



Climate Change in Northeast Region Coastal Parks

Synthesis of a Workshop on Research and Monitoring Needs

Natural Resource Report NPS/NER/NRR—2013/697



ON THE COVER

Acadia National Park shoreline at Schoodic Peninsula
Photograph by: Charles Roman

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Natural Resource Report NPS/NER/NRR—2013/697

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Introduction

Climate change is impacting coastal habitats of northeast national park units and the processes and biota that govern the structure and function of those habitats. Key natural resources include barrier islands, rocky shores, estuaries, beaches, dunes, salt marshes, submerged aquatic vegetation, grasslands, forests, and freshwater wetlands. Climate change drivers include, among others, sea-level rise, increasing air and water temperature, and altered precipitation patterns, hydrology and storm patterns. Research and monitoring are needed to address the uncertainty associated with predicting the response of coastal ecosystems to climate change, and further, are essential to developing science-based adaptation strategies that may be necessary to maintain sustainable and resilient systems. A workshop was convened December 17-18, 2009, hosted by the University of Rhode Island Coastal Institute and the North Atlantic Coast Cooperative Ecosystem Studies Unit, with the following specific objectives;

- Identify natural resource research and modeling needs that will assist in refining our understanding of potential responses of natural resources and processes to climate change.
- Identify long-term monitoring needs aimed at documenting and understanding responses of natural resources to climate change.

The focus of the workshop was on the ten coastal national park units from Maine to Virginia (Fig. 1) with significant natural resources, but the identified research and monitoring needs are applicable to other coastal conservation areas, including National Wildlife Refuges. The workshop agenda and list of 30 participants from the National Park Service (NPS), US Geological Survey (USGS), US Fish and Wildlife Service (USFWS) and academic and conservation organization cooperators are provided in Appendix A. The workshop included introductory presentations on management policies and climate change; existing monitoring programs; and climate drivers for coastal ecosystems, followed by break-out group discussions. This Workshop Synthesis report is intended to present research and monitoring ideas that were developed in the workshop as research questions or study objectives, statements of research approaches and comments on adaptive management applications. The goal was not to develop exhaustive lists, but rather to identify some needs that are relevant to park natural resource managers. Research ideas provided or will provide the foundation for development of more detailed study proposals. Also included are some new monitoring measures that are specific to understanding climate change responses and are complementary to the already extensive monitoring that is ongoing at coastal national parks.

Although this Workshop Synthesis report is written about three years after the workshop, the workshop deliberations have served to inform a variety of programmatic and project developments in the interim and continue to be relevant. In the interval between the workshop and the report, the NPS has initiated a range of climate change research and monitoring actions that address some of the recommendations; these are noted throughout where appropriate. There is now a national NPS Climate Change Response Strategy and Action Plan, a NPS-Northeast Region Strategy and Action Plan, USGS has established a Northeast Climate Science Center, and the NPS-Northeast Region has a new position of Coastal Climate Adaptation Coordinator (Table 1). The Inventory and Monitoring Networks in the northeast (Northeast Coastal and Barrier Network and Northeast Temperate Network) have prepared a climate change monitoring strategy

and have implemented some elements of the strategy, including a new position for salt marsh elevation monitoring (Stevens et al. 2010). This workshop synthesis report and the recent accomplishments are all within the context of the Department of the Interior Secretarial Order No. 3289 issued in September, 2009. This Order calls for a Department-wide strategy to increase scientific understanding of the impacts of climate change and to develop effective adaptive management tools.

This Workshop Synthesis report is organized into five topic areas: Coastal Processes; Salt Marshes; Marine Ecosystems; Breeding Birds, Amphibians, Reptiles and Freshwater Habitats; and Migratory Species. Each of these sections includes recommended research and monitoring needs.

