity and a representation of a range of system characteristics, such as depths of oyster reefs, keeps more options available for systems or populations and increases the chances of protecting resilient resources or sources for recovery. Maintaining multiple locations of habitats or populations of species reduces risk in the case of disturbance. Maintaining larger population sizes of individual species may ensure sufficient genetic diversity to allow for natural selection under climate change and for possible adaptation to ocean acidification (Pespeni et al. 2013). As climate changes, managers will need to look beyond park boundaries. For marine systems, replication can provide larval sources for recovery of impacted areas. As with representation, coordinating on a larger landscape scale expands replication opportunities. The Pacific Ocean Parks Strategic Plan calls for a seamless network of ocean parks, sanctuaries, refuges and reserves across the Pacific West and Alaska regions.
Protect Refugia	Once resistant and resilient areas have been identified, they need to be provided with additional protections to maintain their refuge status. Marine reserves are coastal examples that have been shown to be more resilient and could be designed within coastal parks as resilience research areas to compare inside and outside areas of additional protections (Bengtsson, Angelstam, and Elmqvist 2003; Roman and Babson 2013). For many parks, resources such as fisheries may reside primarily outside of their boundaries or the scale of an effective marine reserve extends well beyond an individual park; for refugia to be effective adaptation strategies, managers need to work beyond park boundaries and collaborate with partners to manage ecosystems at larger scale. See Schupp, Beavers, and Caffrey (2015), "Case Study 10: Recognizing Coral Adaptations to Environmental Stressors."
Relocate Organisms	The concept of human-facilitated transplantation of species outside of their historical range or to bypass a barrier is less applicable to marine systems without barriers to transport but could be applied to select marine habitats and species and terrestrial coastal habitats. Currently seed banking for environmental restoration efforts have focused on using native, locally adapted, genetically diverse seedlings, but future planning efforts could consider shifting climate envelopes for sourcing seedlings. See also Schwartz et al. (2012) for a discussion of managed relocation, which remains a controversial strategy due to risks, uncertainties, and ethical questions. While marine barriers to migration are not as tangible as for terrestrial species, they do exist and can cause populations to become small and isolated. An example of marine translocation is the sea otter population in southern California by the US Fish and Wildlife Service.

Most strategies in table 4.2 focus on resisting change or increasing resilience, but such strategies may not be successful as conditions continue to change (Millar, Stephenson, and Stephens 2007) and it will be necessary to manage for change (Kareiva et al. 2008; Stein et al. 2014). As thresholds of resilience are passed, planning methods that address uncertainty, such as scenario planning and adaptive management and accompanying monitoring will become increasingly important (Baron et al. 2009). Other adaptation approaches and frameworks are outlined in table 5.1 of Stein et al. (2014). Choosing between approaches, especially whether to manage for change, will depend on the ecosystem, timing, and magnitude of expected impacts and how well understood or effective the adaptation approach is for the park-specific conditions. Management criteria that will influence the decision include landscape context (e.g., regional or national significance of the resource), threatened or endangered species status, cost, stakeholder support, and feasibility. Since the options based on resisting change and increasing resilience may only be effective in the near term through the next couple of decades, flexibility to change between adaptation options needs to be part of the planning process (Baron et al. 2008).

The Adaptation Continuum

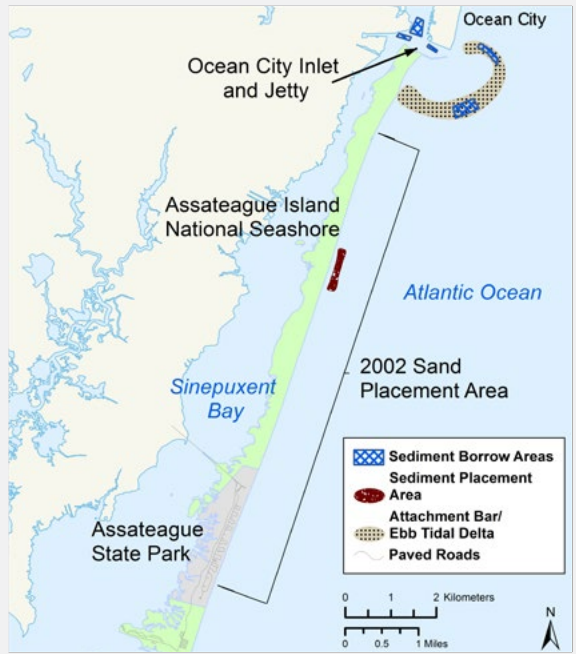
The continuum of adaptation responses of resist, accommodate, and direct change is introduced in "Chapter 1 Introduction" and is illustrated in box 4.1 with an example from Assateague Island National Seashore. A *resist change* approach seeks to preserve existing ecological conditions in spite of the stressors and climate change impacts affecting the ecosystem (Stein et al. 2014). This approach often works to prevent systems from crossing major change thresholds by promoting resistance, enhancing ecological resilience, protecting ecosystems from stress, and supporting recovery after major disturbances. Reducing other stressors (e.g., reducing runoff/pollutants, restoring degraded habitat, controlling competing nonnative species) can be considered a resist change response if it is done with climate change adaptation intentionality such that it explicitly and deliberately addresses climate change impacts.

An *accommodate change* response that allows ecological processes to proceed unimpeded and ecosystems to adapt on their own (i.e., autonomy of nature) may be chosen if other responses are undesirable, impossible, economically infeasible, or likely ineffectual (see NPS Policy Memo [PM] 12-02, "Applying National Park Service Management Policies in the Context of Climate Change" [NPS 2012]), or if those strategies would risk impairment of other park resources and values (NPS Management Policies 2006 Section 1.4.4 "The Prohibition on Impairment of Park Resources and Values"). Accommodating change may also be chosen under an adaptive management approach as a control treatment to monitor the unmitigated effects of climate change and evaluate adaptation interventions in similar areas (Fisichelli, Schuurman, and Hawkins Hoffman 2016). An accommodating change response allows conditions to shift with climate and makes no particular effort to reverse, resist, or direct climate-driven changes. Parks are uniquely suited to provide places where the stories of our legacy of climate change can best be told. In places where we choose an accommodate change response, documenting and interpreting that change will be an important role for the National Park Service.

A *direct change* approach accepts change and attempts, where feasible, to steer towards desired future conditions. An example is assessing where unavoidable threshold changes in ecological systems may be about to happen, such as from freshwater to brackish wetlands, and planning the management towards these future conditions (Stein et al. 2014). These concepts in the adaptation continuum are relatively new and are evolving as they are tested, so this handbook cannot yet provide the guidance for choosing between these responses.

Climate-smart conservation is an approach that helps managers both to develop adaptation strategies and to reconsider overarching goals (desired conditions) in light of climate change, as described in "Chapter 3 Planning" and has the potential as a process to guide parks through these decisions. This new climate-smart conservation process has not yet resulted in a completed coastal park case study; the Climate Change Response Program (CCRP) is supporting the application of the approach to NPS planning in "*Planning for a Changing Climate: NPS Climate Change Adaptation Planning Guidance*" further described in "Chapter 3 Planning". Similarly to the rapidly developing information on adaptation, new information related to climate change impacts is emerging, as described in box 4.2, and the National Park Service is working with partners to stay on top of what these emerging topics mean for coastal adaptation but does not yet have the guidance on these topics to include in this handbook. As the adaptation strategies to address these complex issues develop and park examples of implementation are completed, new and iterative NPS guidance will be necessary.

BOX 4.1. EXAMPLE OF THE ADAPTATION CONTINUUM FROM ASSATEAGUE ISLAND NATIONAL SEASHORE



Management of Assateague Island National Seashore and development of a new general management plan (GMP), which will guide management of the park for the next twenty years, incorporates all three adaptation responses: resist, accommodate, and direct change. The park's preferred alternative **accommodates change** and allows natural processes such as beach erosion and overwash to continue unimpeded and addresses the possibility of alternative transportation, such as a ferry service to access the island if bridges and roads can no longer be maintained. The accommodation approach to natural resources (acceptance of the ongoing beach erosion) requires a **direct change** approach to visitor experience (accessing the park by ferry instead of by personal vehicle).

