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Natural Resource Stewardship and Science

Overview of Climate Change Adaptation Needs, Opportunities and Issues

Northeast Region Coastal National Parks

Natural Resource Report NPS/NER/NRR—2014/789

ON THE COVER
Mouth of Herring River Estuary at Cape Cod National Seashore.
Photograph by: Amanda Babson

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Northeast Region Coastal National Parks

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Amanda L. Babson

National Park Service
University of Rhode Island
Narragansett, RI 02882

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Executive Summary

Many coastal national parks have implemented climate adaptation actions that demonstrate leadership in this important emerging field, motivated by awareness that sea level rise and storm impacts are already affecting resources and operations. Many Northeast Region (NER) parks have begun taking some of the actions needed to reduce current vulnerability and plan for increasing impacts in the future. Based on site visits to nine coastal NER parks in 2012 and conversations with coastal park staff, this report is an assessment of information needs considered necessary to respond and adapt to the impacts associated with climate change. Notable common actions taken and identified needs are summarized by park (Table 1). The visits and this summary were intended to gauge known vulnerabilities, progress and opportunities for implementation in order to inform the development of a regional program that will increase capacity of park and regional staff to implement adaptation actions. It is intended to support development of a research agenda, assist prioritization among objectives of the NER Climate Change Strategy and Action Plan, and facilitate projects that will implement those objectives.

The high priority coastal climate adaptation issues identified are habitat change, landform migration, erosion, visitor experience and damage or degradation of facilities and cultural resources. The primary drivers of change are accelerated sea level rise (SLR) and storm impacts, with changes in hydrology, including groundwater also of concern. Parks are aware of species impacts such as changes in phenology, species migration patterns and invasive species, and some are concerned, but have little information about ocean acidification.

The NER's near term priorities on climate adaptation should be research that will support selection and implementation of adaptation options and integration of climate change information into planning. Focusing on these strategies will build on previous successes and increase the foundation and capacity to meet the larger suite of climate adaptation needs that we currently do not have the understanding or resources to address fully.

A wealth of climate information is available, but the capacity to integrate the relevant information into decisions is limited. The NER should provide support for integrating observations of historic change and projections of future conditions into planning processes and management actions, particularly SLR, storm frequency and intensity, and hydrology. Some parks are looking for consistency across the region, while others prefer the flexibility to use projections consistent with local partners or collaborators. The NER can provide guidance on methods and availability of best available science without being prescriptive. Some of this guidance is being developed at the national scale by the NPS Climate Change Response Program and the NER can assist in applying these tools to NER parks. In addition, the NER needs to manage expectations about limitations of localized climate projections and the high uncertainty about climate information for many variables.

Guidance on vulnerability assessments is needed to improve consistency while maintaining flexibility to be responsive to specific park issues. The purpose of a vulnerability assessment is to identify resources that are most likely to be impacted and understand why and how. The NER should review the vulnerability assessments in progress, which have primarily been focused on a single

natural resource, and transfer successful methods to other parks and resources and expand to other types of resources. There is strong interest in integrated natural and cultural resource vulnerability assessments.

We need to facilitate communication of successful strategies (e.g. technology, funding avenues, methods), results and lessons within and among parks, between parks and partners, and with visitors. Some of the work to date described for each park is highlighted as communication priorities. This will build the adaptation community of practice and expand our impact beyond NPS units.

Table 1. Summary of common adaptation actions and needs by park. Needs are broad categories by topic area including research, planning, capacity and resources. Actions in progress are noted by an o.

	Acadia	**Assateague Island**	**Boston Harbor Islands**	**Cape Cod**	**Colonial**	**Fire Island**	**Gateway**	**Salem Maritime**	**Saugus Iron Works**
Actions									
Join Climate Friendly Parks			✓	✓		✓	✓	☐	☐
Include climate change in GMP		o				o	o		
Include climate change in other strategic plans		o	o					o	
Assess vulnerability	✓	✓	Planned	o					
Undertake scenario Planning		✓		✓					
Monitoring	✓	✓	✓	✓	✓	✓	✓		✓
Restoration		✓		✓			✓		✓
Redesign Infrastructure	✓	✓		✓			o	o	
Undertake cultural resource actions	✓			✓	✓			✓	o
Interp. and Education		✓	✓	✓			✓		

Table 1. (continued) Summary of common adaptation actions and needs by park. Needs are broad categories by topic area including research, planning, capacity and resources. Actions in progress are noted by an o.

	Acadia	Assateague Island	Boston Harbor Islands	Cape Cod	Colonial	Fire Island	Gateway	Salem Maritime	Saugus Iron Works
Needs									
Cultural Resource	✓		✓	✓	✓	✓	✓	✓	✓
Ecological Resource	✓	✓	✓	✓		✓	✓		✓
Erosion	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hydrology	✓	✓		✓	✓	✓			✓

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Introduction

This report highlights the known climate change adaptation needs and work to date for coastal national parks in the Northeast Region (NER) based on site visits to nine parks in 2012, including all of the coastal parks with significant natural resources and two historical sites (Figure 1). Coastal parks are currently experiencing climate change related impacts (Kunkel et al. 2013) and are beginning to adapt to expected future changes. Climate adaptation (strategies that minimize climate change impacts to park resources by promoting ecosystem resilience and enhancing restoration, conservation and preservation of park resources) is a relatively new area for many parks. Resilience is used in this document to mean the amount of change or disturbance that can be absorbed by a system before the system is redefined by a different set of processes and structures (USGCRP, 2008). The visits and this summary were intended to gauge known vulnerabilities, progress and opportunities in order to inform the development of a regional program to increase capacity and implement adaptation actions. Successful efforts and lessons learned to date will be shared among parks. Addressing common needs across multiple parks will help set NER climate adaptation priorities.

Information for this report was provided by park natural and cultural resource professionals as well as facility managers, park interpreters, environmental educators, communication specialists and park managers. The *Accomplishments and Ongoing Activities* section for each park highlights projects and studies that park staff consider applicable to adaptation, but is not comprehensive. This report does not attempt to prioritize among the issues highlighted by the visits, nor is it a comprehensive assessment. It is limited by current awareness of vulnerabilities by park staff professionals. Park staffs were asked to identify top research, monitoring and planning needs to support adaptation and implementation opportunities. Additionally, they were asked what to look for to define successful adaptation, what coordination would be most helpful and what time scales were most relevant to climate adaptation planning.

Additional sources of information on climate change research and monitoring needs for northeast coastal parks include a workshop report on research needs (Roman and Babson, 2013) and a strategy for enhancing monitoring by the Inventory and Monitoring Networks (Stevens et al. 2010).

This report first summarizes ongoing climate change relevant work, known adaptation needs and implementation opportunities for each park. Common needs and issues that were identified by multiple parks and recommended actions are detailed in the conclusion.

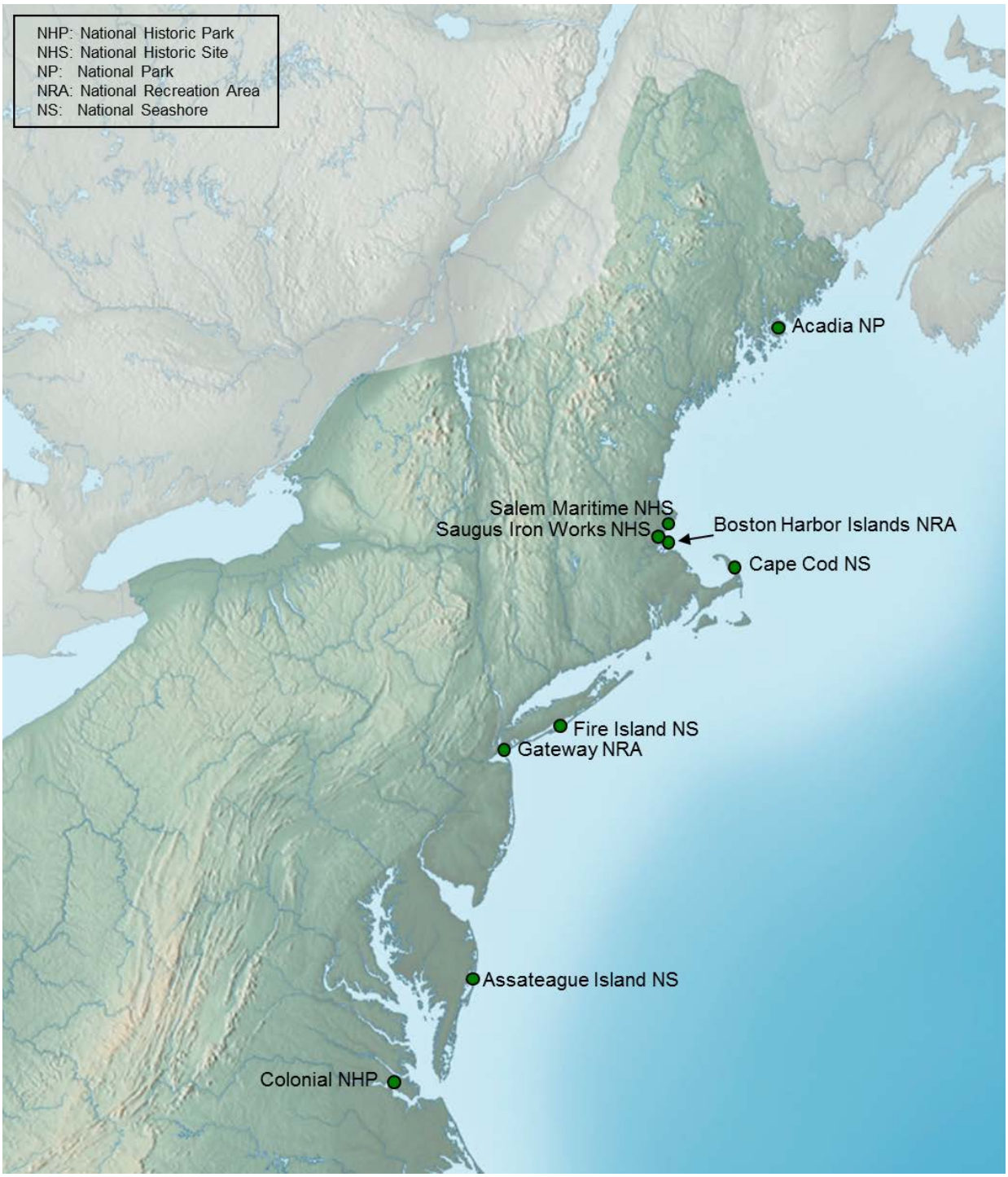

Figure 1. Map of NER coastal parks included in this report.

