Atlantic National Seashores in Peril
The Threats of Climate Disruption

At stake are the resources and values that make the Atlantic Coast national seashores special places that Americans love.

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About RMCO

The Rocky Mountain Climate Organization (RMCO) works to reduce climate disruption and its impacts. We do this in part by spreading the word about what a disrupted climate can do to us and what we can do about it. Visit www.rockymountainclimate.org to learn more about our work.

About NRDC

The Natural Resources Defense Council (NRDC) is an international nonprofit environmental organization with more than 1.3 million members and online activists. Since 1970, our lawyers, scientists, and other environmental specialists have worked to protect the world's natural resources, public health, and the environment. NRDC has offices in New York City; Washington, DC; Los Angeles; San Francisco; Chicago; Livingston, Montana; and Beijing. Visit us at www.nrdc.org.

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Executive Summary

Human-caused climate change is the greatest threat ever to Cape Cod, Fire Island, Assateague Island, Cape Hatteras, Cape Lookout, Cumberland Island, and Canaveral national seashores.

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Canaveral NS

Human disruption of the climate is the greatest threat ever to America's national parks. Certainly among the most vulnerable units of the national park system are the seven Atlantic Coast national seashores: Cape Cod National Seashore (NS) in Massachusetts, Fire Island NS in New York, Assateague Island NS in Maryland and Virginia, Cape Hatteras and Cape Lookout national seashores in North Carolina, Cumberland Island NS in Georgia, and Canaveral NS in Florida. This report details how climate change already is affecting them and the far greater threats it poses in the future.

A common thread throughout this report is that how much these national seashores will be disrupted depends on the future levels of heat-trapping pollutants. Protecting the resources and values of these special places is among the many reasons for acting now to protect our climate.

Perhaps for most visitors to the Atlantic Coast national seashores, the highlight of the trip is the beach. Each of these national seashores offers beaches as nature intended—long stretches of sandy beaches, backed by dunes and other undeveloped lands. The seashores also harbor other nationally important resources, from barrier islands, largely undisturbed ecosystems, nesting sea turtles, globally important bird areas, wild horses that charm visitors, lighthouses, and other historical resources.

The seashores draw over 11 million visitors a year, whose spending supports nearly 8,000 jobs as detailed in Table ES-1. Threats to the resources that draw these visitors are also threats to the economies of the seven states in which the seashores are located. An additional, immeasurable economic value of the seashores is that they contain islands, spits, dunes, and other shoreline features that are the first line of defense protecting human

Spending and Jobs from Visitors to Atlantic National Seashores

	Visitors In 2010	Visitor Spending in 2010	Jobs Supported in 2010
Cape Cod NS	4,653,706	$171,182,000	1,856
Fire Island NS	613,057	$35,076,000	390
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Cape Hatteras NS	2,193,292	$108,475,000	1,615
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Table ES-1. Total recreational visits to the Atlantic Coast national seashores, spending by all visitors to the seashores, and jobs supported by spending by non-local visitors in 2010. Sources: NPS and Stynes.

populations and developments from the sometimes devastating effects of winds and surging flood waters from hurricanes, nor'easters, and other coastal storms.

More Heat

For this report, the Rocky Mountain Climate Organization (RMCO) analyzed the temperature trends at the seven Atlantic national seashores, using weather stations with long-term records in or near the seashores. As shown in Table ES-2 on the right, which summarizes information presented in a figure in the report, annual temperatures in the seashores have become markedly hotter than they used to be. The table shows how much the average temperatures of the last 11 years have changed compared to earlier periods—1961–1990 for all the seashores except Assateague Island, and 1971–1990 for that seashore, where records do not go back any earlier.

Higher Seashore Temperatures in 2000-2011

National Seashore	Temperature Change	Baseline For Comparison
Cape Cod NS	+1.7°F	1961-1990
Fire Island NS	+1.8°F	1961-1990
Assateague Island NS	+0.8°F	1971-1990
Cape Hatteras NS	+1.2°F	1961-1990
Cape Lookout NS	+1.8°F	1961-1990
Cumberland Island NS	+0.8°F	1961-1990
Canaveral NS	+1.3°F	1961-1990

Table ES-2. Temperature trends for Atlantic national seashores, from weather stations in or near the seashores, for 2001–2011, compared to 1961–1990 averages, except for Assateague Island NS,which is compared to 1971–1990).

RMCO also developed new projections of how much hotter year-round (or annual) average temperatures in the Atlantic national seashores could become as a result of human emissions of heat-trapping gases. Projections were made for two different possible futures: one scenario with a lower level of future emissions of heat-trapping pollutants and the other with medium-high emissions. Projected changes in year-round average temperatures with lower future emissions ranged from increases of 2.6°F to 3.6°F by 2081–2090, compared to 1981–2010 levels. With medium-high future emissions, year-round average temperatures could instead increase by 5.1°F to 6.5°F. This is one of several illustrations of how the extent of future climate change depends in large part on whether future emissions of heat-trapping pollutants continue at a relatively high rate or are instead reduced to a lower rate.

RMCO also projected the possible change in their summer temperatures, as shown in Table ES-3 on the next page. Summer temperatures are particularly important, for two reasons. First, summer is the season with the most visitation for all the Atlantic seashores except for Canaveral NS. Second, people visiting national seashores typically are outdoors, not in air-conditioned buildings, and for many people, outdoor activities, even beach-going, may simply become intolerably hot. Beaches are traditional spots for a break from the heat, but a tipping point could be reached, with baking heat trumping cooling breezes. When temperatures are in the 80ºs and 90ºs, going to the beach may offer relief. But when temperatures are in the 100ºs, the experience could be a lot less enjoyable.

The good news is that summers in Assateague Island NS need not get as hot as those of Key West, and summers in Cape Hatteras NS need not get as hot as those of Galveston. As indicated, these projections are based on a medium-high level of future emissions. While even higher emissions are certainly possible and in fact consistent with recent trends, it also is true that future emissions can be held to lower levels. Then summers in the seashores would get hotter than now, but not by as much.

Assateague Island NS. Photo: NPS.

Hotter Future Summers in Atlantic National Seashores Projections with Medium-High Future Emissions		
National Seashore	**2051–2060**	**2081–2090**
A. Cape Cod NS		
Average projection	+3.4° (to 79.6°)	+6.1° (to 82.3°)
Effect of average projection	As hot as recent summers in Long Island, NY (79.6°)	Nearly as hot as recent summers in Cape May, NJ (82.4°)
Range of projections	+1.9° (to 78.1°) to +5.0° (81.2°)	+3.9° (to 78.1°) to +8.2° (84.4°)
B. Fire Island NS		
Average projection	+3.6° (to 82.4°)	+6.5° (to 85.3°)
Effect of average projection	As hot as recent summers in Cape May, NJ (82.4°)	As hot as recent summers in Atlantic Beach, NC (85.4°)
Range of projections	+1.9° (to 80.7°) to +5.5° (84.3°)	+3.1° (to 81.9°) to +8.7° (87.1°)
C. Assateague Island NS		
Average projection	+3.4° (to 86.3°)	+6.2° (to 89.1°)
Effect of average projection	As hot as recent summers in Charleston, SC (86.2°)	As hot as recent summers in Key West, FL (89.1°)
Range of projections	+1.6° (to 84.5°) to +5.4° (88.3°)	+3.1° (to 86.0°) to +8.7° (91.6°)
D. Cape Hatteras NS		
Average projection	+3.0° (to 86.2°)	+5.4° (to 88.6°)
Effect of average projection	As hot as recent summers in Charleston, SC (86.2°)	As hot as recent summers in Galveston, TX (88.7°)
Range of projections	+1.3° (to 84.5°) to +4.5° (87.7°)	+3.0°(to 86.2°) to +7.7° (90.9°)

Table ES-3, continued on next page. Projected changes in average summer (June-July-August) mean temperatures in Atlantic national seashores by 2051–2060 and 2081–2090, in degrees Fahrenheit, compared to 1981–2010 averages. Results from 16 downscaled climate models assuming a scenario of medium-high future emissions of heat-trapping gases, showing the averages and ranges of those projections. Also shown are what would be each seashore's average summer daily maximum temperature if its average 1981–2080 maximum temperature increased by the amount of increase projected for its mean temperature (the values in parentheses) and a location with a comparable average summer maximum temperatures in 1981–2010.

National Seashore	2051–2060	2081–2090
E. Cape Lookout NS		
Average projection	+3.1° (to 89.3°)	+5.6° (to 91.8°)
Effect of average projection	As hot as recent summers in Daytona Beach, FL (89.3°)	As hot as recent summers in Fort Myers, FL (91.7°)
Range of projections	+1.2° (to 87.3°) to +4.4° (90.6°)	+3.1° (to 89.3°) to +8.1° (94.3°)
F. Cumberland Island NS		
Average projection	+3.4° (to 92.7°)	+6.3° (to 95.6°)
Effect of average projection	As hot as recent summers in Houston, TX (92.7°)	As hot as recent summers in White Sands National Monument, NM (95.5°)
Range of projections	+1.5° (90.8°) to 5.1° (94.4°)	+3.3° (92.6°) to 10.2° (99.5°)
G. Canaveral NS		
Average projection	+3.3° (to 94.1°)	+6.1° (to 97.0°)
Effect of average projection	As hot as recent summers in El Paso, TX (94.2°)	As hot as recent summers in Desert Rock, NV (97.0°)
Range of projections	+1.8° (92.7°) to +4.0° (94.9°)	+2.7° (93.6°) to +7.7° (98.6°)

Table ES-3, continued.

Storm Surges and Island Disintegration

The natural forces of winds, waves, water, and especially storms shape coastal areas through such processes as flooding, erosion of beaches, dunes, and marshes, and buildup of new areas by deposits of sand and other sediments. Human-caused climate change is magnifying to a new, unnatural extent these natural forces, by raising sea levels and making coastal storms stronger. As a result, the seashores now are being shaped not just by natural forces but by a new mixture of natural and unnatural forces, which yield different consequences.