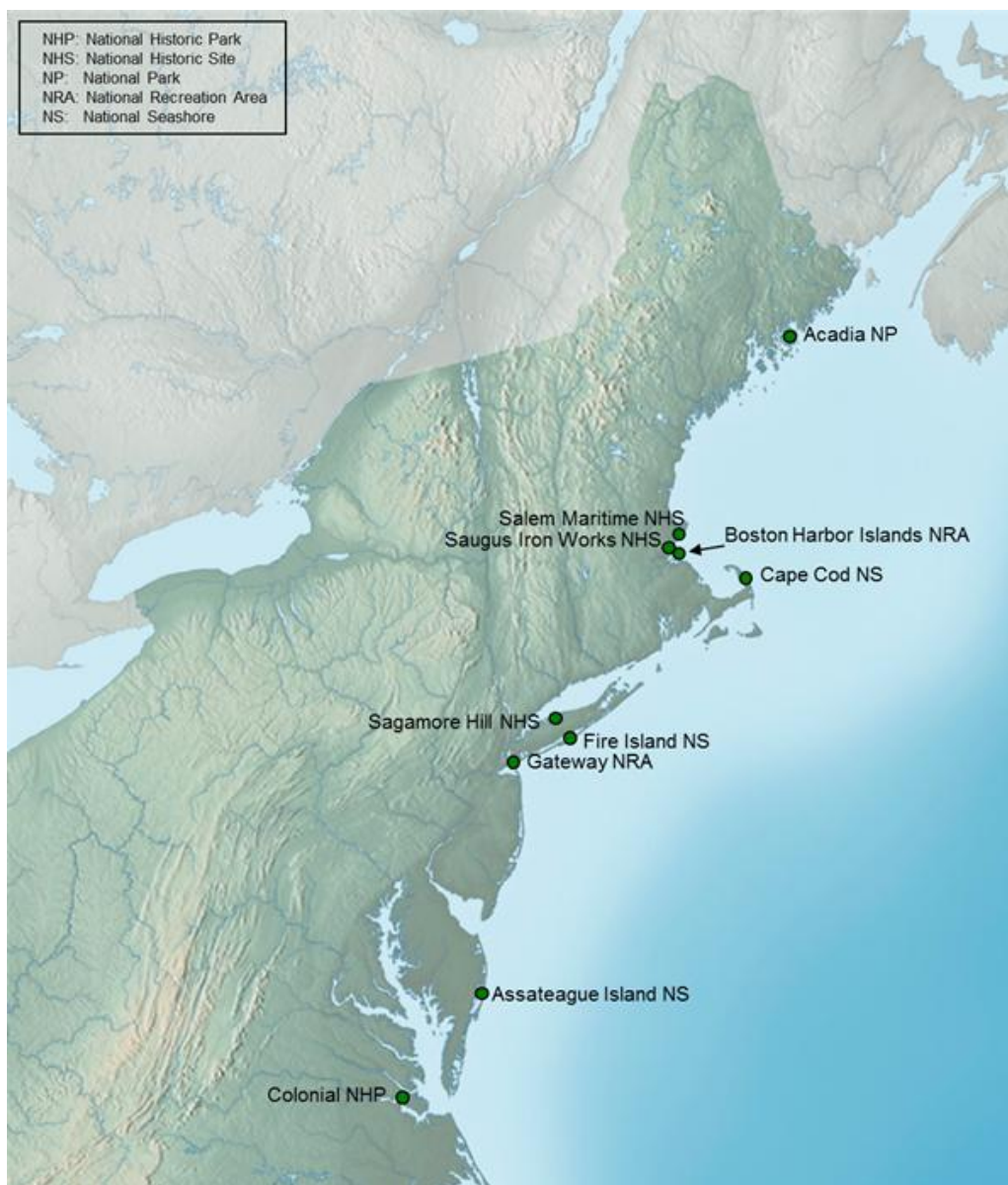


Figure 1. Map of coastal northeastern US, highlighting coastal parks from Maine to Virginia.

Table 1. Links to some relevant National Park Service and Department of the Interior documents on climate change strategies and policies.

NPS Climate Change Response Strategy	http://www.nature.nps.gov/climatechange/docs/NPS_CCRS.pdf
NPS Climate Change Action Plan 2012-2014	http://www.wilderness.net/toolboxes/documents/climate/2012_NPS-CCRPActionPlan.pdf
Northeast Region (NER) Climate Change Strategy and Action Plan for 2011-2014	http://classicinside.nps.gov/documents/20110610_NER_Climate_Change_Strategy_web.pdf (Not a public server)
Strategy for Enhanced Monitoring of Natural Resource Condition in North Atlantic Coastal Parks to Address the Effects of Rapid Climate Change	Stevens et al. 2010 https://irma.nps.gov/App/Reference/Profile/2166645
Department of the Interior Secretarial Order No. 3289 "Addressing the Impacts of Climate Change on America's Water, Land and Other Natural and Cultural Resources"	http://www.nps.gov/sustainability/documents/Quick-Links/SecOrder3289%5B1%5D.pdf
NPS guidance memo on applying management policies	http://www.nps.gov/policy/MPandCC.pdf

Coastal Processes and Geomorphological Development

Sea-level rise, storm surge, sediment supply, inundation, and other drivers significantly contribute to and influence the dynamism of the coastal landscape, altering natural habitats and threatening cultural resources and infrastructure (e.g., Psuty et al. 2005, Williams et al. 2009). Barrier islands and spits have the ability to migrate in response to sea-level rise (Leatherman 1979), but there is limited understanding of how to determine threshold rates of sea-level rise above which barrier islands would begin to lose their existing character and perhaps undergo irreversible change (Nicholls et al. 2007). Whereas there is an extensive literature on coastal processes associated with ocean shorelines, it is also important to understand physical processes and responses of coastal bluffs (e.g., Himmelstoss et al. 2006, Giese and Adams 2007) and the more protected shores of estuaries and back-barrier lagoons (e.g., Nordstrom and Jackson 2012).

Research Needs

Dynamic inundation modeling

To better understand the geomorphic response of beaches, dunes, barrier islands, bluffs and other coastal landforms to different scenarios of sea-level rise and storm intensities and frequencies, there is a need to develop a dynamic model that goes beyond simple inundation modeling. Such a model could be applied to parks individually as needed. Most efforts evaluating sea-level rise impacts in the northeast have been simple inundation models (often referred to as bathtub models), which do not account for sediment budget variation, sediment redistribution, and biological processes (e.g., McLeod et al. 2010, Murdukhayeva 2012). Dynamic models are specific to the local coastal processes, and require site specific data to develop and validate. Offshore bathymetry, offshore sediment dynamics and river sediment sources need to be included, as would response to storm events.

As with simple inundation models, the quality of the elevation data is an important factor; LiDAR is currently the best elevation data that is widely available. Some parks have complete and repeated coverage whereas other parks are looking to achieve base coverage. There needs to be additional guidance available for those parks without strong geospatial capacity to determine for which purposes LiDAR has sufficient accuracy and what return frequency is necessary for a dynamic model.

Managers would benefit from a dynamic model with a better understanding of the vectors of change that describe the evolution of the physical features, and to consider the potential impacts to natural and cultural resource risks, including impacts to facilities as well as potential locations of barrier island breaches and focused erosional areas.

A research approach was suggested to:

- a) Develop a conceptual model that will define the variables required in such a model (e.g., sediment budget, sediment source, wave climate, substrate type). Conceptual models eventually need to be site-specific. The dynamic model objective is to determine areas (under different sea-level rise and storm scenarios) likely to erode, accrete, be inundated, result in a changed landform, etc.
- b) Assemble required data sets and develop a dynamic and quantitative predictive model.

Several efforts are in progress that may be a foundation for filling this need. The USGS Northeast Climate Science Center funded, in 2012, a study to develop a framework for sea-level rise impact modeling for the U.S. Atlantic coast, distinguishing where dynamic models are essential, and using a habitat evolution model in locations where applicable (<http://necsc.umass.edu/projects/research-and-decision-support-framework-evaluate-sea-level-rise-impacts-northeastern-us>). This builds on Bayesian Network modeling of long term shoreline change (Gutierrez et al. 2011) which is being applied to Assateague Island National Seashore as part of a study of Piping Plover habitat. In addition, a NPS supported study starting in FY2013 aims to provide sea-level rise and storm surge projections for all coastal NPS units using available models, primarily using simple inundation models and NOAA storm surge tools (principal investigator Dr. Maria Caffrey of University of Colorado, Boulder).

