National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Designing and Scoping Climate Change Vulnerability Assessments for Coastal National Parks in the Northeast Region

Guidance and Lessons Learned

Natural Resource Report NPS/NER/NRR—2017/1426



ON THE COVER
Photograph of damaged walkway at the Assateague National Seashore.
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Designing and Scoping Climate Change Vulnerability Assessments for Coastal National Parks in the Northeast Region

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Natural Resource Report NPS/NER/NRR—2017/1426

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April 2017

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Ricci, G., D. Robadue, Jr., and A. L. Babson. 2017. Designing and scoping climate change vulnerability assessments for coastal national parks in the northeast region: Guidance and lessons learned. Natural Resource Report NPS/NER/NRR—2017/1426. National Park Service, Fort Collins, Colorado.

NPS 962/137989, April 2017

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Executive Summary

To plan for climate change adaptation, park resource managers need scientific information identifying the susceptibility of resources to climate change, when impacts are expected and how they are expected to interact with existing stressors. Climate change vulnerability assessments are a priority for many parks to support adaptation planning, but there is a need for park specific guidance on scoping, implementing and using vulnerability assessments. Several frameworks and resources are available focusing on coastal communities and on natural resources. This document summarizes some of these and draws lessons from assessments already completed or underway in parks in the Northeast. The National Park Service (NPS) has initiated a range of climate change research and monitoring actions that address park vulnerability assessment needs. This guide provides additional materials to assist coastal parks in the Northeast Region (NER) to move forward with their vulnerability assessments and describes how to apply results to management. While the frameworks and examples that are the focus of this guide were primarily developed for natural resources, cultural resources and facilities examples are provided as available. This guide represents the combined experience and guidance from NER coastal park resource managers in hopes that others in the region will be aware of the numerous activities happening and lessons learned in the region.

Acknowledgments

Thanks are extended to the park and regional staff who provided input through interviews for the lessons learned section. This report was improved through review comments by Rebecca Beavers, Carmen Chapin, Patrick Gonzalez, Bill Hulslander, and Neil Winn. Thanks to Robin Baranowski and Nikki Long for formatting assistance.

Introduction

The National Park Service (NPS) continues to show progressive leadership in addressing climate change. This is a particularly challenging task because of the diversity of resources, missions and goals that need to be addressed by individual parks. Before wise climate adaptation can take place, detailed understanding of how systems are vulnerable to climate change is important. Due to the high level of uncertainty and complexity of projecting the future, assessing vulnerability is a challenging yet vital task for effectively managing NPS sites. The purpose of a vulnerability assessment (VA) is to identify resources that are most likely to be impacted by climate change and understand why and how. Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. The material that follows draws from the extensive methods and general frameworks that are already available for vulnerability assessments.

Key messages in this guide

- Use the intended application of the assessment to guide design elements of the VA. Only collect the information and level of detail necessary for management to move forward.
- Determine the relative emphasis of conservation, cultural and infrastructure concerns, mixing approaches from the most relevant and feasible methods.
- Partner with neighboring communities to reduce costs, coordinate analysis and work at larger coastal landscapes.
- Focus on assessing the habitats, ecological systems and geophysical settings to see the big picture.
- Allow for climate uncertainty.

The aim of this document is to provide specific guidance for the managers of coastal parks in the Northeast Region (NER) on how to make the best use of available expertise, time and opportunities to design, conduct and interpret vulnerability assessments targeted for the attributes and management needs of parks. The NER coastal parks are shown in Figure 1. This document also shares some lessons learned from the growing number of climate change vulnerability assessments already underway or completed in NER parks.

NPS has initiated a range of climate change research and monitoring actions that address Park needs. This includes a national NPS Climate Change Response Strategy and Action Plan, a Northeast Region Strategy and Action Plan, a climate change monitoring strategy has been developed by the Inventory and Monitoring (I&M) Networks in the northeast (Northeast Coastal and Barrier Network and Northeast Temperate Network) (Stevens et al. 2010). These and other reports (Roman and Babson, 2013; Babson 2014) all call for vulnerability assessments to support adaptation. This guide provides additional materials to assist coastal parks in the NER to move forward with their vulnerability assessments and describes how to apply results to management.

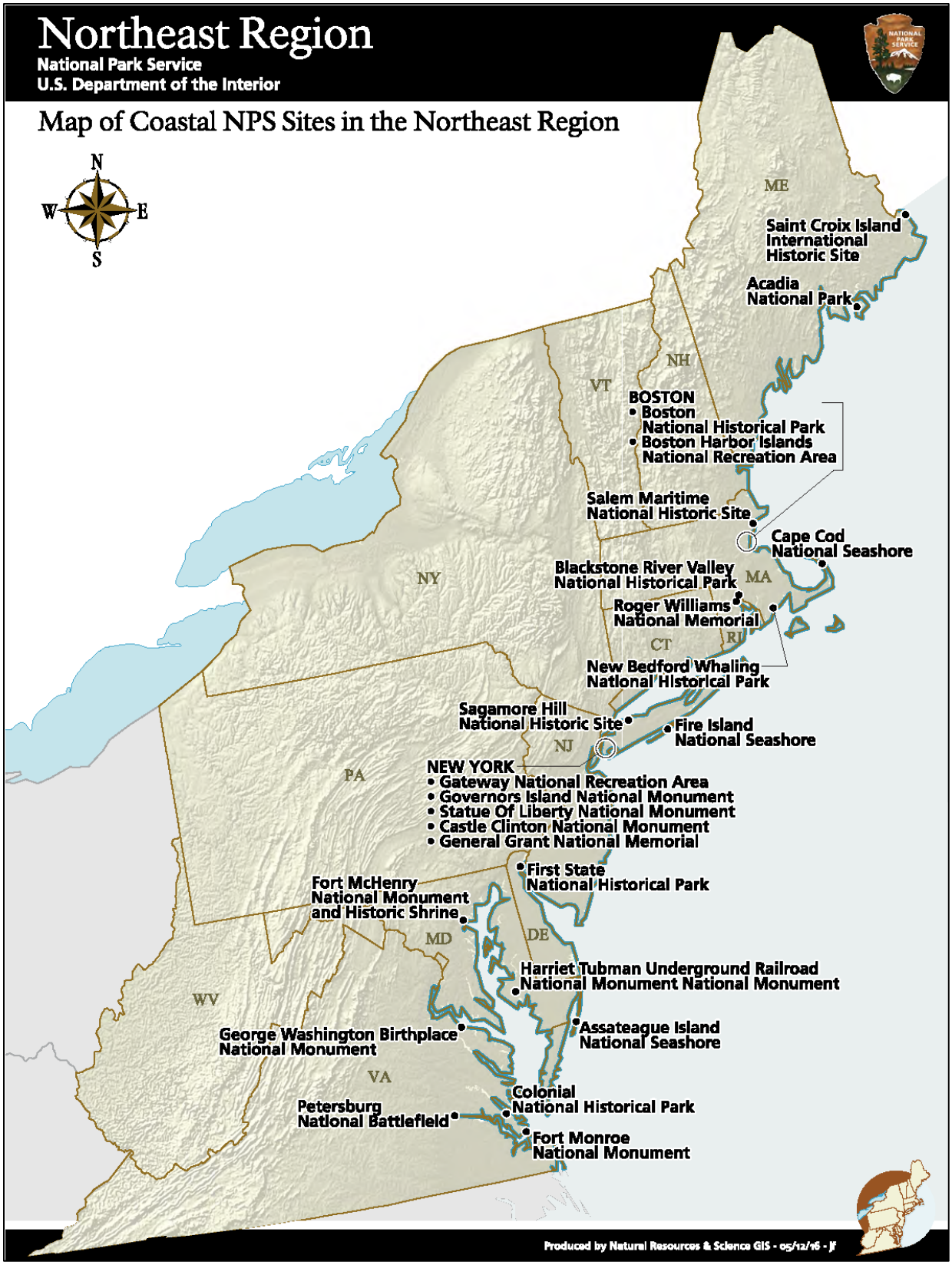


Figure 1. Map of coastal NPS sites in the NER.

The guide primarily uses frameworks and examples developed for natural resources, with cultural resources and facilities examples provided as available. It draws extensively on the approach set out in great detail in Scanning the Conservation Horizon (Glick et al. 2011) which in turn is based upon the general framework of the Intergovernmental Panel on Climate Change (IPCC) “in which vulnerability assessments are founded on evaluations of exposure, sensitivity and adaptability to climate changes” as well as practical approaches such as the US Fish & Wildlife Service’s Planning for Climate Change on the National Wildlife Refuge System (Czech et al. 2014). More broad ranging technical approaches to facilities and infrastructure provide additional perspectives, such as Adapting to Climate Change: A Planning Guide for State Coastal Managers (NOAA 2010). This summary guidance identifies existing materials, methods and practical experience related to conducting vulnerability assessments. A detailed discussion of specific adaptation policies and best practices is not within the scope of this guide, however more information can be found in the examples and bibliography.

Climate Change and Vulnerability

Climate Change Summary for the Northeast Region

The US National Climate Assessment summarizes the impacts of climate change on the US, broken down by region and sectors (Figure 2). The Northeast chapter provides a summary of the climate trends for the Northeast (Horton et al. 2014) as well as guidance on vulnerabilities that should be considered.

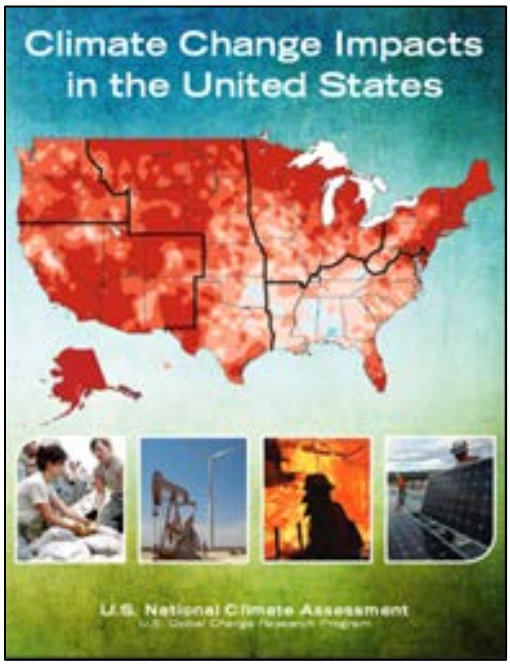


Figure 1. Report: 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment.* (Melillo et al. 2014) http://www.globalchange.gov/.

For many parks, a VA will move from higher level regional vulnerability information to locally specific trends and projections, as specific to park resources. Key points include:

- Coastal ecosystems are particularly vulnerable to climate change because many have already been dramatically altered by human stresses; climate change will result in further reduction or loss of the services that these ecosystems provide, including potentially irreversible impacts.
- Heat waves, coastal flooding, and river flooding will pose a growing challenge to the region's environmental, social, and economic systems.
- Infrastructure will be increasingly compromised by climate-related hazards, including sea level rise, coastal flooding, and intense precipitation events.
- Fisheries and ecosystems will be increasingly compromised over the next century by climate change impacts. Adaptive capacity, which varies throughout the region, could be overwhelmed by a changing climate.

- The Northeast's coastal ecosystems and the species that inhabit them are highly vulnerable to rising seas. Beach and dune erosion, both a cause and effect of coastal flooding, is also a major issue in the Northeast. Impervious surfaces and coastal barriers such as seawalls limit the ability of marshes to migrate inland as sea levels rise.
- As sea levels rise, the Chesapeake Bay region is expected to experience an increase in coastal flooding and drowning of estuarine wetlands. The lower Chesapeake Bay is especially at risk due to high rates of sinking land (known as subsidence). Climate change and sea level rise are also likely to cause a number of ecological impacts, including declining water quality and clarity, increases in harmful algae and low oxygen (hypoxia) events, decreases in a number of species including eelgrass and seagrass beds, and changing interactions among trophic levels (positions in the food chain) leading to an increase in subtropical fish and shellfish species in the bay.

Distinctive Climate Change and Adaptation Characteristics of the Northeast Region

When conducting vulnerability assessments for the NER, incorporate the following distinctive characteristics to tailor the analysis to local conditions. This can result in greater clarity of potential impacts and increased acceptance by stakeholders:

- Urban density and surroundings: The NER is one of the most populated regions of the country with significant infrastructure in the coastal zone. Density increases the number of stakeholders surrounding Parks and the economic pressures to encroach upon park areas and associated ecosystem services. Urban areas also offer more partners to link assessments with to share resources and integrate analyses.
- Cultural Resources: The NER has over 5000 historic structures across 80 sites. Many of the Parks in this region are focused on cultural resources which have different vulnerabilities and adaptation limitations (Morgan et al. 2016).
- Tidal ranges: When considering sea level rise (SLR) and storm surges, recognize the influence of tidal range on elevation capital; some NER parks have large tidal ranges while others are micro-tidal which can present its own adaptation challenges.
- Rapidly subsiding coast: Adding to the accelerated SLR rates, the long-term land subsidence for much of the mid-Atlantic raises the immediacy of the risks.
- Unique endangered and protected species: General methods and assessments should be tailored to the unique species that are endangered and protected. Climate vulnerability of threatened species may prioritize funding allocation or scope of assessments.
- Mix of ecological zones (Mid-Atlantic and Cold Northern species ranges overlap): The NER encompasses two ecological zones which have a greater overlap in the ranges of many species, adding to the complexity of assessments.
- Significant number of sites with barrier islands exposed to storm energy: A prominent coastal feature for much of the NER is sandy barrier islands. These are dynamic systems that are continually on the move, despite society's engineering efforts. There are tradeoffs between

working with natural processes and engineering efforts intended to protect historic structures, recreational access or adjacent landowner's infrastructure.

- Generally supportive public that understands climate change and need for action: Based on recent national surveys (Howe et al. 2015), the NER has an educated and supportive citizenry open to using the latest climate science and taking action. When difficult adaptation decisions need to be made, specific stakeholders may question the science supporting actions impacting their interests, increasing the demand for high quality vulnerability assessments.

Vulnerability Frameworks and Concepts

Basic conceptual framework

The basic conceptual framework that serves to unify the approaches taken to vulnerability assessments (Figure 3) is detailed for natural resources in *Scanning the Conservation Horizon* (Glick et al. 2011). However the diagram in Figure 3 and the reasoning behind it is applicable to cultural resources and facilities and is found in a wide range of climate change vulnerability assessments for coastal and inland areas. Climate changes, such as sea level rise, changes in temperature, precipitation and extreme storm patterns, along with ocean acidification, will exacerbate existing hazards. This will potentially cause impacts to the extent that resources, such as beaches, wetlands, habitats, park facilities, and cultural resources are sensitive to those effects. How well nature and humans can adapt to the new conditions will determine overall vulnerability.

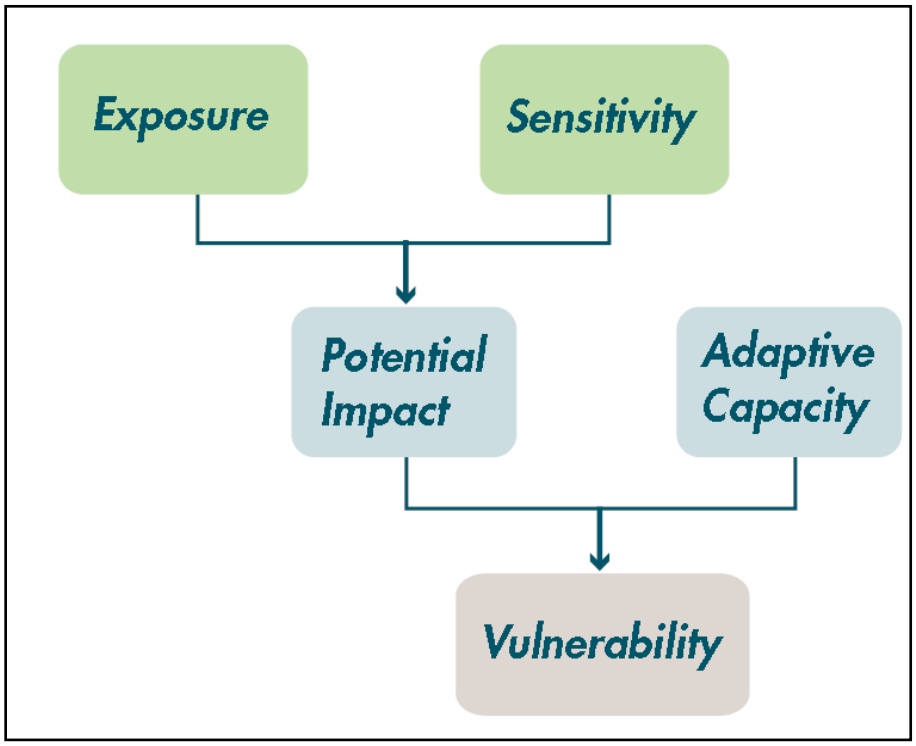


Figure 2. Basic concepts comprising a vulnerability assessment. Figure from Glick et al. (2011).

This basic exposition of vulnerability is very broad and covers all scales and types of resources. In contrast, much of the guidance developed to date to assist the NPS places greatest emphasis on natural resources and systems.

What vulnerability assessments can contribute

Outputs of vulnerability assessments can then be used in decision-making processes, which often apply risk management frameworks that assign values of likelihood and consequences. Vulnerability assessments are helpful in situations where uncertainty is high resulting in the inability to assign accurate risks.

Timing is Critical

The primary purpose of conducting a vulnerability assessment is to inform management actions. The timing of assessments can be critical to their use and application in park planning and decision making. NPS has several planning products that can be informed by timely assessments. Assateague Island National Seashore (ASIS) conducted a scenario planning workshop as an initial phase in the process of updating its General Management Plan. This provided an exceptional opportunity for park staff, planners and contractors to become more knowledgeable about existing data as well as current resource conditions and trends. This greater understanding provided a strong foundation for developing practical alternatives for future management of the barrier island.

NPS Description of a Robust Vulnerability Analysis for Natural Resources

- Vulnerability to climate change is the degree to which a system is susceptible to and unable to cope with adverse effects. Gonzalez (2011) sets out a clear definition of design features to include in a robust NPS vulnerability analysis: Examination of all three components of vulnerability: exposure, sensitivity, and adaptive capacity.
    - **Exposure** is the extent of climate change experienced by a species or ecosystem: for example, degrees of annual temperature change per century.
    - **Sensitivity** is the change in a species or ecological variable for each increment of change in climate: for example, increased tree mortality of 5% per degree of average temperature increase.
    - **Adaptive capacity** is the ability of a species or ecosystem to adjust: for example, increased germination to compensate for the increased tree mortality.
- Detection and attribution of historical changes.
- **Analyses of observed and projected data**. Because of time lags between the emission of greenhouse gases, the expression of changes in climate, and ecological responses, vulnerability is a function of historical and future climate changes.
- **Quantification of uncertainties**. Computer model errors, future emissions scenario assumptions, field measurement errors, and statistical variation all combine to create a range or probability distribution of possible values for any calculation.

- **Identification of vulnerable areas and potential refugia**. Spatial analyses that map patterns of vulnerability will identify the locations of the most vulnerable areas and potential refugia. This provides the scientific data needed to prioritize areas for adaptation.

Putting Vulnerability Assessments and Scenario Planning into Context: They each have their place

Scenario planning and vulnerability assessments are both important tools for adaptation planning and can be similar in that they attempt to understand the future under uncertain conditions. Each has their strengths and roles (Table 1). This document focuses on vulnerability assessments, recognizing that the outputs from such assessments can then be incorporated into scenario planning exercises or that scenario planning may identify the scope of a needed vulnerability assessment.

Table 1. Putting Vulnerability Assessments and Scenario Planning into Context: They each have their place.