An example of **resist change** is along the north end of the island where the Ocean City Inlet has caused island narrowing and retreat. In 2002, beach nourishment occurred along the northern 8.08 mi (13 km); beginning in 2004, sand has been mechanically bypassed from the inlet shoals to the shallow nearshore area twice each year (see inset figure 4.1 from Schupp and Coburn 2015). The park plans to continue bypassing sediment to the north end of the island to prevent further degradation of the habitat and geologic integrity and to prevent that vulnerable area from crossing a major change threshold such as submergence, recognizing that increased storm intensity and sea level rise will continue to weaken this area of the island.

For additional information on the new GMP, see Schupp, Beavers, and Caffrey (2015), "Case Study 23: Incorporating Climate Change Response into a General Management Plan." The draft GMP and Environmental Impact Statement were available for public comment from January through May 2016.

BOX 4.2. EMERGING COASTAL CLIMATE CHANGE ISSUES

OCEAN ACIDIFICATION

The breadth of ecosystem impacts of ocean acidification and methods for monitoring it are the focus of most research on this topic, but following close behind is research into adaptation options. Because other factors influence coastal acidification, strategies based on reducing non-climate stresses like reducing nutrient inputs can have a buffering effect. Identifying resilient corals for added protection or active management is described in Schupp, Beavers, and Caffrey (2015), "Case Study 10: Recognizing Coral Adaptations to Environmental Stressors, National Park of American Samoa." Seagrasses have the potential to benefit from increased seawater CO_2, and their carbon uptake capacity and associated influence on seawater chemistry could thereby effectively buffer against acidification (Hendriks et al. 2015).This emerging research field may demonstrate seagrass restoration, or other habitats, as an adaptation strategy, providing multiple ecosystem services as refugia to counter ocean acidification, and has added carbon sequestration benefits.

BLUE CARBON

Blue Carbon is a term for carbon stored in coastal wetlands including salt marshes, mangroves, and seagrass meadows, which store carbon at much higher rates than tropical forests (Murray et al. 2011). Methods and research to quantify carbon sequestration of wetlands is expanding and development of a model for marketing carbon credits for these coastal systems (after forest sequestration protocols) has the possibility of providing financial incentives for restoration. The proposed Herring River Estuary restoration at Cape Cod National Seashore is part of a feasibility assessment to see if Blue Carbon credits could be applicable to this project and, thus, be the first Blue Carbon restoration project with credits marketed.

HARMFUL ALGAL BLOOMS (HABS)

Climate change may influence the frequency, duration, or geographic range of HABs (algal blooms that produce toxins or other negative effects on ecosystems or human health), though currently the link is poorly studied (Moore et al. 2008). Potential mechanisms include warming waters favoring harmful species or stratification intensifying blooms; changes in salinity expanding ranges for HABs species into freshwater systems; and changes in precipitation patterns increasing nutrient inputs or increases in carbon dioxide favoring rapid growth. The complexity of these processes, limited understanding of HAB physiology and ecology, and the limited long term datasets at time scales that capture HAB events mean that this is a research area to follow more than a current adaptation field (Moore et al. 2008).

WATER QUALITY

Climate change is adding new hurdles as parks work to address water quality issues, as Great Lakes phosphorus loading, Gulf Coast hypoxia, and Combined Sewer Overflows are all exacerbated by increases in heavy precipitation events. Saltwater intrusion, driven by groundwater pumping in some areas, is emerging as an issue for many more coastal parks because it is driven by sea level rise.

PHENOLOGY

Phenological (the timing of life events of plants and animals) responses of marine and coastal species are more difficult to study than terrestrial species, so the climate related changes are much less well documented, with the exception of migratory birds. Visualizations of phenological changes, including for migratory raptors at Acadia National Park, are part of the Whenology project. The National Ocean Policy Implementation Plan (National Ocean Council 2013) calls for actions to "develop and begin to implement a plan for incorporating species phenology information…from coastal and ocean ecosystems in the National Phenology Network" so a Marine and Coastal Phenology Project is underway.

Climate Adaptation Issues for Designated Wilderness Areas

Change is inherent in natural processes, especially in the case of dynamic coastal landforms. Designated wilderness areas, where natural resources have the least interference from human activity, provide excellent sites to study the ecological resilience or other responses of natural processes and natural resources to climate change. As climate change pushes natural processes outside the bounds of natural variability, these places will teach us what happens when thresholds are crossed. Wilderness area designation limits some active management adaptation actions and relies primarily on accommodate change responses but applies the strategy of removing non-climate stresses. While the restraints of the Wilderness Act limit some active adaptation strategies, where there is certainty that such actions will be effective, there is flexibility to implement provided procedural processes to justify the actions are followed (Long and Biber 2014).

One example, described in more detail in "Chapter 9 Lessons Learned from Hurricane Sandy," occurred at Fire Island National Seashore. There, Hurricane Sandy caused two breaches that didn't close immediately. One occurred in the Otis Pike Fire Island High Dune Wilderness, where policy disallows artificially closing the breach, allowing the natural processes of the barrier island to continue. In contrast, the second breach occurred outside of the wilderness area and was artificially closed. Intensive study of the open breach continues, allowing documentation of the continuing changes to the landforms and the water quality benefits to the adjacent Great South Bay (see "Chapter 9 Lessons Learned from Hurricane Sandy"). The breach that was artificially closed has remained closed.

Coastal wilderness areas are a portion of a much larger coastal ecosystem and are affected by anthropogenic actions taken outside of designated wilderness areas. For example, at Gulf Islands National Seashore, the wilderness area of the Mississippi barrier islands migrates westward with shoreline changes until it reaches the adjacent shipping channel, where it is no longer considered wilderness. Regular dredging of the major shipping channel shaves off the western tip of the wilderness area at a higher rate than accretion is occurring at the eastern tip. Human actions occurring outside of wilderness boundaries may compromise the area's ecological resilience. In "Case Study 13: Consideration of Shackleford Banks Renourishment" (Schupp, Beavers, and Caffrey 2015), Cape Lookout National Seashore decided against placement of dredged material on a barrier island, a proposed wilderness area, until more information on the potential impacts was known.

When choosing climate adaptation strategies in wilderness areas, the tradeoffs between short- and long-term impacts on wilderness character must be evaluated. A comprehensive assessment is needed to understand how action or inaction may impact the qualities of wilderness character. Designation of new wilderness areas may be a feasible climate adaptation strategy for some parks. Additional guidance on adaptation actions related to wilderness policy is provided in "Chapter 2 NPS Policies Applicable to Coastal Adaptation."

Science to Support Climate Adaptation for Natural Resources

Adaptation strategies will depend on the articulated goals, magnitude of climate change, rate of change with respect to identified thresholds, and availability of management resources. Vulnerability assessments inform managers of the magnitude of climate change and potential impacts on the resources articulated within goals, as well as the adaptive capacity of resources. There is a variety of scientific resources to inform these vulnerability assessments and adaptation strategy development.

Parks are encouraged to use best available science, which can bring up questions about which tools to use in the crowded field of sea level rise, storm surge, and inundation modeling. Models, projections, and scenarios developed from broader data sets such as the National Oceanic and Atmospheric Administration (NOAA) Digital Coast, the Landscape Conservation Cooperatives (LCC), and sea level rise and storm surge maps for all coastal NPS units (see Schupp, Beavers, and Caffrey 2015, "Case Study 24: Storm Surge and Sea Level Data Support Planning") use the best available science at a larger regional or national scale, but this may not be best available at a local scale. The need for data consistency for regional or national tools often means that locally specific data of higher quality is not incorporated. Parks have the flexibility to choose from locally specific information when it is available or from regional or servicewide-scaled products. Since there are many sources of uncertainty in each of these tools, for most purposes, it is more important to develop a flexible and iterative adaptation process than to invest in the most complex, locally detailed model.