Model changes in sediment budgets and couple geomorphic models with habitat responses

For some coastal parks, there has been extensive research to understand sediment budgets (e.g. Cape Cod National Seashore, Giese et al. 2011; Fire Island National Seashore, Hapke et al. 2010; Gateway National Recreation Area, Psuty and Pace 2008). The next step is to model how sea-level rise, changes in sediment budget, and changes in wave energy and storm intensity could alter the evolving geomorphology. For other units, there is a need to understand the current sediment budget before climate change impacts can be studied.

There is the opportunity to coordinate coastal landform modeling with salt marsh, coastal dune, and other habitat modeling; these dynamic features are interrelated. We need to better understand the systems as they currently function, but also consider scenarios where these features respond differently in the future due to climate change thresholds. Roman and Nordstrom (1988) evaluated the relationship between geomorphic evolution and barrier island vegetation and identified an erosion rate threshold that would result in a persistent overwash vegetation community at Assateague Island National Seashore. More sophisticated and site-specific models are required.

Human-caused barriers to landform migration

With sea-level rise and storms, barrier islands and salt marshes will often migrate landward and retain their structure and function, but shoreline stabilization structures can hamper natural sediment transport processes and landform migration (e.g., Nordstrom and Jackson, in press). To support an adaptation strategy of removing barriers to allow landforms/habitats to respond to sea-level rise and storms, there is a need to: 1) identify human-caused barriers to landform migration on barrier islands and other ecosystem types (e.g., dunes, beaches, marshes), 2) identify the current function of each structure in protecting cultural or natural resources, 3) identify opportunities to facilitate landform and habitat migration by removing or mitigating the structures, 4) prioritize structures that can be removed cost-effectively or abandoned without adverse impacts on required infrastructure, and 5) evaluate or predict the response of landforms and habitats to the structure removal. This information 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.

The NPS-Geologic Resources Division has initiated a study at select coastal parks (e.g., Colonial National Historical Park, Dallas et al. 2013; Gateway National Recreation Area, Dallas et al. in

press) to accomplish the first objective above (identify structures). The NPS-Northeast Region supported an ongoing study, beginning in 2010 to accomplish the remaining objectives (principal investigators, Drs. Karl Nordstrom and Nancy Jackson, Rutgers University and NJ Institute of Technology, respectively).

In addition to these ongoing reconnaissance and technical assessment projects, an accompanying research need would be to establish pilot or demonstration projects, on a small-scale to study the geomorphological response to structure removal that will allow landform migration to proceed.

Vulnerability assessments and scenario planning

Specific adaptation strategies will depend on local vulnerabilities and management options. In order to determine adaptation strategies, vulnerability assessments and scenario planning are tools to help identify priority resources. Where there are known vulnerabilities, there is a need to test management strategies to see how well they improve resilience or adaptive capacity. Among the decisions that scenario planning can help is the question of which cultural resources should we invest in and save. A variety of cultural resources were built on dynamic landforms and there will be an increasing need to identify those to protect in place, to move, or to document and limit future investment.

Monitoring Needs

Enhanced water level monitoring

The Inventory and Monitoring Program includes several Vital Signs important to the Coastal Processes Research Needs: Shoreline Position Change, 2D Coastal Topography and 3D Topography (Psuty et al. 2010, Psuty and Skidds 2012). An additional monitoring need is to improve tide gauge coverage. Long term tide gauges are essential to understanding local sea-level rise (e.g. for monitoring salt marsh response, supporting process models) and to support climate adaptation (e.g. a record of tidal exceedances at vulnerable park locations supports decisions to protect or relocate infrastructure). Many coastal Northeast Region parks rely on NOAA's National Water Level Observation Network (NWLON), but there are gaps in long term tide gauge coverage for part or all of some parks. The first step to address this need is to identify where tide gauge coverage is inadequate and develop a partnership with NOAA or other agencies to begin to fill the most important gaps. Needs may vary by location on the technology and quality control necessary to fill gaps, but some important questions to address include: What length of coverage at a local site is sufficient to then be able to extrapolate from NWLON gauges? How localized does sea-level rise information need to be to support monitoring and research? There is a need to move beyond the conventional siting based on NOAA's operational guidelines, to cover different ecosystems (e.g. salt marshes).

A first level assessment of gaps in NWLON gauge polygons for all coastal NPS units has been done by Thom Curdts of NPS's Water Resources Division based on methods from NOAA Technical Memorandum NOS CO_OPS 0048 (Gill and Fisher, 2008). NER parks lacking in coverage are: ASIS (Bay side), CACO (South half outer coast), COLO (small gap, West end of park) and FIIS (no coverage). This analysis does not include other gauges, such as the USGS gauge in western Great South Bay for FIIS. Whereas the NWLON analysis is an initial step which demonstrates gaps for datum determination purposes and relative sea-level trends, further analysis is necessary considering the range of uses for tide data.

Salt Marshes

Salt marshes are dynamic environments, increasing in elevation and migrating landward as sea-level rises (Redfield 1965). However, with predicted accelerated rates of sea-level rise the potential for loss of marsh area increases, with possible conversion of vegetated marsh to mudflat or open water (Orson et al. 1985, Stevenson and Kearney 2009). There is evidence that some northeast coastal marshes may be in early stages of submergence (e.g., Connecticut, Orson et al. 1998; Rhode Island, Donnelly and Bertness 2001), while in Jamaica Bay (Gateway National Recreation Area, NY) there is currently a rapid conversion of vegetated marsh to tidal flat or open water (Hartig et al. 2002). Throughout the northeast the NPS and other agencies maintain a network of Surface Elevation Tables (SET) and surface accretion horizon markers, a method designed to monitor marsh elevation in response to sea-level rise (Cahoon et al. 1999, Roman et al. 2007).

Some of the information needs identified for Coastal Processes are also relevant for Salt Marshes. These include; fill gaps in the tide gauge network, understand biotic impacts of geomorphological changes, inventory built barriers to marsh migration and better understand sediment budgets.