Feature	Scenario Planning	Vulnerability Assessment
Purpose	Identify actions that will be most effective across a range of potential futures or that promote desired outcomes.	Identify which resources are impacted by climate change and why
Process	Start with plausible future states, then determine how management could respond	Start with current trends and projections for key resources, then understand the possible impact to resources
Output	Detailed stories of future states and how management could respond	Vulnerability of resources under specific projections and within a selected timeframe
Inputs	Driving forces and potential impacts (including vulnerability assessment data if available), projections, current management context	Exposure projections, sensitivity attributes of resources and adaptive capacities

Sources of general guidance

Guidance from Intergovernmental Panel for Climate Change

Broad definitions of the scope of a vulnerability assessment tend to be comprehensive, for example the IPCC's Fifth Assessment, states that "vulnerability at the national and subnational levels is affected by geographic location, biophysical conditions, institutional and governance arrangements, and resource availability, including access to technology and economic stability", while at the same time recognizing that "adaptation needs are highly diverse and context specific" (IPCC, 2014). The more focused definition provided by the NPS in 2013 extends Gonzalez' original formulation for natural systems to encompass park-wide, and multi-hazard, covering all natural resource areas, or all facilities. National parks in the NER also provide and maintain public access infrastructure. Most parks also have historic buildings and many other cultural resources to manage. Many NER parks include extensive cultural resources that can be at risk from climate impacts. Assessments involving structures and cultural resources require different expertise and considerations, as well as a different concept of adaptive capacity (Rockman et al. 2016).

Guidance from Scanning the Conservation Horizon

*Scanning the Conservation Horizon (*Glick et al. 2011*)* sets out an assessment approach that retains an emphasis on species and habitats, including how to address the uncertainty that tempers the confidence that users of a vulnerability assessment will have in its information, projections and recommendations. A vulnerability assessment offers latitude in the scope, goals and objectives, assessment targets, and methods used. The *Designing a vulnerability assessment* section sets out the authors' assessment road map in a step by step fashion. They also recommend considering an iterative, adaptive management approach to "maximize the likelihood of an acceptable outcome". A monitoring plan is important in this approach to determine the interplay of climate and non-climate stressors, as well as to critically assess the effectiveness of adaptation actions.

Guidance from NPS Documents

The NPS approach to vulnerability assessment acknowledges the challenges of uncertainty and offers creative methods for incorporating climate change, impact uncertainty and socio-economic dimensions. The NPS Director's policy memorandum (PM) 12-02, "Applying National Park Service Management Policies in the Context of Climate Change" points out that "widespread, cascading effects from climate change challenge park managers even a few decades ago" (NPS 2012a).

The NPS has produced several model vulnerability assessments, including a marine habitats methodology for Cumberland Island National Seashore (CUIS) (Peek et al. 2016). More information on this method is available later in this guide.

One frequently mentioned recommendation is that it may be time to update site goals. Environments are continually changing. Forward looking NP sites continually review their goals and objectives to ensure they are in line with environmental and climate shifts. ASIS used the outputs of their scenario planning workshop and other SLR data to recognize the reality that visitor facilities and other seashore infrastructure needed to be more sustainable and resilient in the face of future environmental conditions. The NPS and Glick et al. (2011) both encourage sites to adapt their management goals based on likely future climate conditions.

The usefulness of scenarios

Scenario planning explores and describes characteristics of several plausible futures, enabling managers to consider how to define and meet their goals (desired conditions) under changing, and new circumstances. Recognizing the need to start planning for adaptation in the context of high uncertainty and a lack of information, NPS provides support to conduct scenario planning processes. The NPS produced a resource guide to assist in this endeavor: *Using Scenarios to Explore Climate Change: A Handbook for Practitioners* focuses on dealing with these unprecedented circumstances and landscape-scale challenges (Figure 4) (NPS 2013a). This concise document offers thorough guidance for applying one approach used by the NPS. While scenario planning can be done in the absence of a vulnerability assessment, there are benefits to incorporating existing vulnerability assessment findings to further refine the plausible futures used in scenario planning. Additionally, at the conclusion of a scenario process, the findings may suggest the need for a detailed vulnerability assessment on specific aspects of the system, thus reducing the scope and costs of an assessment.

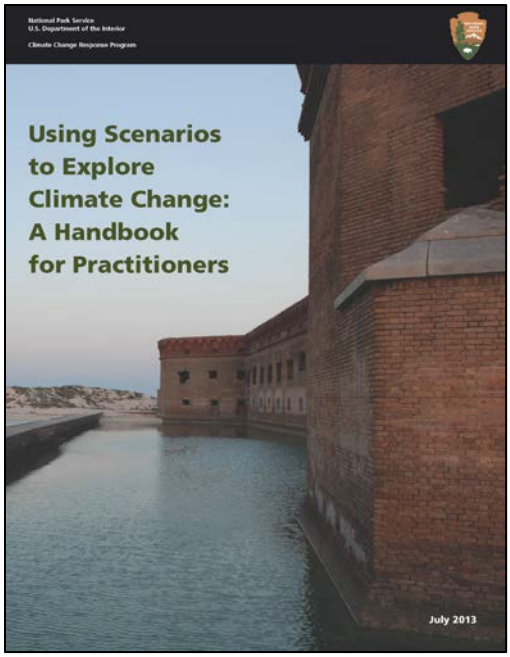


Figure 4. Report: *Using Scenarios to Explore Climate Change: A Handbook for Practitioners* (NPS 2013a). http://www.nps.gov/subjects/climatechange/upload/CCScenariosHandbookJuly2013.pdf

Acknowledging the importance of a science-based vulnerability process, nonetheless, "What models cannot do, is reveal exactly when, where, or how these impacts will occur, nor can they predict how extreme events might interact with complex natural systems to cause dramatic changes on a landscape" (NPS 2013a). An additional benefit of the ideas in the *Using Scenarios to Explore Climate Change* handbook (Figure 5) is the broader scope it encourages in the assessment process.

Park managers are finding scenario planning as a valuable way to introduce more appropriate time frames for both conservation and facilities vulnerability.

Considering Multiple Futures: Scenario Planning to Address Uncertainty in Natural Resource Conservation presents a broad synthesis of scenario planning concepts and approaches, including the NPS scenario planning process (Figure 6) (Rowland et al. 2014). It is particularly valuable for those interested in understanding the theory behind different scenario planning approaches and gaining access to additional literature and examples.

A multivariate climate change scenario exercise "might consider mixture of climate variables (such as temperature, precipitation, storm frequency) and sociopolitical forces (funding, support, political leadership)" (NPS 2013a). NPS guidance for climate adaptation for cultural resources and facilities will provide specifics on how vulnerability assessment frameworks can be adjusted for those resources. A table of *Climate Change Impacts on Cultural Resources* (Morgan et al. 2016) looks across archeological resources, cultural landscapes, ethnographic resources, museum collections and buildings & structures for how temperature, precipitation, sea level rise and combined stressors may affect each resource. Watch this space for updates on further resources for cultural resource

vulnerability information:
http://www.nps.gov/subjects/climatechange/adaptationforculturalresources.htm.

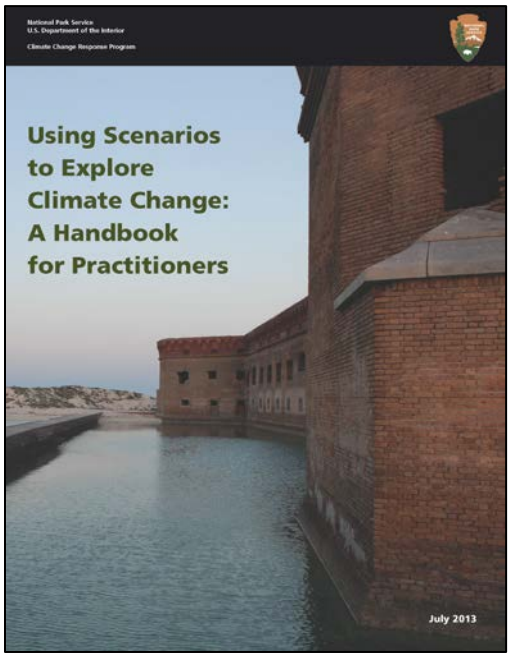


Figure 5. Report: *Using Scenarios to Explore Climate Change: A Handbook for Practitioners*. (National Park Service, 2013).
http://www.nps.gov/subjects/climatechange/upload/CCScenariosHandbookJuly2013.pdf

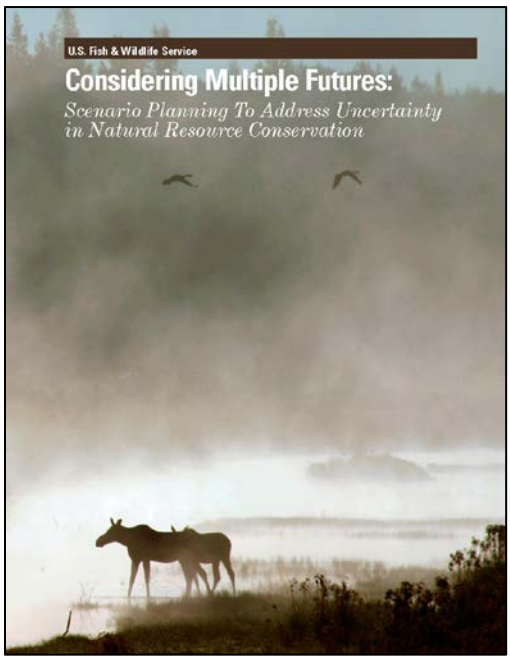


Figure 6. Report: *Considering Multiple Futures: Scenario Planning to Address Uncertainty in Natural Resource Conservation* (Rowland et al. 2014).
https://www.fws.gov/home/feature/2014/pdf/Final%20Scenario%20Planning%20Document.pdf

Cultural resources adaptation guidance has been provided via a PM 14-02 “Climate Change and Stewardship of Cultural Resources” (NPS 2014a) and in the report from the meeting “Preserving Coastal Heritage” held in New York (NPS 2014c).

Adaptive Capacity Frameworks

Perhaps the part of vulnerability that contains the most uncertainty is calculating the adaptive capacity of a system. Adaptive capacity is a relatively new concept with many different interpretations on what it is and how to measure it across ecological and social dimensions. Two frameworks are presented below to highlight ecological and social examples of how to assess adaptive capacity. The IPCC presented a social framework (Smit et al. 2001) that identified six determinants of adaptive capacity in the context of climate change (Table 2). This captures most of the concepts shared by other researchers.

In relation to NPS site assessments, the adaptive capacity is primarily focused on the NPS’s internal organizational capacity to adapt, though other stakeholders neighboring the sites certainly should be considered. In the case of ASIS’s assessment of facilities, they used current replacement values as an indicator of capacity to adapt (discussed later in the document, ICF International 2012). While this is a limited interpretation of the concept of adaptive capacity, it does start to incorporate social and institutional dimensions using fixed values.

From an ecological perspective there are several frameworks that recognize the inherent adaptive capacity of nature and organisms. The greater challenge is determining the hidden adaptive capacity when under great stress beyond the normal range of conditions.

Table 2. Determinants of adaptive capacity. Table from Smit et al. (2001).

Determinant	Rationale
Economic resources	Greater economic resources increase adaptive capacity Lack of financial resources limits adaptation options
Technology	Lack of technology limits range of potential adaptation options Less technologically advanced regions are less likely to develop and/or implement technological adaptations
Information and skills	Lack of informed, skilled and trained personnel reduces adaptive capacity Greater access to information increases likelihood of timely and appropriate adaptation
Infrastructure	Greater variety of infrastructure can enhance adaptive capacity, since it provides more options Characteristics and location of infrastructure also affect adaptive capacity
Institutions	Well-developed social institutions help to reduce impacts of climate related risks and therefore increase adaptive capacity Policies and regulations may constrain or enhance adaptive capacity
Equity	Equitable distribution of resources increases adaptive capacity Both availability of and entitlement to resources are important

Consider exploring NPS Museum Collections. Primary data collection on localized climate history can be expensive and complicated. Acadia National Park (ACAD) realized that their Historical Museum records contained a wealth of natural history information related to species distribution and phenology. Seek out NPS museums and other local collections to take advantage of historical data on trends in climate, sea level and responses to past extreme events.

The CUIS marine assessment measured adaptive capacity from a purely ecological dimension – such as salinity and pH ranges and growth rates. While the ecological dimension certainly is a major factor, for many coastal habitats, specifically those near human settlements, there are also socio-economic factors at play to influence adaptive capacity influencing management decisions. These include controlling tidal flushing volumes and beach replenishment.

Challenges of Modeling Fundamental and Realized Adaptive Capacity of Species

The USFWS notes that the ability of species within the national system of refuges to adapt to the unprecedented rate and magnitude of climate changes being experienced in the 21st century, such as precipitation and temperature, may not be sufficient to keep pace. This includes the concern that "disruptions to the synchrony among species could cause cascading ecosystem effects, affecting reproduction, mortality and distributions of species" (Table 3).

An important dimension of vulnerability assessment at the species level is incorporating the adaptive capacity of individual key species that are the focus of biodiversity conservation efforts in view of the challenge of global climate change. Beever et al. (2015) set out a broad conceptual framework. The authors "call for an inter-disciplinary synthesis and research effort to: A) develop a consensus for how adaptive capacity is defined and applied in resource management decisions; and B) draw from disparate fields such as genetics, ecology, and conservation biology, and synthesize what is known about species' adaptive capacity using consistent terminology."

Table 3. Factors influencing species vulnerability. Table adapted by Czech et al. (2014) from Gitay et al. (2002).

Factor	Highly Vulnerable Species	Less Vulnerable Species
Population Size	Small	Large
Dispersal Mechanisms	Limited, slow	Various, rapid
Range Extent	Restricted or patchy	Wide and contiguous
Elevation	High or low	Intermediate areas
Habitat Requirements	Narrow or specific	Broad or general
Climatic Range	Limited	Extensive

Consider four key elements of intrinsic adaptive capacity of a species, including life history traits, dispersal and colonization abilities of the species, genetic diversity and phenotype plasticity. In addition there are a number of potential extrinsic factors, such as habitat loss from land cover change

or pollution, and competition among species (Table 3). Management interventions are possible to aid in enhancing realized adaptive capacity of a species, though the complexity and uncertainty is substantial.

A similar analysis of the challenges of assessing adaptive capacity at the species and ecosystem levels (Figure 7) was presented by Williams et al. (2008), in which they concluded that:

> *What is needed is a complete working framework for assessing the vulnerability of species that explicitly links: the various components of biotic vulnerability; the regional and local factors determining exposure to climatic change; the potential for both evolutionary and ecological responses, resilience, and active management to mediate the final realized impacts; and the potential for feedback effects. Such a framework would be invaluable as it would integrate and guide thought, research programs, and policy in the biodiversity/climate change arena and allow significant gaps in knowledge to be clearly identified.*

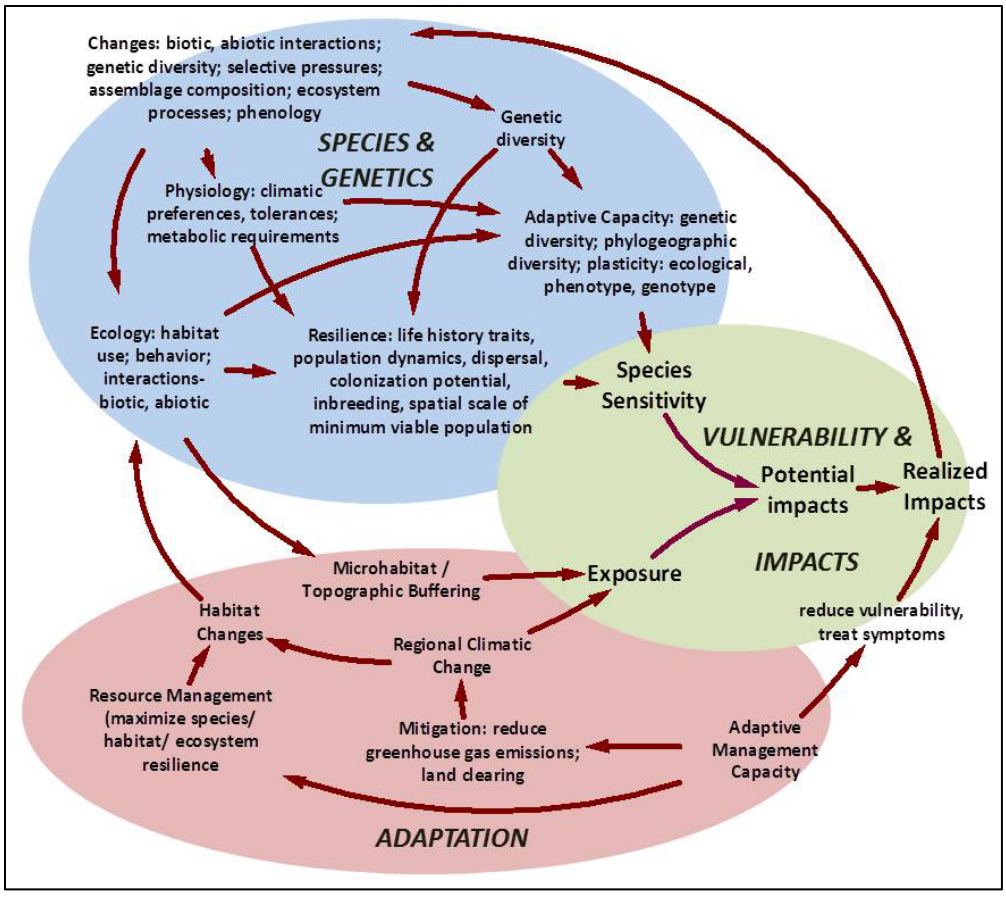


Figure 7. An integrated perspective on incorporating species realized adaptive capacity in vulnerability assessment. Figure adapted from Williams et al. (2008).

A vulnerability assessment for species needs to focus attention on the interplay of many feedback loops leading to realized impacts. Species sensitivity to climate impacts is mediated by genetic and

habitat factors causing vulnerability and leading to potential impacts, which management measures to address climate change, and to improvements to natural resources management can help reduce.

This formulation of the challenge of assessing species vulnerability views management interventions are possible to aid in enhancing realized adaptive capacity. However the scientific information requirements and complexity of designing and carrying out required management interventions likely lies out of reach for park-specific assessments.

Recent Vulnerability Assessments and Follow up Actions for Natural Resources, Cultural and Infrastructure Assets in NPS NER Parks

As of 2015, no singular exemplar has emerged of a coastal park climate change vulnerability assessment covering all three facets of national park assets: natural, cultural and facilities. However, in the past decade, NER parks have collectively carried out a range of vulnerability assessment activities. These have made a significant contribution to good practices toward an overall approach that addresses the unique attributes of the region. Appendix A provides examples of elements of vulnerability assessment carried out in Northeast and Southeast Region parks, summarizing the vulnerability method used, the assets targeted, key vulnerabilities discovered and lessons learned, and finally actions taken, if any, as a result of the assessment. Appendix B highlights vulnerability assessment included in an NPS coastal adaptation case studies report (Schupp et al. 2015).

A range of vulnerability assessment techniques are employed across the parks. A thorough assessment of marine resource vulnerabilities was done for Cumberland Island National Seashore (CUIS), which could be a good NER example even though it is located in the Southeast Region (Peek et al. 2016). The US Geological Survey (USGS) has prepared very helpful integrated visuals of its coastal vulnerability index for several national parks including Cape Cod National Seashore (CACO), Fire Island National Seashore (FIIS), Gateway National Recreation Area (GATE), and Assateague Island (ASIS). ASIS also has included vulnerability information in a scenario planning approach to adaptation, which was then incorporated into its General Management Plan update. Adaptation approaches for certain facilities have also been primary considerations of the purpose and need for removing and relocating two popular public parking areas that were damaged by Hurricane Sandy within the Seashore's developed area.

Studies aimed at the vulnerability of salt marsh and coastal wetlands have been conducted in Acadia National Park (ACAD), CACO and FIIS. GATE's recently adopted General Management Plan update incorporates climate change concerns by including priority banding of structures by categories of preserve, stabilize and ruin based partially on vulnerability to future storm events. Most of the technical assessments are issue focused and for the most part represent a stepwise approach rather a comprehensive assessment of vulnerability. More details on some of these experiences are provided in Appendix A and in relevant steps of the Designing a Vulnerability Assessment Process sections below. These partial, pragmatic efforts are making successful contributions to ongoing decision-making, in the absence of more comprehensive integrated assessments and resources to support them.