Acadia National Park (ACAD)

Acadia's northern climate determines the suitability for species diversity and recreational opportunities, and these are likely to change with warming and changing precipitation regimes. Impacts of changing seasonality, heavier precipitation events and timing of snowpack melt are already affecting park resources and future changes are going to require adaptation. While the rocky coast, gravel beaches and steep shores of ACAD are much less susceptible to erosion and sea level rise impacts than many of the coastal parks with low-lying sandy beaches, sections of road are low-lying and vulnerable to storm impacts; relocating these sections presents challenges both due to their historic characteristics and the steep surrounding landscape.

Accomplishments and Ongoing Activities

ACAD has undertaken a wide variety of climate change relevant research. Bird banding, and studies of vulnerabilities of nesting seabirds and migratory songbirds highlight ACAD's strength in bird research. Studies underway include the potential effects of sea level rise on sea bird nesting sites (principal investigator Dr. John Anderson, College of the Atlantic) and the effects of climate change on salt marsh birds in the park (principal investigator Dr. Brian Olsen, UMaine). Citizen science monitoring has been integrated with efforts to synthesize historical records of phenology (timing of life cycle events), distribution and abundance to both document observed changes in the past century, and to use those results to evaluate the vulnerability of species based on characteristics of what has been lost in that time and what species types have changed in response to warming. A project titled *Identify Species Vulnerable to Climate Change at Acadia National Park* has been initiated in FY2013 (principal investigator Dr. Richard Primack, Boston University). The results of that study will inform management plans for vulnerable species and identification of future invasive species threats. The methods developed for this project will be transferrable to other parks looking to use their natural history collections and records to document impacts of climate change, such as Theodore Roosevelts's bird study at Sagamore Hill National Historic Site. An additional collaboration on this project is exploring plant traits associated with species that have declined versus those that have expanded over the past 100+ years (principal investigator Dr. Christine Lamanna, UMaine). An effort to inform studies of long term change is in its third summer using Youth In Parks funds to help digitize historical records, create metadata, and make them accessible via the IRMA (Integrated Resource Management Applications) portal.

A salt marsh vulnerability assessment for a static inundation scenario of 60 cm of sea level rise (SLR) has been completed by USGS (Nielsen and Dudley, 2013). The study mapped areas likely to be inundated (neglecting increased accretion), adjacent low-lying upland areas and barriers to migration. A separate nutrient modeling study (Huntington et al. 2012) for Bass Harbor Marsh, one of two substantial salt-water marshes in Acadia, considered SLR impacts on the tidal ratio upstream of the tidal restriction, and the implications for eutrophication of that marsh; work continues investigating the effects of SLR on the functioning of Bass Harbor Marsh.

Many of the drainage features on the carriage and motor roads are undersized for current conditions, leading to flooding and erosion. The Northeast has seen a change in the recurrence interval and duration of extreme precipitation events, which can lead to premature infrastructure disruptions;

projections indicate that this trend is expected to continue (Kunkel et al. 2013). ACAD has inventoried these structures and begun the process of rehabilitating stream crossings as an adaptation effort. Improvements to stream crossings benefit aquatic animal passage and reduce flooding and erosion, thus maintenance costs. When culverts have been rehabilitated, cultural resource staff has been involved in order to maintain the character-defining features of the historic structures. This practice is a model for other parks integrating cultural resource, natural resource and facilities adaptation.

Research and Adaptation Needs

Building on the previous culvert work, there are a variety of needs related to expected changes in hydrology and stream flow. In continuing to replace undersized stream culverts, projections of future peak flows would adapt those road crossings to expected changes over the lifetime of the replacement structure, rather than just addressing the changes since the structure was originally built. Examples of studies modeling hydrology for culverts design include Stack et al. 2010. Tidal restrictions (where culverts and road crossings limit tidal exchange for an upstream tidal marsh) are another issue to address; the expectation is that restoring full tidal exchange increases the resilience of the marsh. An adaptation research need is to design a restoration experiment that is able to test how much increasing tidal exchange increases the ability of that marsh to keep pace with sea level rise.

An additional hydrologic modeling need is for addressing flooding in the Great Meadow and Sieur de Monts area. This area regularly floods; some flooding has been due to beaver activity which is currently managed, but some is related to changes in streamflow patterns due to climate change. NPS has contracted to design a replacement or repair for the Great Meadow culvert; that design should take into account projected future streamflow changes. Adaptation plans that look at the Wild Gardens of Acadia, the Abbe Museum and the Nature Center and Sieur de Monts Spring Interpretive trail would benefit from a comprehensive approach that addresses long term changes affecting all of these resources as well as the roads, parking lots and restroom facilities.

While the rocky coastline with very few beaches means that erosion is less of a concern for ACAD than many coastal parks, storm impacts are an issue. Thunder Hole is a geologic feature where visitors can watch and hear the power of waves from a path with a railing. The maintenance requirements for access to this site will grow if storm intensity or frequency increases; adapting the design of the access infrastructure should be considered when it needs to be replaced.

Another area with repeat storm damage is the Otter Cove Causeway. During storms large cobbles get thrown onto the road requiring clearing and damaging the road surface. Other roads that may be vulnerable to storms include sections of the Park Loop Road and the Schoodic Loop Road, both of which are on the National Register of Historic Places, as well as roads in the Seawall section of the park. Planning is needed for determining options to protect or move infrastructure and under what level of damage to stop rebuilding in the same place or manner, taking into account historic characteristics.

A research need is to understand the potential changes to the composition of the forest corridor along the loop road. This mature spruce forest with shallow roots and soils may be increasingly susceptible to blowdowns and impacts from increased salt exposure should there be an increase in storm activity. This will act in conjunction with future changes in habitat suitability as tree species' ranges are expected to shift in response to warming and changing precipitation patterns (Fisichelli et al. 2013). Increasing invasive plant species, especially after disturbance events are an additional concern. Increases in health pests (e.g. ticks which carry Lyme disease) were also mentioned as a concern for the park. A study underway is investigating the physiological ecology and effects of climate change on some of the rare forest communities at ACAD, especially those associated with pitch pine and jack pine (principal investigator Dr. Michael Day, UMaine). As habitat suitability shifts, the adaptation options necessary to protect rare communities, such as by protecting refugia, will be different than those for dominant species.

The warmer winters and earlier springs result in an expanding shoulder season (Kunkel et al. 2013, Huntington et al. 2003). Roads traditionally closed for snow will be able to remain open longer. There will be visitor interest in opening facilities earlier, and associated staffing and maintenance needs. This represents an opportunity to adapt by expanding visitorship into this shoulder season, but a potential loss of winter sports visitors. Already cruise ship traffic has substantially increased in the autumn, and is starting earlier in the spring.

Implementation Opportunities and Recommendations

There are a variety of educational and outreach opportunities to share adaptation successes as a strategy develops. The Schoodic Education and Research Center (SERC)'s education programs engage students and adult learners who would be invested in how results of their contributions inform adaptation decisions. SERC serves Acadia, but also all of the Northeast Temperate Network (NETN), including the Appalachian Trail, so there are opportunities for sharing the adaptation lessons learned with non-coastal parks. A related opportunity that SERC was involved in is a study led by George Mason University aimed at engaging and training meteorologists in climate science. As part of the citizen science portion of the study, a partnership of SERC, Cornell Lab of Ornithology, National Environmental Education Foundation, Boston University, and USA National Phenology Network developed local stories on climate impacts. Communications examples such as this should be compiled and methods and lessons learned shared among NER parks.

A cultural resource vulnerability assessment has been recommended for funding beginning in FY2014, which will include convening an expert workshop to review assets and threats, and to prioritize them.

A project titled *Develop Climate Change-Resilient Restoration Techniques on Cadillac Mountain* has been recommended for funding for FY2015. This would test restoration techniques for alpine summit habitats with species that are likely to be suited to future projected temperature and rainfall intensity, comparing with natural succession and seeding with native plants that previously grew on the summit. Since ACAD is doing research on both coastal and mountain resources being impacted by climate change, this adaptation capacity across resource types is an excellent opportunity to expand the adaptation community of practice to bring in non-coastal parks.

Assateague Island National Seashore (ASIS)

Assateague Island is a dynamic environment and ASIS expects to continue to be shaped by storm events, with increased overwash and shoreline change. Quality and quantity of island groundwater resources have been identified as particularly vulnerable to climate change, through salt water intrusion and changes in the depth of the water table and hydrology.

Accomplishments and Ongoing Activities

Climate change is the centerpiece of the current General Management Plan (GMP) update for Assateague Island National Seashore. Each alternative for management recognizes the importance of climate change to the future of the seashore. The GMP planning process has involved extensive climate change research, outreach and education on projected climate impacts for park resources, staff, partners and the community.

Because the National Seashore boundary encompasses lands managed by the US Fish and Wildlife Service as well as the Maryland Department of Natural Resources, these adjacent partners and their management policies affect options available for ASIS. The Virginia portion of Assateague Island is managed by the US Fish and Wildlife Service as the Chincoteague National Wildlife Refuge. The NPS manages a one mile recreational beach within the refuge through a Memorandum of Understanding. The refuge is currently updating its Comprehensive Conservation Plan (a 15 year plan setting goals to guide the management of the refuge), so decisions made through that process will in part be a large determinant of what future adaptation options are available. In Maryland, the Department of Natural Resources manages the Assateague State Park, which is located immediately adjacent to the only bridge that provides access to the Maryland portion of the island. The management decision by the Maryland State Park Service to include dune maintenance affects ASIS adaptation options by creating discontinuities between where the dune is allowed to migrate landward and where its location is held static.

Since the dominant longshore sediment transport along ASIS is from north to south, and transport has been disrupted to the north, sediment management is a critical resource issue. To protect the integrity of the entire barrier island and prevent impairment, the NPS has established a long term agreement with the US Army Corps of Engineers (USACE) to restore the sediment supply to northern ASIS through sand bypassing around the Ocean City inlet jetty system. Sand is dredged from the inlet and adjacent shoals biannually, and is deposited in the nearshore along ASIS to restore the natural sediment budget. By restoring the sediment budget, the natural processes are expected to be more resilient to sea level rise, for the entire island to migrate landward while maintaining the same processes and systems in the face of increased disturbance and change.

In 2009 ASIS took part in a climate change scenario planning workshop (NPS, 2013). The scenarios and background material developed for that workshop provided a starting point for increased park capacity to integrate climate change considerations into the GMP update and other adaptation opportunities.

The *Alternative Transportation Systems Planning Study and Business Plan for Alternative Transportation* (Morse et al. 2012) includes plans for future transportation changes including those in response to sea level rise, climate change and the GMP alternatives that address them.

Actions to address high risk facilities and visitor use in the Virginia district have involved transitioning from traditional asphalt parking areas to a more sustainable clay and clam shell alternative, as well as designing movable facilities, which serve as examples of climate adaptation options. The lessons learned in the development of these facilities and for their maintenance will inform how and whether they are implemented in the Maryland district. They are also held up as examples of adaptation implementation for other parks. By sharing the design, cost and maintenance specifics, ASIS is helping other parks assess whether these options are feasible alternatives.