Research Needs

Determine marsh elevation capital

It is important to determine the elevation of the marsh surface relative to local sea level and to determine rates of elevation change. Are the marshes located high or low within the optimum growth range for marsh vegetation? If marshes are high in the growth range, they will have a greater or longer capacity for survival with accelerated rates of sea-level rise (i.e., high elevation capital; Cahoon and Guntenspergen 2010). Marshes low in the growth range, or with low elevation capital, are more readily susceptible to prolonged inundation. It is particularly important to determine marsh surface elevations and sea level in the vicinity of SET monitoring stations, but also on marsh platforms that may be remote from SET stations. It may be appropriate to consider adaptive management approaches for marshes with minimal elevation capital.

A suggested research approach is as follows:

- a) Using GPS-RTK, or survey methods of higher accuracy, determine elevation of SET benchmarks and the marsh surface in the vicinity of SET benchmarks at all NER coastal parks. This task was completed (in 2012) by the NPS Inventory and Monitoring Networks.
- b) As LiDAR technology improves for acquiring elevation in vegetated habitats (like marshes) or through systematic elevation surveys using ground-based methods (e.g., GPS-RTK or total station surveys), produce elevation contour maps for salt marshes in NER parks.
- c) Establish temporary tide gauges and relate marsh surface elevation to local sea level. Determine depth and frequency of flooding of the marsh and determine the growth range of *Spartina alterniflora* at each marsh site. This task has been accomplished by the Northeast Coastal and Barrier Network for several NER coastal parks.

- d) Produce maps identifying marsh areas along the continuum of high to low elevation capital, highlighting areas of low elevation capital and thus more susceptible to submergence.

Marsh areas identified as having low elevation capital may be the most appropriate for consideration of adaptation management approaches that would increase marsh surface elevation. Studies being conducted by the NPS, US Army Corps of Engineers and others are underway to evaluate restoration methods to restore elevation to the deteriorating Jamaica Bay marshes (Rafferty et al. 2010).

In 2013 Cape Cod National Seashore is initiating a study to evaluate the vulnerability of salt marshes to accelerated rates of sea level rise; this project will include extensive marsh elevation mapping.

Determine the maximum rate of sea-level rise that northeastern US salt marshes can tolerate

Based on an elaborate model, it has been suggested that salt marshes of the southeastern US can be sustained at a rate of sea-level rise not exceeding 1.2 cm/yr (Morris et al. 2002). These marshes generally have a high input of inorganic sediment from riverine inputs. It is expected that this rate will be quite different for the organic-rich peat-dominated marshes of the northeastern US. It is important to understand what this threshold rate may be for northeast marshes; a model applicable to northeastern salt marsh systems could be used to estimate this rate. This knowledge, coupled with the previously mentioned elevation capital assessment, will enable managers to better anticipate time-frames for when management actions may be necessary to sustain particular salt marshes.

Models of marsh response to climate drivers

Numerous processes, drivers, and complex interactions influence salt marsh vertical development in response to sea-level rise (Fig. 2; Cahoon et al. 2009). Using this conceptual model as a guide, it would be useful to develop new conceptual models that are specific to the varying settings of salt marshes within the northeast region (e.g., high and low tidal range systems, back-barrier or lagoonal marshes, drowned river valley marshes, fringing marshes, extensive marshes, pocket marshes, human-impacted vs less impacted marshes). Conceptual models will assist in understanding the response of marshes to climate drivers (e.g., sea-level rise, storms, temperature, freshwater flow, altered hydrology, salinity, increased CO₂, species shifts, etc.) and interacting environmental drivers (e.g., nutrient inputs, contaminants), providing a more comprehensive basis toward identifying priority needs for a predictive or numerical model. Separate conceptual models should be developed for each coastal park or for similar groups of parks in an effort to understand the future survival of salt marshes in response to various scenarios of sea-level rise.

Environmental Drivers & Biogeomorphic Process Controls on Vertical Wetland Development