The next section examines some of the different starting or entry points park managers are using to address climate change impacts and how these might fit into an overall process for assessing vulnerability in a way that can lead fruitfully to adaptation planning and implementation.

Designing a Vulnerability Assessment Process

The sampling of NPS experience provided in Appendices 1 and 2 illustrates that park managers in the NER in practice are using many different entry points for beginning to incorporate climate change concerns and adaptation strategies into planning and ongoing decision making. The geographic scope, time horizon and likely impacts included in these examples vary considerably. To date, most guidance documents and examples tend to focus on natural resources in parks, however more recent information and experience is emerging on how to address facilities and cultural resources.

Recent NPS documents highlight and encourage staff to integrate their vulnerability assessments (VAs) across themes and resources. PM 12-02 on climate change (NPS 2012a), and the NPS Vulnerability Assessment Brief (NPS 2013b) highlight the multi-faceted nature of park manager responsibilities that intersect with the need for vulnerability assessments. This includes conserving natural systems, protecting historic heritage, determining the desired user experience for each park, changes in species associated with parks, concern for the integrity and potential loss or damage to cultural resources, park facilities, and the effect on park planning and management.

Assessing vulnerability to climate change can seem overwhelming in the degree of complexity and uncertainty. Several Parks overcome limited resources by doing smaller studies that over time help contribute to a larger systems analysis. For example, ACAD initially had USGS partners conduct a study constrained to only salt marsh inundation. Later additional studies on plant, trees and animal vulnerability were completed. These studies were integrated through a scenario planning workshop. The benefits of this approach include the ability to use small budget allotments to move forward, rather than waiting for a single large budget. By doing several small studies it also provides rich detailed data for when a larger climate assessment is conducted.

In broad terms, entry points for conducting a vulnerability assessment include:

- Full stand-alone vulnerability assessment for all park resources and areas
- Smaller focused assessments of specific resource (e.g. habitats, species, collections) or specific impacts and issues of concern
- Incorporation of climate change vulnerability information into the Foundation Document, General Management Plan update or other planning process (e.g. Resource Stewardship Strategy) as part of mainstreaming climate adaptation into planning processes.

The choices for how to design the VA will be influenced by available resources, nature of the climate impacts, the level of risk in terms of how many and how often significant impacts are expected and opportunities that present themselves during ongoing park planning activities. Figure 8 lays out the key steps for a vulnerability assessment from Glick et al. (2011), which will be an organizational framework for next sections of the document. Figure 9 (adapted from Stein et al. 2014) highlights potential paths along the VA process for parks to consider with select examples.



Figure 8. Key steps for assessing vulnerability to climate change.

This generalized framework for adaptation planning and implementation mirrors many existing conservation planning and adaptive management approaches and can be used either as a stand-alone planning process or to inform the incorporation of climate considerations into existing planning and decision making processes.

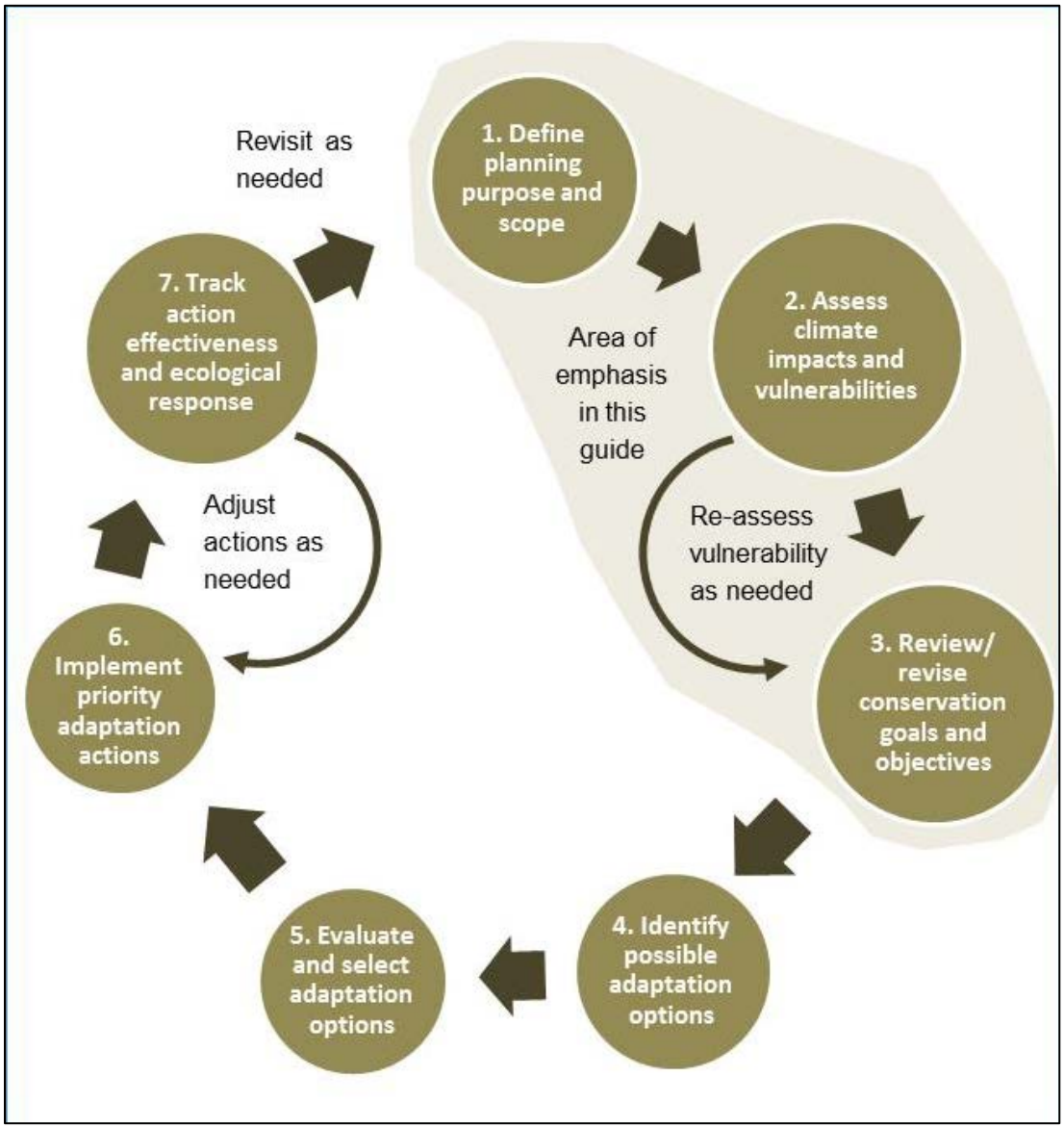


Figure 9. Climate-Smart conservation cycle. Figure adapted from Stein et al. (2014).

Steps, Paths and Examples for Conducting a Vulnerability Assessment

A. Determining objectives and scope of a vulnerability assessment

Key points of this section

There are many examples from National Park Service to help in determining the scope and objectives for a vulnerability assessment. Much of this includes ways to examine park goals and to broaden an assessment to address ecological and social dimensions. There is a considerable amount of National Park Service policy and guidance to help managers. Finally, park managers have found it valuable to link to regional climate strategies.

Determining objectives and scope

- Identify resource management question requiring climate change vulnerability insights
- Identify audience, user requirements, and needed products
- Engage key internal and external stakeholders
- Establish and agree on goals and objectives
- Identify suitable assessment targets
- Determine appropriate spatial and temporal scales
- Select assessment approach based on targets, user needs, and available resources

Paths to consider in view of park situation

- Conduct a park-wide VA. that includes a combination of ecological, cultural and facilities – financial and personnel resource intensive, benefits from regional landscape scale partnerships, helps see the bigger picture
- Conduct a VA only for selected assets/ specific issues or a specific area or system within a park – this can be less resource intensive yet lacks the integration across systems.

Helpful Examples and Sources of guidance (see Methods and Tools/resources sections)

Refuge Vulnerability Assessment and Alternatives (RVAA) Technical Guide (Figure 10) provides step-by-step details for scientific and technical staff for conducting vulnerability assessments for refuges and their supporting landscapes and to develop strategies and alternatives for management in the face of current and future drivers of change (Christ et al. 2012a). Similarly the *Manager's Guide to Refuge Vulnerability Assessment and Alternatives: Overview and Practical Considerations* (Christ et al. 2012b) is designed for managers who coordinate and conduct actual assessments. Both cover widely used conservation planning and management concepts and approaches such as vulnerability assessment, cumulative effects assessment, ecosystem-based management, and adaptive management.

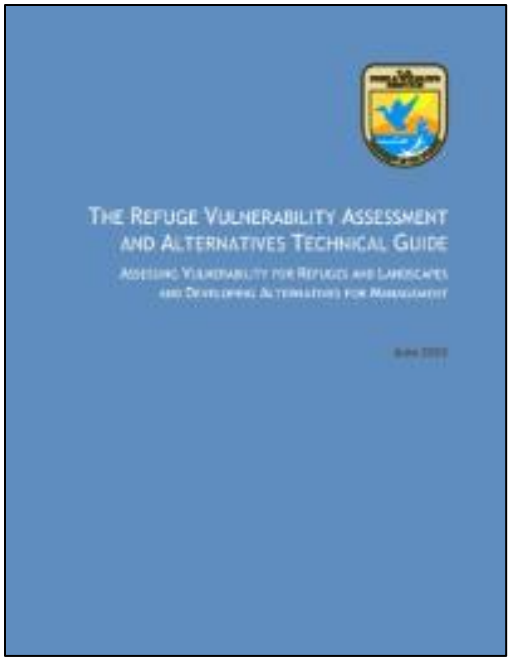


Figure 10. Report: Refuge Vulnerability Assessment and Alternatives Guide (Christ et al. 2012a). http://www.natureserve.org/biodiversity-science/publications/refuge-vulnerability-assessment-and-alternatives-technical-guide

Scanning the Conservation Horizon (Glick et al. 2011) is designed to assist natural resource managers and other conservation resource professionals to better plan, execute and interpret climate change vulnerability assessments (Figure 11).

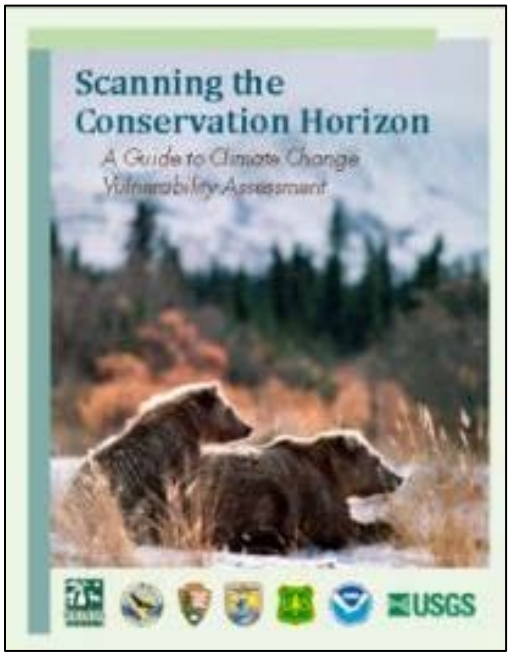


Figure 11. Report: Scanning the Conservation Horizon. (Glick et al. 2011). http://www.habitat.noaa.gov/pdf/scanning_the_conservation_horizon.pdf

The best NPS example of a completed VA that includes both cultural and natural resources is the *Badlands National Park Climate Change Vulnerability Assessment* (Amberg et al. 2012) (Figure 12). Initiated by the NPS Climate Change Response Program with two priorities in mind: 1) to assess the potential vulnerability to climate change of natural and cultural resources through the development and implementation of a CCVA, and 2) to develop a methodology for projecting regional climate changes and a process for assessing natural and cultural resource vulnerability to these changes.

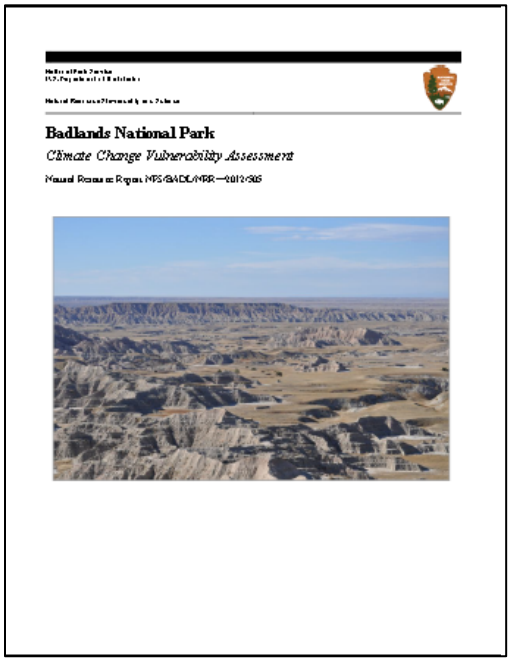


Figure 12. Report: Badlands National Park Climate Change Vulnerability Assessment. (Amberg et al. 2012) http://www.cfr.washington.edu/research.cesu/reports/J8W07100036_final_report.pdf

Setting New Park Goals In Line With Climate Change

A climate adaptation guidebook *Climate-Smart Conservation* (Stein et al. 2014), sees assessment and adaptation as ongoing activities that emphasize discovery, learning and adjustment (Figure 13). Of particular significance in this representation is the dynamic between steps 2 and 3 in the process (Figure 9), where "review/revise conservation goals and objectives" prompts a rethinking of what is considered to be vulnerable. Steps 6 and 7 capture another important dynamic, which is the rethinking and adjustment needed when adaptation actions do not appear to have the desired effect. The overall "climate-smart" cycle links these two dynamics.

The authors emphasize that it is better to align conservation strategies with the dynamics of changing climate than to hold on to traditional goals, which is particularly challenging for parks, but is a challenge NPS is beginning to address (NPS 2012a). "While the prospect of revising goals may be unsettling, the principles and practice of conservation have been far from static over time. Indeed, conservation goals are a reflection of human values, and there has been a continuing evolution in how society understands and values nature and ecological resources." (Stein et al. 2014).

This perhaps helps explain the low degree of emphasis on setting specific conservation or facilities adaptation targets in the policy and guidance on vulnerability assessment or adaptation planning for parks. An exception might be for decision making on specific park actions that incorporate some kind of climate lens, such as moving public access facilities away from high hazard areas or considering shoreline protection measures. Park managers do not get many second chance opportunities to revise a facility decision, as adaptive management would otherwise recommend, due to the cost and length of time needed to redesign and redo approval processes.

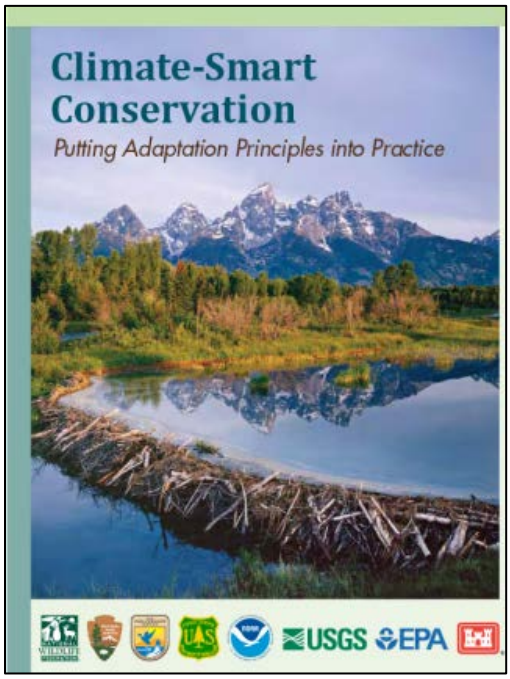


Figure 13. Report: *Climate-Smart Conservation: Putting Adaptation Principles into Practice.* (Stein et al. 2014) http://www.nwf.org/~/media/PDFs/Global-Warming/Climate-Smart-Conservation/NWF-Climate-Smart-Conservation_5-08-14.ashx

It is not yet common to encounter vulnerability assessments or plans for adaptation that set specific timing or priorities on required actions or a level of resilience to be accomplished. Environmental impact assessments for facilities actions in parks may mention sea level rise and other climate change impacts but NPS is just at the beginning of explicitly take climate change into account for these and NER examples that include climate change impact-related projections are in progress or in the early stages. The NPS recommended approach to scenario planning helps park managers think about dealing with uncertainty but has primarily been used for more general exploration of management implications rather than a blueprint approach to achieving a management goal. Projections about climate impacts, for example the increasingly fine-scale analyses of sea level rise, can help reveal the potential severity of change.

Benefits of Conducting Vulnerability Assessments through Ecological and Socio-Economic Dimensions

The value of NPS sites can be attributed to a combination of the ecological, cultural and facilities assets managed through a socio-economic institutional arrangement. In other words vulnerability and adaptation is dependent upon several dimensions which should be incorporated into the analysis to improve accuracy and acceptance by stakeholders.

Carrying out vulnerability assessments that combine the ecological and management dimensions will provide park managers with a clearer orientation on future planning and management, including funding requirements. While this guide focuses on the ecological dimension of vulnerability assessments, there are some models and experience in the cultural and facilities dimension that should be considered. A facilities-oriented assessment workshop was conducted for ASIS specifically aimed at facility adaptation to climate change (ICF International 2012). When ACAD realized that SLR would inundate much of their low lying wetlands within the Park's boundary, they worked with their Friends of Acadia to protect refugia through conservation easements.

The USFWS also initiated an integrated approach in 2012, "refuge vulnerability assessment and alternatives" which is aimed at supporting collaborative landscape management. This included addressing climate change, in order to "see where we should concentrate on conserving remaining high-quality areas and what actions would most effectively achieve this" as well as ranking stressors that prevent achieving conservation goals (Crist, Comer, and Harkness 2012). This guide is detailed and provides guidance on how a site could integrate facilities into an ecological assessment. Another important spatial dimension to consider is that where parks are adjacent or near refuges, they should coordinate on prioritizing conservation areas and management actions related to those areas. This strategy also holds true for other conservation programs neighboring NPS sites, so as to increase coordination, sharing and reduce costs.

Useful Resources for Determining the Scope and Objectives of a VA

Adapting to Climate Change: A Planning Guide for State Coastal Managers (Figure 14) is designed by the National Oceanic and Atmospheric Administration (NOAA) for the coastal management sector. It highlights the unique characteristics of coastal areas, how to design a vulnerability assessment process, key resources to gather data and adaptation options.

Planning for Climate Change on the National Wildlife Refuge System is intended to help Refuge System managers and planners prepare for these impacts and fulfill USFWS and Department of Interior mandates to incorporate climate change considerations into planning documents (Czech et al. 2014) (Figure 15). Designed especially for Refuge System personnel and Service-oriented issues, this guide includes over 500 literature citations and went through extensive review within the USFWS and partner organizations prior to production

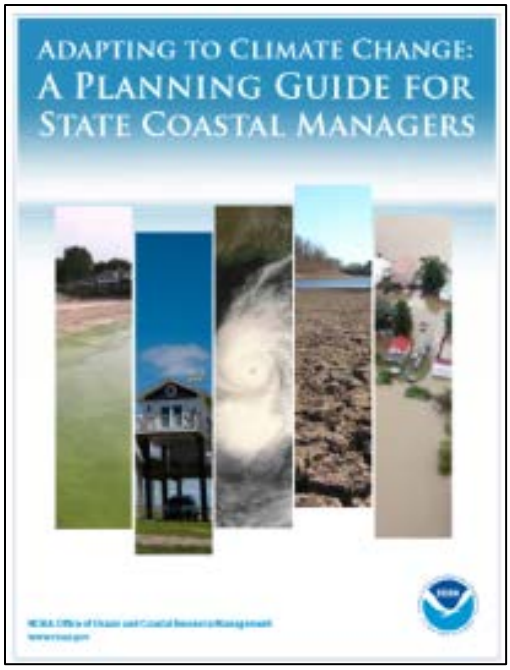


Figure 14. Report: Adapting to Climate Change: A Planning Guide for State Coastal Managers (NOAA 2010).