The Atlantic Coast national seashores are experiencing sea-level rise (SLR) at least equal to the global average, with Cape Cod, Fire Island, Assateague Island, and Cape Hatteras national seashores clearly experiencing above-average rates. The northeastern coast, including Cape Cod, Fire Island, and Assateague Island, has been identified as part of a "hot spot" of accelerated SLR and is expected to continue experiencing above-average SLR.

Higher seas especially make a difference in magnifying the effects of coastal storms. With a higher initial sea level, storms surges push farther inland than they did when beginning atop earlier, lower seas.

Coastal storms are also getting stronger. North Atlantic hurricanes have become stronger in the last 30 years—especially the most powerful ones. This increase in storm strength coincides with about a 2°F increase in sea-surface temperatures where hurricanes form. Average summer wave heights have also increased along the Atlantic coastline since 1975 because of the stronger hurricanes. Atlantic hurricanes are likely to continue getting stronger during this century, with higher peak winds, rainfall intensity, and storm-surge height and strength.

Barrier islands, which form the centerpiece of all of the Atlantic seashores except Cape Cod, are especially vulnerable. An illustration is the effects of Hurricane Katrina in 2005 on a group of barrier islands in Louisiana, the Northern Chandeleur Islands. Katrina's storm surge was high enough and the islands were low enough that the islands were completely submerged, stripping the islands of sand. What remained after the storm was a discontinuous series of marsh fragments. Erosion has continued since 2005, suggesting that a threshold has been crossed and natural processes may not contribute to the rebuilding of the barrier in the future.

The authors of this report, interpreting a comparative assessment by the U.S. Geological Survey (USGS) of the relative vulnerabilities of different portions of the U.S. Atlantic Coast to sea-level rise based on six particular factors, suggest that Assateague Island, Cape Hatteras, Cape Lookout, and Canaveral national seashores are in a top tier of vulnerability based on those factors, followed in order by Fire Island NS, then Cumberland Island NS, and finally Cape Cod NS, as summarized in Table ES-4 below.

The six factors on which the assessment summarized in Table ES-4 was based are tidal range, wave height, coastal slope, shoreline change, geomorphology (vulnerability to erosion), and historical rate of relative sea-level rise. Each stretch of coastline was assigned a numerical ranking for each factor as well as a cumulative ranking. The vulnerability rankings of individual stretches for coastline were not tabulated for larger areas such as an entire national seashore, so the summaries in Table ES-5 ultimately represent interpretations by the authors of this report, not the USGS ratings themselves.

Low-Elevation Seashore Lands

This report presents new maps of the Atlantic seashores showing lands that are less than one meter (39.4 inches) above the current sea level. One meter is widely accepted as a reasonable possibility for how much the global average sea level might rise in this century.

This is the first set of maps showing for the Atlantic national seashores their lands that are low-lying enough to be at particular risk of inundation by higher seas and, prior to that, of storm surges, erosion, and disintegration of barrier islands and landforms.

The figures show that in each of Fire Island, Assateague Island, Cape Hatteras, Cape Lookout, and Canaveral national seashores a majority of the seashore's land is in this category of highest risk. Important lands in the other seashores are also in this category.

Visitor Access

As seas rise and coastal storms become stronger, some Atlantic seashores face a potential loss of the bridges and roads that now provide most visitor access to them.

The most vulnerable roads are those that already have been periodically subject to overwash and washout, necessitating expensive repairs and rebuilding, especially in Assateague Island and Cape Hatteras national seashores. In the near term, the threats primarily are of more frequent and long-lasting temporary closures of key bridges and roads that provide visitor access to those seashores.

In the long term, the current transportation infrastructure may not be adequate, forcing permanent closures of the current roads and their replacement with alternative methods of access. At some point, the decisive factor in whether to continue maintaining current roads or to provide alternative access likely will be the relative governmental expenses in either repeatedly repairing them or replacing them with alternative transportation.

Ultimately, if extensive lands as well as bridges, roads, and other visitor-access facilities were to be lost to higher seas or erosion, there would be obvious consequences for both visitor access to and visitation levels at the seashores. But so long as substantial land remains above the sea, the seashores doubtless will remain attractive to visitors even if the methods of access may change, as demonstrated at Cape Lookout and Cumberland Island national seashores, reachable only by boat.

Continuing to provide visitor access will require new planning and funding.

In developing a draft of a new general management plan (GMP) to guide management of the seashore for the next 20 years or so, Assateague Island has begun the process of addressing visitor access to the seashore in a pioneering way. Two of the four preliminary management alternatives under consideration contemplate shifting

An Assessment of Relative Vulnerability Of Atlantic National Seashores

National Seashore	Summary of USGS Coastal Assessment
Cape Cod NS	Almost entirely low vulnerability.
Fire Island NS	Primarily high vulnerability. Less area of moderate vulnerability.
Assateague Island NS	Almost entirely very high vulnerability.
Cape Hatteras NS	Almost entirely very high vulnerability.
Cape Lookout NS	Almost entirely very high vulnerability.
Cumberland Island NS	Nearly equal areas of very high and moderate vulnerability. Less area of high vulnerability.
Canaveral NS	Entirely very high vulnerability.

Table ES-4. Summaries of vulnerability of ocean coastal areas of Atlantic national seashores to sea-level rise based on six factors (see text).

visitor access to Assateague Island primarily to commercial ferry service once bridge access is lost in a major storm. The NPS has pointed out that attempting to maintain the current bridges, roads, and other infrastructure to support motor vehicles on the island could actually reduce future visitor access because of the months or years needed to restore that access after storm-related closures. This forthright consideration of climate change impacts and new management options based on them is a fundamentally different and encouraging step by the NPS. The public seems ready to embrace this new approach; in comments on the GMP alternatives, the most support was expressed for an alternative based on long-term sustainable recreation and climate change adaptation.

Wildlife and Ecosystem Impacts

Hotter temperatures, stronger storms, rising seas, and other manifestations of a changing climate are affecting the wildlife and ecosystems of the Atlantic seashores.

Sea turtles, which are found at all of the Atlantic national seashores and nest from Assateague Island NS to Canaveral NS, have suffered extensive losses of nests from hurricanes and coastal storms. A hotter climate threatens sea turtles in another, particularly insidious way. The sex of their young is controlled by temperature, with more females hatched from eggs incubating at higher nest temperatures. Already, populations of turtles in southern parts of the United States are currently heavily skewed toward females and are likely to become much more so with even slight further increases in temperature.

Leatherback sea turtle hatchling, Cape Lookout NS. Photo: NPS.

Coastal species of birds are particularly at risk to climate change, especially beach-nesting species such as piping plovers, a threatened species. Other wildlife in the seashores facing threats from climate change include manatees, alligators, and butterflies.

Ecosystems at particular risk as the climate changes are salt marshes, which can be overtaken by rising seas; sandy beaches, subject to high erosion rates; and ocean waters, which are becoming hotter and more acidic, affecting marine wildlife.

Other Impacts

An altered climate will affect many additional resources and values of the Atlantic seashores, including the enjoyment of visitors, who may face more overcrowding as people escape the heat by going to the beach.

Lighthouses and other historical and cultural resources may be lost to a rising sea. Already, the NPS has relocated the Cape Hatteras lighthouse once to keep it ahead of a higher sea, at a cost of more than $11 million, and made arrangements at its new location to prepare it for the next move.

A hotter climate is expected to increase levels of ground-level ozone, which already harms people's health in some of the seashores, which do not now meet health-based air quality standards.

Tackling Climate Disruption

As the risks of a changed climate dwarf all previous threats to our national seashores and other units of the national park system, new actions to face these new risks must also be on an unprecedented scale. Actions are needed by the NPS to identify and protect threatened seashore resources, and funding and other support from Congress is essential. The parks also can lead in reducing their own emissions of heat-trapping pollution, and educating visitors on climate change threats and examples of emission reduction efforts. With 279 million visits in 2011, the national park system can play a unique role in raising awareness about the threats to the national seashores and other parks Americans so love and what can be done to protect them.

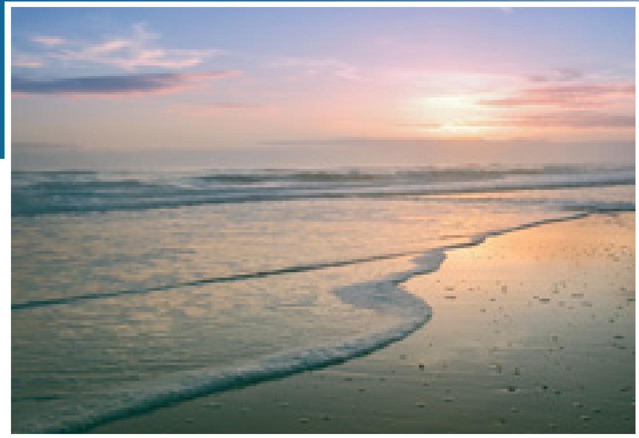
Ultimately, to protect the national seashores and parks we need to act now to reduce emissions of climate-changing pollutants, which come mostly from the burning of fossil fuels. Key steps include:

- Establishing comprehensive mandatory limits on carbon pollution to reduce emissions by at least 20 percent below current levels by 2020 and 80 percent by 2050;
- Protecting the current Clean Air Act authority of the U.S. Environmental Protection Agency (EPA), allowing EPA to do its job of protecting American's health by cutting pollution;
- Overcoming barriers to investment in energy efficiency to lower emission-reduction costs, starting now; and
- Accelerating the development and deployment of emerging technologies to lower long-term emission reduction costs.

1

INTRODUCTION

The seven national seashores on the Atlantic Coast are among the units of the national park system that are most vulnerable to a disrupted climate.



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Canaveral NS

Human disruption of the climate is the greatest threat ever to America's national parks.[1] Certainly among the most vulnerable units of the national park system are the seven Atlantic Coast national seashores: Cape Cod National Seashore (NS) in Massachusetts, Fire Island NS in New York, Assateague Island NS in Maryland and Virginia, Cape Hatteras and Cape Lookout national seashores in North Carolina, Cumberland Island NS in Georgia, and Canaveral NS in Florida. This report details how climate change already is affecting them and the far greater threats it poses in the future.