Managing for an Uncertain Future

It is important to incorporate information on uncertainty into the decision-making process. A chapter on "Managing Under Uncertainty" within Climate-Smart Conservation offers guidance on how to understand and work with uncertainty, instead of delaying decisions while awaiting additional information (Hoffman et al. 2014). Sources of uncertainty are not limited to future climate and sea level rise projections; they include how ecosystems will respond, how managers will respond, the effectiveness of adaptation actions, and randomness (Hoffman et al. 2014).

Multiple planning strategies and resources are available to help make management decisions for an uncertain future. Scenario planning is one approach for decision-making under uncertain conditions that the National Park Service has explored more than other methods; it is described in "Chapter 3 Planning." The uncertainty estimates provided in the park-scale climate resource briefs (see Monahan and Fisichelli 2014; e.g., Gonzalez 2015) and trend reports are well constrained for these physical variables, but many ecological variables have limited information on uncertainty and require more qualitative estimates. An example of qualitative treatment of uncertainty is estimating levels of confidence, such as high/low for the amount of evidence and high/low for the amount of agreement between them (Kareiva et al. 2008). This method was applied to evaluating the efficacy of the adaptation approaches in table 4.2 as applied to the National Park Service; three approaches were high in both categories and the remainder was low in both categories (Kareiva et al. 2008).

Incorporating Uncertainty into Inundation Models

When considering the uncertainty in inundation models, it is important to weigh the vertical accuracy of the elevation data (both land and bathymetry) relative to the sea level rise scenarios (Murdukhayeva et al. 2013). Figure 4.2 compares the minimum vertical accuracy of the US Geological Survey (USGS) National Elevation Dataset (NED) (available for the study sites described Schupp, Beavers, and Caffrey 2015, "Case Study 24: Storm Surge and Sea Level Data Support Planning"), Light Detection and Ranging (LiDAR) data (not available everywhere), and high-accuracy elevation data (e.g., Real Time Kinematic-Global Positioning System [RTK-GPS] data), relative to a sea level rise scenario of 3.28 ft (1 m). Often the planning horizon will be within a few decades, in which case sea level rise projections are of smaller magnitude than the vertical accuracy of USGS NED values and many LiDAR products, most of which have a maximum accuracy of + 5.9 in (15 cm) depending on the system and processing. The application of the models (e.g., planning site level restoration vs communication tools) will influence the accuracy needed and how much to invest in higher accuracy data or more complex models.

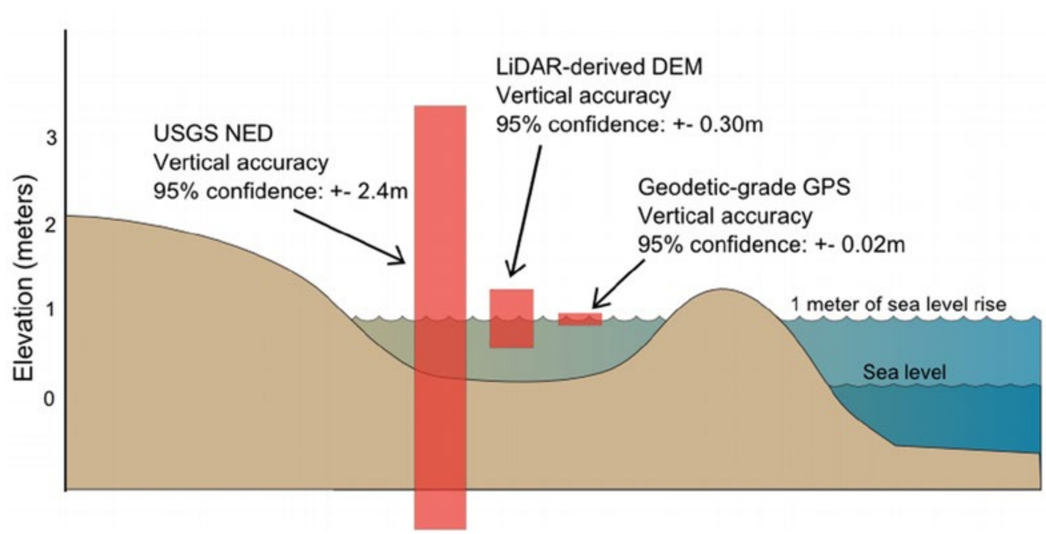


Figure 4.2. Vertical accuracy estimates of Digital Elevation Models.
Note: Figure from Murdukhayeva (2012), mapping 3.28 ft (1 m) of sea level rise on land, adapted from Gesch (2009). Digital elevation models with different vertical root-mean-square errors result in inundation zones with different 95% confidence intervals and estimates of uncertainty.

The field of inundation modeling is ever growing, and it can be challenging to determine which tool to use to better understand the coastal system response to sea level rise and storm surge. NOAA has a "low-tech" guidance document Incorporating Sea Level Change Scenarios at the Local Level intended for community planners to support the application of modeling results to mapping (NOAA 2012). USGS has a Sea-level rise modeling handbook—Resource guide for coastal land managers, engineers, and scientists for those wanting to dig into more technical detail (Doyle et al. 2015). Errors in tidal datum calculation, vertical landform position accuracy, and biases in oceanographic and atmospheric models can lead to challenges in accurately representing exact location and magnitude of storm surge across landscapes at the scale of coastal properties contained within park boundaries. To provide guidance in managing changing coastal systems in the national park system, the National Park Service is currently supporting partnering efforts with universities and other government agencies such as NOAA and the USGS to continue to support parks in utilizing this expertise.

Another consideration for inundation modeling is when and where it is appropriate to use static models (often referred to as "bathtub models") instead of dynamic models. The type of model needed will depend on the resources at risk and the particular park. Static inundation models do not account for sediment budget variation, sediment redistribution, and biological processes. Static models also do not capture water level changes in narrow water bodies or complex shorelines. Dynamic coastal landforms such as dunes and salt marshes respond to sea level rise in ways that are locally specific, so local models may be necessary. Lentz et al. (2015) developed a framework for categorizing which coastal response needs to be dynamically modeled, and applied it using a Bayesian model to the northeastern United States. Static inundation models were used for exposure assessments of park assets in 40 coastal parks (Peek et al. 2015) and will be available for all coastal park units by 2016 (see Schupp, Beavers, and Caffrey 2015 "Case Study 24: Storm Surge and Sea Level Data Support Planning"); other methods have been done by individual parks and regions (Nielsen and Dudley 2013; Shaw and Bradley 2014; URI and NPS 2014).

There is a range of dynamic models in development that are being applied to coastal parks. These models include different geomorphic and biologic processes and have varying degrees of complexity and data requirements (Fuller et al. 2011; Roman and Babson 2013). While this discussion has primarily focused on inundation modeling, related questions about static vs dynamic models apply to other types of models, such as species climate envelope modeling or groundwater modeling. Other Bayesian models build on sea level rise models and have been applied to barrier island groundwater modeling or shorebird nesting habitat suitability (Gutierrez, Plant, and Thieler 2011; Masterson et al. 2013; Gieder et al. 2014).

Additional Resources for Data and Collaboration

The National Park Service is engaged in many efforts and with many organizations to develop datasets and partnerships that will improve resource management. Several of these resources are described below as they relate to coastal climate adaptation.

NPS Inventory and Monitoring Program

The NPS Inventory and Monitoring (I&M) program provides valuable resource specific information and data that can be used to understand climate change effects and to support adaptation planning. The I&M program is enhancing monitoring to support climate change in several ways, including expanded coverage of Surface Elevation Tables to monitor tidal marsh surface elevation and monitor salt marsh breeding birds (Stevens et al. 2010). Other vital signs important to coastal adaptation include shoreline position, seagrass condition, and water quality including nutrient enrichment. Standard and park-specific monitoring protocols are available at http://science.nature.nps.gov/im/monitor/.