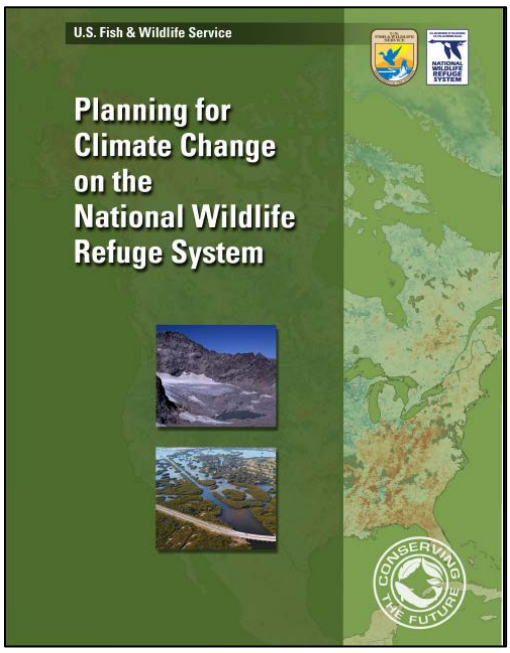


Figure 15. Report: Planning for Climate Change on the National Wildlife Refuge System (Czech et al. 2014).

Integrating Climate Change into Northeast and Midwest State Wildlife Action Plans is aimed at State Wildlife Action Plans, providing a synthesis of what is known and what is uncertain about climate change and its impacts across the Northeast Climate Science Center region, with a particular focus on

the responses and vulnerabilities of Regional Species of Greatest Conservation Need (RSGCN) and the habitats they depend on (Staudinger et al. 2015) (Figure 16).

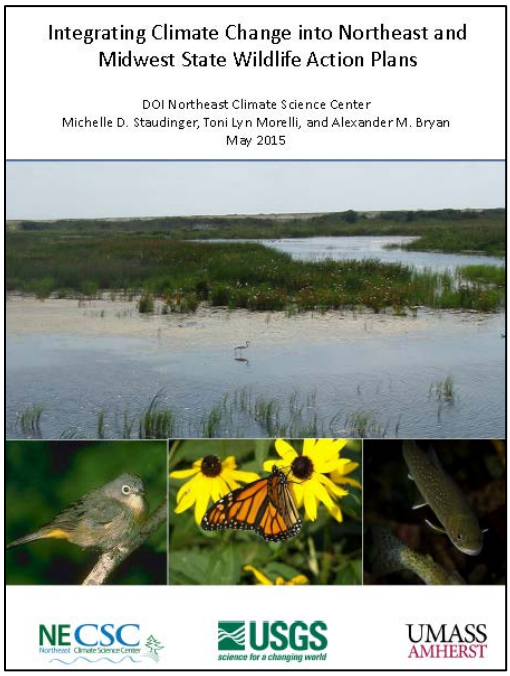


Figure 16. Report: Integrating Climate Change into Northeast and Midwest State Wildlife Action Plans (Staudinger et al. 2015).
https://necsc.umass.edu/sites/default/files/Staudinger%20et%20al.%202015%20Integrating%20Climate%20Change%20into%20NE%20and%20MW%20SWAPs.pdf

Step by step guidance for selecting the objectives and scope of a VA is provided by the following group of documents, which reflect the views of interagency and interdisciplinary working groups and writing teams, and are written in an accessible style. Some are tailored to the park context while others feature the broader coastal landscape. There is relatively less guidance and experience with facilities and cultural resources.

Many of the conservation-focused approaches to vulnerability assessment acknowledge climate change scenarios out to 2100, however, time frames relevant to near term concerns are less frequently highlighted. Some guidance is strongly recommending consideration of revising conservation goals to allow natural adaptation to occur, but this approach is not as appropriate for vulnerable facilities or cultural resources that are at existential risk.

Scoping the Scale of Coastal Vulnerability Assessments

Spatial Scale

If possible, spatial analyses that map patterns of vulnerability will identify the locations of the most vulnerable areas and potential refugia. This provides the scientific data needed to prioritize areas for adaptation.

Boundaries

For coastal parks, whether to include the marine environment may depend on park boundaries. Even if the park boundary ends at mean low water, look beyond your park boundaries and seek opportunities to partner with groups interested in understanding the larger coastal ecosystem. The marine environment is highly connected requiring a larger scale of analysis to see the linkages, and parks can be vital components of adaptation for the larger seascape.

Scale for Projections

Establish a time horizon for the projections to be used in the assessment that is meaningful to management horizons, but still long term enough to capture accelerating change. While shorter time points provide more certainty they may hide the larger changes coming in late century. Many available projections have been developed for 2100, though intermediate decadal time periods are becoming more available since this more distant future may have contributed to delaying action.

Time to Conduct Assessment

Since many of the inputs into VAs have significant uncertainty, there's no perfect assessment. If localized, high resolution info isn't currently available for in depth assessment, we recommend moving forward with a rapid assessment that can then be included in policy dialogue and influence other VAs.

National Support for Conducting Vulnerability Assessments

Use the following documents to support your case in conducting a VA. Proposals will want to see how your VA will support larger policy goals. The NPS has taken a strong leadership role in climate adaptation and mitigation. Emerging policy guidance exhibits broad based concerns for natural resource, facilities and cultural resource vulnerability.

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

This 2009 Secretarial Order created a Climate Change Response Council tasked with planning, building scientific capacity, applying a landscape approach, addressing the specific needs of American Indians and Alaska Natives. While the term "vulnerability assessment" is not used, bureaus and offices are directed to "consider and analyze potential climate change impacts when undertaking long range planning exercises, setting priorities for scientific research, developing multi-year management plans and making major decisions regarding potential use of resources under the Department's purview", which provides strong support for a mainstreaming approach to assessments.

Policy Memorandum 14-02 Climate Change and Stewardship of Cultural Resources

Park managers are directed to incorporate adaptive research and management of cultural resources into planning and reporting, to innovate for emerging threats, include mitigation in the adaptive reuse of historic buildings, and reduce risk in siting museum facilities and collections (NPS 2014). Climate adaptation concerns need to influence the focus of inventory work, integrate resource vulnerability and significance, understand the range of climate effects, and consider the value of cultural resources in answering questions about climate change and adaptation.

Policy Memorandum12-02 Applying management policies in the context of climate change:
This memo addresses the issue of reconciling management policies that require preserving resources with no impairment by park activities, with external threats such as climate change impacts (NPS 2012a). The guidance confirms that park managers can continue to work to remove invasive species and other stressors, maintain natural processes, restore ecosystems and other measures that support resilience, while at the same time contributing to the mitigation from external sources such as human-induced climate change.

Policy Memorandum 15-01 Addressing Climate Change and Natural Hazards for Facilities:
The memo recaps recent NPS policies and guidance, and directs park managers to "proactively identify and document facility vulnerabilities to climate change and other natural hazards", to know the hazards affecting each location, their relative important to the park, and the measures that can be taken to promote resilience (NPS 2015).

Link to Regional Strategies

There are several strategies, action plans and networks of peers in the NPS and beyond who are working on coastal VAs. Link up with these groups and highlight how your VA will contribute. The following documents reflect the policy direction, providing additional detail and examples of themes and issues that are being taken into consideration in the NER.

NPS Climate Change Response Strategy (NPS 2010) provides direction to the NPS and its employees to address the impacts of climate change, describing goals and objectives to guide their actions under four integrated components: science, adaptation, mitigation and communication (Figure 17). It strongly urges conducting scientific research and vulnerability assessments to support "on-the-ground adaptation planning".

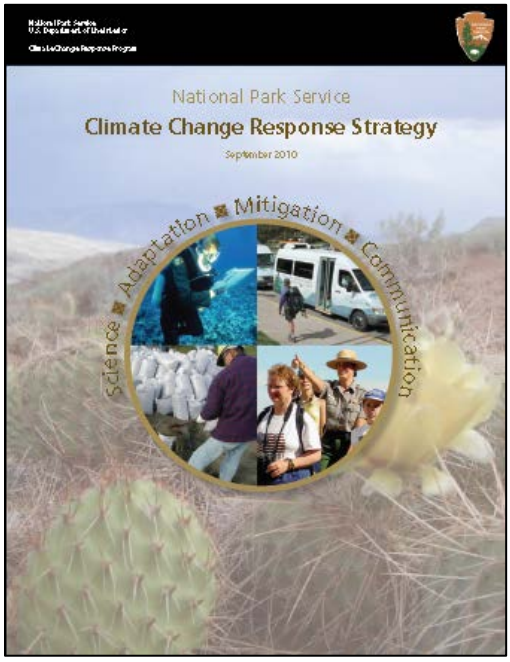


Figure 17. Report: NPS Climate Change Response Strategy (NPS 2010).
https://www.nature.nps.gov/climatechange/docs/NPS_CCRS.pdf

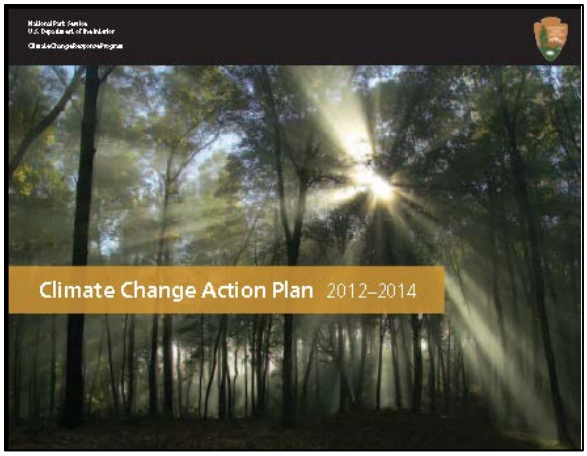


Figure 18. Report: NPS Climate Change Action Plan (NPS 2012b).
http://www.wilderness.net/toolboxes/documents/climate/2012_NPS-CCRPActionPlan.pdf

Northeast Region Climate Change Strategy and Action Plan 2011-2014 (NPS 2011)reflects the application of the national NPS strategy, setting out 13 goals and their implementation for science, adaptation, mitigation and communication (Figure 19). http://classicinside.nps.gov/documents/20110610_NER_Climate_Change_Strategy_web.pdf (available on NPS intranet only).

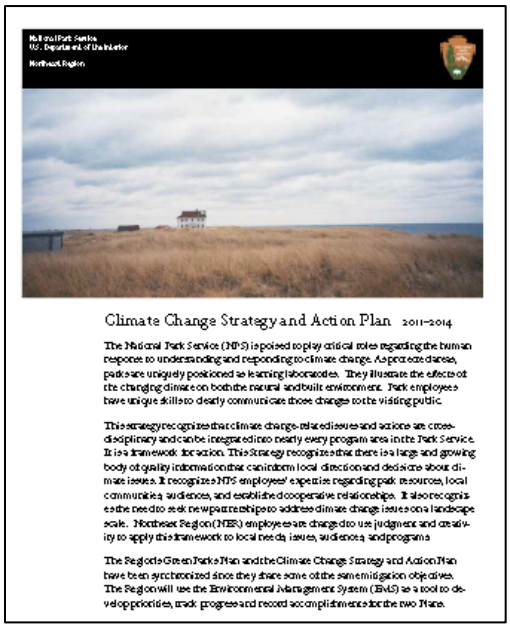


Figure 19. Report: Northeast Region Climate Change Strategy and Action Plan (NPS 2011).
http://classicinside.nps.gov/documents/20110610_NER_Climate_Change_Strategy_web.pdf

*Climate change in Northeast Region coastal parks: Synthesis of a workshop on research and monitoring needs (*Roman and Babson 2013*)* identifies research, modeling and monitoring needs and promising approaches to address vulnerability related to cultural resources, facilities, coastal

processes, salt marshes, marine ecosystems, fresh water habits and the fauna which depend on them, and migratory species (Figure 20).

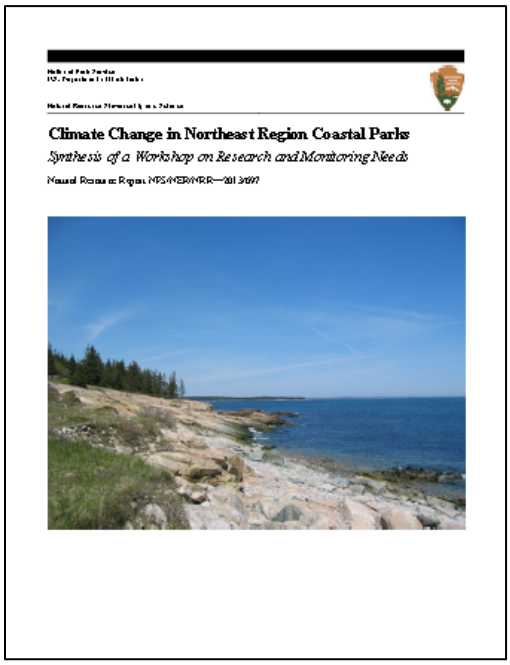


Figure 20. Climate change in Northeast Region coastal parks (Roman and Babson 2013). http://irmafiles.nps.gov/reference/holding/475468.

B. Gathering Relevant Data and Expertise

Key Points of this Section

Even without local data, there are significant data and models available from the internet that can reduce costs to the assessment and provide information beyond the park area. Another key action would be to reach out to local experts in academia and neighboring land use managers, as they may have existing data or are interested in combining resources to broaden the analysis.

Gathering Relevant Data and Expertise

- Review existing literature on assessment targets and climate impacts
- Reach out to subject experts on target species or systems
- Obtain or develop climatic projections, focusing on ecologically relevant variables and suitable spatial and temporal scales
- Obtain or develop ecological response projections

Paths to consider in view of park situation

- Identifying climate phenomena and projections
- Applying remote sensing and mapping of trends and scenarios
- Identifying biophysical impacts

- Identifying socio-economic impacts

Identifying Climate Phenomena and Projections

The North Atlantic Landscape Conservation Cooperative (LCC) is a partnership comprised of federal, state, tribal, academic and non-profit conservation communities working together to address increasing land use pressures and widespread resource threats and uncertainties amplified by a rapidly changing climate. The partnership addresses these regional threats and uncertainties by agreeing on common goals for land, water, fish, wildlife, plant and cultural resources and jointly developing the scientific information and tools needed to prioritize and guide more effective conservation actions by partners toward those goals. Spatial data is provided via their Conservation Planning Atlas https://nalcc.databasin.org/ (Figure 21).



Figure 21. The Conservation Planning Atlas compiles data layers developed by the North Atlantic Landscape Conservation Cooperative that can be used for vulnerability assessments.

Park-specific Climate Briefs

The NPS offers a range of resources both for the public and on internal NPS intranet websites including information on individual parks. These park specific climate briefs include analysis of temperature and precipitation extremes, projections for park visitation and changes in trees, pests and weeds http://science.nature.nps.gov/climatechange/ (Figure 22).

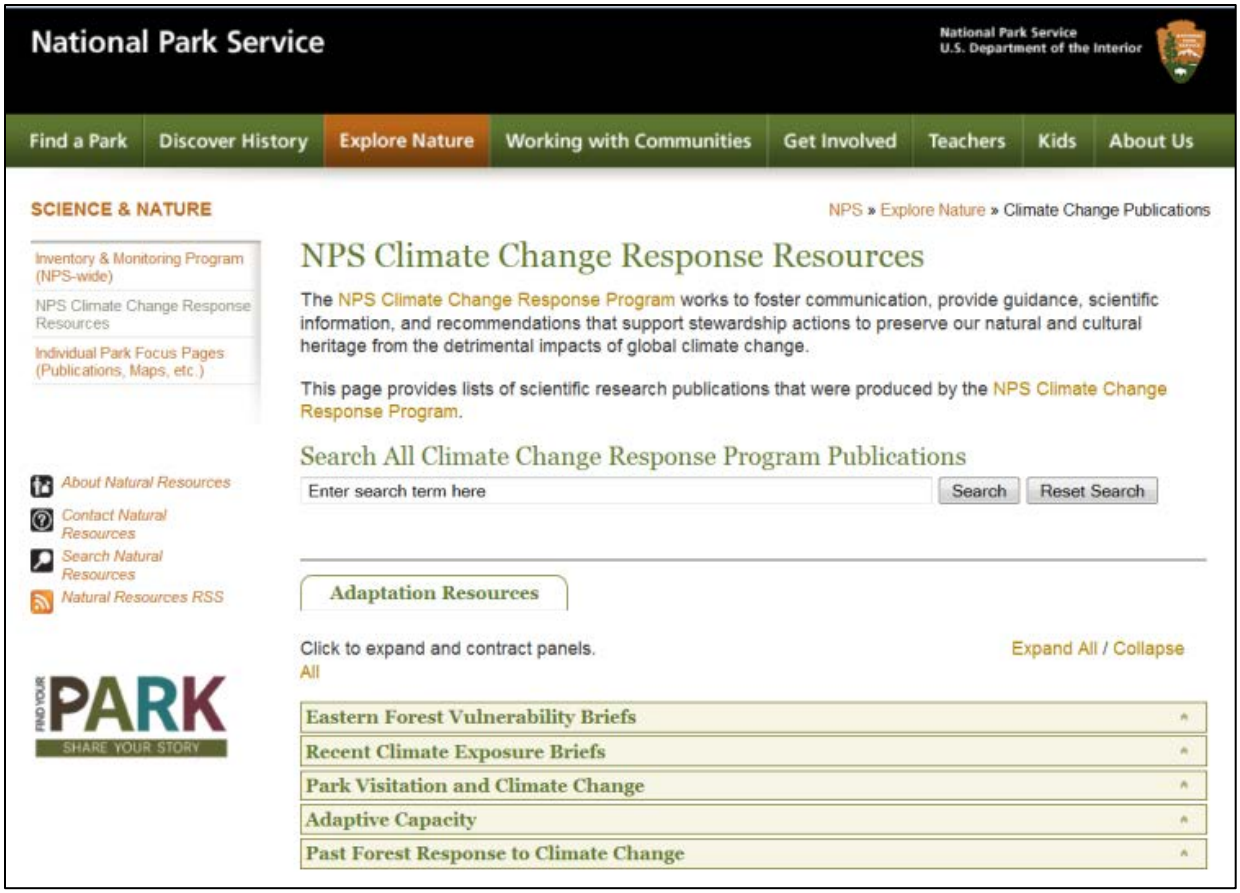


Figure 22. NPS Climate Change Response Reports.

NPS Climate Change Summary Reports

Historical and projected trends in temperature and precipitation are being provided for all parks through Climate Change Summaries. Figure 23 is an excerpted example from Colonial National Historical Park, Virginia. (https://irma.nps.gov/DataStore/Reference/Profile/2224550)

Climate Change Summary, Colonial National Historical Park, Virginia

Patrick Gonzalez

Natural Resource Stewardship and Science, U.S. National Park Service, Washington, DC

April 7, 2015

Climate Trends for the Area within Park Boundaries

- Average annual temperature increased at a statistically significant rate in the period 1950-2010 (Table 1, Figure 1). Warming has been great in the summer (June-August).
- Average total precipitation has increased since 1950, but the rate has not been statistically significant (Table 1, Figure 2). Autumn (September-November) precipitation has increased at a statistically significant rate of 51 ± 25% per century.

Figure 23. Climate Change Summary Report, Colonial National Historical Park, Virginia.

Useful Resources for Identifying Climate Phenomena and Projections

A variety of sources of climate data that will be useful for vulnerability assessments is available at national, regional and local scales. This section gives an overview of and points to some potential data sources. Both historical trends and future projections are needed for exposure analysis. Issues to consider include data quality (e.g. horizontal resolution, vertical accuracy), time horizon (are there earlier than end of century projections), and the relevance of the variable (e.g. is it annual average when the period of interest is seasonal or peak?).