All of the planet and our nation face the consequences of how people are disrupting the climate and its natural cycles. But the Atlantic national seashores deserve particular attention. They are units of the national park system, which includes national parks and monuments and other types of areas along with national seashores. All were set aside by Congress to protect their significant natural and cultural resources and all are managed by the National Park Service. What could happen to them illustrates how, if we do not limit our pollution of the atmosphere with heat-trapping gases, the places many Americans most love will never be the same. These national seashores, in fact, are unusually vulnerable, as they face bigger storm surges, more erosion, and, in many areas, inundation by a rising ocean. In these seashores, human alteration of the climate threatens to undercut our national promise that these special places will be preserved unimpaired for the enjoyment of future generations.

For many of us, the threat to these special places brings climate change home in a way that threats to distant places does not. And this is a powerful incentive for us to stop taking so many unnecessary actions that disrupt the climate.

This report summarizes what is known about the impacts on these national seashores from human emissions of heat-trapping pollutants. The report contains new analyses of how the seashores have become hotter in recent years and new projections of how they could become much hotter in the future. Other information is drawn from government and scientific reports, journal articles, other publications, and especially from the authors' consultations with scientists and other professionals of the National Park Service and other federal and private experts who study these seashores.

A common thread throughout this report is that how much these national seashores will be disrupted depends on the future levels of heat-trapping pollutants, most of which come from the burning of fossil fuels like coal, oil, and natural gas in vehicles, power plants, and industrial facilities. If we humans continue to spew forth high levels of heat-trapping emissions, the consequences on these special places will be drastic. If we reduce emissions, the worst impacts can be avoided. And the sooner we act, the more we will avoid impacts.

The good news is there are many ways to reduce heat-trapping pollution—by making major pollution sources more efficient and relying more on clean energy sources such as wind, solar, and geothermal power. These steps also can strengthen our national, local, and personal economies. In many ways, this transition has already begun, but we need more policies now at the local, state, and federal level to make it happen faster. (See Section 9 on page 49.)

Protecting the resources and values of the Atlantic Coast national seashores is among the many reasons for acting now to protect our climate.

"I believe climate change is fundamentally the greatest threat to the integrity of our national parks that we have ever experienced."

Jonathan Jarvis, Director, National Park Service[2]

2

Natural and Economic Values at Stake

The Atlantic national seashores are special places, with unique natural, recreational, economic, and shore-protection values, all at risk as humans change the climate.

Assateauge Island. Photo: FWS.

The seven Atlantic Coast national seashores are areas of great national, regional, and local significance.

Perhaps for most visitors to the Atlantic Coast national seashores, the highlight of the trip is the beach. Each of these national seashores offers beaches as nature intended—long stretches of sandy beaches, backed by dunes and other undeveloped lands. Every year, these beaches are enjoyed annually by millions of Americans—sunbathers, swimmers, beachcombers, sand-castle makers, surfers, fishermen, boaters, wildlife watchers, hikers, campers, and more. On a coast with a huge population and growing development, where accessible natural beaches are few, the beaches at the national seashores stretch for 55 miles at **Cape Cod**, 26 miles at **Fire Island**, 37 miles at **Assateague Island**, 72 miles at **Cape Hatteras**, 56 miles at **Cape Lookout**, 19 miles at **Cumberland Island**, and 24 miles at **Canaveral**.

The beaches are just part of what these seashores offer. Six of the national seashores are entirely or mostly located on barrier islands, and the seventh, **Cape Cod NS**, contains small barrier islands. These islands are fascinating, dynamic landforms, not like the stable landforms of the interior, but naturally in flux—eroding, building up, shifting, and reshaping themselves in response to waves, tides, winds, and especially storms. On these islands, the forces of nature are particularly vivid.

The seashores harbor a wide variety of other nationally important resources. Their ecosystems include not just beaches and dunes but also grasslands, shrublands, forests, freshwater ponds and wetlands, salt marshes, estuaries, and open ocean. Endangered sea turtles nest from **Assateague Island NS**, where loggerhead nests are uncommon, to **Canaveral NS**, where 3,000–4,000 loggerheads, up to 300 green sea turtles, and a few leatherbacks nest annually. The seashores include some of the most important and popular birding spots on the Atlantic Coast. **Assateague Island**, **Cape Lookout**, and **Cumberland Island national seashores** are home to wild horses that charm seashore visitors. Cultural resources include lighthouses, prehistoric and historic communities, the nation's first African Baptist Church, and the home of a signer of the Declaration of Independence. Popular forms of recreation at the seashores include hiking, bicycling, camping, boating, sightseeing, wildlife watching, and of course beach going.

The threats of climate disruption to the national seashores on the Atlantic Coast are also threats to the economies of the seven states in which the seashores are located. The seashores together draw about 11 million visitors a year, contributing to the economy of those seven states by annually generating more than half a billion dollars in visitor spending and supporting nearly 8,000 jobs. These calculations of the seashores' economic benefits come from a Michigan State University researcher who annually compiles data on the local economic contributions of all national parks.[3] The latest such report covers 2010, with the results shown in Table 1 on the next page.

Two examples of communities dependent on national seashores are Dare County, North Carolina, and the Town of Chincoteague, Virginia.

In Dare County, which includes **Cape Hatteras NS**, tourism is the number-one industry, with 61% of the county's employment related to the tourism industry.[4] In the peak visitation season—the summer—the labor force increases by about 75%. In 1999, the revenue in the peak season represented more than 70% of the annual economy in Dare County.

The Town of Chincoteague is almost entirely dependent on beach-going and nature-based visitation to neighboring **Assateague Island NS** and Chincoteague National

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	Visitors In 2010	Visitor Spending in 2010	Jobs Supported in 2010
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Totals	11,154,421	$566,373,000	7,556

Table 1. Total recreational visits to the Atlantic Coast national seashores, spending by all visitors to the seashores, and jobs supported by spending by non-local visitors in 2010. Sources: NPS and Stynes.[5]

Wildlife Refuge, most of which overlays the seashore. The town's permanent resident population is only 4,300, but in the summer it swells to 15,000, with the increase primarily driven by the beach of the seashore and refuge.[6] "Seventy to 80 percent of the town's businesses depend on the beach," says Mayor Jack Tarr.[7] The Town's Comprehensive Plan clearly states that proximity to Assateague Island NS and Chincoteague NWR is the town's largest economic development opportunity.[8] Accomack County, in which the town is located, also gets over $400,000 in hotel tax revenue from the town's commercial lodging. The town's property represents nearly one-third of the county's real estate value and property tax revenue, and vacation or second homes make up 45% or more of Chincoteague's homes.[9]

An additional, immeasurable economic value of the seashores is that they contain islands, spits, dunes, and other shoreline features that are the first line of defense protecting human populations and developments from the sometimes devastating effects of winds and surging flood waters from hurricanes, nor'easters, and other coastal storms.[10]

"These figures generated from NPS visitation statistics are a fraction of Fire Island's overall benefit to the local economy."

Chris Soller, Superintendent, Fire Island NS [11]

All of these contributions of the Atlantic seashores are at risk as people continue to alter the climate with emissions of heat-trapping pollution.

Profiles of the Atlantic National Seashores

All of our national seashores are part of the national park system, meaning that they are managed by the National Park Service "to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."[12]

Cape Cod NS was authorized by legislation signed in 1961 by President John F. Kennedy—who knew the Cape well and as a senator from Massachusetts had worked for the seashore legislation. Cape Cod extends farther into the Atlantic Ocean than any other peninsula in the contiguous United States. The most visited of the Atlantic national seashores, Cape Cod NS includes the entire beach from Chatham—at the elbow of the arm-like shape of the Cape—around the tip at Provincetown, in places spanning the width of the peninsula and so also including the beaches and other shorelines of Cape Cod Bay.

Fire Island NS, established in 1964, covers most of a 32-mile barrier island as well as other landward small islands, sand flats, and wetlands, all along the southern shore of Long Island. Only 40 miles from Manhattan, the seashore is within the most densely populated metropolitan area in the East. People can reach the western and easternmost ends of the seashore by bridges from Long Island, or, as most people do, by taking ferries to several points within the seashore. Within the seashore, visitors travel mostly on foot or by bike on the beaches and a network of boardwalks, concrete walks, and sand and gravel roads. Visitors come primarily to visit the beaches, but many enjoy other seashore resources, including a lighthouse, a seven-mile stretch that is the only federal wilderness area in New York, a "sunken" low-lying forest, and more. Also on Fire Island are 17 small communities, a state park, and a county park.

Assateague Island NS, established in 1965, is on a barrier island stretching from the Ocean City Inlet in Maryland south into Virginia. Bridges and roads provide separate access to the Maryland portion of the seashore and an adjacent state park and to the Virginia portion of the seashore and Chincoteague National Wildlife Refuge. Between the two areas with road access are 33 miles of undeveloped, natural beaches, backed by dunes, grasslands, maritime forests, salt marshes, and coastal bays.

Cape Hatteras is our first national seashore, authorized in 1937 and designated in 1953 when sufficient lands had been donated. It covers much of the Outer Banks, a chain of barrier islands 175 miles long on the North Carolina coast. The seashore includes 70 miles of the three northernmost islands of the chain, stretching from southern Bodie Island across Hatteras and Ocracoke islands, which also contain Pea Island NWR and several communities. These islands are mostly very narrow, often less than 500 yards wide. They are remote, too, separated from the mainland by Pamlico Sound, up to 26 miles wide. The full length of the seashore can be reached from the north by a coastal highway or by ferries that serve Ocracoke Village at the southern end.

"The purpose of Cape Hatteras National Seashore is to permanently preserve the wild and primitive character of the ever-changing barrier islands, protect the diverse plant and animal communities sustained by the coastal island processes, and provide for recreational use and enjoyment that is compatible with preserving the distinctive natural and cultural resources of the nation's first national seashore."