In October 2012, ASIS was a pilot park for a Facilities Adaptation workshop, led by the Sustainable Operations and Climate Change branch (SOCC/WASO). This workshop applied a park level risk screening approach to look at each asset in the Federal Management Software System. Each asset (e.g. building, road, parking lot) was scored for exposure based on multiple factors, but highly weighted for elevation, sensitivity based on Facility Condition Index and adaptive capacity based on current replacement value to determine vulnerability. Based on an initial scoring, workshop participants then adjusted each score based on an understanding of the asset, through discussion, if necessary. With an updated vulnerability score, workshop participants then worked through adaptation options for several of the more vulnerable assets. Hurricane Sandy, which hit just a few weeks after this workshop, was a way to test where the assessment was accurate and where there were surprises. The discussions on adaptation options that were theoretical at the workshop needed to be practical in the response and recovery. A lessons learned evaluation, including both comparison of observed impacts and adaptive capacity, would be beneficial to determine what elements of such planning exercises should be expanded from a pilot to a broader program. The NER should include an evaluation component for any pilot effort before expanding to multiple parks.

Additional projects by partners include a U.S. Geological Survey (USGS) project (Sea-Level Rise Hazards and Decision Support) to make probabilistic predictions of the future state of coastal environments (based on Bayesian statistical analysis framework to integrate existing data for parameters such as shoreline change, wetland sustainability, and depth to groundwater) in response to different SLR scenarios. It is expected that this research will address the broad objective of integrating SLR impact assessments with coastal management decisions. One component of this project is a specific study on the effects of accelerating sea-level rise on the habitat of Atlantic Coast Piping Plovers (*Charadrius melodus*) (principal investigator Dr. Sarah Karpanty, Virginia Tech). The methods from the Piping Plover study will be transferable to similar parks; CACO has a similarly strong monitoring record that would be a good basis for refining the methods in another location. USGS also did a coastal vulnerability assessment for ASIS as part of applying a Coastal Vulnerability Index to 22 national parks, based on geomorphology, regional coastal slope, rate of relative sea level rise, rate of shoreline change, mean tidal range and mean wave height (Pendleton et al. 2004a).

Other focus topics may include management of groundwater resources and the less salt tolerant species that depend upon them, placement of park infrastructure, and long-range land use planning.

ASIS recently collaborated with the University of Maryland's Center for Environmental Science - Integration and Application Network to develop a suite of new outreach and educational products focused on climate change. A white paper on *Climate change effects on Assateague Island Morphology, Habitats, and Species* (Griswold et al. draft); as well as a new website, site bulletin and park brochure were produced to provide educational resources explaining climate impacts and natural processes for barrier beach islands by highlighting Assateague Island. http://www.teachoceanscience.net/teaching_resources/education_modules/barrier_islands_and_sea_level_rise/get_started/. The white paper and website should be shared among NER parks as examples of science communication.

A salt marsh restoration effort to fill mosquito ditches has been underway for several years. It is possible that restored marshes are more resilient to sea level rise, or that there are actions that can be done in conjunction with this effort to achieve that goal. Research into whether and how ditch filling affects resilience would be a tremendous opportunity to evaluate this as an adaptation strategy.

Research and Adaptation Needs

The Resource Management program has been effective at implementing a robust long term monitoring program which provides a baseline for studying climate change impacts and can inform future adaptation planning. While ocean side processes tend to be more dynamic and large changes can occur in a single event, bayside inundation due to SLR needs to be addressed as well. The tidal range is small, so salt marshes do not have a lot of elevation capital. Nutrient loading may limit marsh ability to keep pace vertically with SLR through organic matter accumulation, so inorganic sediment sources, including overwash deposits, are particularly important. Better understanding sources and impacts of watershed and local nutrient loading to marshes would support management options for increasing marsh resilience to SLR by reducing outside stressors. Additional studies on baseline conditions and expected changes in salt marshes, maritime forests and land subsidence are critical needs.

Salt water intrusion and changes in the depth of the water table and hydrology are likely to impact groundwater and ephemeral freshwater sources. This will impact sensitive habitats, such as freshwater wetlands, threatened species and the popular wild horses. There is a need to monitor groundwater levels and to develop adaptation strategies for responses to saltwater intrusion and a shallower water table. Depending on how actively the Seashore decides to manage vegetation shifts, there will be a need to research the effectiveness of management responses to impacts on salt intolerant vegetation, such as reducing browsing following overwash events in order to reduce additional stresses during recovery periods.

To date, much of the facilities adaptation focus has been on Assateague Island, since they are more immediately vulnerable. An important next step for longer term thinking is to assess the off island vulnerabilities, which will help identify where to focus investment as plans are made to move facilities off island. A breach management plan based upon the best available science that balances

the geomorphological, ecological and socio-economic impacts of breaching to maximize ecosystem benefits and barrier island resiliency has also been identified as a critical need.

Implementation Opportunities and Recommendations

In the Virginia district, the primary issue is the immediate vulnerability of the recreational beach and associated facilities. While adaptation actions there have prolonged the accessibility of beach facilities, long term sustainable solutions are being studied, including moving the access, parking and visitors center further north to a wider, less erosional part of the island. Options for such a move depend on Chincoteague NWR, where climate change is being considered in their planning process, but significant public pressure to keep the access in the same location is being received.

Also in the Virginia district, the Sheepshead Creek bridge is currently impacted by sea level rise, requiring significant rehabilitation because the underside is now inundated regularly, and the salt water is degrading the materials. Efforts to rebuild at a higher elevation would require redesign of the larger causeway and funding was not secured to accomplish this, so a short term patch is being done instead.

In Maryland, due to the impacts associated with Hurricane Sandy, ASIS is planning to relocate the Bayside Peninsula parking area and the South Ocean Beach parking area to more stable island locations. The surface of each new parking area will also be converted from asphalt to a more sustainable clay/clam shell base, similar to the design of the Virginia parking areas. Long term planning also needs to address the vulnerability of the Maryland district access bridge which is owned by the State of Maryland. ASIS is including alternative transportation options within the GMP, including ferry access and new visitor access points in the event that bridge access will be lost.

Boston Harbor Islands National Recreation Area (BOHA)

Sea level rise and potential changes in storm frequency or intensity are the primary climate change threats for Boston Harbor Islands. Seawalls and other coastal engineering structures with a range of ages going back to the late 1800's will present adaptation challenges related to their ability to continue to protect cultural resources and infrastructure from storms and how they impact surrounding natural resources and sediment budget through erosion.

Accomplishments and Ongoing Activities

The Boston Harbor Islands Partnership coordinates management of the park including NPS, city, state and non-profit partners. To date, NPS has been the climate change lead of the partnership, such as by becoming a Climate Friendly Park (an NPS program to help parks measure park-based greenhouse gas emissions, develop strategies to reduce them and educate the public about these efforts), with an Action Plan adopted in 2010, though implementation has been intermittent. If BOHA takes the lead on climate adaptation, the other partners would likely be supportive. Some of the BOHA islands are demonstration sites for sustainability and "green" technology. Spectacle Island, a former landfill which was capped with fill from tunnel construction in Boston, now serves as an interpretive model of sustainability, with a "green" visitor center, solar panels and composting toilets. Boston's municipal wastewater treatment on Deer Island models a variety of renewable

energy and energy efficiency measures; in addition the 1989 design planned for 1.9 feet of SLR by 2050.

BOHA has begun developing a Resource Stewardship Strategy (RSS), which has a 10-20 year horizon. Identification of desired future conditions and the strategies to achieve them should include consideration of climate change. Guidance on how to integrate climate change into planning processes including a RSS is in development by the NPS Climate Change Response Program.

A marsh sedimentation study will help identify which salt marshes have greater capacity to keep up with SLR and which may need to migrate upland where possible (principal investigators Drs. FitzGerald and Hughes, Boston University). These results combined with the sediment elevation tables (SET) through the Inventory and Monitoring Network could be used to identify vulnerable marsh areas.

During the summer of 2012, BOHA hosted a George Melendez Wright Climate Change Intern who developed a Grade 6 curriculum on Weather, Water and Warming to integrate BOHA into the Boston Public Schools curriculum. This should be part of the NER climate communication compilation as an example of curriculum development.

BOHA has been collecting data on replicate tagged plants from several species as part of the regional and national phenology monitoring protocols since 2009. The long term monitoring projects through the Inventory and Monitoring Program will yield important information on the impacts of climate change on park resources, including coastal breeding birds and rocky intertidal communities.

Research and Adaptation Needs

BOHA is concerned about failing historic seawalls and the cultural and natural resources behind them at multiple locations around the park, with the highest priority at Fort Warren on Georges Island. At Fort Warren, erosion has been occurring around and behind sections of failing seawall. There may be an opportunity to share experiences with other managers of coastal forts throughout NPS who are addressing similar challenges. Many other seawalls that were originally built to protect structures no longer protect the same structures on those islands, instead protecting natural resources and cultural landscapes and facilities of varying importance and levels of active management. Prior to major work on the seawalls, a study to understand which provide a benefit, a detriment or have no effect on shoreline protection of other areas should be done. The Nordstrom and Jackson study on removing barriers to shoreline migration (see Regional section) has identified the opportunity to repurpose quarry stone between where shoreline protection structures are interfering with habitat migration on some islands and could be removed and reused to reinforce seawalls protecting cultural resources on other islands, with the added benefit of historic compatibility of materials.

Maintaining a sediment budget is a concern for non-armored shorelines. In areas with erosion concerns, resources at risk include cultural resources (buildings, ruins, known and unknown Native American sites, cemeteries), bird nesting areas, and locations with rare plant species. The most urgent erosion related resource issue at BOHA is the threat to the cemeteries. Erosion of drumlin bluffs is an important part of the harbor's sediment budget, but there are concerns about loss of

resources and facilities if these processes accelerate, and no planning has yet occurred to guide responses when structures are threatened. On Peddocks Island, the process of rehabilitating some Fort Andrews buildings and removing others determined to be safety hazards has been in process, without including flooding risk in the criteria. The chapel is slated for rehabilitation, even though it is located close to the water. Before future restoration goes forward, potential increases in flooding risk due to SLR should be included in prioritization and design. For priority buildings close to sea level, moving the building should be considered where possible.

A tern nesting area on Lovells Island was abandoned in 2008 following a 100% predation event, but in the past two years there has been a partial return to that location. A second former tern colony site on Rainsford Island has not been utilized for several years, possibly due to increasing tide and storm surge levels. A rare plant species (sea-beach dock) grows below the eroding bluff on Prince Head on Peddocks Island, but has apparently been extirpated from coastal locations on Grape and Bumpkin islands where it was seen as recently as 2002. Erosion of bluffs is a natural process which provides sediment to the system and habitat value for species which rely on disturbed or early successional habitats.

Figure 2. Lovells Island at Boston Harbor Islands NRA (photo courtesy of Andrew Neil).