Sea level rise and Storm surge

When thinking about SLR and inundation risk, both storm vulnerability and daily tidal inundation need to be considered, but are two different vulnerabilities/exposures. Whether storms in the Northeast are becoming more intense or frequent is an active area of research, with projections that North Atlantic hurricanes may increase in intensity and rainfall rates (Melillo et al. 2014). Even without changes in storm characteristics, SLR is projected to yield large changes in the frequency and intensity of coastal flooding (Horton et al. 2015).

Historical rates of SLR based on NOAA's long term tide gauges can be found at http://tidesandcurrents.noaa.gov/sltrends/mslUSTrendsTable.htm.

NOAA calculates SLR over the entire period of record for a particular gauge. NOAA recommends using a minimum of a 30 years record for calculating rates of SLR in order to account for long term variability. Parks may want to calculate rates of SLR over shorter periods, such as to compare with shorter Sediment Elevation Table (SET) records, but should note the loss of accuracy if not accounting for seasonal and tidal variability (up to the scale of a tidal epoch of 19 years). Sources of water level data for NER parks, including non-NOAA gauges, has been compiled and mapped in a database available at https://irma.nps.gov/App/Reference/Profile/2220635

NPS and Western Carolina University did a 1m SLR Exposure Study (Peek et al. 2015) covering 40 coastal parks including15 NER parks, and a follow up study that includes the remaining NER coastal parks is in progress. Results from this group of initial coastal parks yielded over 39% of the assets designated as high exposure, with a cumulative value of over $40 billion. The majority of the high risk assets were from the Southeast Region low-lying barrier island parks; however, the NER also had over one-third of its assets designated as high exposure, many of which are historically and culturally significant to NPS (Peek et al. 2015).

There are many ways to develop projections of future SLR, depending on which sources are included, local corrections and desired level of uncertainty/risk. See Elevation Data section for data considerations for inundation modeling. One way to skirt large uncertainty is to map static inundation (sometimes called bathtub modeling) to certain depths without specifying when that amount of SLR is expected. For 9 NER parks in the Monumentation project, SLR inundation risk for sentinel sites at these parks for scenarios of 60 cm, 1 m and 2 m were estimated. GIS layers are available on IRMA (Integrated Resource Management Applications) and a map viewer with results is at http://www.arcgis.com/apps/OnePane/basicviewer/index.html?appid=e004f38e68634a178d61b239f3cd98b3.

Another source of SLR inundation mapping for all coastal NPS units is in development. Consistent projections of SLR based on IPCC rates of SLR and local corrections for land level change where long term local NOAA tide gauges are available for all coastal NPS units are in development, to be finalized in 2016 (see Schupp et al. 2015 Case Study 24 for a project description). Using the US Army Corps of Engineers Sea Level Change Curve Calculator (available at http://www.corpsclimate.us/ccaceslcurves.cfm) intermediate time horizons including 2030 and 2050 will be provided. Intermediate products of park briefs have been provided directly to parks for Foundation Document and State of the Park workshops (e.g. Caffrey 2014).

While static inundation models are useful in many areas, it is important to consider where landforms are more likely to exhibit a dynamic response and a more complex model may be necessary. A USGS study provides a framework for sea-level rise impact modeling for the U.S. Atlantic coast, distinguishing where static inundation (bathtub) models are sufficient and where dynamic models are likely to be more applicable http://pubs.usgs.gov/of/2014/1252/. This builds on Bayesian Network modeling of long term shoreline change (Gutierrez et al. 2011) which is being applied to ASIS as part of a study of Piping Plover habitat. The need to develop dynamic and predictive models by landform type was identified in a 2009 NER climate change research needs workshop (Roman and Babson 2013); examples of habitat evolution models currently being applied to NER coastal salt marshes include the Marsh Equilibrium Model (based on Morris et al. 2002).

Both the NPS-wide (Caffrey) and NER projects (Monumentation) also include storm surge modeling using NOAA's SLOSH (Sea Lake and Overland Surges from Hurricanes) model. This tool provides storm surge modeling at current sea level. Combining with sea level rise scenarios isn't simply additive post-model run because SLOSH dynamically models water levels and the hydrodynamics would be different when run with different basin depths. Storm surge maps for the NPS-wide effort by storm category and at both mean tide and high tide are available at https://www.flickr.com/photos/125040673@N03/sets/. For the 9 NER Monumentation parks, similar storm surge modeling was corrected with higher accuracy elevation data (Light Detection and Ranging [LiDAR] vs default USGS National Elevation Dataset [NED]) for mean tide; GIS layers are available through IRMA. A comparison of the two efforts which vary only by the elevation data show a large percentage of sites where the NPS-wide effort says will be inundated for a given Category storm that are not estimated to be inundated in the NER project due to differences in the elevation data (see Elevation Data section).

Temperature and Precipitation

Inventories of climate information has compiled by the I&M program in an NPS Climate Database available at https://irma.nps.gov/DataStore/Reference/Profile/2167254 with links to active online data sources at http://science.nature.nps.gov/IM/inventory/climate/index.cfm

For the nine coastal NER I&M parks, (289 parks were analyzed nationally), Monahan and Fisichelli (2014) categorized temperature and precipitation variables as "extreme" if the most recent 10, 20, and 30-year intervals, on average, exceeded 95% of the historical range of conditions(1901–2012). All 9 parks had at least 2 extreme warm variables, no extreme cold variables and at least 1 extreme

wet variable. All but one (ASIS) had no extreme dry variables. Park specific briefs are available at http://science.nature.nps.gov/im/inventory/climate/recent.cfm

Climate summaries of historical trends and modeled projections in temperature and precipitation are being provided for parks as they do Foundation Document workshops (e.g. Gonzalez 2014) and are available via the IRMA Portal. These are based on statistical downscaling of global climate models to locally relevant scales of 800 m for temperature and 8 km for precipitation. http://share.inside.nps.gov/sites/nrss/div/ccrp/shared/Planning/Climate Change Science for Parks

Maps of projections for the entire Northeast by decade (2010-2080) done by the Northeast Climate Science Center are available through the North Atlantic LCC Conservation Planning Atlas for the following variables: Mean Maximum Summer Temperature, Mean Minimum Winter Temperature, Growing Season Degree Days and Total Annual Precipitation. https://nalcc.databasin.org/galleries/bb0f2f56119b4f89a33f7f3bd4c1732b#expand=52764

The spatial resolution of these downscaled projections (600 m) is locally specific for parks, but for most NER parks, is not useful for distinguishing spatial differences within a park.

An example of a study that includes both dynamical and statistical downscaling technique was modeling of temperature and humidity variability at Shenandoah National Park (Lee et al. 2014).

Applying remote sensing and mapping of trends and scenarios

Elevation data

Elevation is one of the major contributors to determining exposure to sea level rise and storm surge. It is determined relative to a known geodetic vertical datum (e.g. NAVD88) or tidal datums (e.g. Mean Sea Level, Mean Higher High Water relative to the current National Tidal Datum epoch 1983-2001). Bathymetry datasets (water depths) may need to be merged with topography data, which often is mapped to a different datum. VDatum is a tool developed by NOAA that can be used to convert between tidal, orthometric and ellipsoidal datums. Beyond understanding inundation risk, tidal datums are important for considering vulnerability of ecosystems that are adapted to particular tidal regimes, such as salt marshes, and the species that depend on them for habitat. Tidal datums are available for NOAA tide gauges, both the long term stations and many additional shorter term historical stations. http://tidesandcurrents.noaa.gov/datums.html?id=8443970

Parks may have additional needs for measuring a local tidal datum, such as where conditions are substantially different than the nearest NOAA station due to basin geometry. At SET sites, the I&M networks calculate a local tidal datum. Depending on the use and length of record, NOAA has methods to correct these to longer term stations, but it should be kept in mind that these corrections rely on the1983-2001 tidal epoch and sea level may have risen enough since then for a noticeable offset.

When considering the uncertainty in inundation models, it is important to weigh the vertical accuracy of the elevation data relative to the sea level rise scenarios (Murdukhayeva et al. 2013). Elevation data options include the USGS NED, LiDAR and survey grade GPS (Global Positioning System)

such as RTK-GPS (Real Time Kinematic) and Total Stations. The NED compiles available elevation data into a digitally seamless grid at 1/9, 1/3, 1 and 2 seconds of arc resolution depending on the location. In the Northeast, almost all areas are either at 1/9 or 1/3 arc second resolution, but in other areas the vertical accuracy can be as poor as 2.4 m. In areas with 1/9 arc second coverage, LiDAR data has been incorporated. LiDAR accuracy depends on the processing, but stated vertical accuracy is 15-30 cm. Comparisons in Murdukhayeva et al. (2013) between LiDAR and RTK-GPS have a RMSE (root mean squared error) of 0.53 m for CACO and 0.33 m for ASIS. Survey grade GPS has a stated vertical accuracy of 1-2 cm.

Geospatial datasets of high accuracy elevation data (RTK-GPS) for "sentinel sites" selected by each of 9 NER parks, along with the inundation modeling described above are available at http://www.arcgis.com/apps/OnePane/basicviewer/index.html?appid=e004f38e68634a178d61b239f3cd98b3

Capturing Tacit Knowledge

A project at ACAD interviews their retiring staff to capture institutional knowledge from long-serving staff. Consider using this tactic for all staff who are either moving on or currently work at the site to capture their experience with changing climate and impacts.

A comparison between available LiDAR and RTK-GPS at these points for 5 parks varies between parks with average differences of 0.26-0.69 m depending on the park, with maximum differences as much 5 m.

Some of the issues with LiDAR are a result of processing for "bare earth" when there are structures that the processing removes. Some applications of inundation mapping are most interested in the structures that have been removed. A building elevation data collection process developed at GATE that map 1st floor threshold elevations using RTK-GPS tied to FMSS (Facilities Management Software System) is being expanded to other NER parks and other regions.

Some of the tools (e.g. SLOSH) that rely on less accurate elevation datasets can still be a useful first screening for exposure, and based on that, needs for where higher accuracy elevation data is needed can be prioritized.

> *As part of the USGS Sea-Level Rise Hazards and Decision-Support project, this assessment seeks to predict the response to sea-level rise across the coastal landscape under a range of future scenarios by evaluating the likelihood of inundation as well as dynamic coastal change. The research is being conducted in conjunction with resource managers and decision makers from federal and state agencies, and non-governmental organizations and utilizes a structured decision-making approach to ensure research outcomes meet decision making needs."* http://woodshole.er.usgs.gov/project-pages/coastal_response/index.html

Identifying biophysical impacts

There are several groups and online sources that can provide biophysical data. Much of the data is not climate change specific but that should be a concern. This section gives an overview of and

points to some potential sources for gathering biophysical data. Issues to consider include identifying priority species of concern, and combining secondary data with limited primary data collection needs to keep VA costs low.

NEclimateUS.org (a.k.a. 'NExUS')

This is a searchable online database that provides a gateway to climate information for the Eastern US. NExUS summarizes available data, tools, plans and reports; climate-related organizations; ongoing projects; and needs for climate information identified largely in publications (Figure 24). http://neclimateus.org/

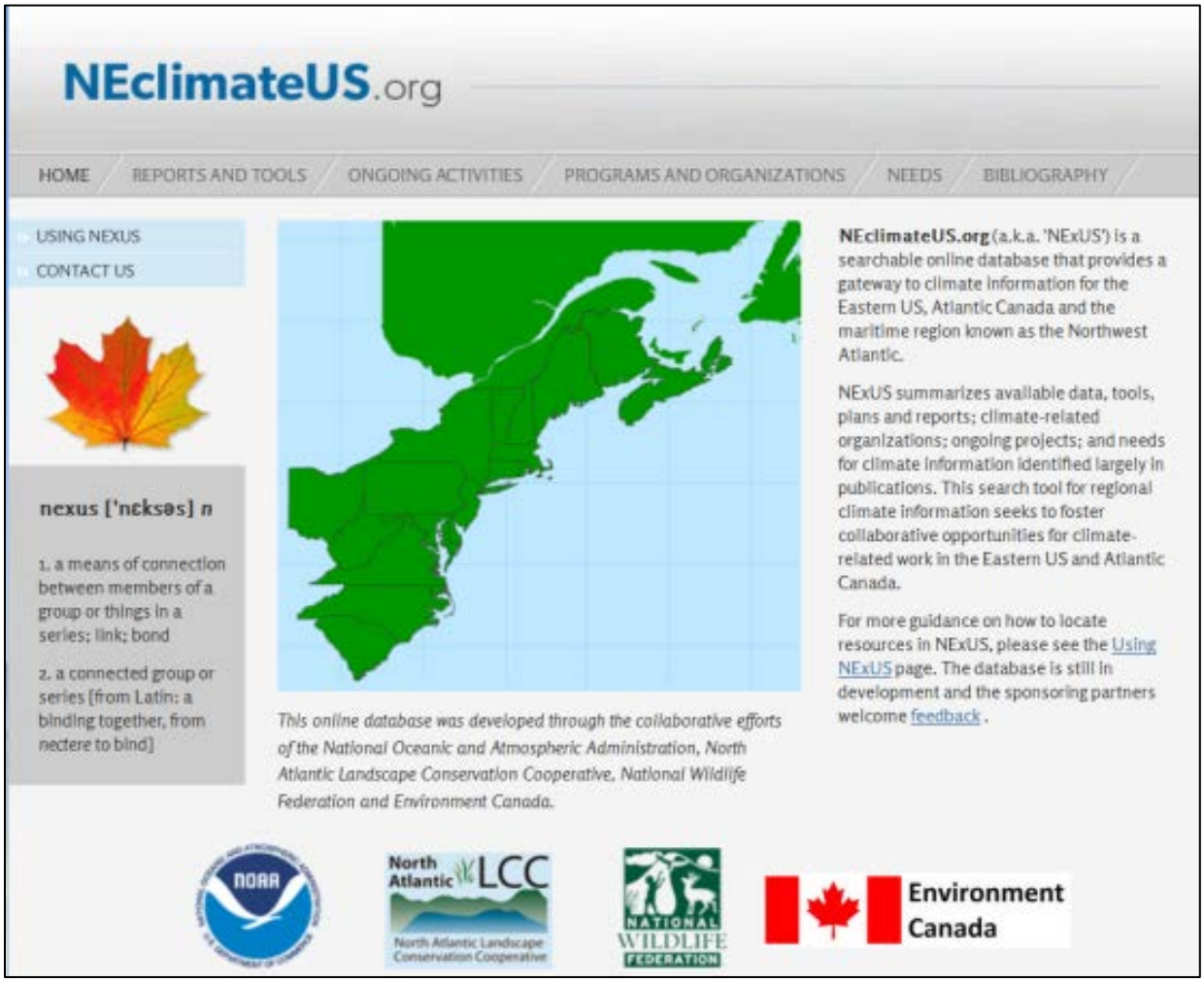


Figure 24. Resource: Online climate database for the Northeast. http://NEclimateUS.org

Climate Change Vulnerability Assessment for Natural Resources Management: Toolbox of Methods with Case Studies, Version 2.0.

This document contains a variety of guidance on how to assess and gather data on key species and habitats (Figure 25) (Johnson 2014). This is survey of some of the principal CCVA methods in use

today for: (1) species; (2) habitats; (3) places (protected areas, watersheds, landscapes); (4) ecosystem processes; (5) ecosystem services; (6) water resources; and (7) coastal resources.

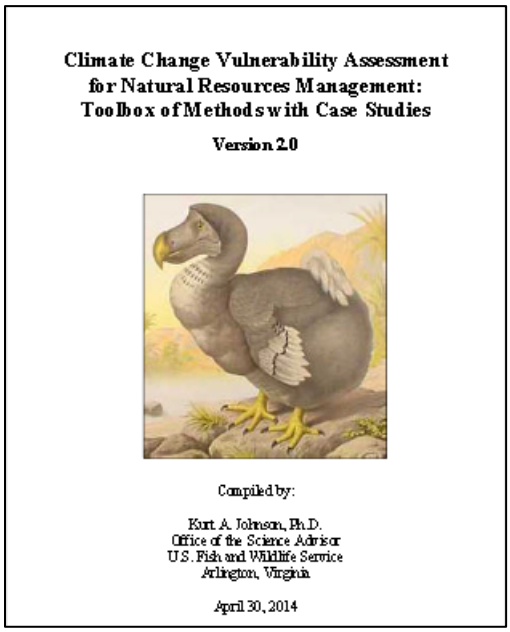


Figure 25. Report: Toolbox of Methods with Case Studies (Johnson, 2014). http://www.fws.gov/home/climatechange/pdf/Guide-to-Vulnerability-Assessment%20Methods-Version-2-0.pdf

A Strategy for Enhanced Monitoring of Natural Resource Condition in North Atlantic Coastal Parks to Address the Effects of Rapid Climate Change

The NPS I&M Networks (Northeast Coastal and Barrier Network and Northeast Temperate Network cover coastal NER parks) are an important resource for collecting baseline and long-term trends (Stevens et al. 2010). This was developed at a 2010 workshop prioritized two groups of Vital Sign indicators for climate change indicators: one related to the collection and analysis of new data (including enhancing existing monitoring) and the second related to the analysis of secondary data sets (existing long-term data collected by other agencies and organizations).

While not all priorities have been funded, focal priorities to assessing the impact of sea level rise on tidal marsh capital as well as the status of salt marsh breeding birds have been providing important data, and are areas of ongoing interagency collaboration.
https://irma.nps.gov/App/Reference/Profile/2166645

Identifying socio-economic impacts

Social Vulnerability Index (SoVI) to environmental Hazards

Developed by the University of South Carolina's Hazards and Vulnerability Research Institute the SoVI provides measures of social vulnerability by county across the USA based on well tested indicators. http://artsandsciences.sc.edu/geog/hvri/sovi-1

NPS Facilities Management Software System (FMSS)

This NPS resource could prove valuable in collecting existing data on facilities. See the ASIS example of use of this database for conditions of existing facilities and potential replacement costs to define adaptive capacity (ICF International 2012).

Economics: National Ocean Watch (ENOW)

ENOW is managed by NOAA to provide time-series data on the ocean and Great Lakes economy, which includes six economic sectors dependent on the oceans and Great Lakes. ENOW is available for counties, states, regions, and the nation in a wide variety of formats. ENOW contains datasets on ecological, social and economic elements.
http://coast.noaa.gov/dataregistry/search/collection/info/enow

The National Ocean Economics Program (NOEP)

NOEP provides a full range of the most current policy-relevant economic and demographic information available on changes and trends along the U.S. coast, Great Lakes, and coastal waters.
http://oceaneconomics.org/

Examples from NPS Experience

Parks pursue vulnerability information in a variety of ways. For example CACO has been involved in: 1) regional transportation scenario planning, 2) USGS Coastal Vulnerability Index, and 3) a salt marsh vulnerability assessment that is underway.

C. Assessing components of natural resource, cultural resource and facilities vulnerability

Key Points of this Section

Much of the emphasis in the guidance documents presented in the earlier section on determining objectives and scope is on natural resources and conservation and is relatively general in nature. Many studies of single habitat types or locations within parks are becoming available. Fortunately new work is now offering examples of a more integrated approach to natural resource vulnerability assessment within a park that also places park resources in a broader context. A good example is the marine vulnerability assessment for CUIS (Peek et al. 2016), which is further discussed in the next section. This section offers guidance on:

- Assessing components of natural resource, cultural resource or facilities vulnerability
- Evaluate climate sensitivity of assessment targets
- Determine likely exposure of targets to climatic/ecological change
- Consider adaptive capacity of targets that can moderate potential impact
- Estimate overall vulnerability of targets
- Document level of confidence or uncertainty in assessments

Useful Resources for Assessing the Components of natural resource, cultural resource and facilities vulnerability

Though before selecting specific methods and tools for the VA, it is vital that an overall approach is selected that can ensure adherence to the goals of the assessment, the resources available and the

availability of quality data to trust the outputs. The Department of Interior's Northeast Climate Science Center has developed a guide for how to conduct vulnerability assessments using a variety of models. They compare the benefits and constraints for three types of modelling – correlative, mechanistic and trait-based (Staudinger et al. 2015). Some approaches are relatively inexpensive and don't require significant data such as the correlative models and Trait-based assessments. Though these approaches may not be as informative on the adaptive capacity aspect of VAs like the Mechanistic models provide. Regardless of the approach, there will always be significant levels of uncertainty if the timelines go out a decade or more due to the inherent complexity of the systems involved.