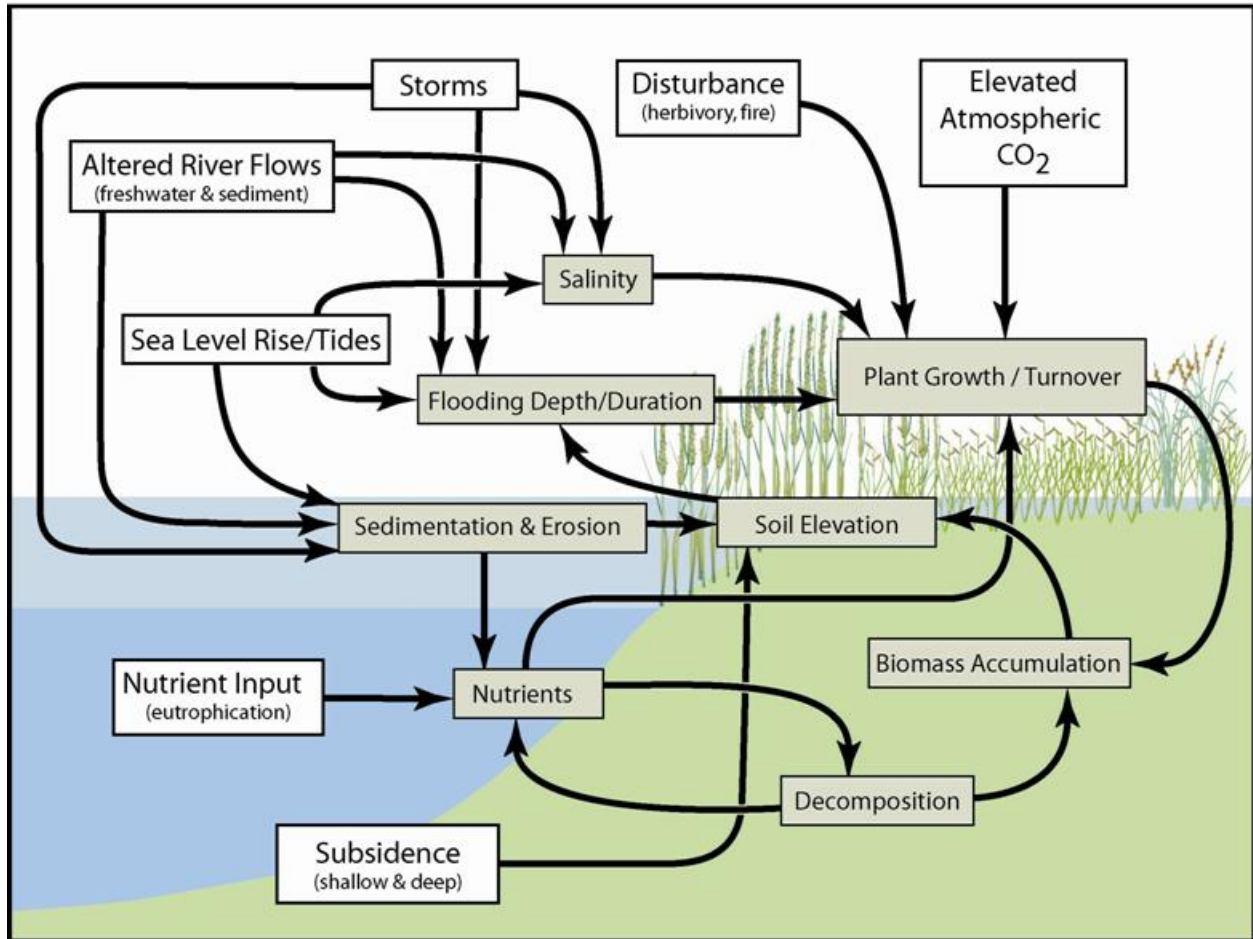


Figure 2. Conceptual model of processes that influence marsh vertical development (reprinted from Cahoon et al. 2009).

Models of salt marsh response to sea-level rise need to include both processes that control vertical persistence and the potential for landward/upslope migration. A study that investigated the potential for landward migration of salt marshes in and around Acadia National Park delineated where there was significant upland area available, as well as identified barriers to marsh migration (Nielsen and Dudley 2013).

An existing and widely applied model option is SLAMM (Sea Level Affecting Marshes Model; Craft et al. 2009). SLAMMv.5 may be useful in identifying potential migration trajectories for some systems, though more sophisticated process-driven models with dynamic feedbacks are being considered (e.g., Kirwan et al. 2010). Improvements to SLAMM are being developed in version 6. The NPS should consider application of the revised SLAMM, as well as collaboration with those developing new numerical models. The NPS, with ongoing monitoring of marsh surface elevation change and accretion dynamics, can contribute excellent data sets to model

development and verification. An example of SLAMM being applied in parks is Murdukhayeva (2012), for Assateague Island and Cape Cod National Seashores.

To support model development, it is important to determine the sediment budget. It is recommended that three components be considered: establish a sediment budget; determine the sediment load from terrestrial and marine sources; and determine the relative importance of organic matter versus mineral sediments. Research is ongoing within the Jamaica Bay estuary to better understand sedimentation processes in relation to salt marsh elevation dynamics and response to sea-level rise (e.g., Renfro et al. 2010).

Salt marsh ditches and marsh elevation dynamics

It is important to understand the role of the extensive mosquito-control ditch network on marsh development and the response of marsh elevation and accretion dynamics to proposed ditch restoration methods, including ditch filling or ditch plugging. The feasibility of filling ditches at Fire Island National Seashore was evaluated with the conclusion that ditch filling may be appropriate (pending extensive pilot studies), but that some ditches may be required to serve a marsh drainage function (Corman et al. 2012). Active ditch filling, accompanied by long-term monitoring, is ongoing at Assateague Island National Seashore.

Framework to prioritize sites for restoration/adaptation

The above research, including determination of elevation capital, sea-level rise thresholds for northeast marshes, sediment budgets, and inundation or dynamic modeling should be used to identify sites that are vulnerable to sea-level rise and other stressors and guide investment in design and implementation of appropriate adaptation strategies.

Monitoring Needs

Monitor indicator species – System engineers

The Northeast Coastal and Barrier and Northeast Temperate Networks currently monitor salt marsh elevation dynamics, as well as vegetation, nekton, and marsh bird community dynamics (e.g., James-Pirri et al. 2012). These data are useful in understanding responses to climate change drivers. Changes in species composition and abundance can be documented over-time.

However, this community monitoring could be supplemented by focusing on key salt marsh ecosystem engineers – those species that may serve an important role in maintaining resilience of the marsh ecosystem under regimes of accelerated sea-level rise or temperature and precipitation changes. Species to consider may include *Spartina alterniflora* (particularly above and belowground biomass), the ribbed mussel (*Geukensia demissa*) and marsh crabs (e.g., fiddler crabs, *Uca*; marsh crab, *Sesarma*; non-native green crab, *Carcinus*; Holdredge et al. 2008).

Marine Ecosystems

Marine ecosystems, both nearshore ocean and bay environments, represent a major stewardship responsibility for coastal park managers. Marine habitats represent a significant 70% of total park area at Fire Island National Seashore, 66% at Assateague Island National Seashore, and 38% at Cape Cod National Seashore. Climate change is expected to alter fundamental characteristics of the marine environment including, temperature, currents, sea-level rise, swell and storms, hypoxia and ocean acidification, among other factors (Doney et al. 2012). Consequences of these changes on marine systems are complex, but will likely include; species range changes (e.g., Oviatt 2004, Helmuth et al. 2006, Findlay et al. 2010), exotic and nuisance species introductions (e.g., Harris and Tyrrell 2001, Stachowicz et al. 2002), altered rates of nutrient cycling (e.g., Townsend et al. 2010), hypoxia (e.g., Rabalais et al. 2009), disease (e.g., Ford 1996), and altered productivity (e.g., Muren et al. 2005, Helmuth et al. 2006, Nye 2010, Short and Neckles 1999).

Research Needs

Inventory marine habitats to quantify future changes

The most fundamental of natural resource inventories are often minimal or nonexistent for the marine portions of coastal parks (Hart et al., 2013). The Northeast Coastal and Barrier Network implements the estuarine nutrient enrichment protocol, monitoring water quality and seagrass habitat parameters (Kopp and Neckles, 2009), but many gaps remain, especially with regard to knowledge of marine habitat distribution and associated biota.