Access and transportation are major issues for the park since the islands (almost the entire park area) are only accessible by boat. Changes in storm frequency or intensity may change seasonal operations, but the scientific uncertainty surrounding observed and projected changes to hurricanes has limited action on this issue. There is a need to study how marine transportation systems will be affected by climate change and incorporate those issues into long term planning.

Implementation Opportunities and Recommendations

The replacement pier for the George's Island ferry is being designed. The design should elevate the pier to account for SLR over the expected lifetime of the structure. As piers and docks require major maintenance or replacement, designs should be elevated to account for sea level rise.

Since climate adaptation is a nascent field, there is a need to test the efficacy of potential adaptation actions. The BOHA islands present an opportunity for experimental design with each island as a replicate (e.g. restoration design, invasive species treatments).

Cape Cod National Seashore (CACO)

Cape Cod is a dynamic environment and the park has a history of managing that change as part of the character of the seashore. While the primary climate change impact awareness is on how sea level rise affects salt marsh health and erosion rates for dune and bluff systems, the park understands that there will be a range of less clear impacts, such as on benthic species, water quality and cultural resources, that need to be prepared for too. There is strong research capacity, both in monitoring records and in staff interest, to develop the science necessary to inform adaptation actions.

Accomplishments and Ongoing Activities

The Atlantic Research Center (ARC), an NPS Research Learning Center, and the Cape Cod Ecosystem Monitoring program which preceded, but is currently integrated with, the Inventory and Monitoring Network, have long term data sets going back to the late 1990's. These data provide a baseline for studying climate change impacts and will be able to inform adaptation planning. Several longer term monitoring datasets initiated in the 1970's (multi-decadal pond water quality, forest composition monitoring, etc.) are available for analysis to determine if any climate trends have been observed to date. Data includes multi-decade forest monitoring, the longest SET record in northeast parks, and a coastal geomorphology record going back the Marindin study in the 1880's. There is a 12 year record of groundwater level which supports a detailed hydrology model, which does not explicitly model climate change impacts. Incorporating changing future precipitation patterns into this hydrology model would be valuable future project.

USGS did a coastal vulnerability assessment for CACO (one of four NER parks) by applying a Coastal Vulnerability Index based on geomorphology, regional coastal slope, rate of relative sea level rise, rate of shoreline change, mean tidal range and mean wave height (Hammar-Klose et al. 2003).

In 2010 CACO held a Climate Friendly Parks workshop and subsequently developed an Action Plan. While primarily focused on providing strategies for greenhouse gas emission reduction, adaptation actions including repair and maintenance, reconstruction/strengthening, relocation, abandonment and improve redundancy were highlighted as important management recommendations. CACO

developed a public presentation which focused on impacts in the Northeast, salt marsh vegetation change, salt marsh elevation change, changes in kettle ponds and coastal change due to storms and flooding. Since then, this presentation has been adapted to include climate change information and discussion in a variety of public, science and stakeholder meetings.

In 2010-2011, Cape Cod National Seashore participated in the Interagency Transportation, Land Use, and Climate Change Pilot project which used scenario planning to develop a regional development strategy that would reduce greenhouse gas emissions and consider SLR impacts (Volpe, 2012). Mitigation and adaptation were treated separately, and it was found that the modeling in the study was better suited to the scale of mitigation scenarios, but that there were trade-offs between the recommendations for each that it was important to discuss.

At Herring Cove Beach, a bathhouse was replaced and was moved landward and designed in a way that it could be moved should erosion accelerate. While the replacement bathhouse was being designed, rapid erosion of the macadam in front of the old bathhouse and of the north parking lot escalated planning needs. Temporary measures were put in place while a public planning process was begun. This planning process included climate change considerations and an opportunity to choose an alternative that will be adaptive. The alternative recommended by the Advisory Committee in response to the erosion of the parking lot and macadam at Herring Cove Beach anticipates sea level rise that is expected to accelerate, yet additional adaptive management options may be necessary in the long term. There is a need to build on the understanding and monitoring of erosion, to understand how erosion rates and patterns are responding to accelerated sea level rise. The main parking lot in that location will be vulnerable in the long term and it is recommended that alternatives for it be developed well in advance of erosion impacting it.

Multiple salt marsh restoration projects (e.g. East Harbor, Hatches Harbor) have been done at CACO, primarily by increasing tidal exchange at tidal restrictions. These projects are thought to confer resilience, but require additional research and monitoring in order to develop metrics which could measure the expected resilience to sea level rise. The Herring River Estuary restoration currently being planned is explicitly taking SLR into account for planning, monitoring and an adaptive management plan. Modeling of anticipated water levels included three mid-century scenarios of low, medium and high rates of sea level rise with values based on US Army Corps of Engineers guidance. The adaptive management methods from this project will be a model for restoration projects throughout the NER. It is recommended that metrics of resilience be developed for inclusion in the monitoring plan to evaluate the actual benefits of the restoration as climate change adaptation.

A Department of Energy Atmospheric Radiation Measurement study in North Truro, the Two Column Aerosol Project, is an ongoing study begun in 2012 with both a portable observatory and research aircraft to better understand the warming and cooling effects of clouds and aerosols. The results of this study will help improve global climate model parameterizations as well as support outreach activities including curriculum development.

Research and Adaptation Needs

CACO needs to build on its history of adapting to the dynamic environment of the Seashore as a basis for adapting to additional climate change driven variability and change. Following the loss of the parking lot at Coast Guard Beach in Eastham during the Blizzard of ’78, the replacement parking lot was built ¾ mile inland with a shuttle to the beach. In 1996 Nauset Light was moved 300 feet landward from the eroding bluff it sits on and Highland Light in Truro was moved 453 feet. Breaches in the barrier beach in Chatham in 1987 and 2007 impacted bay tides, currents and high water events. The erosion associated with inlet development led to the loss of seasonal beach cottages and the highly contested removal of others in advance of expected loss to avoid the potential damage debris can cause. Prior to the park formation, seasonal cottages have a history of relocation in response to change. Building on this history of adaptation to the dynamic environment, CACO needs to communicate future adaptation in the context of past responses. Past responses to changes in the dynamic landscape, especially erosion, are opportunities to interpret the change and provide examples and lessons for what may be needed more in the future. The stories of the loss of the Outermost House, the loss to date at the Marconi Station site, moving the parking lot for Coast Guard Beach, moving Nauset and Highland Lights and removal of the seasonal cottages lay the foundation for planning for further change in the future.

Building on the public presentation and stakeholder processes to date, there is a strong public information need. In addition to developing interpretive displays and programs for visitors, methods to keep the local communities aware of climate change impacts and adaptation strategies will need to be sustained and supported. The relationship with neighboring communities, including with seasonal community members, is an important priority for the park due to its enabling legislation which established a model with a high degree of integration between the park and towns. One challenge for adaptation projects is the length of time required to develop a major project and turnover within local town government can result in the loss of project supporters before a project is finalized. In addition, there are governing mechanisms so that seasonal homeowners’ voices are heard in stakeholder processes. The park has worked to begin building public awareness of upcoming climate change impacts that will change the status quo, but support for a sustained effort will be needed.

For the restoration of the Herring River Estuary, there are a variety of additional monitoring needs to support the adaptive management plan, some of which are relevant to climate adaptation. These include water level monitoring for the impacted properties and upstream road crossings, stream gauge monitoring, sediment transport and response of vegetation and benthic communities to the restoration of tidal exchange and future salinity and tidal range. Funding for baseline data for some of these components has been committed, while others have been proposed, but it will require a committed monitoring program throughout the restoration to follow through on the adaptive management goals.

For the East Harbor, an initial restoration in 2002 has restored some of the hydraulic connection, but a more extensive restoration effort is needed to fully restore tidal exchange. The estuary is more likely to be resilient to climate change with full tidal exchange, but that system may need to be more actively managed under future flooding and sea level. The more visible climate change threat in this

area is to the beachfront side of East Harbor, where the Truro cottages, road and underground utility right-of-way are threatened by erosion, which will be exacerbated by higher sea level. An initial study is underway by the Woods Hole Group for the town of Truro of culvert opening and exchange flow needs, including the management options being considered by the town for the aging culvert and pipe, beach and adjacent road.

Water quality in the kettle ponds (freshwater ponds created by retreating glaciers) may be affected by changes in both surface water and groundwater hydrology and changes in seasonal stratification. The aquatic organisms that depend on the kettle ponds may shift their range or be negatively impacted. The ponds are highly acidic, but there is strong evidence that suggests they are naturally acidic (Winkler, 1988). There is a 35 year monitoring program for the kettle ponds, which include nutrients, dissolved oxygen, temperature and pH at the deepest point. A 2009 NCBN resource brief describes climate change impacts in kettle ponds (NCBN, 2009). This record of change to date is an important baseline for monitoring and interpreting change as well as for developing management strategies to adapt. As temperature changes impact suitability of kettle ponds for key species, managing nutrients and pH are options to reduce other stressors. A citizen science based phenology program monitors ice cover on ponds, as well as maritime dune shrubs, red wing blackbird activity, red cedar, white oak, and salt marsh vegetation (Buchanan and Tyrrell, 2011).

Erosion of the bluffs at the Marconi Station (platform of site of first transatlantic wireless communication) is a natural process, progressively impacting additional parts of the site. While SLR could slightly accelerate the process, the important question for management response is what is the rate of erosion, rather than how much is SLR is accelerating erosion. There are currently remnants for two of the original pillars, which will at some point be eroded as well. Given the erosion, the trail and visitor display building will need to be moved as the bluff edge moves. The visitor display is dated and plans for updating the display are under discussion. A great addition to the display would be to indicate previous bluff locations and explain how the rate of erosion has changed and that it could accelerate in the future. Interpreting historical coastal processes in conjunction with projections of future climate change are both a challenge and an opportunity; the climate change component is highly uncertain, but CACO has a history of responding to uncertain, episodic events that can guide adaptation strategies.

In another bluff in Wellfleet, an ancient shell midden of unknown age has been exposed through erosion and is now being evaluated and documented through a study of endangered archeological sites by Public Archeology Lab Inc. A report will be released, followed by a monitoring strategy for continued park documentation of the resource as erosion continues. This strategy can be a model for other types of archeological resources affected by erosion, such as shipwrecks.

There is a need for seabed and shallow water habitat mapping, especially as a baseline (Hart et al. 2010); projects by the Provincetown Center for Coastal Studies have begun to fill some gaps, and there is the opportunity to pursue funding for more complete baseline coverage. Baseline habitat maps would allow assessment of climate impacts if habitats change in response to warming waters or climate driven changes in sediment and nutrient inputs. We need to know where critical spawning habitat is for climate sensitive species in order to work with partners across jurisdictions. Changing

light and CO2 availability, as well as salinity and nutrients may impact submerged aquatic vegetation (SAV) (Short and Neckles, 1999). An additional benefit of nearshore bathymetric mapping is supporting hydrodynamic and geomorphic inundation modeling.