Involving Long Term Staff in Assessing Trends

For decades, Ishmael Ennis, a now retired chief of maintenance for ASIS, experienced the cycle of storm damage followed by repairing facilities. Realizing the futility, he and his team had been tinkering with the infrastructure, making it resilient and adaptable to shifting sand and flooding. Ennis was quoted by the Washington Post (Guo 2014) when reflecting on how they assessed their vulnerability and decided to adapt – "Maintenance," he said with a shrug, "is just common sense." When conducting your assessment, try to find long-term staff members who can recall the changes in the environment but also facilities management. They likely have stories to tell that can fill in the data gaps.

Natural Resources

This section provides examples and guidance on how to assess natural resources.

Marine Vulnerability Assessment of Cumberland Island National Seashore

The CUIS study by Western Carolina University (Peek et al. 2016) contains a detailed field level analysis of the marine habitats and coastal processes through the use of a matrix scoring system. The report offers park managers a well-thought through outline and attempts to introduce an ecosystem oriented perspective (Figure 26). The authors note that they applied all four steps of the approach described in Scanning the Conservation Horizon (Glick et al. 2011), so it provides a carefully worked through example of the method. Important climate stressors in Cumberland Island include sea level rise, ocean acidification, temperature changes and salinity. The habitat focus of the study encompasses marine nearshore subtidal, intertidal beach, low salt marsh, salt flats, high fringing salt marsh, tidal mud flats, shellfish bets, tidal creeks and estuarine nearshore subtidal. The study creates metrics for the vulnerability of each habitat which are combined into an index of combined climate and non-climate stresses for the marine component of the park. Incorporating the non-climate stress element helps place the resources of the park in a regional context, which will be valuable in the adaptation planning stage.

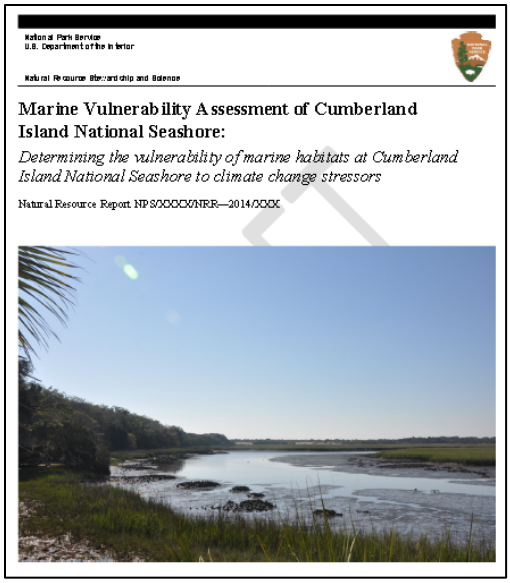


Figure 26. Report: Marine Vulnerability Assessment of Cumberland Island National Seashore (Peek et al. 2016). http://psds.wcu.edu/marine-vulnerability-assessment-of-cumberland-island-national-seashore/\

EPA's Climate Ready Estuaries Massachusetts Bay Salt Marsh Assessment

Program piloted a rapid VA methodology using expert elicitation for select ecosystem processes in Massachusetts Bay (US EPA 2012). (Figure 27) The rapid VA was centered around a two-day workshop to capture expert judgments on the sensitivities of ecosystem process components under future climate scenarios - two distinct but scientifically credible climate futures for a mid-century (2040-2069) time period. The VA focused on only two key salt marsh ecosystem processes: sediment retention and community interactions within salt marsh sharp-tailed sparrow nesting habitat. The methodology applied was a modification of formal (usually quantitative) expert elicitation that uses qualitative judgments to explore complex ecological questions. Influence diagrams showing causal relationships among variables were used to capture the experts' collective understanding of selected ecosystem processes under current conditions and under two climate scenarios. One of the findings from the pilot was that using the experts' judgments on the sensitivities of key ecosystem process components to future climate conditions, it is possible to identify 'top pathways' for which there are available adaptation options.



Figure 27. Report: Climate Ready Estuaries Vulnerability Assessment (US EPA 2012).

NPS Beach Nourishment Guidance

This manual is intended to be used as guidance by NPS staff to better plan and manage beach nourishment projects when beach nourishment has been determined to be consistent with NPS Management Policies (Figure 28) (Dallas et al. 2012). This manual provides tools for resource managers to interface with partners that are completing technical designs and outlines best management practices that can be utilized to avoid or minimize potential adverse impacts.

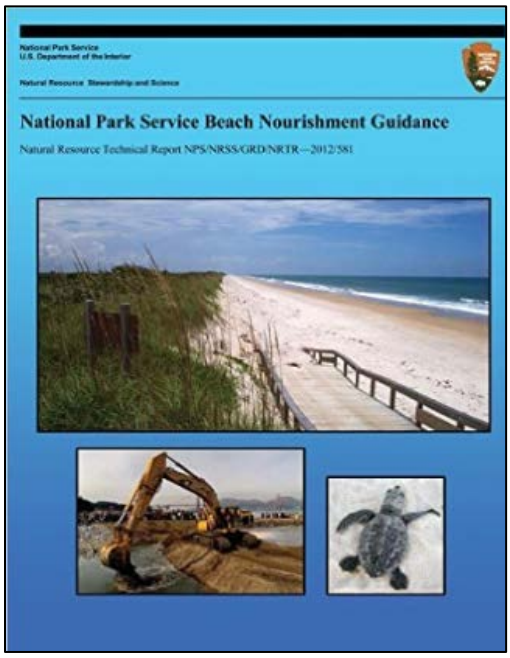


Figure 28. Report: NPS Beach Nourishment Guidance (Dallas et al. 2012).

NOAA Fish Stock Climate Vulnerability Assessment Methodology

NOAA is finalizing a methodology rapidly assess the vulnerability of marine fish stocks (Morrison et al. 2015). (Figure 29) The methodology will assist with assessing stocks as well as identifying what type of additional data is required to improve the analysis.
http://www.st.nmfs.noaa.gov/ecosystems/climate/activities/assessing-vulnerability-of-fish-stocks



Figure 29. Report: Fish Stock Climate Vulnerability (Morrison et al. 2015).

Marshes on the Move: A Manager's Guide to Understanding and Using Model Results Depicting Potential Impacts of Sea Level Rise on Coastal Wetlands

Intended for people who don't develop models, though they want to use model outputs for decision-making (Figure 30) (The Nature Conservancy and NOAA 2011). The guide explains the key dynamics affecting wetland response to SLR and associated input parameters and data needs for modeling.

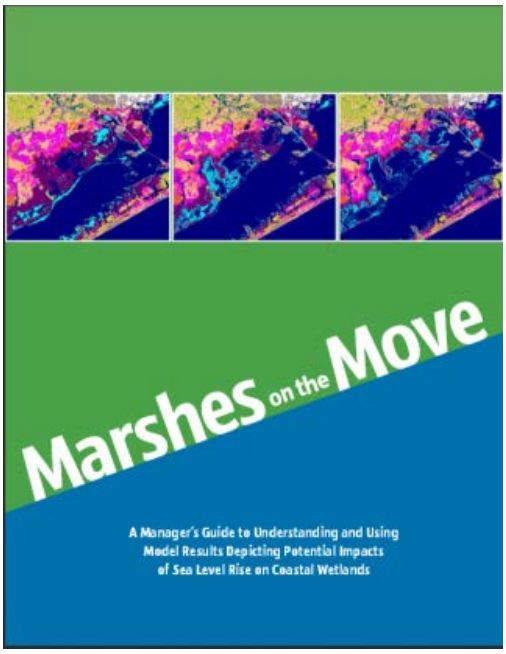


Figure 30. Report: Marshes on the Move (The Nature Conservancy and NOAA 2011).

Make Way for Marshes: Guidance on Using Models of Tidal Marsh Migration to Support Community Resilience to Sea Level Rise

This report covers the entire modeling lifecycle from developing a modeling approach and working with data to communicating modeling results (Northeast Regional Ocean Council 2015) (Figure 31). The focus is on the northeastern US, though the can be used for modeling of marsh migration in other regions.



Figure 31. Report: Make Way for Marshes (Northeast Regional Ocean Council 2015).

USGS Coastal Vulnerability Index

This Coastal Vulnerability Index (CVI) was a national assessment to determine the risks due to SLR. USGS supported NPS in applying the CVI to coastal park units (Hammar-Klose et al. 2003) (Figure 32). The CVI approach combines a coastal system's susceptibility to change with its natural ability to adapt to changing environmental conditions, and yields a relative measure of the system's natural vulnerability to the effects of SLR. Reports and digital data are available on the website http://woodshole.er.usgs.gov/project-pages/cvi/.



Figure 32. Resource: Coastal Vulnerability Index.

Cultural Resources

The NPS convened a group of leaders in planning, architecture, landscape architecture, historic preservation, archeology, science, and park and cultural resource management in 2014 to identify strategies for preserving cultural heritage in coastal parks. While focused on developing decision-making frameworks for adaptation, they identified some priority issues that can assist in assessing the climate change vulnerability of cultural resources in order to support adaptation decisions. These include:

- A national inventory and prioritization of vulnerable sites would help to assess the singularity / uniqueness of sites.
- A regional inventory or documentation of threatened resources, including timeframe and level of vulnerability, would help plan and set priorities.

- A resource in poor condition due to deferred maintenance or insufficient funding has a different kind of vulnerability.
- Distinguish the vulnerability of historic resource itself from the vulnerability of its infrastructure; the latter may have more adaptability.
- Vulnerability assessment phase must also include a risk assessment; recalibrate the dilemma of saving one resource at the expense of another.
- Establish a way to quantify resiliency in order to measure buildings against each other.
- Cultural resources cannot be managed in isolation; we must take natural resources and the surrounding landscape context into account.

Preserving Coastal Heritage: Summary Report

Figure 33 shows a summary report from a work session of leaders in the fields of planning, architecture, landscape architecture, historic preservation, archeology, science, and park and cultural resource management to provide input on the forthcoming NPS cultural resources climate adaptation strategy ((NPS 2014c; Rockman et al. 2016). That strategy will build on this workshop report and other efforts and will include vulnerability assessment guidance specific to cultural resources.

A service wide preliminary "Assessment of National Park Service Museum Facilities' Vulnerability to Climate Change" was released in September 2014 intended to inform the scoping of a new Park Museum Facility Management Plan (NPS Park Museum Management Program 2014). Of the 58 NER units assessed, 55 had a threat risk from flood, 51 from wind, 8 from HVAC, 13 from Biology (pest and/or mold) and 18 from Staff (experience/ capacity limitations). None were at risk from drought or permafrost. Follow up risk assessment of collections are now in progress in NER parks.



Figure 33. Report: Preserving Coastal Heritage (NPS 2014c). http://www.achp.gov/docs/preserve-coastal-heritage.pdf

Facilities Assets

Adapting to Climate Change in Coastal Parks

Western Carolina University completed the first phase of its estimates of park asset exposure to 1 meter of sea level rise, which includes information for 15 Northeast Region parks (Figure 34) (Peek et al. 2015). It determined that one-third of the assets listed as of 2013 in the Facilities Management Software System were deemed high exposure, including many that have high historical and cultural value. The report compared Hurricane Sandy impacts to their 1 meter analysis and FEMA post-Sandy flood zones in the case of GATE and found that the sea level rise analysis was in fact conservative. The authors determined that about 28% of the assets were High Exposure, while the post-Sandy analysis put this value at 57% and FEMA's new flood maps showed that in some areas, such as Sandy Hook, the value was as high as 82% High Exposure. This report and its companion website: http://www.nature.nps.gov/geology/coastal/coastal_assets_report.cfm include detailed information for each of the analyzed parks. For example in ASIS, 95% of 179 asset items valued at $135 million are considered to be facing high exposure.

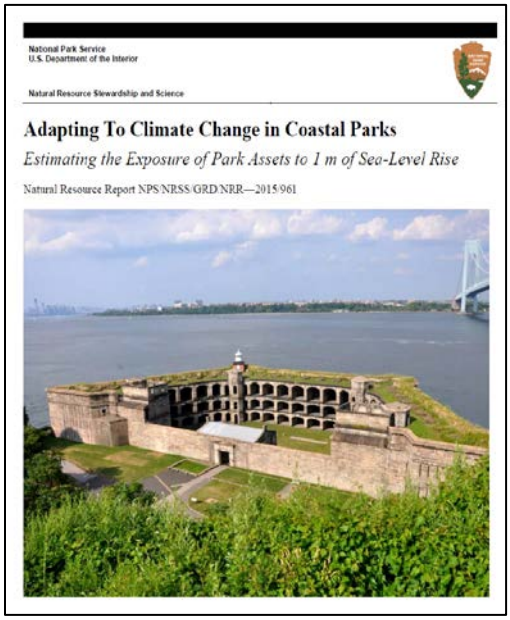


Figure 34. Report: Adapting to Climate Change in Coastal Parks (Peek et al. 2015).

Examples of NPS Experience

In 2012, ASIS participated in a pilot project to address climate adaptation issues in its facilities. A two-day workshop was able to determine that $146 million in assets could be classified as moderately or highly vulnerable (Figure 35). Participants were also able to generate adaptation options for a number of the assets (ICF International 2012).

The NER piloted a multi-disciplinary VA for Historic Structures at Salem Maritime National Historic Site (SAMA). The effort was similar to the facilities assessments below. Based on existing FEMA Flood Zone maps and NOAA projections for SLR in forty years they included GPS elevations of historic structures at SAMA. The focus was on the location and height of potential building

penetration from flood waters. Based on the measurements and projections, strategies are proposed to resist flooding and build resiliency of the structure and operations. Levels of risk and effort are assigned to assist in priority setting. The methodology and associated data sheets will be available soon. At FIIS, efforts have been underway since 2002 to quantify marsh elevation change in relation to recent SLR. The long term study involves benchmark pipe, elevation table, pin measurements. The salt marshes likely to be submerged, *Spartina patens* is being replaced by *Spartina alternaflora* as marshes subside, offsetting vertical accretion.

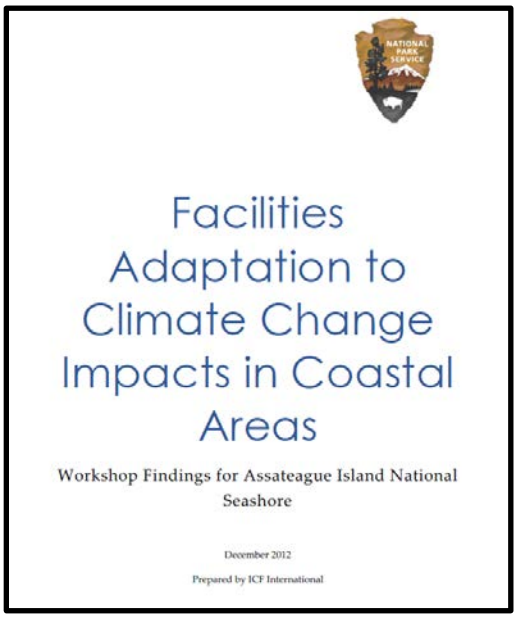


Figure 35. Report: Facilities Adaptation to Climate Change (ICF International 2012).

In ASIS, LiDAR is being used to provide morphological data for modeling barrier island dynamics. Areas of concern include beaches and dunes park-wide, including alongshore as well as cross shore dynamics. Simulations combined with experience of storms are expected to be helpful for visualizing impacts.

Natural Disasters can provide a lens into the future. After Hurricane Sandy, GATE had firsthand experience, evidence and stories that gave stakeholders a real sense of what extreme events could be in the future under certain climate conditions. This helped GATE communicate how today's extreme events might become 5 or 20 year recurring events in the future, without having to rely on data and charts that lack the emotional dimension of a recent storm. Recent events can also attract funding for collecting data that will be valuable for vulnerability assessments. GATE, ASIS and FIIS received habitat mapping funds post-Sandy.

D. Applying the results of a vulnerability assessment to park management

Key Points of this Section

One of the core objectives of an assessment is to influence park management decision-making, actions and budgets. Completing a vulnerability assessment is only one step in the larger process of management.

Applying assessment to Park adaptation planning

- Explore why specific targets are vulnerable to inform possible adaptation responses
- Consider how targets might fare under various management and climatic scenarios
- Share assessment results with stakeholders and decision-makers
- Use results to advance development of adaptation strategies and plans

Paths to consider in view of park situation

- Consult regional and national websites and projects that aggregate VA experiences in parks and conservation areas
- Engaging in Social Networking – Learning from others in NER
- Deciding How to Use VA Outputs in park decision-making
- Interpretative Programs and Materials for engaging stakeholders and visitors
- Participate in ongoing regional events by partner organizations who are exchanging technical information for conservation, cultural resources and facilities planning

So, the results of the vulnerability assessment are in, what's next?

An assessment is only as good as its outputs are used for guiding management actions. There is an important social aspect to the assessment that ensures the support of stakeholders and NP leadership. Previous leadership at ACAD didn't prioritize vulnerability assessments. Only after many years of small studies and education on the topic did the staff and new leadership see the importance of conducting assessments and acting on climate change. Don't let the details of different assessment and scientific methods distract from the critical role of getting and maintaining leadership understanding and support. This will assist in the uptake of the assessment outputs in management planning.

Useful Resources for Applying the Results of a VA

Deeper and More Integrated Analysis

- Explore why specific targets are vulnerable to inform possible adaptation responses.
- Consider how targets might fare under various management and climatic scenarios.
- Feed the VA data into a scenario planning exercise.

Communicate Widely

- Share assessment results with stakeholders and decision-makers.
- Incorporate key findings into park's Communication for Interpretation and Management.

- An upcoming NPS wide interpretation of climate change guide can assist in communicating the results of the assessment to the public and key audiences.
- Recognizing the need for improved internal NER communication on climate change and broader outreach to parks, a strategy for climate related communication across NER Resource Stewardship and Science as well as Planning, Facilities, and Conservation Assistance is in progress. This will include a compilation of a central repository to share available resources (e.g. Sharepoint/ Google site) and coordination roles and mechanisms for sharing of successes and projects in progress.

Enhance the NER social network

A NPS database, the Climate Adaptation Resource Explorer (NPS CARE) is under development, that arose from the need to centralize information about climate adaptation examples where multiple people could access and share data. Once it is finalized parks will be encouraged to enter examples. While focused on adaptation more than assessments, this will be an opportunity to share VA experiences and show how VAs have been used for adaptation.

Professional Networking

- Engaging in Social Networking and Communities of Practice – Learning from others in the NER and other coastal parks
- Identify ways to connect with Peers inside NPS and partners within the Northeast that can support VA – data, tools, funding
- Improve the staff culture of the NPS to be more receptive about the value of vulnerability assessments and willing to fund these activities. Once they are supportive of the assessments it will likely improve the chances of staff incorporating the results into their activities.

Continually updated events listings

Climate Adaptation Knowledge Exchange: The Climate Adaptation Knowledge Exchange (CAKE) was founded by EcoAdapt and Island Press in 2010, and is managed by EcoAdapt (Figure 36). It aims to build a shared knowledge base for managing natural and built systems in the face of rapid climate change. Just as importantly, it is intended to help build an innovative community of practice. It helps users to get beyond the limitations of their time and the unwieldy thicket of books, papers and articles by: Vetting and clearly organizing the best information available, Building a community via an interactive online platform, creating a directory of practitioners to share knowledge and strategies, and Identifying and explaining data tools and information available from other sites. http://www.cakex.org/virtual-library



Figure 36. Resource: Climate Adaptation Knowledge Exchange.