Basic information needs are as follows;

Habitat Maps – Within the estuarine and ocean boundaries of coastal parks, habitat maps are required that depict, among other layers, bathymetry, surface sediment type, and biotic features (e.g., seagrass, shellfish beds, algal beds). The Coastal and Marine Ecological Classification Standard (CMECS), the classification system required by the Federal Geographic Data Committee, should be used. The NER recently convened a workshop to evaluate state-of-the-art technologies for mapping in shallow and often turbid waters that are common to coastal parks (Hart et al. 2010) and conducted a pilot shallow water habitat mapping project at Fire Island National Seashore's Great South Bay (Shumchenia and King 2010). Assateague Island National Seashore has collaborated with the Maryland Geological Survey to map sediments throughout Sinepuxent and Chincoteague Bays. Cape Cod National Seashore, in cooperation with the Provincetown Center for Coastal Studies, is engaged in nearshore sediment mapping to better understand ocean shoreline sediment dynamics.

Inventory Biotic Species Composition and Abundance – Quantify the species composition and abundance of the benthic, fish (resident and migratory) and crustacean (crabs, shrimp, lobster), seagrass, and macroalgal communities. Much of this kind of baseline inventory will be required as the ground-truth phase to the habitat mapping.

Marine species tolerance to climate drivers

Environmental tolerance levels should be established for key species or invasive species, including northern and southern limits, and the variables (e.g. temperature, salinity and light) that determine those limits. This kind of information is essential to understanding how marine

environments are responding to climate change drivers and to developing scientifically-informed adaptation strategies.

Evaluate resilience role of marine reserves

Reserves can be an effective management tool for protecting marine systems through reducing stressors, preserving food webs and biological/genetic diversity, and protecting species life history stages, thus maintaining or enhancing ecosystem resilience and sustainability (Bengesson et al. 2003, Lubchenco et al. 2003). Marine reserves could be established in coastal national parks to enhance the resilience to climate change conferred by additional protections. Reducing human-induced stressors, such as species harvest, dredging, and other activities will enhance the capacity of marine ecosystems to respond to environmental change associated with climate change (e.g., invasive species, harmful algal blooms, disease, etc.; McLeod et al. 2009). Marine reserves could be designed at coastal parks to compare biota inside and outside of the reserve, compare no fishing zones with recreational only fishing zones, what size should reserves be to sustain populations, among others. Data collection within a reserve should include baseline information on density and diversity of populations; stressors; phenology of spawning/arrival of migrants, and flowering; disease, genetic diversity, and others – all critical to predicting and understanding responses to climate change factors.

Monitoring Needs

Water quality

The Northeast Coastal and Barrier Network estuarine nutrient enrichment monitoring is focused during a summer index period (Kopp and Neckles 2009). It would be appropriate to supplement this program with year-round monitoring of important climate change response parameters, such as water temperature, salinity, pH, and turbidity or light extinction. Further, where park-based or nearby meteorological monitoring are not available, parks would benefit from monitoring atmospheric climatic factors that directly control marine processes, such as wind speed and direction, air temperature, light, and precipitation.

Benthic habitat monitoring

The Northeast Temperate Network has developed a protocol for monitoring the rocky intertidal environments at Acadia National Park and Boston Harbor Islands national park area (Long and Mitchell 2012). It would also be appropriate to develop and implement long-term monitoring protocols for the other major intertidal and shallow subtidal marine and estuarine habitats of coastal national parks, with a focus on benthic resources and understanding responses to climate change drivers. These habitats may include intertidal sand/mud flats (common at Acadia, Boston Harbor Islands, Saugus Iron Works, and Cape Cod), ocean and estuarine beaches, and mixed-substrate (sand-cobble-boulder) shores. Benthic communities represent excellent indicators because they integrate responses to environmental changes over the long-term, and further, successful indices of biotic integrity have been developed and implemented for estuarine benthos (e.g., Chesapeake Bay, Llanos et al. 2009).

Phenology of key species

Phenology of marine species is much less well-documented than terrestrial species, including time of spawning, flowering (submerged aquatics) or arrival/departure of migrants (Edwards and Richardson 2004). A marine phenology monitoring program could focus on key indicator species, invasive species, and perhaps diseases.

Breeding Birds, Amphibians, Reptiles, and Freshwater Habitats

Recent climate change has had a significant influence on the earth's plant and animal populations and the anticipated acceleration of warming is expected to have even greater impacts on species range shifts, phenology, species morphology, and genetic frequency shifts (e.g., Root et al. 2003, Parmesan and Yohe 2003). Within the eastern United States, an analysis of 150 bird species found that many of the species that currently occupy the northern portion of the region are moving northward into Canada and many species currently restricted to the south are expanding their range or shifting their abundance core northward (Matthews et al. 2004). For land birds these shifts in range distribution and phenology may be related to climate-driven changes in habitat availability including quantity and quality, food availability, and changes in reproductive success and survivorship. Shorebird and waterbird populations are expected to be impacted by sea-level rise and flooding events, dietary shifts, and altered nesting habitat, among other climate influenced factors – these climate factors, coupled with intense development throughout the coastal zone, could result in dramatic changes to coastal bird populations (e.g., Galbraith et al. 2002, Seavey et al. 2011).

Vernal pools, common throughout coastal ecosystems, are essential breeding habitat for amphibians and support an impressive diversity of invertebrate species (Colburn 2004). With increased temperature and altered precipitation patterns to include more intense weather events and prolonged droughts in the northeastern US, Brooks (2009) has suggested that changes to pond hydrology (i.e., duration of flooding and temporal pattern of flooding) and associated faunal responses will be significant.

Research Needs

Beach nesting birds

With accelerated rates of sea-level rise and more intense storms, there will be substantial changes to highly dynamic coastal habitats (e.g., barrier islands, barrier spits), and in turn nesting populations of coastal bird species will be impacted (e.g., Piping Plover, American Oystercatcher, Least Tern, Common Tern, Roseate Tern). Research, similar to a recent study conducted at Fire Island National Seashore (Seavey et al. 2011), is required to model and predict the extent of breeding habitat change under several scenarios of sea-level rise and storm surge. There is an obvious opportunity for shorebird ecologists to collaborate with coastal process scientists in an effort to develop coupled physical and habitat models.