Implementation Opportunities and Recommendations

One potential direction forward is to identify climate change and sea level rise impacts on coastal erosion as one of several priority themes for the ARC. In doing so, the ARC could be identified as an NPS "hub" for coastal climate change science for Atlantic coastal parks. Research initiatives could include research related to the preservation of natural and cultural resources, and facilities design.

The methods developed for the Piping Plover study for ASIS could be transferrable to CACO. There is a similarly rich data record, as well as a need to understand localized impacts on Piping Plover habitat and associated conservation strategies. CACO is also an important roseate tern staging area, which may be an opportunity to test how these methods transfer to additional habitats and species with different, but related vulnerabilities.

CACO initiated a salt marsh vulnerability assessment in FY2013 that is looking at sediment, elevation and vegetation relationships. It will examine vegetation community boundaries in the context of upland development/land use and determine the extent to which a combination of sediment characteristics and nutrient inputs influence zonation and marsh elevation capital. Additionally, high marsh species may be vulnerable to changes in freshwater delivery as climate change impacts precipitation intensity and drought. A Boston University student is studying the combination of these effects and crab herbivory on *S. patens* supported by a George Melendez Wright Climate Change Fellowship.

In some locations, stairs and other beach infrastructure need to be replaced annually, so there is an opportunity to develop alternate ways to construct or maintain stairs and other access points that are more resilient and less damaging to the bluffs. Similar issues exist for infrastructure (e.g. bridges, paths) along marshes, though they may not be replaced as frequently. Design considerations need to account for whether the key issues in a location are gradual or episodic erosion, sea level rise or storm exposure, or a combination of these issues.

The upcoming monitoring strategy for archeological resources will be a model for other coastal parks. There is a need for parks with erosion issues to proactively inventory archeological sites likely to be exposed, to establish monitoring strategies for them and to prepare for the budget needs in advance of exposure so a rapid response to document or move archeological resources as necessary is in place.

Colonial National Historical Park (COLO)

Key archeological sites at Jamestown Island need to be protected from flooding and inundation. There is both risk of event flooding due to storm surge, and periodic flooding on perigean spring tides as sea level rises, which may be more likely to flood from the marsh side. Protection of the Colonial Parkway from erosion is one of COLO’s most urgent climate relevant management priorities. While erosion of the bluffs is a natural process, sea level rise could be accelerating erosion

at the toe of the bluff, and changes in heavy precipitation events could be accelerating erosion at the bluff crest. Alternatives to shoreline hardening for sections of the Colonial Parkway were discussed, but currently any option that would affect historic characteristics, including relocating sections of the parkway, is considered contrary to the park's mission. While in the long term, protecting the parkway in this exact configuration is an expensive prospect, relocating any threatened section of the parkway would be considered an impairment by COLO management, requiring an Environmental Impact Statement. In some locations, relocation could require Congressional approval to expand the legislative boundary and agreement from the Navy to transfer additional land.

Accomplishments and Ongoing Activities

There are several sections of the Colonial Parkway where active erosion is a concern. The Environmental Assessment (EA) for additional shoreline hardening to address erosion in the Bellfield Straits section is in process. All alternatives, except the no action one, included shoreline hardening. Large sections of the coast along the parkway were included in this EA to prepare for expected future erosion. The Environmental Assessment was the template for multiple sections, but within each section there is room for adjustment. Construction of the initial section of this new hardening is expected to complete the first 800 linear feet of the four miles total under consideration in 2013.

The impacts from 2003 Hurricane Isabel to Jamestown Island and the collections housed there brought hazard risk and preparation to the forefront. NPS invested in a redesigned collections building and developed a plan for moving the collection ahead of a large storm. Future considerations for protecting the NPS collection include moving it off the island. Preservation Virginia, which co-manages Jamestown Island and owns the site of the original settlement, is an important partner to involve in adaptation planning for the collection.

The demonstration glass blowing building was flooded during Hurricane Isabel. At the time, the exterior walls of the building were removed according to seasonal practices. An adaptation practice that was learned from that experience was to remove the walls ahead of a storm. The Eastern National concession housed in the building now evacuates and clears all stock in advance of a major storm. In 2011, Hurricane Irene was less severe than Isabel, which was accompanied by large storm surge, but still resulted in significant resource impacts due to waves and flooded the original Glasshouse stone kiln site and exhibit.

An inventory of coastal engineering projects identified 153 structures in or immediately adjacent to COLO, stabilizing 39% of the shoreline (Dallas et al. 2013a). As part of a larger NER study to identify locations where barriers to landform migration could potentially be removed as a sea level rise adaptation strategy, candidates sites at COLO focused on locations where no cultural resources or infrastructure could be impacted (see Regional section and Nordstrom and Jackson, 2013). These projects highlight a history of building hard shoreline protection structures, for which the protective value is not always clear.

Research and Adaptation Needs

Adaptation for archeological sites is an emerging field and Jamestown Island is a priority site for researching adaptation options. Jamestown is susceptible to flooding from immediately seaward, from the marsh behind and from groundwater changes from below. A seawall was built by the USACE in 1907, was patched after Hurricane Irene and exhibits some current weaknesses. This wall does not extend to the Newtown section of the island, where the next section of shoreline is lined with riprap, with evidence of erosion due to overtopping where it meets the lawn.

Sea level rise is likely to affect the water table with associated impacts on below ground archeological resources. The Glasshouse stone kiln ruins are of particular concern, since damaging salt deposits due to wicking of groundwater have already required changes in the glass enclosure and heating practices at the site. A higher water table, a fluctuating water table and saltwater intrusion all can impact archeological resources. For the settlement site, groundwater should be monitored near areas that have not yet been excavated so that vulnerable sites can be excavated before changes in groundwater would affect their viability. There are a number of groundwater wells that remain in place from a previous study by investigators from the College of William and Mary. Research is needed into how sites will be preserved under future climate scenarios for potential of salt exposure, groundwater changes and inundation frequency. Planning, guidance and monitoring will then be needed by archeological site to prepare for determining which sites and under what conditions to move to a Phase II or Phase III response (standards of archeological survey and recovery).

The sandy beach adjacent to the Glasshouse has interpretive value to demonstrate that the kiln would have been built near a sand source for making glass. The benefits of keeping this a sandy beach should be incorporated into any shoreline protection measures. There is currently a small section of covered riprap, and there has been updrift dredge disposal, which may have acted as a sand source.

There is a need to evaluate the shoreline hardening for Jamestown Island and prioritize which archeological sites need additional protection, and what structures are blocking natural processes without conferring any protective value to cultural resources. Once the Nordstrom and Jackson study is completed, COLO may consider implementing recommended priority removal of unnecessary shoreline structures.

Another issue of concern for Jamestown Island is the bridges. During Hurricane Isabel the wooden road crossings were dislodged and floated into the adjacent marsh, moving a considerable distance. Storm preparedness measures to prevent repeat damage or future loss would be advisable. Erosion at the base of the bridge to Jamestown Island is a concern, as well as inundation and decay of the bulkhead on the marsh side. Designs to address these current impacts would benefit from including sea level rise and other climate adaptation considerations.

The erosion processes affecting bluffs adjacent to the Colonial Parkway are occurring both from wave undercutting from below and slumping from above. There is a need to understand the sediment processes on bluffs, how much of erosion is from above, and how much from below. Management options to address the slumping at the top of the bluff need to be developed. To date, some effort has been made to fill the slumps with large cobbles and fill. If the slumps are being exacerbated by

drainage problems, then it is possible the slumping will become a greater problem due to climate change depending on how local precipitation patterns are affected. It remains to be shown whether the erosion at the top of the bluff is a climate change concern. Sea level rise is likely contributing to increased erosion at the bottom of the bluff, but that erosion is also a natural process, providing sediment to the rest of the system. The hardened shoreline prevents this beneficial sediment from remaining in nearshore local system.

At College Creek, to address erosion at the base of the bridge, the park, with federal highway funding, will be extending the riprap at the base of the bridge. There is a concern about whether this will exacerbate erosion of the adjacent bluff. Above the bluff is an archeological site, so minimizing the bluff erosion rate is also a priority. There is a need to study the potential impacts of additional shoreline hardening as well as to understand the factors driving bluff erosion.

For the Yorktown unit, there is a need for information on the vulnerability of the earthworks to changes in precipitation extremes or freeze/thaw events, but this unit is thought to be of lower climate change vulnerability in general.

Implementation Opportunities and Recommendations

The historic significance of Jamestown Island presents a communication opportunity to tell the story of how climate change is impacting archeological resources and the difficult choices NPS will have to make about whether to protect resources in place.

Fire Island National Seashore (FIIS)

The work and needs described here are based on a January 2012 visit and discussions, prior to Hurricane Sandy, which impacted many of the resources discussed below. Climate adaptation has been a factor in the emergency response and recovery activities, but neither the impacts nor the response actions are addressed in this report.

The relationship with private property owners within the communities and the state and county parks affect what island-wide adaptation strategies are possible. Balancing the needs of NPS and the vitality of the communities presents challenges and opportunities to demonstrate adaptation strategies to communities outside protected areas. Currently, individual communities determine their need for beach nourishment and beach scraping projects, requiring approval by the Seashore and the state.

Accomplishments and Ongoing Activities

FIIS is in the process of updating its General Management Plan (GMP). The updated GMP will include an appendix on climate change trends and projections for the northeast coast.

The time frames that currently guide FIIS management include the 20 year horizon of the GMP, 50-60 years for new buildings and 150-275 year old historic buildings, which all are relevant to increasing impacts of climate change.

The Fire Island to Montauk Point Reformulation Plan (FIMP) is a USACE led project, in cooperation with NPS, other federal agencies and state agencies to evaluate and recommend protection solutions

to hurricane and storm damage in the study area, including FIIS. FIMP will account for climate change and adaptation in the recommended protection solutions.

FIIS is a Climate Friendly Park; the workshop was held in 2008 and an Action Plan was subsequently developed.

Extensive work has been done to understand the ocean side sediment dynamics (e.g. Hapke et al. 2010), and upcoming work will use that foundation to study how it is likely to be impacted by accelerated SLR and other climate impacts. USGS did a coastal vulnerability assessment for FIIS (as one of four NER parks), applying a Coastal Vulnerability Index based on geomorphology, regional coastal slope, rate of relative sea level rise, rate of shoreline change, mean tidal range and mean wave height (Pendleton et al. 2004b).

A pilot project at the beach west of Sailor's Haven Marina built an erosive berm from dredged sand at a gentle grade on a beach adjacent to an area with previous erosion due to the marina infrastructure disrupting sediment transport. The berm construction ended up with a larger volume and different slope than the design, so it was a demonstration of an erosive upland, more than a berm. The project is monitoring how the sediment moves through the system, to demonstrate how it can act as a feeder beach. This may be a model for other erosion spots adjacent to infrastructure that disrupts sediment transport.

Figure 3. Overwash at Fire Island National Seashore (NPS photo courtesy of Diane Abell).