CRAVe – Climate Registry for the Assessment of Vulnerability: A public registry of vulnerability assessments for natural and human resources operated by USGS and linked to other platforms (Figure 37). Contains information on targets, scope, methods, drivers and costs of assessments. Recent coastal adaptation case studies of NPS units (Schupp et al. 2015) has been added to this registry. http://crave.cakex.org/.

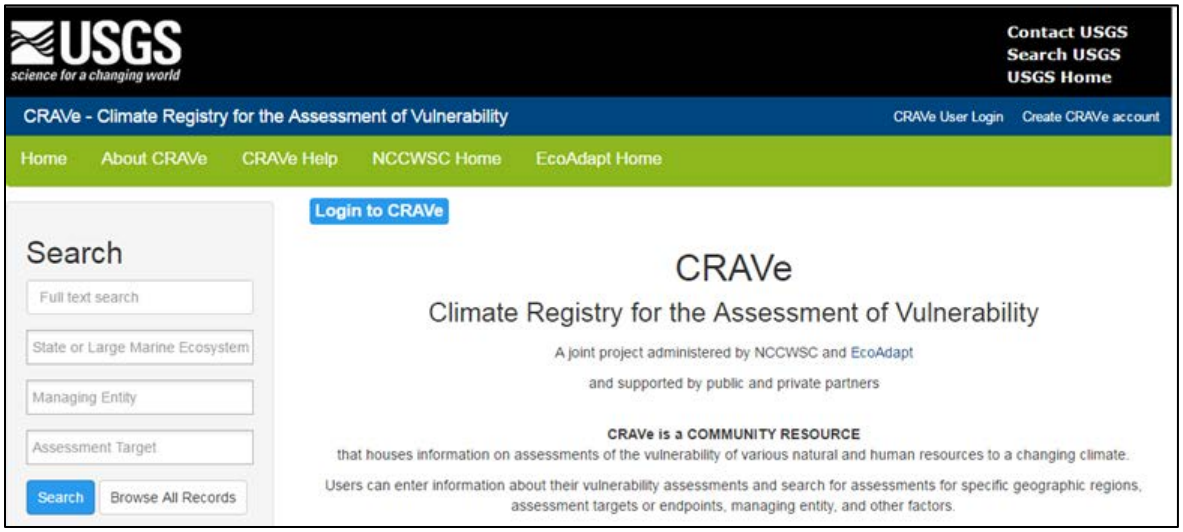


Figure 37. Resource: Climate Registry for the Assessment of Vulnerability.

National Conservation Training Center: Trainings based on these concepts, focusing on Scanning the Conservation Horizon (Glick et al. 2011) are available through the National Conservation Training Center (Figure 38). NPS staff were involved in training development and NER staff have participated in past trainings.

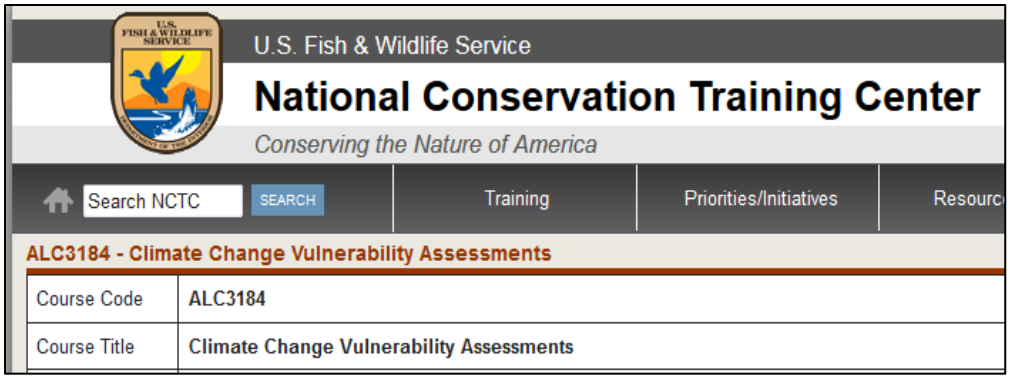


Figure 38. Resource: National Conservation Training Center.

Climate Fundamentals Academy

NPS has supported NER staff training through the Climate Fundamentals Academy, workshops presented by the Association of Climate Change Officers (ACCO) (Figure 39). The Climate Fundamentals Academy provide curriculum on topics including understanding climate science and variability, identifying climate hazards and conducting vulnerability assessments, basics of greenhouse gas accounting, explanations of the food-water-energy nexus, and fundamental governance and stakeholder engagement strategies, with a regional focus added for the New England. http://www.climatefundamentals.org/

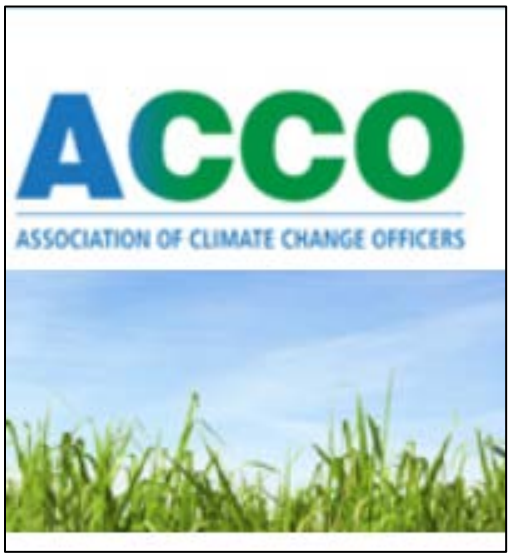


Figure 39 Resource: ACCO runs the Climate Fundamentals Academy.

Management Planning

- Use results to advance development of adaptation strategies and plans
- Ensure all staff understand the park's vulnerability, how climate change fits into other aspects of park management and the benefits of integrating climate change into these aspects.
- Apply the results to Interpretative Programs and Materials for engaging stakeholders and visitors

- Deciding How to Use VA Outputs in park decision-making.

Examples from NPS Experience

In ASIS, park staff leadership and ingenuity led to important park contributions to the overall practice of vulnerability assessment (Schupp et al. 2015). See Appendices A and B for examples and details. These include infrastructure in flood prone and eroding, landscape migrating areas park-wide activities. Staff members have been planning in advance for vulnerable facilities, and finding creative temporary structure options, working to make infrastructure resilient, adaptable, and portable. The approach by staff is expressed as using 'common sense' to adapt to the island, not to prioritize human needs.

Lessons Learned

In the production of this guide, the authors interviewed staff members at NER parks who have been involved in climate change vulnerability assessments. There were numerous insights and lessons that are valuable to share across the NER network. Within this document we summarized each site's story about using VAs and included some short vignettes on their experience. Below are the general lessons learned by NPS park staff.

- Start Small to See the Big Picture - Since doing a large full park assessment is resource intensive, start with smaller, topic focused assessments, while maintaining the 'big picture' for overall climate change at the site and nearby area.
- Don't let VA methods distract from the critical role of building internal buy-in since attracting funding and acting on results are social processes.
- Leverage resources with partners to accelerate data collection, increase scope and scale, and strengthen likelihood to apply the assessment results.
- Timing of a VA is Critical, try to conduct the VA before major planning events for a site to increase the chances of application to management.
- Use NPS sites' historical museum records as a means to learn about local climate history and collect data. This still takes time and resources.
- Recent hazard events can portray future climate threats, try to use the extreme event as a means to communicate a likely future climate and hazard risk.
- Go with a Plan B or C: If you can't save the cultural resources at risk then proceed with the process of documentation and accept that not all artifacts can be protected.
- Update management goals to reflect changes in climate and other factors.

Literature Cited

Amberg, S., K. Kilkus, S. Gardner, J. E. Gross, M. Wood, and B. Drazkowski. 2012. Badlands National Park: Climate change vulnerability assessment. Natural Resource Report NPS/BADL/NRR—2012/505. National Park Service, Fort Collins, Colorado.

Assateague Island National Seashore. 2011. Assateague Island National Seashore General Management Plan Climate Change Adaptation Alternatives. National Park Service, Northeast Regional Office, Philadelphia, Pennsylvania.

Assateague Island National Seashore. 2013. Bayside Picnic and South Ocean Beach Parking Areas Removal and Relocation Environmental Assessment. National Park Service, Northeast Regional Office, Philadelphia, Pennsylvania.

Babson, A. L. 2014. Overview of climate change adaptation needs, opportunities and issues: Northeast Region coastal National Parks. Natural Resource Report NPS/NER/NRR—2014/789. National Park Service, Fort Collins, Colorado.

Beever, E, J. O'Leary, C. Mengelt, J. West, S. Julius, D. Green, L. Petes, B. Stein, A. Nicotra, J. Hellmann, A. Robertson, M. Staudinger, A. Rosenberg, E. Babij, J. Brennan, G. Schuurman, and G. Hofmann. 2015. Improving conservation outcomes with a new paradigm for understanding species' fundamental and realized adaptive capacity. Conservation Letter, 1 July 2015. doi:10.1111/conl.12190.

Blumberg, B. 2009. In Focus: CESUs—Sea-level rise, climate change, and salt-marsh development processes at Fire Island. Park Science 26(2):16–17. Available at http://www.nature.nps.gov/ParkScience/archive/PDF/Article_PDFs/ParkScience26(2)Fall2009_16-17_Blumberg_2631.pdf (accessed 18 September 2016).

Caffrey, M. 2014. Sea Level and Storm Surge Trends for the State of the Park Report Boston Harbor Islands National Recreation Area. National Park Service Climate Change Response Program, Fort Collins, Colorado.

Cape Cod National Seashore. 2014. Herring Cove Beach North Public Access Site Plan Environmental Assessment. National Park Service, Northeast Regional Office, Philadelphia, Pennsylvania.

Carroll, A., McNamara, D. and Schupp, C. 2009. Modeling the Response of Human Altered Natural Barrier Island Dynamics Along Assateague Island National Seashore to Climate Change. The Smithsonian. American Geophysical Union, San Francisco, California. December 15, 2009.

Coburn, A. S., A. D. Griffith, and R. S. Young. 2010. Inventory Coastal Engineering Projects in Coastal National Parks. Natural Resource Technical Report NPS/NRPC/GRD/NRTR—2010/373. Fire Island Appendix. National Park Service, Fort Collins, Colorado.

Crist, P. J., P. Comer, and M. Harkness. 2012a. The Refuge Vulnerability Assessment and Alternatives Technical Guide. U.S. Fish and Wildlife Service, Arlington, Virginia.

Crist, P.J., M. Harkness, and P. Comer. 2012b. Manager's Guide to Refuge Vulnerability Assessment and Alternatives: Overview and Practical Considerations. U.S. Fish and Wildlife Service. Arlington, VA.

Czech, B., S. Covington, T. M. Crimmins, J. A. Ericson, C. Flather, M. Gale, K. Gerst, M. Higgins, M. Kaib, E. Marino, T. Moran, J. Morton, N. Niemuth, H. Peckett, D. Savignano, L. Saperstein, S. Skorupa, E. Wagener, B. Wilen, and B. Wolfe. 2014. Planning for Climate Change on the National Wildlife Refuge System. U.S. Fish and Wildlife Service, National Wildlife Refuge System, Washington, D.C.

Dawson, T., S. Jackson, J. House, I. Prentice, and G. Mace. 2011 Beyond Predictions: Biodiversity Conservation in a Changing Climate. *Science* 1 April 2011. 332 (6025) 53-58.

Dallas, K., J. Eshleman, and R. Beavers. 2012. National Park Service Beach Nourishment Guidance. Natural Resource Technical Report. NPS/NRSS/GRD/NRTR—2012/581. Published Report-2185115. National Park Service, Natural Resource Stewardship and Science, Fort Collins, Colorado.

Fisichelli, N., Peters, M., Iverson, L., Matthews, S., Hoffman, C. 2014. Climate Change and Forests of the Acadia National Park Region Projected Changes in Habitat Suitability for 83 Tree Species. Natural Resource Report NPS/ACAD/NRR—2013/733. National Park Service, Northeast Regional Office, Philadelphia, Pennsylvania.

Gateway National Recreation Area. 2014. General Management Plan. National Park Service, Natural Resource Stewardship and Science, Fort Collins, Colorado.

Gitay, H., A. Suarez, and R. T. Watson. 2002. Climate change and biodiversity: IPCC Technical Paper V. Intergovernmental Panel on Climate Change. Geneva, Switzerland.

Glick, P., B. A. Stein, and N. A. Edelson, editors. 2011. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment. National Wildlife Federation, Washington, D.C.

Gonzalez, P. 2011. Science for Natural Resource Management under Climate Change. Issues In Science And Technology, Summer 2011.

Gonzalez, P. 2014. Climate Change Summary, Cape Cod National Seashore, Massachusetts. National Park Service Climate Change Response Program. Washington, DC.Guo, J. 2014. December 2. The old man and the rising sea. Washington Post. Available at http://www.washingtonpost.com/news/storyline/wp/2014/12/02/the-old-man-and-the-rising-sea-2/ (accessed 18 September 2016).

Gutierrez, B. T., N. G. Plant, and E. R. Thieler 2011. A Bayesian network to predict coastal vulnerability to sea level rise, J. Geophys. Res., 116, F02009, doi:10.1029/2010JF001891.

Hammar-Klose E. S., E. A. Pendleton, E. R. Thieler, S. J. Williams. 2003. Coastal Vulnerability Assessment of Cape Cod National Seashore (CACO) to Sea-Level Rise, U.S. Geological Survey, Open file Report 02-2. Available at http://pubs.usgs.gov/of/2002/of02-233/ (accessed 18 September 2016).

Horton, R., C. Little, V. Gornitz, D. Bader, and M. Oppenheimer. 2015. New York City Panel on Climate Change 2015 Report, Chapter 2: Sea Level Rise and Coastal Storms. Annals of the N.Y. Academy of Sciences. 1336 (2015) 36–44.

Horton, R., G. Yohe, W. Easterling, R. Kates, M. Ruth, E. Sussman, A. Whelchel, D. Wolfe, and F. Lipschultz. 2014. Ch. 16: Northeast. Climate Change Impacts in the United States: The Third National Climate Assessment. Pages 371-395 *in* J. M. Melillo, T.C. Richmond, and G. W. Yohe, editors. U.S. Global Change Research Program, Washington, D.C. doi:10.7930/J0SF2T3P.

Howe, P., M. Mildenberger, J. Marlon, and A. Leiserowitz. 2015. Geographic variation in US climate change opinion at state and local scales. *Nature Climate Change* 5:596–603.

ICF International. 2012. Facilities Adaptation to Climate Change Impacts in Coastal Areas. Workshop findings for Assateague National Seashore. National Park Service, Northeast Region, Philadelphia, Pennsylvania.

Intergovernmental Panel on Climate Change. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. R.K. Pachauri and L.A. Meyer, editors. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

John A. Volpe National Transportation Systems Center. 2012. A Framework for Considering Climate Change in Transportation and Land Use Scenario Planning Lessons Learned from an Interagency Pilot Project on Cape Cod. John A. Volpe National Transportation Systems Center, Cambridge, Massachusetts.

Johnson, K.A., 2014. Climate Change Vulnerability Assessment for Natural Resources Management: Toolbox of Methods with Case Studies, Version 2.0. US Fish and Wildlife Service. Available at https://www.fws.gov/home/climatechange/pdf/Guide-to-Vulnerability-Assessment%20Methods-Version-2-0.pdf (accessed 22 November 2016).

Lee, T. R., S. F. J. De Wekker, and J. E. B. Wofford. 2014. Downscaling temperatures to Shenandoah National Park using gridded climate data sets, high-resolution atmospheric models, and surface observations: Final report in completion of cooperative agreement 484010004. Natural Resource Technical Report NPS/SHEN/NRTR—2014/875. National Park Service, Fort Collins, Colorado.

Maine Department of Environmental Protection. 2010. People and Nature: Adapting to A Changing Climate. Charting Maine's Course. Maine Department of Environmental Protection, Augusta, Maine.

McElroy, A., M. Benotti, G. Edinger, A. Feldmann, C. O'Connell, G. Stewart, R. L. Swanson, and J. Waldman. 2009. Assessment of Natural Resource Conditions Fire Island National Seashore. Natural Resource Report NPS/NRPC/NRR—2009/139. National Park Service, Fort Collins, Colorado.

Melillo, J. M., T. C. Richmond, and G. W. Yohe, editors. 2014. Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, Washington, D.C. doi:10.7930/J0Z31WJ2.

Messaros, R., M. Morgan, G. Woolley, and P. Rafferty. 2011. The Sustainability of a Tidal Salt Marsh Restoration Effort in Jamaica Bay, New York. Presented to the National Conference on Ecosystem Restoration, Baltimore, Maryland, 02 August 2011. US Army Corps of Engineers, New York District.

Monahan W. B., and N. A. Fisichelli. 2014. Climate exposure of US national parks in a new era of change. PLoS ONE 9(7): e101302. doi:10.1371/journal.pone.0101302.

Morgan, M., M. Rockman, C. Smith, and A. Meadow. 2016. Climate Change Impacts on Cultural Resources. Cultural Resources Partnerships and Science. National Park Service, Washington, D.C.

Morris, J. T., P. V.Sundareshwar, C. T. Nietch, B. Kjerfve, and D. R. Cahoon. 2002. Responses of coastal wetlands to rising sea level. *Ecology* 83:2869-2877.

Morrison, W.E., M. W. Nelson, J. F. Howard, E. J. Teeters, J. A. Hare, R. B. Griffis, J.D. Scott, and M.A. Alexander. 2015. Methodology for Assessing the Vulnerability of Marine Fish and Shellfish Species to a Changing Climate. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OSF-3, 48 p.

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

NOAA. 2016. Economics: National Ocean Watch (ENOW) Data. Based on data from the Bureau of Labor Statistics and the Bureau of Economic Analysis. NOAA Office for Coastal Management. Charleston, South Carolina.

National Park Service Park Museum Management Program. 2014. Assessment of National Park Service Museum Facilities' Vulnerability to Climate Change. National Park Service, Washington, D.C.

National Park Service (NPS). 2010. National Park Service Climate Change Response Strategy. NPS Climate Change Response Program, Fort Collins, CO.

NPS. 2011. Northeast Region Climate Change Strategy and Action Plan. Available at http://classicinside.nps.gov/documents/20110610_NER_Climate_Change_Strategy_web.pdf (accessed 22 November 2016).

NPS. 2012a. Applying National Park Service management policies in the context of climate change. US DOI National Park Service Policy Memorandum 12-02. March 6, 2012. Available at https://www.nps.gov/policy/PolMemos/PM_12-02.pdf (accessed 22 September 2016).

NPS. 2012b. National Park Service Climate Change Action Plan 2012-2014. NPS Climate Change Response Program, Fort Collins, CO. http://www.nature.nps.gov/climatechange/docs/NPS_CCActionPlan.pdf (accessed 07 August 2016).

NPS. 2013a. Using Scenarios to Explore Climate Change: A Handbook for Practitioners. National Park Service Climate Change Response Program,Fort Collins, Colorado.

NPS. 2013b. Vulnerability Assessment Brief: Assessing the Vulnerability of Park Resources, based upon Gonzalez, P. 2011. National Park Service, Natural Resource Stewardship and Science, Climate Change Response Program, Fort Collins, Colorado.

NPS. 2014a. Climate change and stewardship of cultural resources. US DOI National Park Service Policy Memorandum 14-02. Available at http://www.nps.gov/policy/PolMemos/PM-14-02.htm (accessed 28 April 2015).

NPS. 2014b. Climate Change Vulnerability Assessment Framework for U.S. National Parks. National Park Service, Natural Resource Stewardship and Science, Washington, D.C.

NPS. 2014c. Preserving Coastal Heritage. Summary Report. April 3-4, 2014. Federal Hall, New York City, New York, USA. Available at https://sites.google.com/site/democlimcult/ (accessed 7 October 2014).

NPS. 2015a. Addressing Climate Change and Natural Hazards: Facility Planning and Design Considerations. US DOI National Park Service Policy Memorandum 15-01. Available at http://www.nps.gov/policy/PolMemos/PM_15-01.htm (accessed 28 April 2015).