A climate inventory of stations and data sources adjacent to NPS units is compiled by the I&M program in an NPS Climate Database. There is a need for additional science communication products; guidance for developing these is provided in "Chapter 7 Communication and Education."

Landscape Conservation Cooperatives

LCCs can provide applied science, tools and resources for parks to address conservation challenges at a larger, landscape and seascape-level, trans-boundary scale, and the longer time scale needed to address climate change. These cooperatives are groups of conservation professionals who partner to work collaboratively to identify best practices, connect efforts, identify science gaps, and avoid duplication through conservation planning and design. In some places, a park may be one of a handful of protected areas and conservation organizations, and identifying and engaging partners could be fairly straightforward. In more fragmented landscapes like along the Atlantic coast of the United States, the Great Lakes, and the mainland Pacific coast of the United States, protected areas tend to be smaller while the number of conservation organizations working on the landscape is larger, making the development of collaborative partnerships more time-consuming. Although cooperatives do not have the capacity to take on every issue, they usually attempt to address broad issues that most conservation professionals are facing in that general ecosystem.

For example, sea level rise is affecting many places in the southeastern United States. Most coastal managers are dealing with saltwater intrusion, loss of marsh, narrowing beaches, and increased and more frequent storm surge. To prepare for these changes, the South Atlantic LCC, the Gulf Coast Plains and Ozarks LCC, the NPS Southeast Regional Office, and the National Oceanic and Atmospheric Administration collaborated on a Gulf Coast Vulnerability Assessment. The report identifies exposure, sensitivity, and adaptive capacity of 4 key ecosystems and 11 associated species to the effects of climate change, sea level rise, and land use change across the US portion of the Gulf of Mexico.

Climate Change Vulnerability Assessment

Climate change vulnerability assessment is a tool for examining the "extent to which a species, habitat, ecosystem, place, or project is susceptible to harm from climate change impacts" (Stein et al. 2014). Climate change vulnerability assessments, as described in "Chapter 3 Planning," are intended to support decision-making; thus, it is vital to involve decision makers from design through completion of the assessment. It is also important to consider that the process of a vulnerability assessment is just as important as the conclusion. Furthermore, an assessment can be quantitative or qualitative depending on management needs and availability of data, funding, and capacity. There is no single approach that applies to all situations. Information from an assessment is primarily intended for guidance and analysis purposes; it does not outline a management response.

There are four key steps for assessing vulnerability to climate change (Glick, Stein, and Edelson 2011):

1. Determine objectives and scope.
2. Gather relevant data and expertise.
3. Assess components of vulnerability.
4. Apply assessment in adaptation planning.

A marine vulnerability assessment methodology that qualitatively categorizes sensitivity, exposure, and adaptive capacity for four climate stressors (sea level rise, temperature change, salinity change, and ocean acidification) on nine marine habitats is being developed and piloted for Cumberland Island National Seashore (Peek et al. 2016). Understanding relative vulnerability between habitats and the contributions between stressors will inform the development and implementation of strategies for adapting these resources to climate change.

Tools

An array of tools that specifically relate to coastal climate change have been developed, many of which are focused on natural resources. Table 4.3 highlights some of the tools available and their various applications.

Table 4.3. Examples of Tools and Resources for Climate Change Adaptation of Coastal Natural Resources.

Tool	Agency/ Organization	Summary	Website	Models	Case Studies	Plans	Data	Tools	Training and Collaboration
Surging Seas	Climate Central	Offers plans, actions, and resources for preparing for sea level rise. Highlights national and state-specific tools such as the NOAA Coastal Inundation Toolkit and California's Cal-Adapt.	http://sealevel.climatecentral.org/responses/plans	X	-	X	-	-	-
Digital Coast	NOAA	Offers data, tools, training, and stories from the field on coastal issues and climate change.	http://coast.noaa.gov/digitalcoast/	X	X	X	X	X	X

Table 4.3. Continued

Tool	Agency/ Organization	Summary	Website	Models	Case Studies	Plans	Data	Tools	Training and Collaboration
Sea, Lake, and Overland Surges from Hurricanes (SLOSH)	NOAA	The SLOSH model estimates storm surge heights resulting from historical, hypothetical, or predicted hurricanes. The National Park Service is providing all coastal parks SLOSH inundation maps as part of coastal climate briefs (see Schupp, Beavers and Caffrey 2015 case study 24).	http://www.nhc.noaa.gov/surge/slosh.php	X	-	-	-	-	-
Sea Level Change Calculator	US Army Corps of Engineers	This on-line sea level change calculator provides sea level change curves from 1992 to 2100 adjusted for NOAA tide gauge stations.	http://corpsclimate.us/ccaceslcurves.cfm	-	-	-	X	X	-
Climate Ready Estuaries Adaptation Planning Workbook	EPA	Includes case studies, Climate Ready Estuaries, examples, and related links to illustrate what is being done in coastal communities to protect people and property.	http://www2.epa.gov/cre/risk-based-adaptation	-	X	-	-	X	-
Climate Adaptation Knowledge Exchange (CAKE)	EcoAdapt	One-stop shopping for adaptation information: case studies, tools, vulnerability assessments, virtual library, etc.	www.cakex.org	-	X	-	-	X	X
Climate Registry for the Assessment of Vulnerability (CRAVe)	USGS	Clearinghouse of climate change vulnerability assessments, compatible with CAKE.	https://nccwsc.usgs.gov/crave/	-	X	-	-	-	-
Collaboratory for Adaptation	Hosted by Notre Dame University	Website hosted by Notre Dame. Similar to CAKE—one-stop shopping for adaptation information: resources, climate tools and models, workflows, case studies, etc.	https://adapt.nd.edu/	X	X	-	X	X	X
National Climate Assessment	US Global Change Research Program	Provides an integrated assessment of observed and projected climate changes and key impacts on the regions of the US Northeast, Southeast and Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska and the Arctic, and Hawai'i and the Pacific Islands, as well as coastal areas, oceans, and marine resources. This report is revised every four years.	http://ncadac.globalchange.gov/	-	X	-	X	-	-
National Fish, Wildlife, and Plants Climate Adaptation Strategy	Multiple	Authoritative guidebook on adaptation written by large number of government and nongovernment entities.	http://www.wildlifeadaptationstrategy.gov	-	-	X	-	-	-
National Climate Change Viewer	USGS	Historical and future projected changes for temperature and precipitation variables at the county, regional, state, and watershed levels.	http://www.usgs.gov/climate_landuse/clu_rd/nccv.asp	X	-	-	X	X	-

Table 4.3. Continued

Tool	Agency/ Organization	Summary	Website	Models	Case Studies	Plans	Data	Tools	Training and Collaboration
FedCenter.gov	FedCenter	Provides links to numerous tools and agency sites for climate change adaptation.	https://www.fedcenter.gov/programs/climate/	-	X	X	-	X	-
Great Lakes Climate	The Ohio State University	Includes education, ecosystems, infrastructure, public health, public policy, water, and webinars.	http://www.climategreatlakes.com	-	-	-	-	-	X
Great Lakes Coastal Resilience Planning Guide	NOAA and partners	Shows how coastal communities are using science-based information to address coastal hazards such as flooding, shore erosion, and lake-level fluctuations.	http://greatlakesresilience.org/	-	X	-	-	-	-
Coastal Resilience	The Nature Conservancy	A network, mapping tool and apps to view flood and sea level rise risk, alongside coastal habitat, social and economic information.	http://coastalresilience.org/	X	X	-	X	X	X
Community Resilience Building	The Nature Conservancy	Workshop guide process, where participants identify top hazards, current challenges, strengths, and priority actions to improve community resilience to all natural and climate-related hazards today, and in the future.	http://www.community-resiliencebuilding.com/	-	X	X	-	X	X
Climate Change Vulnerability Assessment Tool for Coastal Habitats	NOAA National Estuarine Research Reserves	Spreadsheet based decision support tool for land managers, decision makers, and researchers to identify habitats that are likely to be affected by climate change and the ways in which they will be affected.	http://www.northinlet.sc.edu/stewardship/CCVATCH/Overview.html	-	-	-	-	X	-
Guide for Considering Climate Change in Coastal Conservation	NOAA	Step by step guide to including climate change in conservation plans for coastal environments.	https://coast.noaa.gov/data/digitalcoast/pdf/considering-climate-change.pdf	-	-	X	-	X	-

The number and wide range of complexity of tools for coastal climate adaptation can be overwhelming. Table 4.3 provides an overview of examples of the wide array of available tools. The climate-smart conservation scoping steps within the first step of identify planning purpose and scope of: articulate planning purpose; clarify existing goals and objectives; specify geographic scope and time frame; and determine data needs and acceptable levels of uncertainty, can be useful to work through before choosing a tool (Stein et al. 2014). The climate-smart conservation scoping process actions within the first step,"Identify planning purpose and scope" (articulating the planning purpose, clarifying existing goals, specifying geographic scope and timeframe, and determining data needs and acceptable levels of uncertainty) can be useful to work through before choosing a tool (Stein et al. 2014).