Research and Adaptation Needs

There is an understanding that climate adaptation will require additional monitoring beyond what the Northeast Coastal Barrier Network Inventory and Monitoring program currently covers. Guidance on how to monitor habitat and vegetation change is needed. The maritime holly forest is of particular concern. This needs to be integrated with guidance on how to manage in the context of the large uncertainty of the associated natural resource responses.

Bayside erosion is of concern in areas where the sediment transport has been disrupted. The project at Sailor's Haven Marina is an erosion hotspot. Erosion on both sides of the marina is a problem, not just on the downdrift side. On the east side of Fire Island Pines, which is the boundary between the community and the park, where the bulkheads end, the beach is eroding extensively. The Burma Road that used to go east from this location, has been moved south twice and the previously buried electric and telephone cables that were located under the Burma Road had to be replaced. With continued erosion, there is an electric substation in the area that will become at risk.

The dock and gangway at Talisman have experienced repeated storm damage in the few years since it was built, specifically related to sedimentation near the dock which has affected its usability. Given the exposure in this location, alternative designs that include seasonal removal of exposed infrastructure should be considered.

Wastewater disposal for the private landowners within the communities is based on septic systems. The functioning of the septic system is a major criterion of whether a building can be rebuilt after storm damage. Climate change is likely to affect the groundwater system and subsequently the functioning of septic systems. NPS facilities, that include treatment of marina pump-out stations, also rely on septic systems. Providing pump-out stations is an important management strategy for minimizing water quality impacts, especially at Watch Hill. Research to better understand the nutrient loading due to the marina wastewater systems and the impacts to adjacent salt marshes is needed to build upon the USGS study of nitrogen loads in groundwater (Schubert et al. 2010). Research into wastewater treatment alternatives including greywater systems, or pumping and off island transfer for treatment should be considered.

Beach scraping (the transfer of sand from the beach to the primary dune) is currently ongoing in some of the communities, although research has shown that it is not effective at reducing erosion (Kratzmann and Hapke, 2012). Additional research and a communication strategy on the impacts of this practice in the context of SLR and alternatives should be considered.

A deer management plan is currently under development. Overgrazing by deer is currently a stressor on vegetation, particularly in the maritime holly forest. Adaptation strategies for this important habitat need to reduce non-climate stressors, such as overgrazing. Temperature increases could potentially increase the tick population and the spread of Lyme disease, which is an emerging, understudied, climate change human health concern. Research into this impact could be incorporated into the deer management plan.

Potential climate adaptation issues for the William Floyd Estate, a historic FIIS site off-island, include changes in invasive species management, especially how it impacts the cultural landscape, erosion at archeological sites and water quality concerns if flooding events in the ponds where DDE (a DDT byproduct) was historically dumped is washed into marshes and the bay. The marshes there are heavily ditched, with some ditch plugging.

Flooding is a concern for headquarters buildings in Patchogue, as well as the ferry terminal there. The relative vulnerability of different buildings should be considered in space allocation and location of building mechanical systems.

FIIS is concerned with climate adaptation at a landscape scale. For migratory species including the federally listed Piping Plover, what is happening to habitats outside the park can affect a species more than actions within the park. There is a need for connecting the monitoring and management programs, such as for habitat and vegetation shifts with conservation efforts all along the east coast. Park decisions need to be integrated with projects happening outside the park (e.g. do we invest heavily on protecting migratory species if other habitats are highly vulnerable in locations with minimal adaptive capacity?).

There is interest in support for climate change communication, for NPS talking points, for sharing of examples from other parks and guidance on developing localized information on projected climate impacts.

Implementation Opportunities and Recommendations

Concessions contracts can be for greater than ten years. As contracts come up for renewal, there are opportunities to incorporate adaptation strategies that impact the elevations of ferry terminals and marinas, wastewater treatment, shifting shoulder season usage and hurricane season impacts.

For parks with ferry systems, or ones that may need them in the future, there will be climate change impacts and adaptation opportunities that need to be studied. Given FIIS's dependence on ferry service, a study of the system may be a model for other parks.

Gateway National Recreation Area (GATE)

Sea level rise is a threat to Gateway's natural resources including beaches and salt marshes, especially where the urban environment and additional stressors limit any natural ability to migrate landward. Increasing frequency and duration of heat waves and extreme precipitation events will impact visitor experience, as well as affect infrastructure and sensitive species. The potential for climate change to increase storm intensity or frequency threatens GATE's cultural resources and recreational infrastructure. The vast number of structures at GATE presents a challenge of prioritization when there are many vulnerable structures of varying significance and condition. The work and needs described here are based on a September 2012 visit and discussions, prior to Hurricane Sandy, which impacted many of the resources discussed below. By necessity, the emergency response and recovery activities have accelerated the climate adaptation planning discussions, but with many needs, near term responses and funding exigencies lead park planning priorities. Hurricane Sandy significantly impacted GATE, including many of the areas where known

needs were highlighted prior to the storm. As planning around response and rebuilding progresses, climate adaptation will remain a component of the discussion.

Accomplishments and Ongoing Activities

GATE is in the process of revising its General Management Plan. Climate change and SLR are included as planning considerations common to all action alternatives; strategies encompass mitigation, adaptation, science and communication. In particular, addressing storm vulnerabilities has become integrated through all alternatives with the greater awareness brought by Hurricane Sandy impacts.

Erosion at Sandy Hook has historically been a concern in the area referred to as the Critical Zone. As part of addressing this, a sand slurry pipeline was built to pass sand back from an area of accretion to the Critical Zone. Tests of the system were never fully successful, and erosion in that area has not been an immediate concern since it was built, likely due to beach nourishment programs updrift for New Jersey beaches.

GATE is involved in the New York City Climate Change Adaptation Task Force, which is part of the larger PlaNYC, a sustainability plan for NYC in 2030 (Bloomberg, 2011). In particular, GATE has been involved in the Wastewater and Open Space workgroup. Another partnership between the City of New York and NPS that emerged from a recent joint planning effort between the NPS and NYC is the Jamaica Bay Science and Resilience Institute, which aims to establish a science research center focused on urban ecosystem restoration and resiliency.

GATE held the first NPS Climate Friendly Parks workshop in 2003 and subsequently developed a Framework for Local Action Planning with five strategies for reducing greenhouse gas emissions and increasing climate change awareness.

USGS did a coastal vulnerability assessment for GATE (one of four NER parks), applying a Coastal Vulnerability Index based on geomorphology, regional coastal slope, rate of relative sea level rise, rate of shoreline change, mean tidal range and mean wave height (Pendleton et al. 2005).

The first part of a multi-park research project to evaluate the potential for removing shore protection structures that are barriers to landform migration for NER coastal parks was completed for Sandy Hook (Nordstrom and Jackson, 2013). An inventory of coastal engineering projects in Gateway National Recreation Area identified 254 coastal structures within and adjacent to the park, as well as a history of beach nourishment and dredge projects (Dallas et al. 2013b). These two projects together could be a basis for prioritizing which shoreline protection structures to maintain, which to allow to deteriorate in place and which to test whether removal confers adaptation benefits.

A partnership with the USACE to restore salt marsh islands in Jamaica Bay is restoring degraded islands by adding dredged sediments to increase elevation and planting *Spartina*. While motivated to address salt marsh loss due to multiple stressors, including sea level rise, the restoration lessons learned and methods developed for adding elevation will be important ones as we consider more active management options for assisting salt marsh adaptation to accelerated sea level rise. In 2006 Elders East island was the first project, followed by Elders West. Yellow Bar was completed in 2012,

using lessons from the monitoring of the Elders islands to inform target elevations and planting techniques. In the fall of 2012, sediment was added to Black Wall and Rulers Bar without any plantings in an effort to study how marsh grasses would colonize without planting. The adjacent neighborhood of Broad Channel has concerns about the stability of the new sediment on the bars while unvegetated and a volunteer effort is being developed to do planting for some portions. New work is funded to begin in FY2014 to look at the restoration efforts in the context of elevation capital to incorporate the question of how SLR is expected to affect this restoration program and future efforts for Jamaica Bay adaptation.

Erosion at Plumb Beach is being addressed through a project that includes jetties, a breakwater and beach nourishment. The site is co-managed by the NPS and New York with the goal of protecting the adjacent Belt Parkway. This site will require long term active management to minimize the impacts of sustained and increasing erosion.

Research and Adaptation Needs

In general for all units, there is a need to assess condition, priority and vulnerability for historic structures and landscapes. In order to target maintenance or improvement investments, GATE needs to understand vulnerability so tradeoffs can be weighed between priority, vulnerability and opportunity for adaptation. The park has three tiers to categorize cultural resources, and including a climate change vulnerability component into this process would be one way to integrate climate adaptation into a variety of cultural resource planning. Given the immense number of resources at risk and that all current resources are focused on responses to immediate impacts, GATE needs support for developing a strategy for addressing the most significant impacts. This strategy would benefit from regional context on relative importance of resources beyond the park (e.g. Nike missile sites, bunkers, batteries).

One of the needs brought up by involvement in the mayor's Climate Adaptation Task force is how to include economic valuation of cultural resources and ecosystem services. The methods involved in estimating impacts and recovery needs highlighted the lack of information on estimating the value of a healthy marsh that could take decades to restore, or of irreplaceable historic assets. It was recommended that a workshop to bring together New York area experts in valuation and to develop a state of the science for these questions would be a meaningful way to quickly develop a foundation for this research need.

In order for the Fort Hancock area of Sandy Hook to adapt to climate change, historic structures will require significant attention, investment and difficult decisions. The officers' quarters and the road in front of them are particularly vulnerable to storms and erosion. GATE had pursued developing a partnership to rehabilitate the officers' quarters, but this effort was stalled. One building in the officers' row was rehabilitated, without considering that it is one of the more vulnerable to flooding and erosion. Further investment in these buildings should account for the risk of SLR and potential increased storm intensity. A Fort Hancock 21st Century Advisory Committee was recently formed to make recommendations on adaptive reuse of these buildings.

There are plans to expand the Fort Hancock ferry terminal, which are contingent on approval of mitigation projects for impacts to subtidal clam habitat. Since the updrift area is Coast Guard property with shoreline armoring, there are no opportunities to restore the sediment transport in this area. The chapel, a recently renovated historic structure is at risk from erosion and flooding. There was little consideration of the feasibility or benefits of moving the chapel to protect it from erosion prior to the renovation. The seawalls and bulkheads in the area near the ferry terminal and in front of the chapel are degraded and likely no longer serving their intended shore protection function. Plans for the ferry terminal upgrades include repairs and replacement of some of these structures. It is recommended that longer term alternatives that do not rely on further shoreline armoring, such as moving the chapel, be considered.