As part of a North Atlantic Landscape Conservation Cooperative (NALCC) project on sea-level rise impacts on Piping Plover, a habitat evolution model using Bayesian networks for Assateague Island National Seashore is being developed (principal investigator Dr. Sarah Karpanty, Virginia Tech). Also, to begin in FY2014 the NPS will be supporting a project at Cape Cod National Seashore to better understand factors associated with post-breeding staging of the endangered Roseate Tern – a study that is certain to have implications for understanding the expected response of breeding colonies to major storm events.

Seabird foraging and nesting

Little information is available on seabird foraging habitat and prey. The effects of a changing marine environment on abundance and distribution of marine prey are not well understood. Dietary shifts also affect seabird reproduction.

A 3-yr NPS-funded study (initiated in 2010) on the *Impact of Sea-level Rise on Nesting Seabirds Within the Acadia Archipelago* led by Dr. John Anderson (College of the Atlantic) is intended to inventory Acadia National Park's extensive network of islands for seabird nesting activity, substrates and habitats, and conduct topographic elevation surveys. These data will provide park managers with the ability to forecast the impact of sea-level rise on seabird nesting and support the development of mitigation strategies to enhance seabird nesting resources.

Freshwater wetlands: modeling hydrologic flows

Modeling is required to better understand how a changing climate, particularly increasing temperatures and associated increased evapotranspiration and altered precipitation events (e.g., fewer and more intense precipitation events, changing drought regime) will affect the hydroperiod (duration of vernal wetland inundation) and hydroregime (pattern of inundation) of freshwater wetlands, especially vernal wetlands. Regional-scale climate change predictions can be used to drive vernal wetland hydrologic models and coupled ecological response models to elucidate expected future trends in hydroperiod, rates of evapotranspiration, groundwater trends, and associated responses of amphibian breeding and other faunal responses. Intensive site-specific and experimental research will be required to support model development. Expected trends in pool hydroperiod would be especially important to model given that pool-breeding amphibians require a minimum time period for larval development and some pools may not be capable of supporting amphibian breeding if hydroperiod were shortened (Brooks 2009).

Life history of key vernal wetland species

Regarding insect and other invertebrate fauna, there are significant information gaps on the life history of many species that utilize vernal wetland habitats (Colburn 2004). Before informed predictions can be made on responses to climate drivers, research is needed to understand relationships among wetland characteristics (e.g., water temperature, hydroperiod, seasonal drawdown) and life history strategies.

Pool connectivity

Enhanced understanding of the role of climate change and possible shortened hydroperiod on pool connectivity is required. Will small, shallow pools be lost from the landscape with climate change, thereby impacting genetic exchange and faunal populations?

Monitoring Needs

Freshwater hydrology

Long-term hydrologic monitoring is required to evaluate the effects of sea-level rise, other climate drivers, and urbanization on groundwater and surface water resources of coastal systems.

- Groundwater-level data can assist in the interpretation of the effects of global (climate-driven and sea-level rise; Nuttle and Portnoy 1992) and local agents of change (e.g., urbanization) and be instrumental in interpreting factors associated with ecological change in freshwater systems. A network of groundwater observation wells can provide

information on the direction of groundwater flow, hydraulic gradients, and spatial and temporal fluctuations.

- Water level monitoring of surface water features (lakes, ponds, wetlands, and vernal wetlands) is important for understanding changes in hydroperiod and hydroregime, responses to extreme events (e.g., droughts, storms) and is critical for interpreting factors associated with ecological change.

Cape Cod National Seashore is implementing a long-term hydrologic monitoring protocol that is adaptable to other coastal systems and describes protocols for monitoring groundwater level; lake, pond, wetland and vernal wetland water levels; and stream discharge (McCobb and Weiskel 2002). A FY2013 NPS-funded project at Assateague Island National Seashore will identify baseline conditions and develop a protocol to track and assess changes in the island's groundwater resources related to climate variability and other drivers.

Pond breeding amphibians

Cape Cod National Seashore is implementing two methods to monitor the long-term population dynamics of amphibians – anuran call surveys and egg mass counts (Paton et al. 2003). This monitoring, which is adaptable to other areas throughout the coastal northeast, is intended to address the following questions;

- Are populations of particular species more susceptible to habitat change than others?
- What habitat characteristics seem to be most attractive and productive for particular species?
- How dynamic are populations between years; and may this be leading to false conclusions about possible declines in short-term studies?
- How are species responding to changes in hydroperiod?

Migratory Species

Climate change poses many challenges for coastal migratory species, including sea-level rise, elevated carbon dioxide, phenological mismatches, and habitat change that can alter distribution and abundance of habitats and the quality of primary producers as a food source. For example, climate change responses could be significant as a recent study suggests that songbirds may avoid eating insects that consume leaves exposed to high carbon dioxide levels (Muller et al. 2006). The phenological or trophic mismatch concept states that if the phenology of a species of interest (e.g., a migratory bird) shifts with climate change at a different rate from that of species that make-up its ecological conditions (e.g., insect food sources), this will lead to a mistiming or mismatch in phenology, thus influencing reproduction and growth (e.g., Post et al. 2008, Visser and Both 2005). Migratory species are also challenged by expected changes in the timing of annual life history cycles (e.g., spring migration, fall migration; Coppack et al. 2008) and their ability to adapt to changes or phenotypic plasticity (e.g., Pulido and Berthold 2010). Development of effective adaptation strategies requires an understanding of differing responses of species to climate factors, their matches with changes in prey species, and life histories.

Research Needs

Habitat distribution changes

Utilizing downscaled climate change models to project habitat distribution changes is an important need, but truly downscaling the models to specific park units is a huge task, and perhaps beyond what should be attempted. However, using existing downscaled model results and determining what they project for a given park is quite reasonable.

A suggested approach is to:

1. Apply model projections, incorporating local or smaller-scale factors such as, microtopography, impervious surfaces and hydrologic features.
2. Develop projections of how habitat distribution will change over the next 100 years under a range of scenarios of climate and geomorphological change.
3. Identify key resources impacted by climate change according to the projections (e.g., food sources, specific habitat types essential to various migratory species).
4. Develop monitoring programs that include these key resources to assess the accuracy of the projections.
5. Develop an adaptive management and research model that allows regular evaluation of the research results and restructuring of the research program as needed.

Models of migration

A variety of additional data is necessary to inform models of migration. Life history data needs to be collected, as well as information about migrants' diet and site specific food availability. Global wind patterns and how they are expected to change with climate change may also impact success of migration.