Once a tool is chosen, parks may need technical assistance on using tools and finding the necessary data to run and validate them. Technical assistance resources described in "Chapter 1 Introduction" are available through CCRP, NRSS, and collaboration with partners such as LCCs or cooperative ecosystem studies units.

Opportunities for Adaptation

Revisiting Leopold

Because change is a part of natural processes, there is an opportunity to embrace innate adaptive capacity while managing the trajectory of change. With natural resources for which the pace of change is larger than the resource's ability to adapt on its own, park managers will need to prioritize action early and often. The report Revisiting Leopold: Resource Stewardship in the National Parks (NPSABSC 2012) provides an opportunity to reconsider what is "natural" in a time of change, and how parks make decisions under accelerated, changing conditions. According to the report, "the overarching goal of NPS resource management should be to steward NPS resources for continuous change that is not yet fully understood, in order to preserve ecological integrity and cultural and historical authenticity, provide visitors with transformative experiences, and form the core of a national conservation land- and seascape." The new Director's Order #100 will be a way to implement the ideas in the report to update *Resource Stewardship for the 21st Century*, the guiding principles and policies of resource management and stewardship in the National Park System. Policy Memo 16-01, setting the framework for the new director's order, calls for integrating the precautionary principle into resource stewardship decision making, which in the context of climate change, will be a powerful impetus to address climate adaptation (NPS 2016).

Implement National Fish, Wildlife and Plants Climate Adaptation Strategy

The National Park Service has an integral role in implementing this national strategy for natural resource climate adaptation. All of the goals in the strategy are applicable to coastal park resources, and they are as follows:

- Conserve habitat to support healthy fish, wildlife, and plant populations and ecosystem functions in a changing climate.
- Manage species and habitats to protect ecosystem functions and provide subsistence, recreational, and commercial use in a changing climate.
- Enhance capacity for effective management in a changing climate.
- Support adaptive management in a changing climate through integrated observation and monitoring and use of decision support tools.
- Increase knowledge and information on impacts and responses of fish, wildlife, and plants to a changing climate.
- Increase awareness and motivate action to safeguard fish, wildlife, and plants in a changing climate.
- Reduce non-climate stressors to help fish, wildlife, plants, and ecosystems adapt to a changing climate (NFWPCAP 2012).

As parks implement the strategies described in this chapter, there is an opportunity to share successes and lessons nationally with others working toward achieving these goals as part of a collective effort to adapt.

Expansion of Submerged Resources

Sea level rise may result in additional submerged resources in some ocean and coastal parks. If the park's boundary is based on a static location, such as latitude and longitude or the Intracoastal Waterway, then the boundary will remain fixed, and those parks will begin to manage a larger percentage of submerged resources within their boundaries. However, the majority of ocean and coastal parks have boundaries that are tied to the mean high water line, mean low water line, or some other tidal measure. For these parks, sea level rise will cause the water line and the park's boundary to move landward, resulting in changing park acreage. For more information on park boundaries and jurisdiction, please see NPS 39-1 Ocean and Coastal Jurisdiction Reference Manual (*NPS internal access only*).

Managing at the Landscape Scale

The threat of climate change is prompting organizations including the National Park Service to look across borders and missions to collaborate on responses at a landscape scale, such as through LCCs. Many current management goals will be increasingly difficult to achieve without regional cooperation. Issues such as migratory bird habitats, marine invasive species, and sediment budgets all have landscape-scale management questions exacerbated by climate change impacts. To be good stewards of natural resources within park boundaries, it is important, where possible, to act in concert with other stewards to serve as part of a network of professionals, each doing their part to support habitats and species broadly so that parks are not the last refuge, but part of a functioning landscape that sustains these important resources for future generations.

Review Documentation, Data Integration, and Prioritization (See more in the "Opportunities for Adaptation" section in "Chapter 6 Facility Management.")

Documenting resource condition and change is important to understanding vulnerability and planning for adaptation; the science and monitoring in support of adaptation will be useful to other aspects of natural resource management. There is a growing amount of and accessibility to data related to climate change impacts on natural resources, providing new opportunities for the National Park Service to gather compatible baseline data and to synthesize trends. In addition, CCRP maintains an adaptation database complete with case studies of adaptation from various parks. Parks can either query other parks or input their case studies into the database.

Prioritization of resources is more challenging under climate change. PM 12-02, (NPS 2102) helps to inform prioritization activities. As our adaptation experience grows and servicewide understanding of vulnerability develops, the opportunity to prioritize at regional and national scales will help with allocating resources. Working at a large landscape scale and collaborating with partners, the National Park Service will set priorities to support evolutionary potential of habitats and species.

Inform Natural Resource Decision Making with other Decision-Making Processes

Because climate change affects all resources, adaptation is an opportunity to integrate decision-making processes across cultural resources, facilities, and natural resources. The needs and vulnerabilities of various park functions can inform assessment, selection, and implementation of management actions across a park. An adaptation strategy that works for a facility, for example, (e.g., reducing runoff from stormwater) can also have benefits for natural resources (e.g., less nutrient pollution from stormwater). Another example is the opportunity to examine coastal engineering inventories (see "Chapter 6 Facility Management" and "Chapter 9 Lessons Learned from Hurricane Sandy") and to consider building restrictions and removal of structures to protect and enable migration of beaches, dunes, estuarine shorelines, and wetlands (Nordstrom and Jackson 2016).

Take Home Messages

- Parks can choose from a range of potential adaptation strategies developed for climate-sensitive ecosystems. Applying strategies to coastal systems is park- and resource-specific. There is not yet a clear way forward to know which adaptation options will be most effective, and implementation is an active research field. The scientific resources to support adaptation are varied and growing.
- Uncertainty or the lack of locally specific information should not stop adaptation action. Strategies that are able to incorporate additional information at later steps, such as adaptive management, are well suited to coastal climate adaptation challenges.
- NPS policies to maintain natural processes are consistent with consideration of natural resource adaptation strategies because change is part of natural processes, and natural processes can be highly resilient. Yet climate change functions outside bounds of natural variability and thresholds will be exceeded. Strategies to manage for change, especially where natural systems are more vulnerable, or where thresholds can be anticipated, are a growing challenge.
- Managing for change may require working at a larger landscape scale than a single park and, thus, working with partners.

References

Alongi, D. M. 2008. Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. Estuarine, Coastal and Shelf Science 76(1): 1-13.

Austin, J. A. and S. M. Colman. 2007. Lake Superior summer water temperatures are increasing more rapidly than regional air temperatures: A positive ice-albedo feedback. Geophysical Resource Letters 34(6). doi: 10.1029/2006GL029021 (accessed 4 August 2016).