Erosion of the path at Horseshoe Cove at Sandy Hook, and exposure of previously buried debris indicate that restoration of backshore sediment transport would benefit this area. In addition, the culvert beneath the bridge to the path is partially collapsed into the creek bed. Whether this limits tidal exchange and sediment transport into the cove needs to be determined. The marsh inside the cove would be better able to keep up with SLR if tidal exchange was not restricted and if there was sufficient sediment supply to the marsh to maintain a healthy accretion rate.

Also at Sandy Hook, the ammunition bunkers south of Battery Mills no longer are attached to the shore due to erosion, and water enters them at high tide. The shoreline protection structures in the Kingman and Mills Battery area are in varying states of decay and no longer serving their previous function. It is likely in the medium term with accelerated sea level rise, disruption of the sediment transport system and continued erosion, both Kingman and Mills Batteries will be threatened by erosion. This is the area where the Nordstrom and Jackson (2013) study recommended removal of barriers to landform and habitat migration. There is a need for the park to prioritize which of the cultural resources are the top priorities to protect in the long term, what visitor access to those sites should be protected and to look for opportunities to remove structures that are detrimental to the ability of Spermaceti Cove to respond to SLR.

The Critical Zone at Sandy Hook will need to be monitored and an effective, sustainable solution to long term erosion will need to be developed to avoid breaches. The sand slurry pipeline included a spur to the bay side, in the Kingman Battery area. One option to address erosion in the Kingman-Mills area would be to combine removal of decaying shoreline protection structures and use the pipeline to add sand to the bayside system. Given the level of disruption of the bayside sediment transport system, sand additions without removing structures is unlikely to be a successful adaptation option.

As the northern tip of Sandy Hook accretes, it is encroaching on the shipping channel. The USACE dredges the shipping channel and in 2011-2012, the dredging extended directly onto the beach. This potentially impacted adjacent Piping Plover nesting as well as required beach closures for visitor safety issues. The impacts of this dredging on the bayside sediment transport and Piping Plover habitat need to be understood, and a determination needs to be made if it will require mitigation and what the options would be for that.

As the elevation capital project in Jamaica Bay gets started, there is an opportunity to study some of the basic questions about how restoration confers resilience to sea level rise, look at the long term prospects for salt marshes in Jamaica Bay and incorporate that into an adaptation plan. The other major adaptation strategy should be to address those of the numerous non-climate stressors on this system that can be minimized so that the system is best able to keep pace with SLR.

Figure 4. Big Egg Marsh Restoration at Gateway National Recreation Area (NPS photo courtesy of George Frame).

The Jacob Riis bathhouse is a valuable and vulnerable historic structure in a highly exposed location. Surf entered the first story during both Hurricanes Irene and Sandy. At high tide, the water reaches the promenade in front of it. This would be an excellent example to consider in a valuation workshop. As a large, brick structure, moving options are prohibitive. Its relationship with the associated cultural landscape is also important. Adaptation options include supplementing shore protection measure to protect it as long as possible, but eventually this may be an example of a highly valued cultural resource to document in advance of irreparable storm damage. NPS and GATE need to consider the limits on its medium term viability when deciding how to make the wisest investments in repairs and stabilization.

In the Jamaica Bay Wildlife Refuge, West and East Ponds were created as freshwater ponds, which continue to be managed for bird habitat. Breaching of West Pond during a storm was a known vulnerability and both ponds breached during Hurricane Sandy. Whether to close the West Pond breach is an adaptation question at the intersection of natural resources, cultural resources and visitor experience. Natural resource policy would support leaving open the breach to return to a tidal pond and a switch from the artificial freshwater habitat values to saltwater habitat values. Yet, it could be argued that the history of the refuge and its recreational bird watching value justify closing the breach to maintain that historic use. In the medium term, there are multiple weak points along the pond and new breaches are likely to open.

Great Kills on Staten Island has critical erosional areas that will become even more vulnerable with sea level rise. These have been studied by Dr. Norbert Psuty of Rutgers and plans to address erosion should be done in the context of accelerated SLR and increasing risk.

Implementation Opportunities and Recommendations

At Sandy Hook, there may be mitigation opportunities for occasions when dredging actions by the USACE impact Piping Plover habitat. The Red Knot is a candidate species for Endangered Species protection, and currently forages in the vicinity of the Kingman and Mills Batteries. Adaptive restoration projects for Red Knot habitat could be a mitigation opportunity.

The creation of Floyd Bennett Field involved the fill of an extensive area of Jamaica Bay marsh. Developing a Wetlands Center focused around a large restoration and public education project at Floyd Bennett Field is under consideration. Much of the shoreline at Floyd Bennett Field is hardened, and portions of that shoreline are failing. Research could be initiated to determine where soft shoreline alternatives should be considered, especially in advance of any effort to repair the failing hard shoreline.

The Jamaica Bay Science and Resilience Institute will be an opportunity to take research at GATE to the forefront of the field of adaptation science.

Salem Maritime National Historic Site (SAMA)

For Salem Maritime, climate change is primarily a concern of how sea level rise and flooding risk will affect cultural resources. Preparing for sea level rise will help protect historic structures built at a time of lower sea level.

Accomplishments and Ongoing Activities

SAMA is becoming a Climate Friendly Park, with a workshop held in January 2013. At the time of SAIR's CFP workshop, adaptation was becoming more integrated into the program.

Two separate pilot processes for vulnerability assessments for cultural resources were initiated at SAMA in 2013: one for collections by the Northeast Museum Services Center and one for historic structures by the NER Environmental Management System workgroup.

One of the impacts of inundation of Derby Wharf is that the saturated ground around the dock for the *Friendship of Salem* dock has allowed shifting of the mooring bollards. This system is slated for

replacement in 2015, with a more robust design. Researchers Drs. Douglas Allen and Brad Hubeny at Salem State College have done some localized water level monitoring for Salem Harbor and in proximity to Derby Wharf, which will help inform the redesign of the mooring bollards. This includes collaboration with the Salem Sound Coast Watch, who also partner with SAMA on water quality projects.

In space allocation decisions, there are plans to move offices, collections and computer equipment that are at the basement level of buildings along Derby Street to upper floors of other buildings. While these buildings have not flooded in the past, their vulnerability has increased with sea level rise.

Research and Adaptation Needs

Sea level rise to date has increased the frequency of flooding on Derby Wharf as well as the extent of flooding along Derby Street during major storms. Parts of Derby Wharf, which is the oldest *in situ* cultural resource at SAMA, currently flood multiple times a year, including on the highest tides of the year (perigean spring tides), during large storms and when smaller storms coincide with spring tides. Damage resulting from the flooding includes erosion of gravel along the east side of the wharf, as receding flood waters wash the fill out through holes in the bulkheads. The rate of SLR is projected to accelerate in the future and it will be important to consider a range of possible SLR when addressing flooding concerns and the long term stabilization or adaptation of Derby Wharf.

Figure 5. Derby Wharf at Salem Maritime NHP at high tide (NPS photo courtesy of Amanda Babson).

Derby Wharf will need to be redesigned, reinforced, restored and parts may need to be rebuilt in the long term. In the near term, the erosion impacts of inundation need to be addressed; options include netting to capture the fill that gets washed away, or additional impervious surface. The area around the Light Station has been paved. If the wharf elevation is not addressed, the park will need to close the wharf to visitor access more frequently for visitor safety at times when it is likely to be inundated, with some inundation occurring on all high tides as sea level rises. For the *Friendship*, the redesign and replacement of the bollards is the only expected major investment necessary in the near term. It is possible that the floating docks will at some point need vertical extension of capping to avoid overtopping in the case of extreme storm surge.

Flooding of other resources, while not regular currently, occurs during major storm events. With accelerated sea level rise, buildings that have not previously experienced flooding will become more vulnerable. The buildings on the north side of Derby Street are being assessed for flood risk and necessary precautions should be implemented. The placement of the Pedrick Storehouse building in an area subject to flooding influenced how the space is used and heated; additional adaptation options will need to be considered in the future.

Increases in peak temperatures may affect historic materials and climate control considerations for collections. Additional information would be necessary to determine what the vulnerabilities and associated adaptation options would be.

Implementation Opportunities and Recommendations

A display to interpret the change in sea level since Derby Wharf was built would be an important communication opportunity (e.g. markers for mean high tide at the time the wharf was built, currently and for a range of projected SLR scenarios). Markers that have been developed at Golden Gate National Recreation Area could be a model design.

Saugus Iron Works National Historic Site (SAIR)

Climate change is likely to impact Saugus Iron Works due to its setting on a tidal river, through both sea level rise and changes in river hydrology due to changes in extreme precipitation events.

Accomplishments and Ongoing Activities

A major restoration of the Turning Basin and the southern wetlands along the Saugus River was done in 2007-2009. The joint purposes of the restoration were to restore the historic cultural scene of the turning basin to former open water habitat and to restore the degraded tidal wetland (Phragmites-dominated) to native tidal marsh and intertidal flats. A seven year post-restoration monitoring program is being extended at least into 2016, and provides a wealth of new baseline data from which to look at future adaptation monitoring (e.g. James-Pirri et al. 2010). Long term monitoring through the NETN can yield important information on the impacts of climate change on park resources including water quality and forest breeding birds.

SAIR is becoming a Climate Friendly Park, with a workshop held in January 2013. At the time of SAIR's CFP workshop, adaptation was becoming more integrated into the program.

A pilot vulnerability assessment process for collections was initiated at SAIR in 2013 by the Northeast Museum Services Center.

Research and Adaptation Needs

The vegetation succession and post-restoration sedimentation of the open water and mudflat condition of the Turning Basin and the downstream wetlands will present ongoing management questions, with climate adaptation implications. Invasive species are managed along the berm and in the riparian forest and wetlands on both river banks. As part of the restoration, a berm was constructed downstream of the bridge, to direct the river away from the turning basin and protect smelt spawning habitat above the turning basin. A 2012 egg survey indicated that the smelt continue to utilize the habitat within the park next to the berm, but have also begun utilizing the adjacent

upstream segment just north of the park boundary. The status of the smelt, whether they continue to spawn in this area, as well as how they will be impacted by climate change, is likely to affect management options for this berm. Post-restoration geomorphology monitoring shows that sediment has begun to fill in the turning basin again from the berm side, which could affect the cultural landscape as additional sediments and associated vegetation accumulate in the historically open water basin Over the long term, SLR and changes in the extent and timing of salinity will impact decisions about how actively to excavate sediments and manage invasive species.

Figure 6. Nekton sampling at Saugus Iron Works National Historic Site (photo courtesy of Andrew Neil).

The water quality in the Saugus River is impacted by combined sewer overflows (CSO), as well as what appear to be failing septic systems immediately abutting the park. A 2012 *coliform* bacteria survey of river water within the park indicated regular exceedance of swimming and even boating standards for public health. With increased heavy precipitation events in the future, the frequency of CSO events may increase. The park may want to work with the town to address both the CSOs and to get the abutting property owners to connect to the sewer system.