National Park Service[13]

Cape Lookout NS includes a barrier island chain south of Ocracoke Inlet (which separates this seashore from Cape Hatteras), with three primary sections: Core Banks, Cape Lookout, and Shackleford Banks. The northeast/southwest-oriented Core Banks, running for 45 miles from Ocracoke Inlet to Cape Lookout, currently has three segments divided by two inlets, but these islands are always subject to change by the next big storm. From Barden Inlet near the cape, Shackleford Banks stretches west for nine miles. Designated in 1966, Cape Lookout, more than any other Atlantic national seashore, has retained its natural, untouched state. On Core Banks, miles of empty beaches are backed by low dunes and salt marshes. Cape Lookout and Shackleford Banks are generally higher, with more varied geology and vegetation. These barrier islands can be reached only by commercial ferries or other boats. Camping and rental cabins are available, but there are essentially no other commercial services. Self-sufficient visitors can enjoy these islands as they have been and continue to be shaped by the forces of nature.

Cumberland Island NS, designated in 1972, covers most of Georgia's largest and southernmost island in the Sea Islands, which altogether number more than 100 and stretch from South Carolina into Florida. Sixteen miles long and from three miles to half a mile wide, Cumberland Island is a relatively stable barrier island. Reachable only by ferry or boat, Cumberland Island NS has roads, but visitors must get around on foot or bike. The seashore has historic sites, cultural ruins, undeveloped beaches, federal wilderness areas, and the lowest visitation of any of the Atlantic national seashores.

Canaveral NS, which became a national seashore in 1975, has 24 miles of undeveloped beaches, the longest such stretch on Florida's Atlantic Coast. The seashore is contiguous to both Kennedy Space Center and Merritt Island NWR; the NPS and the FWS jointly manage an area of overlapping jurisdiction. Roads provide access to the mainland portion of the seashore and to either end of the barrier-island beaches, but the central 12 miles of the coast is roadless.

"Since ancient times, this barrier island has provided sanctuary to both people and wildlife. Many threatened animals find refuge here, including sea turtles who nest on its shores. Like Indians and early settlers, you too can find tranquility. Swim in the ocean. Fish in the lagoon. Stroll down a wooded trail. Or reflect on the longest expanse of pristine shore in Florida—the way it used to be."

Canaveral National Seashore, NPS[14]

Figure 1. Locations of the Atlantic Coast national seashores.

3

More Heat

The seashores are expected to get much hotter. In summers, if future emissions are high, the seashores could often be intolerably hot. Summers in Assateague Island could become as hot as recent summers in Key West.


©Natalie Lysenko/ shutterstock.com

Cape Cod

Human activities, principally the burning of fossil fuels, have led to large increases in atmospheric levels of heat-trapping gases over the last century. As a result, the climate is changing, around the world and in the Atlantic national seashores. Future temperature increases are likely to be even greater than those that have occurred already, with the ultimate extent depending on whether and how much we limit future emissions of heat-trapping pollutants.

Perhaps the clearest statement yet of the current scientific understanding of human-caused climate change is a 2009 national impacts assessment report of the U.S. government's interagency Global Change Research Program (USGCRP).[15] That report, *Global Climate Change Impacts in the United States*, begins:

> "Observations show that warming of the climate is unequivocal. The global warming observed over the past 50 years is due primarily to human-induced emissions of heat-trapping pollutants."[16]

This statement supports the central conclusions reached two years earlier by the United Nations-led Intergovernmental Panel on Climate Change (IPCC), which declared that there is more than a 90% likelihood that human emissions have caused most of the temperature increases over the last 50 years.[17] Similar conclusions have been reached by the U.S. National Academy of Sciences, the American Association for the Advancement of Science, the World Meteorological Organization, and other scientific bodies.[18]

According to both the USGCRP and the IPCC, without the effects of heat-trapping pollution, the factors causing natural climate variability likely would have made the world cooler since 1950, instead of markedly hotter.[19]

Recent Temperature Increases

Figure 2 below shows the trend for the past 101 years in global average temperatures by decade (except that the

Global Temperature by Decade, 1901–2011, Compared to 1961–1990

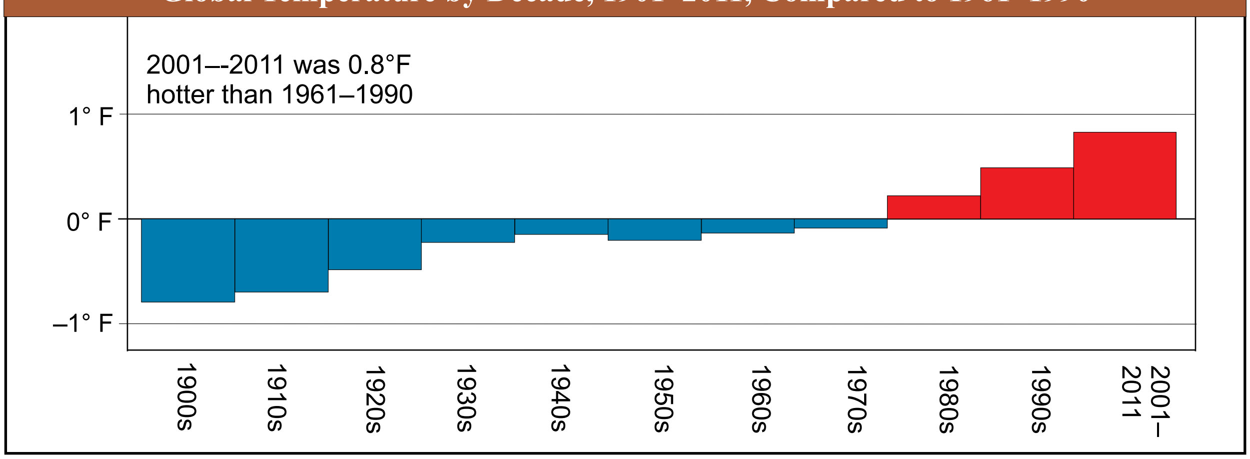


Figure 2. Average global surface temperatures, by decade for 1901–1910 through 1991–2000 and for 2001–2011, compared to the 1961–1990 average. Data source: National Climatic Data Center, National Oceanic and Atmospheric Administration.[20]

last column represents 11 years, 2001 through 2011). As the figure shows, those 11 most recent years averaged 0.8°F hotter than in 1961–1990. That baseline period is used here for ready comparison with the comparable figures, below, of temperature trends at the Atlantic national seashores. Compared instead to a baseline period of the entire 20th century, the world in the last 11 years averaged 1.0°F hotter. Expressed either way, this is the hottest such stretch in the history of instrumental measurements of temperature.

There are many other indications of how unusually hot the planet has been in recent years. Of the 132 years in the instrumental period, the last 25 years (1987–2011) are all among the 27 hottest years (along with 1981 and 1983).[21] The last eleven years include nine of the ten hottest years. The last 35 years have all been above the 20th century average.

Also, the average global temperature for the last 11 years is 1.4°F above that of pre-industrial times.[22] This means that the planet already is 40% to 50% of the way toward what is now defined by international treaty to represent unacceptable human disruption of the climate: 2.0°C (or 3.6°F) above pre-industrial temperatures.[23] And the parties to that treaty, including the United States, have agreed to reexamine that goal in the light of current evidence suggesting that 1.5°C (or 2.7°F) is a more accurate threshold for dangerous climate change.[24]

The United States has gotten hotter, too. According to the 2009 national assessment by the U.S. government mentioned above, the country as a whole has become 1°F to 2° hotter compared to the 1960s and the 1970s.[25]

For this report, the Rocky Mountain Climate Organization (RMCO) analyzed the temperature trends at the seven Atlantic national seashores, using weather stations with long-term records in or near the seashores. (See the Appendix for details of these weather stations and the methodology used for this analysis.) As shown in Figure 3 below, annual temperatures have become markedly hotter than they used to be.

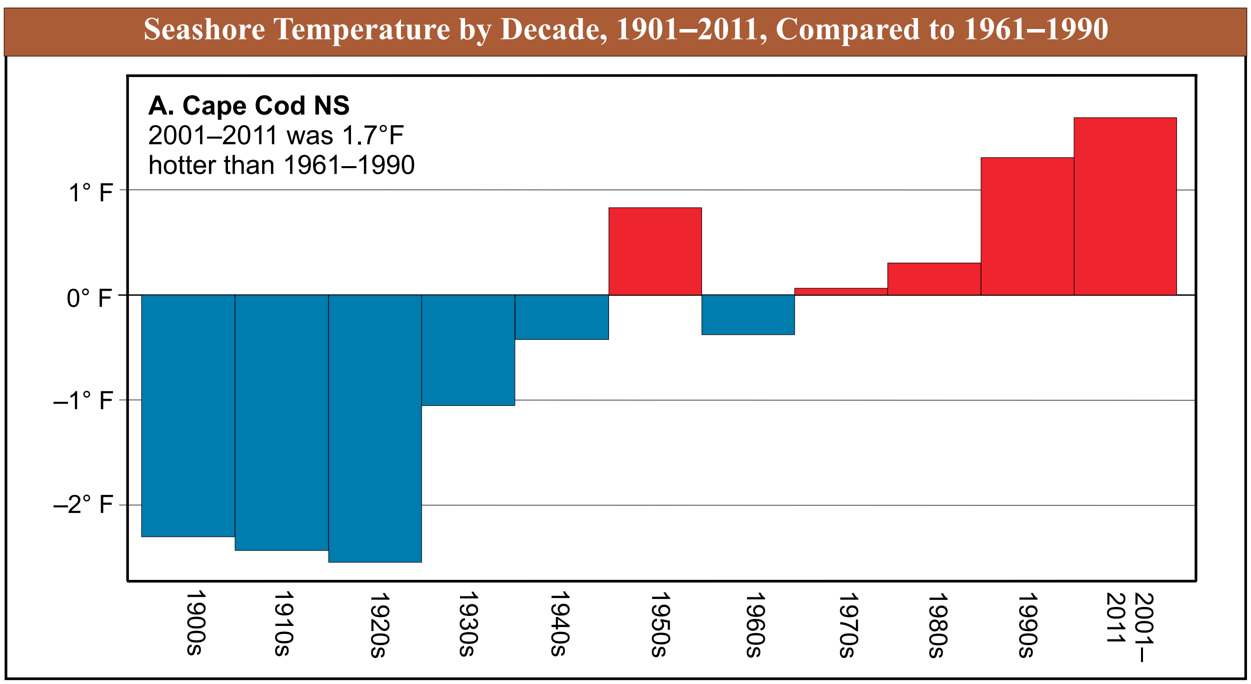


Figure 3 (continued on next two pages). Temperature trends for Atlantic national seashores, from weather stations in or near the seashores, by decade from 1901–1910 through 1991–2000 and for 2001–2011, compared to 1961–1990 averages (except for Assateague Island NS, figure 3C, which is compared to 1971–1990). Data source: National Climatic Data Center, National Oceanic and Atmospheric Administration; see the Appendix for details on sources and methodology.