Baron, J. S., C. D. Allen, E. Fleishman, L. Gunderson, D. McKenzie, L. Meyerson, J. Oropeza, and N. Stephenson. 2008. National Parks. Pages 4-1 to 4-68 in S. H. Julius and J. M. West [eds.]. Preliminary review of adaptation options for climate-sensitive ecoystems and resources. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [J. S. Baron, L. A. Joyce, B. D. Keller, M. A. Palmer, C. H. Peterson, and J. M. Scott [authors]. US Environmental Protection Agency, Washington, DC.

Baron, J. S., L. Gunderson, C. D. Allen, E. Fleishman, D. McKenzie, L. A. Meyerson, J. Oropeza, and N. Stephenson. 2009. Options for National Parks and Reserves for Adapting to Climate Change. Environmental Management 44: 1033-1042.

Bengtsson, J, P. Angelstam, and T. Elmqvist. 2003. Reserves, resilience and dynamic landscapes. Ambio 32: 389-396.

Bjork, M., F. Short, E. Mcleod, and S. Beer. 2008. Managing Seagrasses for Resilience to Climate Change. Stockholm University Botany Department, Stockholm, Sweden.

Burdick, D. M. and C. T. Roman. 2012. Salt marsh responses to tidal restriction and restoration: a summary of experiences. Pages 373–382 in C. T. Roman and D. M. Burdick [eds.]. Tidal marsh restoration. . Island Press, Washington, DC..

Burn, C. R. and A. G. Lewkowicz. 1990. Canadian Landform Examples – 17 Retrogressive Thaw Slumps. The Canadian Geographer 34(3): 273-276.

Callaghan, T. V., L. O. Bjorn, F. S. Chapin, Y. Chernov, T. R. Christensen, B. Huntly, R. Ims, M. Johansson, D. J. Reidlinger, S. Jonasson, N. Matveyeva, W. Oechel, N. Panikov, and G. Shaver. 2005. Arctic Tundra and Polar Desert Ecosystems. Pages 243 – 352in Hassol, S. J. Impacts of a Warming Arctic: Arctic Climate Impact Assessment. Cambridge University Press, Cambridge, UK. http://www.amap.no/documents/doc/impacts-of-a-warming-arctic-2004/786 (accessed 3 August 2016).

Christie, J., and P. Bostwick. 2012. Climate change adaptation plan for Coastal and Inland Wetlands in the State of Michigan. A White Paper Prepared for the Michigan Department of Environmental Quality Wetlands Program and Coastal Management Program. Lansing, Michigan: Association of State Wetland Managers.

Craft, C., J. Clough, J. Ehman, H. Guo, S. B. Joye, M. Machmuller, D. Park, and S. Pennings. 2009. Effects of accelerated sea level rise on ecosystem services provided by tidal marshes: A simulation of the Georgia Coast. Frontiers in Ecology and Environment 7(2): 73-78.

Crain, C. M., K. Kroeker, and B. S. Halpern. 2008. Interactive and cumulative effects of multiple human stressors in marine systems. Ecology Letters 11(12): 1304-1315.

Dobiesz, N. E. and N. P. Lester. 2009. Changes in Mid-Summer Water Temperature and Clarity Across the Great Lakes between 1968 and 2002. Journal of Great Lakes Research 35(3):371-384. doi: http://dx.doi.org/10.1016/j.jglr.2009.05.002 (accessed 3 August 2016).

Doney, S. C., V. J. Fabry, R. Feely, and J. A. Kleypas. 2009. Ocean acidification: the other CO_2 problem. Annual Review of Marine Science 1: 169–92. DOI: 10.1146/annurev.marine.010908.163834 (accessed 3 August 2016).

Doyle, T. W., B. Chivoiu, and N. M. Enwright. 2015. Sea-level rise modeling handbook—Resource guide for coastal land managers, engineers, and scientists. US Geological Survey Professional Paper 1815. USGS, Reston, VA,76 p. http://dx.doi.org/10.3133/pp1815 (accessed 3 August 2016).

Field, C. B., L. D. Mortsch, M. Brklacich, D. L. Forbes, P. Kovacs, J. A. Patz, S. W. Running, and M. J. Scott. 2007. North America. Pages 617-652 in M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson [eds.]. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Fisichelli, N. A., S. R. Abella, M. Peters, and F. J. Krist Jr. 2014. Climate, Trees, Pests, and Weeds: Change, Uncertainty, and Biotic Stressors in Eastern U.S. National Park Forests. Forest Ecology and Management 327: 31-39.

Fisichelli, N. A., G. W. Schuurman, and C. Hawkins Hoffman. 2016. Is 'Resilience' Maladaptive? Towards an Accurate Lexicon for Climate Change Adaptation. Environmental Management 57: 753-758.

Florida Oceans and Coastal Council. 2009. The effects of climate change on Florida's ocean and coastal resources. A special report to the Florida Energy and Climate Commission and the people of Florida. Tallahassee, FL, 34 pp.

Frieler, K., M. Meinshausen, A. Golly, M. Mengel, K. Lebek, S. D. Donner, and O. Hoegh-Guldberg. 2013. Limiting global warming to 2°C is unlikely to save most coral reefs. Nature Climate Change 3: 165-170. doi:10.1038/nclimate1674.

Fuller, R., N. Cofer-Shabica, Z. Ferdana, A. Whelchel, N. Herold, K. Schmid, B. Smith, D. Marcy, D. Eslinger, and P. Taylor. 2011. Marshes on the Move: A Manager's Guide to Understanding and Using Model Results Depicting Potential Impacts of Sea Level Rise on Coastal Wetlands. The Nature Conservancy and National Oceanic and Atmospheric Administration, Narragansett, RI and Charleston, SC.

Gesch, D. B. 2009. Analysis of LiDAR elevation data for improved identification and delineation of lands vulnerable to sea level rise. Journal of Coastal Research SI 53: 49-58.

Gieder, K. D., S. M. Karpanty, J. D. Fraser, D. H. Catlin, B. T. Gutierrez, N. G. Plant, A. M. Turecek, and E. R. Thieler. 2014. A Bayesian network approach to predicting nest presence of the federally-threatened piping plover (Charadrius melodus) using barrier island features. Ecological Modelling, 276: 38-50.

Gledhill, D. K., M. M. White, J. Salisbury, H. Thomas, I. Mlsna, M. Liebman, B. Mook, J. Grear, A. C. Candelmo, R. C. Chambers, C. J. Gobler, C. W. Hunt, A. L. King, N. N. Price, S. R. Signorini, E. Stancioff, C. Stymiest, R. A. Wahle, J. D. Waller, N. D. Rebuck, Z. A. Wang, T. L. Capson, J. R. Morrison, S. R. Cooley, and S. C. Doney. 2015. Ocean and coastal acidification off New England and Nova Scotia. Oceanography 28(2): 182–197. http://dx.doi.org/10.5670/oceanog.2015.41.

Glick, P., B. A. Stein, and N. A. Edelson[eds.]. 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, DC.

Gonzalez, P. 2015. Climate Change Summary, Padre Island National Seashore, Texas. Climate Change Trends. NPS Published Report 2220505. National Park Service Climate Change Response Program, Washington, DC.

Grebmeier, J. M., J. E. Overland, S. E. Moore, E .V. Farley, E. C. Carmack, L. W. Cooper, K. E. Frey, J. H. Helle, F. A. McLaughlin, and S. L. McNutt. 2006. A major ecosystem shift in the northern Bering Sea. Science 311: 1461–1464. doi:10.1126/science.1121365.

Gutierrez, B. T., N. G. Plant, and E. R. Thieler. 2011. A Bayesian Network to Predict Coastal Vulnerability to sea level Rise. Journal of Geophysical Research Earth Surface 116(F02009). doi:10.1029/2010JF001891 (accessed 3 August 2016).

Hendriks, I. E., C. M. Duarte, Y. S. Olsen, A. Steckbauer, L. Ramajo, T. S. Moore, J. A. Trotter, and M. McCulloch. 2015. Biological mechanisms supporting adaptation to ocean acidification in coastal ecosystems. Estuarine, Coastal and Shelf Science 152: A1-A8. doi: 10.1016/j.ecss.2014.07.019 (accessed 4 August 2016).