NPS. 2016. Coastal Hazards and Climate Change Asset Vulnerability Assessment Protocol: Project Description and Methodology. National Park Service, Sustainable Operations and Climate Change, Washington, D.C.

NPS. 2016. Climate Change Response Program, Coastal Adaptation Project Brief. Sea Level Change and Storm Surge Projections. Available at https://www.nps.gov/subjects/climatechange/upload/Sea-Level-Rise-Project-Brief-JAN-2016.pdf (accessed 18 September 2016).

New York City Department of Environmental Protection. 2007. Jamaica Bay Watershed Protection Plan Volume II -The Plan. Jamaica Bay Watershed Protection Plan Volume II -The Plan, New York, New York.

Nielsen, M., and R. Dudley. 2012. Estimates of future inundation of salt marshes in response to sea level rise in and around Acadia National Park. U.S. Geological Survey, Reston, Virginia.

Northeast Regional Ocean Council. 2015. Make Way for Marshes. http://northeastoceancouncil.org/committees/coastal-hazards-resilience/resilient-shorelines/make-way-for-marshes/ (accessed 22 November 2016).

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

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

Pendleton, E., E. Thieler, S. Williams. 2004. Coastal Vulnerability Assessment of Fire Island National Seashore (FIIS) to Sea-Level Rise. U.S. Geological Survey Open-File Report 03-439. Available at: http://pubs.usgs.gov/of/2003/of03-439/ (accessed 18 September 2016).

Primack, R., A. Miller-Rushing, and M. Kraft. 2012. Identify Species Vulnerable to Climate Change at Acadia National Park: Detailed Implementation Plan. Boston University, Boston, Massachusetts.

Rockman, M., M. Morgan, S. Ziaja, G. Hambrecht, and A. Meadow. 2016. Cultural Resources Climate Change Strategy. NPS Climate Change Response Program and Cultural Resources Partnerships and Science, Washington, DC.

Roman, C. T., and A. L. Babson. 2013. Climate change in Northeast Region coastal parks: Synthesis of a workshop on research and monitoring needs. Natural Resource Report NPS/NER/NRR—2013/697. National Park Service, Fort Collins, Colorado.

Rowland, E., M. Cross, and H. Hartmann. 2014. Considering Multiple Futures: Scenario Planning to Address Uncertainty in Natural Resource Conservation. U.S. Fish and Wildlife Service, Washington, D.C.

Schupp, C., R. Beavers, and M. Caffrey. 2015. Coastal Adaptation Strategies: Case Studies. National Park Service Geologic Resources Division, Lakewood, Colorado.

Smit, B., and O. Pilifosova, O. 2001. Adaptation to Climate Change in the Context of Sustainable Development and Equity. Chapter 18 in Climate Change 2001: Impacts, Adaptation, and Vulnerability— Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom.

Staudinger, M. D., Morelli, T. L. and Bryan, A. M. 2015. Integrating Climate Change into Northeast and Midwest State Wildlife Action Plans. Department of the Interior, Northeast Climate Science Center Report, Amherst, Massachusetts.

Stein, B. A., P. Glick, N. Edelson, and A. Staudt, editors. 2014. Climate-Smart Conservation: Putting Adaptation Principles into Practice. National Wildlife Federation, Washington, D.C.

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

Terwilliger Consulting, Inc. 2007. Environmental Assessment, Proposed Update of the 1992 Management Plan for the Threatened Piping Plover on Sandy Hook Unit Gateway National Recreation Area New York – New Jersey. National Park Service, Sandy Hook Unit, Gateway National Recreation Area, New York – New Jersey.

The Nature Conservancy and NOAA. 2011. Marshes on the Move: A Manager's Guide to Understanding and Using Model Results Depicting Potential Impacts of Sea Level Rise on Coastal Wetlands. Available at https://coast.noaa.gov/data/digitalcoast/pdf/marshes-on-the-move.pdf (accessed 22 November 2016).

Tyrrell, M. 2012. Vulnerability assessment of Cape Cod National Seashore's coastal wetlands to sea level rise and other anthropogenic stressors. Detailed Implementation Plan. Signed July 15, 2012; updated April 1, 2015.

US EPA. 2012. Vulnerability Assessments in Support of the Climate Ready Estuaries Program: A Novel Approach Using Expert Judgement, Volume II: Results for the Massachusetts Bays Program (Final Report). EPA/600/R-11/058Fb. U.S. Environmental Protection Agency, Washington, DC,

US Geological Survey. 2014. Assessment of Groundwater Resources to Adapt to Climate Change at Fire Island, New York. U.S. Geological Survey, Coram, New York. Available at http://ny.cf.er.usgs.gov/nyprojectsearch/projects/images/LK00-FIIS-400.pdf (accessed 18 September 2016).

Welling, L., and J. Star. 2012. Scenario Planning Provides a Framework for Climate Change Adaptation in the National Park Service. American Geophysical Union, Fall Meeting 2012, abstract #GC41D-03.

Zimmerman, C. 2010. Assateague Island National Seashore Climate Scenarios. National Park Service. Presented to: Adapting to Climate Change in the Mid-Atlantic Hyatt Regency Chesapeake Bay Resort. Cambridge Maryland. Available at https://www.fws.gov/northeast/climatechange/conference/pdf/330pm_carl_zimmerman.pdf (accessed 18 September 2016).

Appendix A. Vulnerability assessments in the Northeast Region

US National Park **>key resources**	**Analysis Focus / Methods**	**Resources Targeted** ***>Scope-Time Horizon***	**Highlights**	**Action Taken**
Acadia National Park (ACAD) *>Tidal Marshes* *>Rocky Intertidal* *>Nearshore- ocean ecosystem* *>Freshwater ecosystem*	2010 Maine Dept. of Environmental Protection state level study focuses on: SLR, temperature, precipitation, storms, freshwater flows	Salt marshes and wetlands, invasive species in habitat, wildlife *>Parkwide, state-wide; 2100*	ACAD successful collaboration with state initiatives	ACAD submitted proposals as part of the climate adaptation planning process on cold water fisheries, wetlands, and coastal estuaries.
	Rehabilitating Stream Crossings on Historic Roads, Acadia National Park, Maine: precipitation, storm surge (Case Study 15) Schupp et al. (2015).	Historic road systems, culverts *>Damage from flooding and erosion*	Infrastructure improvement will also have biological benefits for fish, amphibians	Vulnerability assessment, additional research including inventory of culverts, bridges; reengineering to address current and anticipate future flooding; incorporate into park policy, fundraising
	Studies analyzing wetlands elevation *LiDAR, static inundation model* Nielsen and Dudley (2012).	Salt Marshes, freshwater wetlands *Within, adjacent to park; 2100*	Question of whether marshes can migrate upland; conversion of fresh to salt water marsh	Barriers to marsh migration identified
	Research proposal for phenology-based assessment using *NatureServe Climate Change Vulnerability Index tool* Primack et al. (2012)	Plant and wildlife species vulnerability *>Park-wide; retrospective - 100 years, current distribution*	–	ACAD. Focus on monitoring and interpretation
	Study of forests and habitat, temperature, precipitation, storms Fisichelli et al. (2014)	83 tree species 6048mi^2 *region including park; >scenarios for 2040, 2070, 2100*	ACAD. Two change scenarios for three time periods. Changes in climate and forest composition will have cascading effects on other resources, park operations, and visitor experiences.	ACAD. Start management actions early in tree lifecycle, foster heterogeneity, restore ecological processes, enhance landscape connectivity

US National Park **>key resources**	**Analysis Focus / Methods**	**Resources Targeted** ***>Scope-Time Horizon***	**Highlights**	**Action Taken**
Boston Harbor Islands National Recreation Area (BOHA) *>Rocky Intertidal* *>Cultural* *>Infrastructure at risk*	Key concerns are erosion and flooding due to SLR Planned FY17 start, now funding uncertain.	Facilities, marshes, shoreline are most at risk	Need a combined approach for facilities and natural resources, better science on SLR, waves	Flood proof at risk buildings
Cape Cod National Seashore (CACO) *>Tidal Marshes* *>Estuaries* *>Beaches, dunes, bluffs* *>Nearshore- ocean ecosystem* *>Infrastructure at risk*	NPS was participant in DOT regional transportation/ land use planning with scenarios, 2012: SLR, precipitation, storms, temperature John A. Volpe National Transportation Systems Center (2012) *Cape Cod transportation models; Community-Viz;*	Land use in flood-prone areas and road access to coastal homes, businesses *>Park-wide and Cape Cod region; time horizon 2030*,	Study concluded that it is difficult to create useful downscaled change scenarios for specific time periods by impact type, i.e. flooding. The regional governance system for Cape Cod is an advantage, the complexity of stakeholder engagement, and limits on the precision of data and scenarios	The study process, while robust, did not focus on CACO assets and issues, so had limited practical application.
	Relative Coastal vulnerability index prepared for CACO in 2003 by USGS: waves, SLR, slope, tidal range, geomorphology USGS (2004)	Shoreline response to SLR and other variables *>Shoreline of the entire seashore, -150 year historical trend*	Geomorphology and regional coastal slope are the most important variables in determining the CVI for CACO	CACO is a dynamic natural environment. The CVI is one way to assess factors contributing to how the park may evolve in the future
	Reducing vulnerability of visitor facilities in Herring Cove (Case Study 17) Schupp et al. (2015) *vulnerability assessment, awareness,*	Resilience of 1950s infrastructure *>recent storm impacts, plus 100 year flood plain; 50 year sea level rise*	Successful stakeholder engagement, reshaping artificial dunes to restore natural processes, relocating important visitor parking and facilities	Resilient infrastructure, adaptation plan, reduce non-climate stressors, incorporate climate change into plans
	Salt marsh vulnerability to SLR study Tyrell (2012). *LiDAR and ground-truthing*	Low and high salt marshes *>Herring River mouth, recent year comparison trend only*	Field studies are needed to refine marsh elevation data from LiDAR; high marsh species are losing out due to SLR, erosion	

US National Park **>key resources**	**Analysis Focus / Methods**	**Resources Targeted** ***>Scope-Time Horizon***	**Highlights**	**Action Taken**
	Relative Coastal Vulnerability Index prepared for FIIS in 2004 by USGS: waves, SLR, slope, tidal range, geomorphology Pendleton et al. (2004)	Shoreline response to SLR *Shoreline of the entire seashore, >150 year historical trend*	Geomorphology and shoreline are the most important variables in determining the CVI for FIIS	FIIS is a dynamic natural environment that is highly vulnerable to SLR. The CVI is one way to assess factors contributing to how the park may evolve in the future
Fire Island National Seashore (FIIS) *>Tidal Marshes* *>Estuaries* *>Beaches, dunes, bluffs*	Quantify marsh elevation change in relation to recent SLR; long term study. Blumberg (2009). *Benchmark pipe, elevation table, pin measurements*	Salt marshes likely to be submerged, Spartina patens is being replaced by spartina alternaflora as marshes subside, offsetting vertical accretion *>Three marshes; Monitoring since 2002*	Long term monitoring is key; preserve inlet processes, take into account impacts of shore stabilization and channel dredging	–
	Assessment of groundwater resources (also in progress at ASIS & GATE) *Groundwater flow monitoring, inventory of coastal engineering works; numerical flow modeling* USGS (2014).	Impact of SLR on groundwater and associated habitat *Parkwide (and regional) baseline condition*	Develop protocols for assessing groundwater change,	–
	Natural resources condition assessment. McElroy et al. (2009). *Large scale natural resources assessment*	Water quality, shoreline, beaches, marshes, infrastructure, ocean and bay side *Park-wide, >SLR up to 2100*	need for close monitoring, given non-climate threats including nutrient loading;	–
Gateway National Recreation Area (GATE) *>Tidal Marshes* *>Estuaries*	Watershed protection New York City Department of Environmental Protection. (2007). *Watershed planning approach—process, vision, detailed strategies*	SLR among reasons for loss of wetlands, beach erosion to storms, flow restrictions *Jamaica Bay and its watershed; 2050 SLR projection; 2030 land use planning horizon*	Consider options for wave attenuation such as fabric logs and mats	Watershed approach to park and environs

US National Park **>key resources**	**Analysis Focus / Methods**	**Resources Targeted** ***>Scope-Time Horizon***	**Highlights**	**Action Taken**
>Beaches, dunes, bluffs *>Cultural* *>Infrastructure at risk*	Restoring Jamaica Bay Wetlands (Case Study 11) Schupp et al. (2015) test of marsh restoration methods to be applied at additional sites	Wetlands elevation and vegetation *>Current situation, revisit after 5 years*	Challenge of interagency coordination, funding needed for research & monitoring, limited availability of clean sediment, sufficient information for good design at outset	Research and data for project design and evaluation; coordination & planning across institutional boundaries, testing and refining restoration methods
	Update of the NPS Sandy Hook Piping Plover plan. Terwilliger Consulting, Inc. (2007). *Management plan for threatened species/ environmental assessment*	SLR, habitat shifts, wetlands loss, shore protection impacts on key habitat vegetation *Sandy Hook Bay complex; retrospective to 1992, present day focused, reference to 'short term, long term'*	Overwash habitat is essential, but trend is long term loss due to shore stabilization projects. Predation impacts on plovers, red knot.	Restore foraging habitat, beaches via sand slurry pipeline, predator control, evaluate non-functioning shore structures, soft shoreline techniques,
	USACOE Marsh Islands Restoration plans Messaros et al. (2011).	SLR, temperature	role of marsh restoration in climate adaptation	extensive restoration projects in Jamaica Bay
	General Management Plan. Gateway National Recreation Area. (2014). *NPS general management plan approach*	impacts of sea level rise and storm intensity on recreation including beach erosion, facilities, precipitation *All 3 park units; > SLR (2020s,2050s, 2080s), 2100, 100 Year Flood plain;*	Include climate adaptation in asset management plans, include climate aware biodiversity conservation strategy; visualize future impacts by combining record of storm impacts with SLR model results; partnering across geographic areas for species protection, deal with non-climate threats	Incorporated issues and approaches into the GMP to demonstrate proactive adaptation; monitoring and research including "Climate Change Plan" and archeological resources plan.
Assateague Island National Seashore (ASIS) *>Estuaries*	Relocating visitor facilities (within Chincoteague refuge) (Case Study 16) Schupp et al. (2015) *Research, planning, options testing adaptations,*	Beach and access roads, parking *>Current situation plus scenarios from USGS modeling*	Testing and adopting best practices to maintain beach use in a more sustainable way. Challenge of working across agencies and with local government	Additional research, public awareness, adaptation planning, resilient infrastructure, managed retreat

US National Park **>key resources**	**Analysis Focus / Methods**	**Resources Targeted** ***>Scope-Time Horizon***	**Highlights**	**Action Taken**
>Beaches, dunes, bluffs *>Nearshore- ocean ecosystem* *>Infrastructure at risk*	Scenario Planning for Adaptation, using 4 approaches: SLR, temperature, habitat dynamics (18) Zimmerman (2010b). *Vulnerability info was incorporated into scenario planning process*	Facilities, flora- salt marsh, maritime forest; hydrology- fresh surface and ground water; coastal barrier movement, sand *>2040 (temperature increase of 1 to 1.9 C;*	Groundwater a major vulnerability, need for flexible, temporary access infrastructure, changed boundaries to accommodate shifting land, seascapes.	Removed parking lots, made infrastructure moveable, incorporate climate change into general management plan, monitored and modeled groundwater.
	EA for Bayside Picnic and Parking Areas: SLR, storms Assateague Island National Seashore. (2013b). *Environmental impact assessment*	Access infrastructure *Applies to specific access facilities; >SLR projection for 2050, 2100*	Impacts post-Sandy similar to those in climate change scenario	Selected option will allow natural shoreline processes to continue: parking lot relocated, natural buffer created
	Park staff leadership and ingenuity. Guo (2014). *Park contributions to National Park Service coastal adaptation handbook*	Infrastructure in flood prone and eroding, landscape migrating areas *Park wide activities: >30 year time frame (expected life span of staff member)*	Plan in advance for vulnerable facilities, find temporary structure options	make infrastructure resilient and adaptable, portable; use 'common sense' adapt to island, not human needs; stop building up dunes use ferries
	Modeling barrier island dynamics. Carroll et al. (2009). *LiDAR morphological data for modeling barrier island dynamics*	Beaches, dunes *Park-wide, including alongshore as well as cross shore dynamics; >no time frame*	Simulations combined with experience of storms helpful for visualizing impacts	–
Cumberland Island National Seashore (CUIS)	Vulnerability assessment considering both climate and non-climate stressors, SLR, ocean acidification, salinity and temperature Peek et al. (2016). *Asset identification including shoreline use and marine habitat mapping; scoring resources based on exposure, sensitivity, adaptive capacity*	Marine resources including nearshore subtidal, intertidal beach, low salt marsh, salt flats, high fringing salt marsh, shellfish beds, tidal mud flats, tidal creeks, & estuarine nearshore subtidal *>Park wide scope; SLR in 2100 ;*	Combined climate change stressor vulnerability scores and habitat rankings within park. Focus on intrinsic adaptive capacity of ecosystem. Identified and rated non-climate stresses.	Propose using the assessment as part of an overall adaptation planning effort for the park, consistent with approach of Glick et al., 2011 “Scanning the Conservation Horizon”.

Appendix B. Vulnerability Assessments in NPS Adaptation Case Studies (Schupp et al. 2015)

CASE STUDY	Improving Resilience, Capacity and Policy									Physical Adaptations									
	Additional research	Monitor CC impacts	Public awareness	Adaptation training & planning	Adaptation plan	Incorporate CC to policies, plans, rules	New or enhanced policy	Coordinate across institutional boundaries	Communicating actions	Resilient infrastructure	Managed retreat: infrastructure	Reduce local CC	Reduce non climate stressors	Enhance technology	Enhance connectivity	Restore wetland	Reduce flood risk	Support natural processes (sediment)	Short term adaptation
CULTURAL RESOURCES																			
Case Study 1: Reservoir Water Level Change Impacts on Cultural Resources, Amistad National Recreation Area, Texas	X	X	X																
Case Study 3: Shell Mound Sites Threatened by Sea Level Rise and Erosion, Canaveral National Seashore, Florida	X		X		X	X													
Case Study 4: Cultural Resources Inventory and Vulnerability Assessment, Bering Land Bridge National Preserve, Alaska Cape Krusenstern National Monument, Alaska	X				X									X					
FACILITIES AND INFRASTRUCTURE																			
Case Study 6: Eroding Shoreline Threatens Historic Peale Island Cabin, Yellowstone National Park, Wyoming	X		X		X	X					X								
Case Study 15: Rehabilitating Stream Crossings on Historic Roads, Acadia National Park, Maine	X					X				X									

	Improving Resilience, Capacity and Policy									Physical Adaptations									
CASE STUDY	**Additional research**	**Monitor CC impacts**	**Public awareness**	**Adaptation training & planning**	**Adaptation plan**	**Incorporate CC to policies, plans, rules**	**New or enhanced policy**	**Coordinate across institutional boundaries**	**Communicating actions**	**Resilient infrastructure**	**Managed retreat: infrastructure**	**Reduce local CC**	**Reduce non climate stressors**	**Enhance technology**	**Enhance connectivity**	**Restore wetland**	**Reduce flood risk**	**Support natural processes (sediment)**	**Short term adaptation**
Case Study 17: Reducing Vulnerability of Coastal Visitor Facilities, Cape Cod National Seashore, Massachusetts			X		X	X				X		X	X						
NATURAL SYSTEMS AND FEATURES																			
Case Study 13: Consideration of Shackleford Banks Renourishment, Cape Lookout National Seashore, North Carolina	X		X		X	X		X											
Case Study 21: Incorporating Climate Change into Florida's State Wildlife Action Plan	X			X		X		X						X					
Case Study 22: Developing a Multiagency Vision for an Urban Coastline, Golden Gate National Recreation Area, California	X					X		X		X	X		X						
Case Study 24: Storm Surge and Sea Level Change Data Support Planning, NPS Geologic Resources Division, Colorado	X	X	X					X	X										

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.

NPS 962/137989, April 2017

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