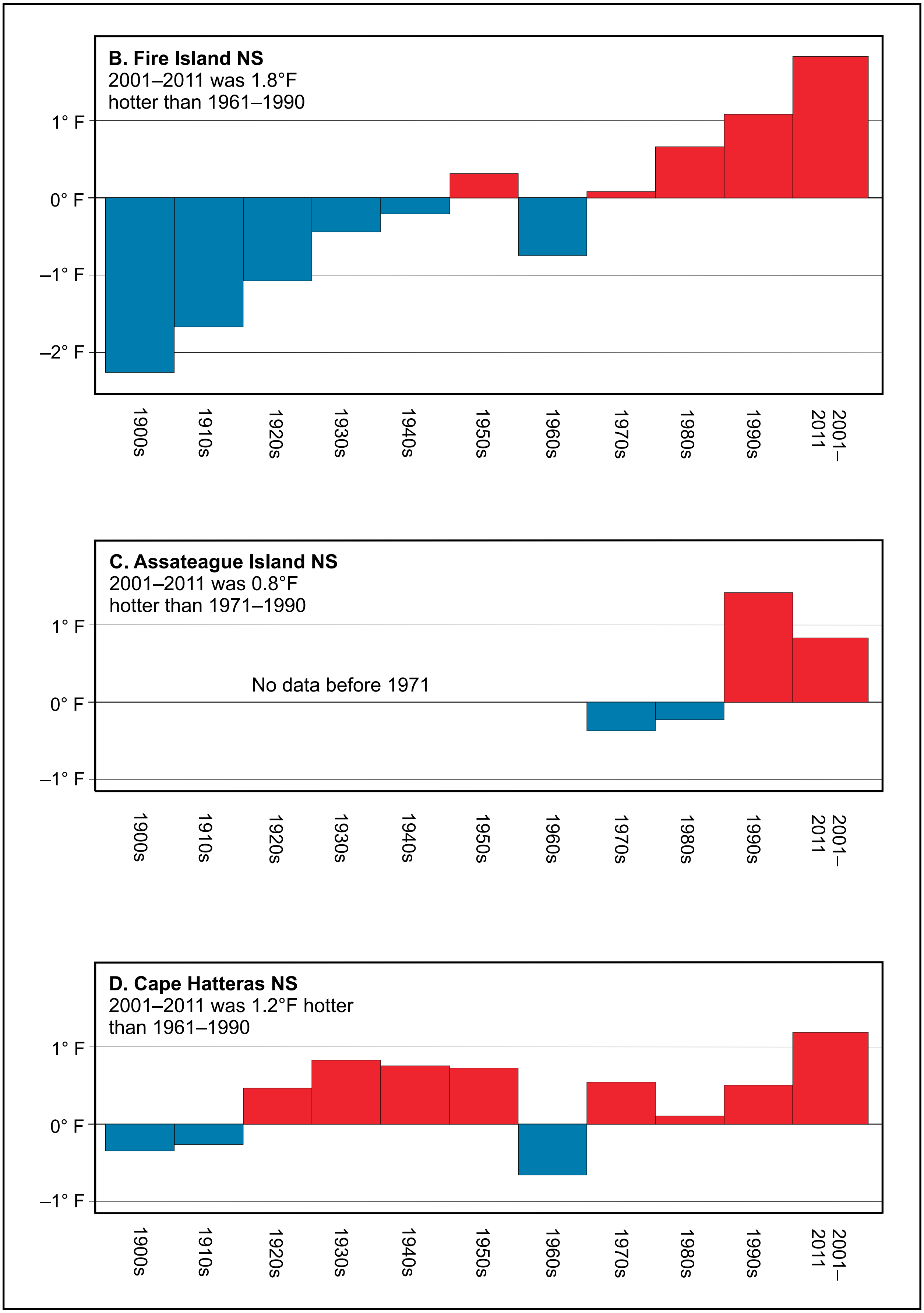


Figure 3, continued.

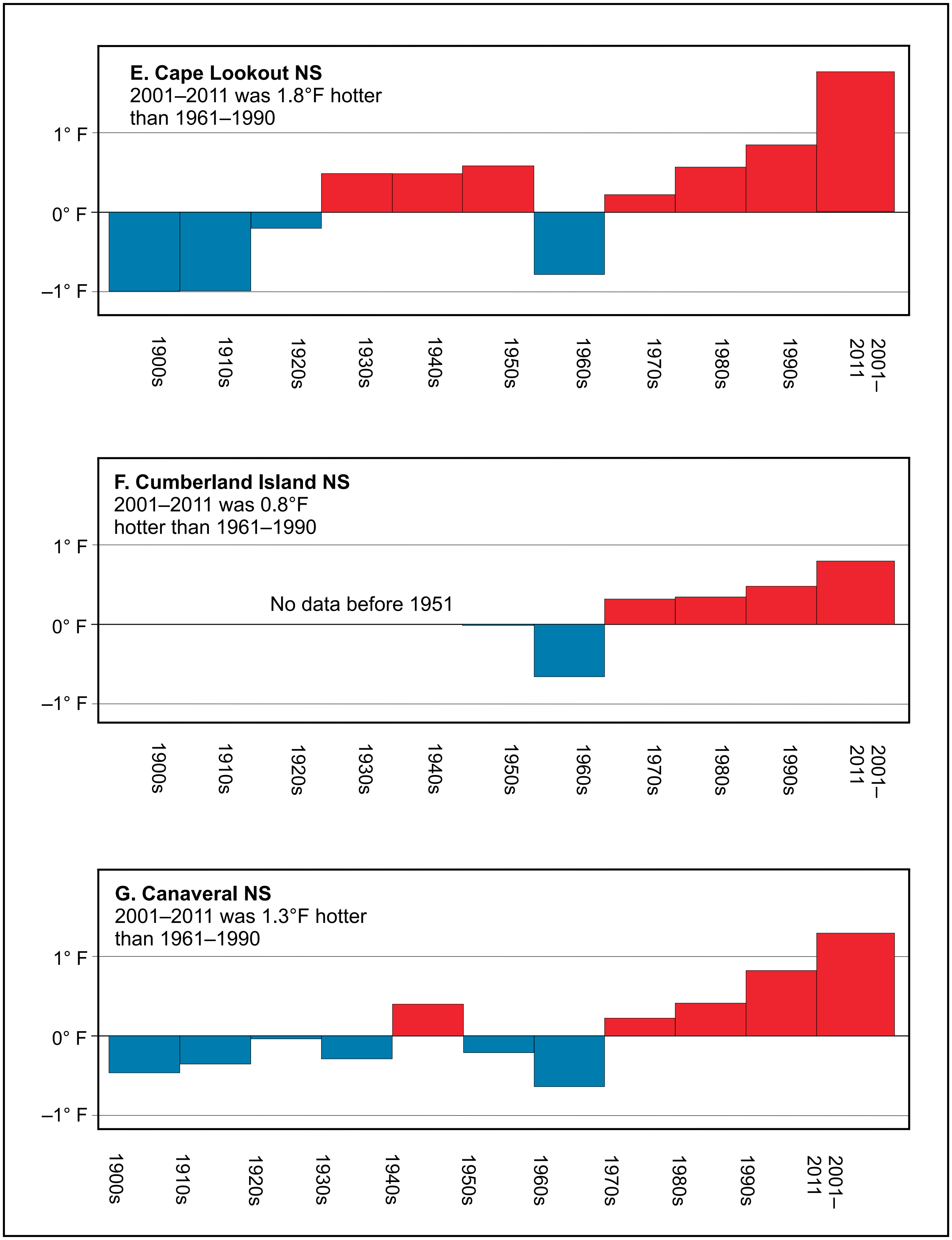


Figure 3, continued.

PROJECTIONS OF FUTURE TEMPERATURES

Some further global temperature increases in the next few decades are nearly certain because of the continuing atmospheric effects of past and present emissions of heat-trapping gases, which can persist in the atmosphere for a century or longer.[26] How much temperatures actually go up will be determined in large part by future emissions levels—by whether we humans take actions to reduce emissions or continue emitting heat-trapping pollutants at high rates.[27]

Annual Average Temperatures

For this report, the Rocky Mountain Climate Organization prepared new projections of how much hotter year-round (or annual) average temperatures in the Atlantic national seashores could become as a result of human emissions of heat-trapping gases. Table 2 below presents the results. (For details on the sources and methodology for these projections, see the Appendix.)

Projections were made for two different possible futures: one scenario with a lower level of future emissions of heat-trapping pollutants and the other with medium-high emissions. The lack of projections based on higher emissions means that these results are skewed toward the low end of possible changes. (See the text box on page 14.)

For each scenario, results were produced from 16 "downscaled" global climate models and for two 30-year time periods, in mid-century and near the century's end. For each emission scenario for each period, the average of all 16 projections is shown, as well as the range from the lowest to the highest of the changes suggested by individual projections.