The slag pile, a key archeological feature of the original iron works, may be vulnerable to erosion with increased sea level rise. In addition to impacts on this primary landscape feature, any erosion would impact water quality by possibly releasing contaminants from the pile into the river and wetlands. Current management practices, which follow a state-issued Activity and Use Limitation for the hazardous site, include mowing and removing invasive species growing on the pile (no digging). Vulnerability to erosion with sea level rise should be studied and adaptation options considered.

Changes in river flow may affect the operation of the water wheels and pumphouse. Additional assessment would be necessary to determine likely impacts and adaptation options.

With high future sea level rise and increased high river flow events, the dock, wharf and small warehouse on the wharf may be impacted in the future. These facilities are not currently highly vulnerable because the mechanical equipment in the building is elevated, but options to prepare these facilities in advance of inundation events should be developed.

Implementation Opportunities and Recommendations

Enhancements are planned for the Nature Trail in the wooded area on the east bank of the Saugus River. Several low areas of the trail are subject to irregular inundation. Adjustments in the trail route or maintenance practices to minimize inundation and impacts when visitors avoid muddy sections would benefit from considering the higher likelihood of mid-term inundation due to sea level rise in combination with increased frequency of high flow events.

The parking lot is being redesigned to capture all of the runoff, with retention basins and other features designed to return precipitation to groundwater. In addition to the environmental benefits from this project, there is an opportunity to design the retention features to match projected future rainfall events, so that it will continue to fully capture all runoff for future conditions. The likely plantings to function in current conditions, once established, would also withstand future conditions, but that can also be an additional consideration.

The Saugus River Watershed Council received funding for adaptation planning and included SAIR as one of the project locations, for which they are currently scoping priorities on which to focus.

Regional (NER)

Regional scale efforts will be providing important foundational products to support climate adaptation in northeast coastal parks. The Monumentation project aims to estimate risk at specific locations in each of 10 northeastern coastal national parks (7 of those included in this report), by establishing an accurate elevation measurement at “sentinel” sites identified by each park and assessing the probability of inundation using the best available models (principal investigators Drs. Peter August and Charles LaBash, University of Rhode Island). The “backbone” of high accuracy geodetic control will serve as a base for future expansion enabling rapid and accurate elevation data collection for future adaptation needs.

As mentioned in the GATE, BOHA and COLO sections, a NER project to support an adaptation strategy of removing barriers to allow landforms and habitats to respond to sea level rise and storms will provide coastal parks with a strategy to guide managers in identifying structures that can be

removed in a cost effective manner, without jeopardizing significant cultural or natural resources or park infrastructure (principal investigators Drs. Karl Nordstrom, Rutgers and Nancy Jackson, NJIT).

The NER Inventory and Monitoring Networks have prioritized Vital Signs indicators of climate change, in particular they are monitoring tidal marsh surface elevation, through expanded coverage of Surface Elevation Tables (SET) read biannually in spring and fall (Stevens et al. 2010). These priorities focus on assessing the impact of sea level rise on tidal marsh capital as well as the status of salt marsh breeding birds.

Conclusion

There is a range of progress on and capacity for climate adaptation among coastal parks, but all parks have an awareness of some climate change vulnerabilities. By sharing experiences from some of the parks leading adaptation efforts, and by providing guidance on common management issues, the NER should be able to move forward more broadly. To date, coordination between climate adaptation projects throughout the NER has been limited. While many of the individual projects further the objectives of the NPS Climate Change Response Strategy (NPS, 2010) and the NER Climate Change Strategy and Action Plan (NPS, 2011), they have been chosen based on responding to park needs and opportunities, so are lacking consistency in methods and prioritization based on regional relative vulnerability or significance. By identifying common needs and having a plan to transfer results among parks, the NER can be more strategic and effective in adapting to climate change. There will be a balance between consistency and flexibility in NER and national NPS climate adaptation guidance and policies so we can best build capacity for individual parks to respond to the variety of climate impacts.

For natural resource managers, the common topics that were identified in many parks include changes in significant habitats caused by accelerated sea level rise (SLR) and increased erosion, landform migration, increases in invasive species following more frequent disturbance, range and phenology shifts in both terrestrial and marine species and changes in hydrology, including groundwater.

For both cultural resources and facilities impacts from SLR and flooding were common concerns for most parks. A need for information on resource risk and guidance on how to prioritize resource protection or investments both based on vulnerability and the importance of resources was common for multiple parks.

For Planning, incorporating climate adaptation into the General Management Plan (GMP) was common to those parks currently in the process of revising their GMP. For other parks, there was an interest in incorporating climate change adaptation in other planning efforts such as the Resource Stewardship Strategy or Shoreline Management Plan and there is the need for regional support and guidance for doing so. While parks expected Foundation Documents to be an upcoming planning need, there was not a clear understanding of what that would involve and how climate change would fit. Additionally, there is a need for support and guidance on incorporating climate change indicators into State of the Parks reports. When discussing the time frame for looking at climate change, there was a wide variety of horizons being considered, but many parks are planning for an annual to five year time frame, with twenty years being the common long term horizon. Given that, the end of century climate projections that are common in climate science and assessments are not meaningful to park planning. Guidance on how to inform medium term planning (20-50 years) should be a NER priority.

Common to all areas was the need for vulnerability assessments. The purpose of a vulnerability assessment is to identify which resources are most likely to be impacted and understand why. Vulnerability is commonly defined as the degree to which a system is susceptible to, and unable to

cope with, adverse effects of climate change, including climate variability and extremes (IPCC, 2007). Park managers have different expectations of what a vulnerability assessment can provide; in some cases a need to understand relative vulnerability across all resources was expressed, while in other cases a spatially explicit assessment for a particular resource is needed. The vulnerability assessments that have been completed and are underway in the region are primarily limited to a single natural resource or habitat, such as salt marshes or the Shenandoah Salamander. The NER should provide an overview of vulnerability assessment methods and approaches, including examples, guidance on scoping and resources to implement (Glick et al. 2011, Bintliff, 2011).

Assateague Island National Seashore and Cape Cod National Seashore have participated in different types of scenario planning workshops. Scenario planning is a method to explore the range of potential conditions that parks may experience and the possible consequences associated with management decisions under high uncertainty (NPS, 2013). Other parks were interested in scenario planning as an adaptation tool, but did not have a clear idea of its purpose, what it could provide and what is involved. The NPS guidebook *Using Scenarios to Explore Climate Change: A Handbook for Practitioners* (NPS, 2013) will be a useful basis for supporting interest in scenario planning. The NER should provide an overview of scenario planning methods and approaches, including examples, guidance on scoping and how it fits with vulnerability assessments and resources to implement.

Another common need was for projections of future conditions, particularly SLR, storm frequency and intensity and hydrology. The time frame of interest is for 20-50 years, whereas many climate model projections target end of century. The uncertainty for mid-century projections can sometimes lead to postponing action until projections are better constrained. Instead, we need to focus on preparing for a range of potential futures. An overview of available climate projections for this medium time frame and the uncertainty associated with it would be useful to all parks. The spatial scale of interest for projections was primarily at a local scale: SLR specific to the park unit or individual bays, stream flow for individual streams. Expectations about temperature projections did not need to be as localized, but they did need to be more resolved than annual averages (e.g. monthly averages and extreme events). For sea level rise, a NPS supported study starting in FY2013 aims to provide SLR and storm surge projections for all coastal NPS units using available models (principal investigator Dr. Maria Caffrey of University of Colorado). This will primarily be using simple inundation models and NOAA storm surge tools, which for some parks will be an important step forward, while other parks have run into the limitations of simple inundation models and are looking for dynamic models (Roman and Babson, 2013). Another new tool for simple inundation modeling is NOAA's Sea Level Rise Viewer which has been released for all of the northeast (http://www.csc.noaa.gov/digitalcoast/tools/slrviewer). As a basis for Foundation documents, NPS has funded analysis of historical and projected climate trends downscaled for each park to 800 m resolution for temperature and 8 km resolution for precipitation (principal investigators Drs. Patrick Gonzalez NPS and John Williams, University of Wisconsin, Madison). With additional support to build park capacity to use these resources, these projects can provide a wealth of information, including associated uncertainties. The NER should provide technical assistance to applying these tools to support park decisions and planning.

Four NER coastal parks have become Climate Friendly Parks (CFP) and have developed Action Plans or incorporated the actions into their Environmental Management Plan (a plan to track environmental compliance objectives), while several more have begun the process. The level of implementation of each plan varies widely among parks, depending on available resources and how park leadership prioritizes the actions. While CFP focuses on mitigation, building awareness of local climate change impacts is part of the program and understanding this is an important starting point for adaptation. CFP workshops in 2013 introduced climate adaptation more explicitly into the discussion, but fundamentally adaptation and mitigation require different actions and it is not recommended that the NER merge the two programs. Of all the climate work going on in parks, CFP has the most consistency, providing a clear structure, while giving parks the flexibility to decide how they want to move forward. When developing new adaptation efforts that are intended to be applicable to a broad range of parks, we can learn from CFP.

There is a wide range of climate communication strategies and needs within parks, whose reach could be expanded with some NER support. The NER should facilitate communication between parks on successful adaptation strategies, such as the designs for portable comfort station facilities and materials specifications for alternative parking lot surfaces at ASIS. A collection of stories about local climate impacts should be compiled and communicated to visitors and outside audiences, and lessons about useful resources and methods to develop these stories should be shared. This would include the phenology impacts at ACAD story developed for the George Mason University led study to engage meteorologists in climate science and CACO's public presentation built off of a CFP workshop. Interpreters at historical parks have been telling stories of the environmental conditions at the time of historic events, and how they have changed since then, such as sea level at Derby Wharf for SAMA; the NER should support being able to add a forward looking component to these stories by providing sound science so we can interpret future change and inform visitors about the changes adaptation will require.

The adaptation needs are greater than the current resources and capacity to address them; the improved understanding of the needs and opportunities outlined in this report can help the NER focus research and action over the next couple years. This should include:

- share results from work in progress
- build on successes
- leverage collaborations
- develop guidance to improve consistency while maintaining flexibility to be responsive to specific park issues
- develop a strategy for addressing the most significant resources
- build the foundation and future capacity to expand actions as we learn what is most effective

The work to date has been a combination of taking advantage of opportunities as they arise, reaction to current impacts, forward thinking leadership and innovation and regional priorities. All of these efforts should continue to be supported, but the NER should provide the long term and regional scale

strategic guidance so that progress is transferrable among parks and we have a clearer path from research to implementation.

In summary, the NER should provide the following support for coastal parks:

- An overview of vulnerability assessment methods and approaches, including examples, guidance on scoping and resources to implement
- An overview of scenario planning methods and approaches, including examples, guidance on scoping and how it fits with vulnerability assessments and resources to implement
- Technical assistance on applying climate projections and impacts tools to support park decisions and planning
- Guidance on how to inform medium term planning when most available climate projections focus on end of century
- Facilitate communication between parks on successful adaptation strategies

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Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

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