The NPS is supporting a 2-year research project, beginning in 2013, at Acadia National Park and the Gulf of Maine region to forecast migratory songbird vulnerabilities/responses to climate change (principal investigators, Curtice Griffin and David King, University of Massachusetts). This study, employing an approach that may be relevant to other regions, will;

- Analyze the relationships among weather, climate, and key ecological variables, such as bird abundance, distribution, phenology, and routes of movement,
- Forecast changes in bird cohorts, habitat use, and migratory routes under a variety of climate change scenarios,
- Assess the vulnerability of different songbird species to climate change,
- Assess the strengths of different monitoring and management actions to respond to the changes.

Species and habitat vulnerability assessment

Different methods are available to evaluate the vulnerability of habitats and species to climate change. One approach, the Designing Sustainable Landscapes project, supported by the North Atlantic Landscape Conservation Cooperative (principal investigator, Kevin McGarigal, University of Massachusetts) is being applied to terrestrial habitats, with a second phase intended to include coastal systems. This project is assessing the capacity of habitats to support sustainable populations of wildlife given landscape-level changes including climate change and urbanization.

Another research approach for assessing vulnerability is based on species characteristics; evaluating whether generalists have a phenotypic plasticity advantage over specialists.

Conclusions

The intent of this brief report, and the accompanying workshop, was to identify some research and monitoring needs relevant to understanding climate change responses at coastal parks that the NPS Northeast Region could pursue as various funding calls are issued. This is far from a comprehensive assessment of research and monitoring needs on the topic, but the two-day workshop did serve to provide the genesis for development of several competitive study proposals and it is expected that this workshop synthesis will trigger more in-depth discussions and preparation of new proposals.

In addition to continuing efforts to initiate highly relevant research and to implement additional monitoring to focus on climate responses, there is a need to initiate focused discussion regarding the growing discipline of climate change adaptation. Salt marsh restoration, removal of barriers to natural habitat migration, marine reserves, and other adaptation strategies are mentioned in this report but more detailed attention is required, perhaps initiated through a follow-up workshop or report that summarizes coastal adaptation methods that are being successfully implemented by others.

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Appendix A: Workshop Agenda and List of Attendees

Climate Change in

Northeast Region Coastal Parks

A Workshop to Identify Research and Monitoring Needs Sponsored by the Cooperative Ecosystem Studies Unit and the University of Rhode Island Coastal Institute / December 17-18, 2009

Event Agenda

Thursday, December 17th

12:15 – 1:00	Welcome & Orientation Lunch: Introductions
1:00 – 1:45	Workshop Charge- <i>Charles Roman</i> , Coastal Ecologist, NPS Northeast Region
	National Park Service Policy Overview Relevant to Climate Change- <i>Mary Foley</i> , Chief Scientist, NPS Northeast Region
	Northeast Region Existing Monitoring in Coastal Parks- <i>Sara Stevens</i> , NPS, Northeast Coastal and Barrier Monitoring Network
	Climate Change Drivers for Coastal Ecosystems- <i>Carl Zimmerman</i> , Chief of Natural Resources, NPS Assateague Island National Seashore
1:45 – 3:15	Coastal Processes- <i>Discussion Leader: Norbert Psuty</i> , Rutgers University
3:15 – 3:30	Break
3:30 – 5:00	Salt Marshes- <i>Discussion Leader: Donald Cahoon</i> , USGS Patuxent
6:30	Group Dinner at the Pump House Restaurant <i>1464 Kingstown Rd • Wakefield, RI 02879</i>

Friday, December 18th

7:45 – 8:15	Continental Breakfast & Day One Recap
8:15 – 9:30	Marine Biota & Habitats- <i>Discussion Leader: Bradley Peterson</i> , Stony Brook University
9:30 – 10:45	Breeding Birds, Herps, & Freshwater Habitats- <i>Discussion Leader: Curtice Griffin</i> , University of Massachusetts Amherst
10:45 – 11:00	Break
11:00 – 12:15	Challenges for Migratory Species- <i>Discussion Leader: Scott McWilliams</i> , URI
12:15 – 1:45	Working Lunch: Breakout Sessions to Identify Priority Needs
1:45 - 2:30	Discussion: Breakout Session Findings
2:30 – 3:00	NPS Panel Responds to Priority Needs
3:00 – 3:30	Synthesis and Future Directions

Workshop Attendees

John Anderson
College of the Atlantic

Peter August
University of Rhode Island

Dave Avrin
Gateway National Recreation Area

Rick Bennett
USFWS Northeast Region

Michael Bilecki
Fire Island National Seashore

Donald Cahoon
USGS Patuxent Wildlife Research Center

Robert Cook
Cape Cod National Seashore

Joe DeVivo
NPS-Southeast Coastal Network

Alan Ellsworth
NPS-Northeast Region

Mary Foley
NPS-Northeast Region

Hector Galbraith
Manomet Center for Conservation Sciences

Howard Ginsberg
USGS Patuxent Wildlife Research Center

Art Gold
University of Rhode Island

Curtice Griffin
University of Massachusetts Amherst

Rick Harris
NPS-Northeast Region

David Manski
Acadia National Park

Andrew MacLachlan
USFWS Northeast Region

Erika Nicosia
NPS-Northeast Coastal and Barrier Network

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University of Rhode Island

Candace Oviatt
University of Rhode Island

William Patterson
University of Massachusetts Amherst

Bradley Peterson
Stony Brook University

Norbert Psuty
Rutgers University

Scott Mc Williams
University of Rhode Island

Charles Roman
NPS-Northeast Region

Dennis Skidds
NPS-Northeast Coastal and Barrier Network

Sara Stevens
NPS- Northeast Coastal and Barrier Network

Dorey Stolley
USFWS Northeast Region

Barry Sullivan
Gateway National Recreation Area

Janith Taylor
USFWS Northeast Region

Carl Zimmerman
Assateague Island National Seashore

University of Rhode Island Coastal Institute IGERT Fellows

Donald Bacoat

Rob Griffin

Julia Hyman

Brita Jessen

Bogdan Prokopovych

Trisha Towanda

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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National Park Service
U.S. Department of the Interior



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