Hotter Year-Round Temperatures in Atlantic National Seashores
Projections with Lower and Medium-High Future Emissions

	Lower Future Emissions		Medium-High Future Emissions	
	2051–2060	**2081–2090**	**2051–2060**	**2081–2090**
Cape Cod NS				
Average of projections	+2.6°	+3.6°	+3.6°	+6.3°
Range of projections	+1.4° to +3.9°	+1.9° to +5.2°	+2.1° to +4.6°	+4.4° to +8.6°
Fire Island NS				
Average of projections	+2.7°	+3.6°	+3.7°	+6.5°
Range of projections	+1.5° to +4.0°	+1.9° to +5.7°	+2.2° to+ 4.8°	+4.2° to +8.8°
Assateague Island NS				
Average of projections	+2.5°	+3.3°	+3.4°	+6.0°
Range of projections	+1.5° to +3.9°	+2.1° to +4.8°	+2.1° to +4.5°	+3.6° to +8.1°
Cape Hatteras NS				
Average of projections	+2.1°	+2.7°	+2.9°	+5.1°
Range of projections	+1.4° to +2.9°	+1.9° to +3.7°	+1.5° to +3.8°	+3.0° to +7.0°

Table 2 (continued on next page). Projected changes in average year-round (annual) temperatures in Atlantic national seashores by 2051–2060 and 2081–2090, in degrees Fahrenheit, compared to 1981–2010 averages. Results from 16 downscaled global climate models, using two scenarios of future levels of emissions of heat-trapping gases, showing the averages and ranges of those projections. See the Appendix for details on sources and methodology.

	Lower Future Emissions		Medium-High Future Emissions	
	2051–2060	2081–2090	2051–2060	2081–2090
Cape Lookout NS				
Average of projections	+2.1°	+2.8°	+3.0°	+5.2°
Range of projections	+1.3° to +2.9°	+1.8° to +3.8°	+1.7° to+ 4.3°	+3.0° to +7.0
Cumberland Island NS				
Average of projections	+2.2°	2.8°	+2.9°	+5.5°
Range of projections	+1.2° to +3.3°	+1.6° to +4.5°	+1.8° to +4.0°	+2.9° to +8.6°
Canaveral NS				
Average of projections	+2.1°	+2.6°	+2.9°	+5.3°
Range of projections	+1.3° to +3.9°	+1.2° to +4.0°	+1.5° to+ 3.9°	+2.7° to +7.7°

Table 2, continued.

The projections in Table 2 illustrate that how much the climate changes depends in large part on whether or not future emissions are limited. In every case, the scenario with higher emissions yields greater temperature increases than the scenario with lower emissions. For **Cape Cod NS**, for example, the average results from the 16 models is for the seashore to get 3.6°F hotter by late in the century with lower emissions, but 6.3° hotter with medium-high future emissions.

Other conclusions are also evident from the information in Table 2. First, the wide ranges of the projections from the 16 models illustrate why these (or any) projections of future temperature changes should be taken only as suggestions of the direction and possible range of future changes, not definitive predictions. Scientists simply do not yet know how sensitive the climate will be to different levels of heat-trapping pollutants. Also, current models are less reliable in estimating future local conditions than in estimating future global averages.[28]

Second, every model shows further increases in temperature (beyond those that have already occurred—see pages 7–9)—for both parks, in each time period, and under either emissions scenario. In no case do the projections show continuation of current temperatures or a decrease in temperatures.

Third, for either emissions scenario, the increases in temperature are projected to be greater later in the century, from the lasting, cumulative effect of both pollutants already in the atmosphere and those newly emitted. This characteristic of heat-trapping pollution is why scientists tell us that reductions in emissions made sooner will do more to limit climate change than reductions made later.[29]

These new projections are generally consistent with other temperature projections along the U.S. Atlantic Coast.[30] The NPS has developed climate projections, including temperature changes, for **Assateague Island NS** showing that year-round temperatures there could increase by 1.8° to 3.5°F by 2040.[31]

> *"Choices made now will influence the amount of future warming. Lower levels of heat-trapping emissions will yield less future warming, while higher levels will result in more warming, and more severe impacts on society and the natural world."*
>
> U.S. Global Change Research Program[32]

Hotter Summers

As the world continues to heat up, heat itself will become a real problem, especially in summers. People visiting national seashores will particularly feel the heat, since they typically are outdoors, not in air-conditioned buildings. For many people, outdoor activities, even beach-going, may simply become intolerably hot. Beaches are traditional spots for a break from the heat, but a tipping point could be reached, with baking heat trumping cooling breezes. When temperatures are in the 80ºs and 90ºs, going to the beach may offer relief. But when temperatures are in the 100ºs, the experience could be a lot less enjoyable. (See page 45.) And for most of the Atlantic seashores, summer is the season of heaviest visitation (see below). Because of the importance of summers in the seashores, RMCO also projected the possible change in their June-July-August temperatures, as shown in Table 3 below.

"Some recreation areas that are already hot during the summer recreation season will see decreases in use."

U.S. Climate Change Science Program [33]

Hotter Future Summers in Atlantic National Seashores
Projections with Medium-High Future Emissions

National Seashore	2051–2060	2081–2090
A. Cape Cod NS		
Average projection	+3.4° (to 79.6°)	+6.1° (to 82.3°)
Effect of average projection	As hot as recent summers in Long Island, NY (79.6°)	Nearly as hot as recent summers in Cape May, NJ (82.4°)
Range of projections	+1.9° (to 78.1°) to +5.0° (81.2°)	+3.9° (to 78.1°) to +8.2° (84.4°)
B. Fire Island NS		
Average projection	+3.6° (to 82.4°)	+6.5° (to 85.3°)
Effect of average projection	As hot as recent summers in Cape May, NJ (82.4°)	As hot as recent summers in Atlantic Beach, NC (85.4°)
Range of projections	+1.9° (to 80.7°) to +5.5° (84.3°)	+3.1° (to 81.9°) to +8.7° (87.1°)
C. Assateague Island NS		
Average projection	+3.4° (to 86.3°)	+6.2° (to 89.1°)
Effect of average projection	As hot as recent summers in Charleston, SC (86.2°)	As hot as recent summers in Key West, FL (89.1°)
Range of projections	+1.6° (to 84.5°) to +5.4° (88.3°)	+3.1° (to 86.0°) to +8.7° (91.6°)
D. Cape Hatteras NS		
Average projection	+3.0° (to 86.2°)	+5.4° (to 88.6°)
Effect of average projection	As hot as recent summers in Charleston, SC (86.2°)	As hot as recent summers in Galveston, TX (88.7°)
Range of projections	+1.3° (to 84.5°) to +4.5° (87.7°)	+3.0°(to 86.2°) to +7.7° (90.9°)

Table 3, continued on next page. Projected changes in average summer (June-July-August) mean temperatures in Atlantic national seashores by 2051–2060 and 2081–2090, in degrees Fahrenheit, compared to 1981–2010 averages. Results from 16 downscaled climate models assuming a scenario of medium-high future emissions of heat-trapping gases, showing the averages and ranges of those projections. Also shown are what would be each seashore's average summer daily maximum temperature if its average 1981–2080 maximum temperature increased by the amount of increase projected for its mean temperature (the values in parentheses) and a location with a comparable average summer maximum temperatures in 1981–2010. See the Appendix for sources and methodology.

National Seashore	2051–2060	2081–2090
E. Cape Lookout NS		
Average projection	+3.1° (to 89.3°)	+5.6° (to 91.8°)
Effect of average projection	As hot as recent summers in Daytona Beach, FL (89.3°)	As hot as recent summers in Fort Myers, FL (91.7°)
Range of projections	+1.2° (to 87.3°) to +4.4° (90.6°)	+3.1° (to 89.3°) to +8.1° (94.3°)
F. Cumberland Island NS		
Average projection	+3.4° (to 92.7°)	+6.3° (to 95.6°)
Effect of average projection	As hot as recent summers in Houston, TX (92.7°)	As hot as recent summers in White Sands National Monument, NM (95.5°)
Range of projections	+1.5° (90.8°) to 5.1° (94.4°)	+3.3° (92.6°) to 10.2° (99.5°)
G. Canaveral NS		
Average projection	+3.3° (to 94.1°)	+6.1° (to 97.0°)
Effect of average projection	As hot as recent summers in El Paso, TX (94.2°)	As hot as recent summers in Desert Rock, NV (97.0°)
Range of projections	+1.8° (92.7°) to +4.0° (94.9°)	+2.7° (93.6°) to +7.7° (98.6°)

Table 3, continued.

These projections are generally consistent with other projections for summer temperatures along the U.S. Atlantic Coast.[34] In the Southeast, not only are the greatest temperature increases projected to occur in the summer months, but also they are expected to be accompanied by a much higher heat index (designed to measure the combined effects of heat and humidity).[35] In addition, heat waves—several days or more of abnormally hot weather—are also expected to become both more common and more extreme. With a medium-high level of future emissions, along the U.S. Atlantic Coast heat waves so extreme that they now happen only once every two decades are projected to happen once a year or once every other year by 2090-2099.[36]

"The number of very hot days is projected to rise at a greater rate than the average temperature."

U.S. Global Change Research Program[37]

As indicated earlier, one of the reasons why increases in summer maximum temperatures in the seashores is important is because of the heavy visitation to them in the summer, shown in Table 4 to the right. Except for **Canaveral NS** (which has somewhat heavier visitation in the spring), summer is the

Share of Visitation in Summer Atlantic National Seashores in 2011

National Seashore	Percentage Of Total Visitation
Cape Cod NS	53.4%
Fire Island NS	73.7%
Assateague Island NS	55.0%
Cape Hatteras NS	55.0%
Cape Lookout NS	40.4%
Cumberland Island NS	38.5%
Canaveral NS	27.0%

Table 4. Visitation to Atlantic national seashores in June—August as share of annual total in 2011. Source: NPS.[38]

busiest season for the Atlantic national seashores, usually by a large margin.

Besides keeping potential visitors away from the seashores, hotter summers also could keep visitors from being able to engage in such popular activities as hiking and camping, and could create health risks for seashore visitors, who are outside and therefore away from the relief of air-conditioned buildings.

"Increased temperatures could hinder physical activities in parks and refuges, resulting in increased heat exhaustion."

National Park Service[39]

The good news is that summers in **Assateague Island NS** need not get as hot as those of Key West, and summers in **Cape Hatteras NS** need not get as hot as those of Galveston. As indicated, these projections are based on a medium-high level of future emissions. While even higher emissions are certainly possible and in fact consistent with recent trends, it also is true that future emissions can be held to lower levels (see the text box below). Then summers in the seashores would get hotter than now, but not by as much. But if we do not change course and end up changing the climate so much that extreme heat keeps visitors away from the seashores in the summer, local businesses and workers that depend on summer's visitors would feel the heat, too.