Hodel, R. G., and E. Gonzales. 2013. Phylogeography of Sea Oats (Uniola paniculata), a dune-building coastal grass in Southeastern North America. Journal of Heredity 104(5): 656-665.

Hoegh-Guldberg, O., P. J. Mumby, A. J. Hooten, R. S. Steneck, P. Greenfield, E. Gomez, C. D. Harvell, P. F. Sale, A. J. Edwards, K. Caldeira, N. Knowlton, C. M. Eakin, R. Iglesias-Prieto, N. Muthiga, R. H. Bradbury, A. Dubi, and M. E. Hatziolos. 2007. Coral reefs under rapid climate change and ocean acidification. Science 318: 1737-1742. doi:10.1126/science. 1152509 (accessed 4 August 2016).

Hoffman, J., E. Rowland, C. H. Hoffman, J. West, S. H. Julius, and M. Hayes. 2014. Chapter 12: Managing Under Uncertainty. Pages 177-187 in B. A. Stein, P. Glick, N. Edelson, and A. Staudt [eds.]. Climate-Smart Conservation: Putting Adaptation Principles into Practice. National Wildlife Federation, Washington, DC.

Jones, S. J., N. Mieszkowska, and D. S. Wethey. 2009. Linking thermal tolerances and biogeography: Mytilus edulis (l.) at its southern limit on the east coast of the United States. The Biological Bulletin 217: 73-85.

Kareiva, P., C. Enquist, A. Johnson, S. H. Julius, J. Lawler, B. Petersen, L. Pitelka, R. Shaw, and J. M. West. 2008. Synthesis and Conclusions. Pages 9-1 to 9-66 in: S. H. Julius and J. M. West [eds.]. Preliminary review of adaptation options for climate-sensitive ecosystems and resources. A report by the U.S. climate change science program and the subcommittee on global change research. J. S. Baron, B. Griffith, L. A. Joyce, P. Kareiva, B. D. Keller, M. A. Palmer, C. H. Peterson, and J. M. Scott, J.M. [authors]. United States Environmental Protection Agency, Washington, DC.

Lenihan, H. S., C. H. Peterson,, J. E. Byers, J. H. Grabowski, G. H. Thayer, and D. R. Colby. 2001. Cascading of habitat degradation: oyster reefs invaded by refugee fishes escaping stress. Ecological Applications 11:748–64.

Lentz, E. E., S. R. Stippa, E. R. Thieler, N. G. Plant, D. B. Gesch, and R. M. Horton. 2015. Evaluating coastal landscape response to sea-level rise in the northeastern United States—Approach and methods. USGS Open-File Report 2014–1252. U.S. Geological Survey, Reston, VA, 26 p. http://dx.doi.org/10.3133/ofr20141252.

Long, E. and E. Biber. 2014. The Wilderness Act and Climate Change Adaptation, Environmental Law 44:623-694.

Lugo, A. E., E. Medina, and K. McGinley. 2014. Issues and challenges of mangrove conservation in the Anthropocene. Madera y Bosques, 20: 11–38.

Manzello, D. P., I. C. Enochs, N. Melo, D. K. Gledhill, and E. M. Johns. 2012. Ocean Acidification Refugia of the Florida Reef Tract. PLoS ONE 7(7): e41715. doi:10.1371/journal.pone.0041715.

Mars, J. C. and D. W. Houseknecht. 2007. Quantitative remote sensing study indicates doubling of coastal erosion rate in past 50 yr along a segment of the Arctic Coast Alaska. Geology 35(7): 583 – 586.

Masterson, J. P., Fienen, M. N., Thieler, E. R., Gesch, D. B., Gutierrez, B. T., and N. G. Plant. 2013. Effects of sea-level rise on barrier island groundwater system dynamics-ecohydrological implications. Ecohydrology 7(3): 1064–1071. doi: 10.1002/eco.1442 (accessed 4 August 2016).

McLeod, E., R. Salm, A. Green, and J. Almany. 2009. Designing marine protected area networks to address the impacts of climate change. Frontiers in Ecology and the Environment 7:362-370.

Millar, C. I., N. L. Stephenson, and S. L. Stephens. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecological Applications 17:2145-2151.

Monahan, W. B., and N. Fisichelli. 2014. Climate Exposure of US National Parks in a New Era of Change. PLoS ONE 9(7): e101302. DOI: 10.1371/journal.pone.0101302 (accessed 4 August 2016).

Moore S. K., V. L. Trainer, N. J. Mantua, M. S. Parker, E. A. Laws, L. C. Backer and L. E. Fleming. 2008. Impacts of climate variability and future climate change on harmful algal blooms and human health. Environmental Health 7(Suppl 2): S4. doi:10.1186/1476-069X-7-S2-S4 (accessed 4 August 2016).

Murdukhayeva, A. 2012. Assessment of Inundation Risk from Sea Level Rise and Storm Surge in Coastal National Parks. Master's Thesis. University of Rhode Island, Kingston, RI, 118p.

Murdukhayeva, A., P. August, M. Bradley, C. LaBash, and N. Shaw. 2013. Assessment of inundation risk from sea level rise and storm surge in northeastern coastal national parks. Journal of Coastal Research 29(6A): 1–16.

Murray, B., L. Pendleton, W. A. Jenkins, and S. Sifleet. 2011. Green Payments for Blue Carbon: Economic Incentives for Protecting Threatened Coastal Habitats. Nicholas Institute Report NI R 11-04. Duke University, Durham, NC. https://nicholasinstitute.duke.edu/sites/default/files/publications/blue-carbon-report-paper.pdf (accessed 10 August 2016).

Nielsen, M. G., and R. W. Dudley. 2013. Estimates of future inundation of salt marshes in response to sea-level rise in and around Acadia National Park, Maine. USGS Scientific Investigations Report 2012–5290. U.S. Geological Survey, Reston, VA, 20 p. http://pubs.usgs.gov/sir/2012/5290/ (accessed 17 April 2015).

National Ocean Council. 2013. National Ocean Policy Implementation Plan. Washington, DC. https://www.whitehouse.gov/sites/default/files/national_ocean_policy_implementation_plan.pdf (accessed 10 August 2016).

National Oceanic and Atmospheric Administration (NOAA). 2012. Incorporating Sea Level Change Scenarios at the Local Level. NOAA Coastal Services Center, Charleston, SC. http://www.ngs.noaa.gov/PUBS_LIB/SLCScenariosLL.pdf (accessed 4 August 2016).

NOAA. 2016. Guide for Considering Climate Change in Coastal Conservation. NOAA Office for Coastal Management, Silver Spring, MD. https://coast.noaa.gov/data/digitalcoast/pdf/considering-climate-change.pdf (accessed 8 August 2016).

National Fish, Wildlife and Plants Climate Adaptation Partnership (NFWPCAP). 2012. National Fish, Wildlife and Plants Climate Adaptation Strategy. Association of Fish and Wildlife Agencies, Council on Environmental Quality, Great Lakes Indian Fish and Wildlife Commission, National Oceanic and Atmospheric Administration, and U.S. Fish and Wildlife Service, Washington, DC. http://www.wildlifeadaptationstrategy.gov/ (accessed 10 August 2016).

National Park System Advisory Board Science Committee (NPSABSC). 2012. Revisiting Leopold: Resource Stewardship in the National Parks. August 25, 2012. Funded by the National Park Foundation. https://www.nps.gov/calltoaction/PDF/LeopoldReport_2012.pdf (accessed 10 August 2016).

National Park Service (NPS). 2006. National Park Service Management Policies 2006. National Park Service, Washington, DC. http://www.nps.gov/policy/MP2006.pdf (accessed 26 March 2015).

NPS. 2012. Applying National Park Service management policies in the context of climate change. US DOI National Park Service Policy Memorandum 12-02. March 6, 2012. https://www.nps.gov/policy/PolMemos/PM_12-02.pdf (accessed 28 April 2015).