Future Emissions of Heat-Trapping Pollution

The climate projections in this report depend on emissions scenarios, which provide assumptions about levels of future emissions of heat-trapping pollutants, and on climate models, which project how the climate may respond to the pollution.[40]

This report refers to the scenarios used in the projections in these ways:

- "Medium-high" future emissions: scenario A2, producing by 2100 about 2-1/2 times today's atmospheric concentrations of heat-trapping pollution.[41]
- "Lower" emissions: B1, producing 2100 levels about 40% above today's.[42]

The lower and medium-high scenarios illustrate how different levels of emissions will impact the amount of future change. But these two scenarios alone do not represent a full, realistic range of possible futures. No higher-emissions scenario is available on the database used by RMCO to make the projections in this report. As a result, the projections in this report are skewed toward the low end of possible future changes.

Actual future emissions also could be well above the levels in any of these current scenarios, even the high scenario. These scenarios were developed in the 1990s, when global emissions of heat-trapping gases were growing at a rate of about 1.1% per year. Since then, emissions have been much higher, in some years, rising faster than assumed in any current scenarios.[43]

The good news, on the other hand, is that future emissions could be well below any of the current scenarios, none of which assume new policies to ward off climate change. The U.S. government's 2009 national assessment report, for example, pointed to a "stabilization" scenario that has the potential to hold further global temperature increases below an additional 2°F and avoid dangerous climate change.[44] Downscaled climate projections are not now available for that scenario. But the key point is that with new policies designed to reduce heat-trapping pollution, many of the possible consequences identified in this report may be avoided. We can, in fact, realize a better future—if we choose to.

Scenarios of Future Emissions

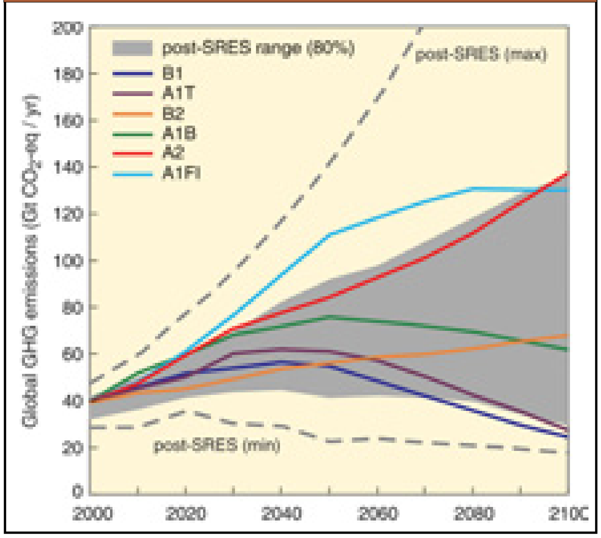


Figure 4. Selected current emissions scenarios, including those cited in this report. Those used in the new RMCO projections are A2 ("medium-high") and B1 ("lower"). Dashes indicate the range of new ("post-SRES") scenarios now coming into use, with the gray area representing the middle 80th percentile of that range. As the figure shows, the "medium-high" scenario used for the RMCO projections is only slightly above the middle of the range of the new scenarios. Figure from the IPCC9.[45]

4

Storm Surges and Island Disintegration

Climate disruption is making seas higher and coastal storms stronger, leading to larger storm surges and other impacts in the Atlantic seashores. Barrier islands may be broken up. Most vulnerable appear to be Assateague Island, Cape Hatteras, Cape Lookout, and Canaveral.

Boardwalk, Assateague Island NS. Photo: NPS.

Storm surges and other consequences of climate-change-driven increases in the level of the seas and the intensity of coastal storms could profoundly affect the Atlantic national seashores. In particular, the barrier islands that are the centerpieces of all the Atlantic national seashores except **Cape Cod** are inherently changeable landforms even in natural, historic conditions and could undergo far greater changes as a result of an altered climate. Cape Cod NS, too, while primarily on a relatively stable peninsula, also contains barrier islands and spits that are similarly vulnerable.

INHERENT VULNERABILITY OF BARRIER ISLANDS

The natural forces of winds, waves, and water shape coastal areas through such processes as:

- Beach erosion.—Waves and currents can remove sand from a beach system, causing it to become narrower and lower in elevation.[46] Erosion of beaches may make them less attractive to visitors and also can threaten coastal properties and infrastructure, such as roads, homes, and businesses. A series of storms can cause significant retreat of the shoreline, leaving coastal property more vulnerable to future storms.
- Dune erosion.—Storm surges can push waves high enough to erode coastal dunes.[47] As sand is removed from a dune, its front face can become steeper and its elevation reduced, inviting more future erosion. Dune erosion makes land further inland more vulnerable to future storms.
- Overwash.—Waves and storm surges can carry sand and other material inland.[48] When waves overtop dunes, overwash can be much more extensive.
- Flooding.—Storm surges can temporarily submerge beaches or beyond. Currents and waves then can carry large volumes of sand inland.[49]
- Marsh erosion.—Waves and currents can erode the soil of marshes. If the erosion is too great, marshes can be lost and replaced by open waters.[50]

The storm effects described above are often greater on barrier islands. On a mainland coastline, overwash can move sand inland; on a barrier island, it can carry it across the width of the island and drop it on the landward side, enabling the landward migration of the entire island that is characteristic of some barrier islands.[51] Also on barrier islands, storms can carve a new channel through an island, bisecting it in a process known as island breaching.[52] Smaller breaches often fill with sand in the months following the storm, while larger breaches may become permanent inlets, with continuing effects on island shapes and stability.

All of these are natural processes which also yield major ecological benefits. Most important is the overall way in which storm surges, overwash, and deposits of sediment build up a barrier island, especially on its landward side, compensating for the loss of land on the seaward side and enabling the island to survive—not in place, because that is not possible with this type of landform, but in motion, typically rolling over toward the mainland.

One of the important national values of the seashores is that they are where these natural forces are largely left to operate without interference, shaping and reshaping coastlines and ecosystems in response to the laws of nature. Under NPS policies “natural shoreline processes (such as erosion, deposition, dune formation, overwash, inlet formation, and shoreline migration) will be allowed to continue without interference.”[53] The natural processes of change at barrier islands (as well as other coastal landforms) also are centrally tied to the importance, resources, and values of the national seashores. At **Cape Hatteras NS**, the first of the Atlantic national seashores for which the NPS has prepared a "Foundation Statement" of major guiding principles, the first element in the NPS statement of the seashore's purpose is "to permanently preserve the wild and primitive character of the ever-changing barrier islands."[54] The first theme guiding NPS interpretive and education programs there is, "Cape Hatteras National Seashore is part of a natural system, with geologic processes unique to/or associated with barrier islands, characterized by constant change and adaptation."[55]

Figure 5 below illustrates barrier island shoreline change by showing how the ocean shorelines at the southern end of **Assateague Island NS** have since 1859 been undergoing the changes that are typical of a barrier island. Note how the ocean shoreline has moved landward since 1933—and how the "hook" area to the south of Toms Cove has built up over that time from sand transported from the eroded beaches to the north.

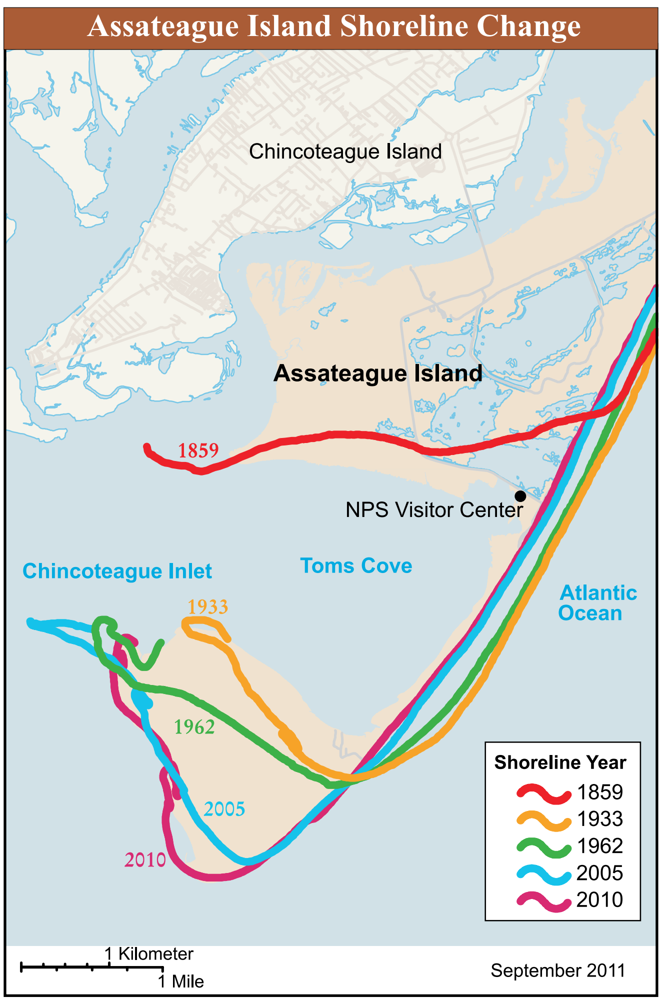


Figure 5. Ocean shorelines at southern Assateague Island in1859, 1933, 1962, 2005, and 2010. Source: Assateague Island NS, NPS.[56]

UNNATURALLY MAGNIFIED FORCES

Human-caused climate change is magnifying to a new, unnatural extent the natural forces of water and wind. The seashores now are being shaped not just by natural forces but by a new mixture of natural and unnatural forces, which yield different consequences.

Higher Seas

The Atlantic Coast national seashores are experiencing sea-level rise (SLR) at least equal to the global average, with **Cape Cod, Fire Island, Assateague Island, and Cape Hatteras national seashores** clearly experiencing above-average rates.[57] The northeastern coast, including Cape Cod, Fire Island, and Assateague Island, has been identified as part of a "hot spot" of accelerated SLR and is expected to continue experiencing above-average SLR.[58] (For background information on sea-level rise, see the Appendix on pages 53–56.)