NPS. 2016. Resource Stewardship for the 21st Century – Interim Policy. US DOI National Park Service Policy Memorandum 16-01. https://www.nps.gov/policy/PolMemos/PM_16-01.htm (accessed 15 June 2016).

Nordstrom, K. and N. Jackson. 2016. Facilitating migration of coastal landforms and habitats by removing shore protection structures: An adaptation strategy for Northeast Region units of the National Park Service. Natural Resource Report NPS/NER/NRR—2016/1240. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2230271 (accessed 10 August 2016).

Peek, K. M., R. S. Young, R. L. Beavers, C. H. Hoffman, B. T. Diethorn, and S. Norton. 2015. Adapting to climate change in coastal national parks: Estimating the exposure of park assets to 1 m of sea-level rise. Natural Resource Report NPS/NRSS/GRD/NRR—2015/961. National Park Service, Fort Collins, Colorado. http://www.nature.nps.gov/geology/coastal/coastal_assets_report.cfm (accessed 10 August 2016).

Peek, K. M., A. Coburn, E. Stafford, B. Tormey, R. Young, H. Thompson, L. Bennett, and A. Fowler. 2016. Marine vulnerability assessment of Cumberland Island National Seashore: Determining the vulnerability of marine habitats at Cumberland Island National Seashore to climate change stressors. Natural Resource Report NPS/CUIS/NRR—2016/1281. National Park Service, Fort Collins, Colorado.

Pespeni, M. H., E. Sanford, B. Gaylord, T. M. Hill, J. D. Hosfelt, H. K. Jaris, M. LaVigne, E. A. Lenz, R. D. Russell, M. K. Young, and S. R. Palumbi. 2013. Evolutionary change during experimental ocean acidification. Proceedings of the National Academy of Sciences of the USA 110: 6937–6942.

Riggs, S. R., and D. V. Ames. 2007. Effect of storms on Barrier Island Dynamics, Core Banks, Cape Lookout National Seashore, North Carolina, 1960-2001. US Geological Survey Scientific Investigations Report 2006–5309. USGS, Reston, Virginia. http://pubs.usgs.gov/sir/2006/5309/pdf/sir2006-5309.pdf (accessed 10 August 2016).

Roman, C. T., and A. L. Babson. 2013. Climate change in Northeast Region coastal parks: Synthesis of a workshop on research and monitoring needs. Natural Resource Report NPS/NER/NRR—2013/697. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/DownloadFile/475468 (accessed 10 August 2016).

Schwartz M.W., J. J. Hellmann, J. M. McLachlan, D. F. Sax, J. O. Borevitz. 2012. Managed Relocation: Integrating the Scientific, Regulatory, and Ethical Challenges. BioScience 62(8): 732–743. doi:10.1525/bio.2012.62.8.6.

Schupp, C., and A. Coburn. 2015. Inventory of coastal engineering projects within Assateague Island National Seashore. Natural Resource Report NPS/NRPC/GRD/NRR—2015/914. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2220096 https://irma.nps.gov/DataStore/Reference/Profile/2220096 (accessed 10 August 2016).

Schupp, C. A., R. L. Beavers, and M. Caffrey [eds.]. 2015. Coastal Adaptation Strategies: Case Studies. NPS 999/129700. National Park Service, Fort Collins, Colorado. https://www.nps.gov/subjects/climatechange/coastaladaptationstrategies.htm (accessed 10 August 2016).

Shaw, N., and M. Bradley. 2014. Sentinel Sites for All Parks in the Northeast Region. NPS Northeast Region. Geospatial Dataset- 2216317. National Park Service, Lakewood, CO. https://irma.nps.gov/App/Reference/Profile/2216317 (accessed 21 April 2015).

Secretariat of the Convention on Biological Diversity (SCBD). 2009. Connecting Biodiversity and Climate Change Mitigation and Adaptation: Report of the Second Ad Hoc Technical Expert Group on Biodiversity and Climate Change. Technical Series No. 41. SCBD, Montreal, Canada,126 pages. https://www.cbd.int/doc/publications/cbd-ts-41-en.pdf (accessed 10 August 2016).

Staudinger, M. D., S. L. Carter, M. S. Cross, N. S. Dubois, J. E. Duffy, C. Enquist, R. Griffis, J. J. Hellmann, J. J. Lawler, J. O'Leary, S. A. Morrison, L. Sneddon, B. A. Stein, L. M. Thompson, and W. Turner. 2013. Biodiversity in a changing climate: a synthesis of current and projected trends in the US. Frontiers in Ecology and the Environment 11: 465–473.

Stein, B. A., P. Glick, N. A. Edelson, and A. Staudt [eds.]. 2014. Climate-Smart Conservation: Putting Adaptation Principles into Practice. National Wildlife Federation, Washington, DC. http://www.nwf.org/pdf/Climate-Smart-Conservation/NWF-Climate-Smart-Conservation_5-08-14.pdf (accessed 19 March 2015).

Stevens, S., B. Mitchell, M. Brown, and P. Campbell. 2010. Strategy for enhanced monitoring of natural resource condition in North Atlantic coastal parks to address the effects of rapid climate change. Natural Resource Report NPS/NCBN/NRR—2010/272. National Park Service, Fort Collins, CO.

Thorne, K. M., J. Y. Takekawa, and D. L. Elliott-Fisk. 2012. Ecological effects of climate change on salt marsh wildlife: a case study from a highly urbanized estuary. Journal of Coastal Research 28(6): 1477-1487. doi: 10.2112/JCOASTRES-D-11.00136.1.

Twilley, R. R., E. J. Barron, H. L. Gholz, M. A. Harwell, R. L. Miller, D. J. Reed, J. B. Rose, E. H. Siemann, R. G. Wetzel, and R. J. Zimmerman. 2001. Confronting climate change in the Gulf Coast Region. A report of the Union of Concerned Scientists and the Ecological Society of America. http://repositories.tdl.org/tamug-ir/handle/1969.3/26295 (accessed 28 April 2015).

US Army Corps of Engineers (USACE). 2013. Sea level change calculator. Online data. http://corpsclimate.us/ccaceslcurves.cfm/ (accessed 17 April 2015).

University of Rhode Island and the National Park Service Northeast Region GIS Office (URI and NPS). 2014. National Park Service NER Sentinel Sites and Inundation Risk. Online database and mapping application. http://www.arcgis.com/home/item.html?id=16c11b61be9042da9b44ced65887d543 (accessed 21 April 2015).

Wassmann, P., C. M. Duarte, S. Agusti, and M. K. Sejr. 2011. Footprints of climate change in the Arctic marine ecosystem. Global Change Biology 17: 1235–1249. doi: 10.1111/j.1365-2486.2010.02311.x.

West, J. M., S. H. Julius, P. Kareiva, C. Enquist, J. J. Lawler, B. Petersen, A. E. Johnson, M. R. Shaw. 2009. US natural resources and climate change: Concepts and approaches for management adaptation. Environmental Management 44: 1001-1021.

West, J. M. and S. H. Julius. 2014. Chapter 8: The art of the possible: Identifying adaptation options. Pages 119-139 in B. A. Stein, P. Glick, N. Edelson and A. Staudt [eds.]. Climate-Smart Conservation: Putting Adaptation Principles into Practice. National Wildlife Federation, Washington, DC. http://www.nwf.org/pdf/Climate-Smart-Conservation/NWF-Climate-Smart-Conservation_5-08-14.pdf (accessed 10 August 2016).

Worm, B., E. B. Barbier, N. Beaumont, J. E. Duffy, C. Folke, B. S. Halpern, J. B. C. Jackson, H. K. Lotze, F. Micheli, S. R. Palumbi, E. Sala, K. A. Selkoe, J. J. Stachowicz and R. Watson. 2006. Impacts of Biodiversity Loss on Ocean Ecosystem Services. Science 314 (5800): 787-790.

This page intentionally left blank.