Especially vulnerable are the low-lying lands of the Atlantic seashores, which are detailed in Section 5.

Higher seas are already affecting the shorelines of the Atlantic seashores. As one example, Figure 6 on the next page shows how the shoreline change on southern Assateague Island in the roughly three decades from 1933 through 1962 was greatly outstripped by the far greater change in the roughly four decades from 1962 through 2005. In 1964, the U.S. Geological Survey planted a marker in the sand near the seashore's public beach and recorded the distance from the marker to the surf—115 yards.[59] Today, the marker is in the surf. Figure 6 also shows how the shoreline change in just the six years from 2005 through 2010 is comparable to that of much longer, earlier periods of time.

An illustration of the combined effects of sea-level rise and strong coastal storms is Hurricane Isabel, which in September 2003 made landfall near Cape Lookout NS and then caused flooding across many Mid-Atlantic coastal areas (see pages 17–19). Near the mouth of the Chesapeake Bay, Isabel was much less powerful than a 1933 hurricane regarded there as the storm of the century; but the flooding from Isabel was equal to that of the earlier hurricane, because the starting point in 2003 was a sea that was higher than 70 years earlier.[60]

"The inference from the present example is very clear; other things being equal, our present sea-level trend will, over time, significantly increase the risk of coastal flooding during hurricanes."

Professor emeritus John Boon, College of William and Mary, comparing Virginia hurricanes of 1933 and 2003[61]

Stronger Coastal Storms

Even in a historic climate, coastline changes from a single storm can equal those that would normally take months or even years. Stronger coastal storms would mean that storm-driven coastline changes would be even greater than in the past.

The U.S. government's 2009 national assessment of climate-change impacts documents an increase in the strength of coastal storms on the Atlantic Coast.[62] North Atlantic hurricanes have become stronger in the last 30 years—especially the most powerful ones, those rated as Category 4 and 5—coinciding with about a 2°F increase in sea-surface temperatures where hurricanes form.[63] Average summer wave heights have also increased along the Atlantic coastline since 1975 because of the stronger hurricanes.[64] The national assessment also states that Atlantic hurricanes are likely to continue getting stronger during this century, with higher peak winds, rainfall intensity, and storm-surge height and strength.[65]

"Sea-level rise and the likely increase in hurricane intensity and associated storm surge will be among the most serious consequences of climate change."

U.S. Global Change Research Program[66]

In the Northeast, the most damaging coastal storms typically are winter nor'easters, much more common there than hurricanes and other tropical storms.[67] Over the past 50 years, winter storm tracks have shifted northward in the Northern Hemisphere, producing stronger storms in the Northeast and similar latitudes; this northward shift is projected to continue, and nor'easters are likely to become more frequent, with stronger winds and higher waves.[68] Examining the frequency and timing of these winter storms, a 2006 assessment of climate change and its impacts in the Northeast concluded that with higher future emissions, by century's end 5% to 15% more serious storms could hit the East Coast in January through March.[69] This would produce about one additional powerful nor'easter in the region per year. **Cape Cod, Fire Island, and Assateague Island national seashores** therefore all could face more nor'easters.

Consequences for Barrier Islands

Higher seas and stronger storms are expected to accelerate the processes that naturally change barrier islands, in at least three ways.[70] First, with higher sea level, storm overwash may occur more frequently. Storm surges coupled with breaking waves will affect increasingly higher elevations of the barrier systems as mean sea level increases, possibly causing more extensive erosion and overwash. Second, storm surges coupled with high waves can create new inlets, which may more often be large enough to persist and lead to accelerated reshaping of the islands. Third, the combined effects of rising seas and stronger storms could accelerate barrier island shoreline changes, from thinning of the island to migration of it landward. These changes can lead to a barrier island becoming less stable and then crossing a threshold, after which it becomes unstable, fragments, and possibly disintegrates.

Hurricanes Isabel in 2003 and Irene in 2011 illustrate how even relatively mild hurricanes can affect barrier islands.

Isabel made landfall in **Cape Lookout NS** in September 2003 as a Category 2 hurricane on the five-point Saffir-Simpson scale, with the northeast quadrant of the storm, where destructive forces always are greatest, extending up the coast into **Cape Hatteras NS**. At Cape Lookout, almost every boat dock and ramp was lost, Portsmouth Village sustained extensive damage from storm surge,

Breach in Hatteras Island, Cape Hatteras NS
Caused by Hurricane Isabel, 2003

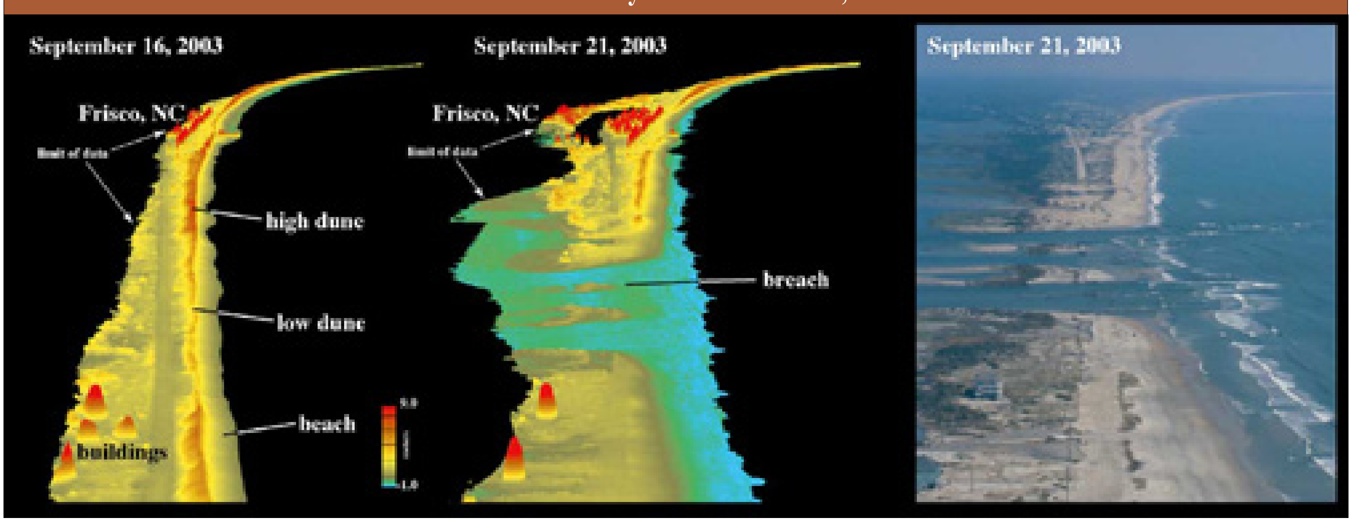


Figure 6. The two images on the left show high-resolution lidar topography of a portion of Hatteras Island two days before and three days after Hurricane Isabel. The colors indicate different elevations, where in general the hotter the color, the higher the elevation. The photograph was taken the same day as the post-storm lidar survey. Images source: USGS.[71]

infrastructure throughout the park (except on Harkers Island) was seriously damaged, and property damages totaled $17 million—all this in a seashore with very little development.[72] On Hatteras Island, the storm surge reached nearly eight feet, campground facilities and docks were damaged, the Bodie Island maintenance shop lost much of its roof, two parking lots washed away, and damages totaled $28 million.[73]

Isabel also created two new inlets severing Hatteras Island.[74] Both the larger breach, about 500 yards wide just north of Hatteras Village (see Figure 6 on the previous page), and the other, a few miles farther south, broke through the island where its elevation is low and its width is narrow.

Breach in Core Banks, Cape Lookout NS
Caused by Hurricane Irene, 2011

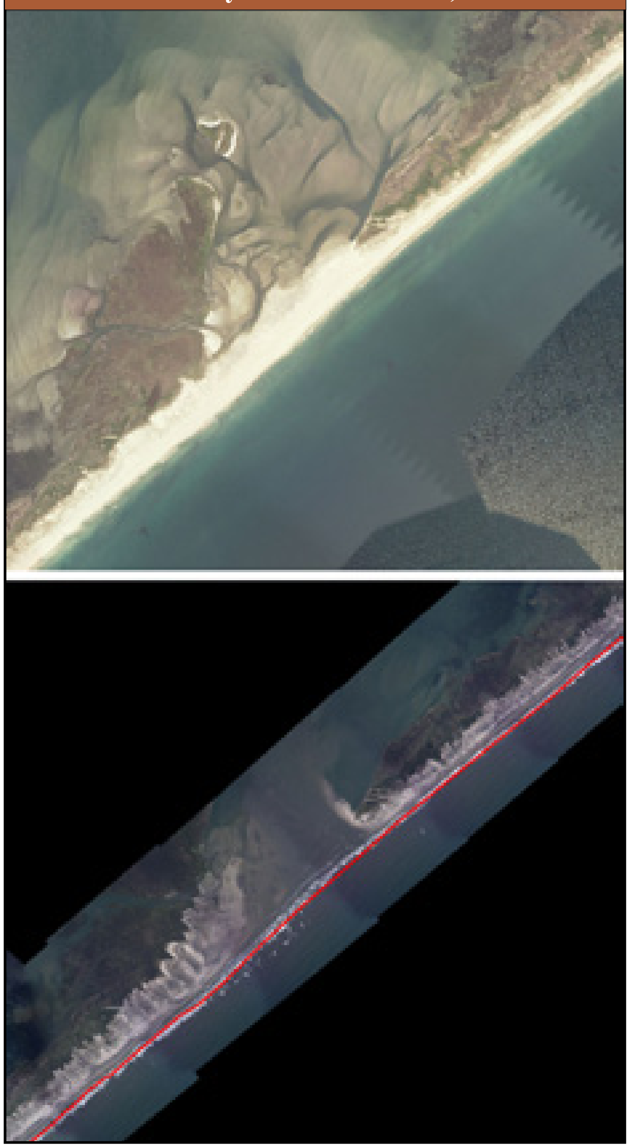


Figure 7. Photographs of Core Banks, Cape Lookout NS, from June 12, 2010 (upper) and August 28, 2011, one day after landfall of Hurricane Irene. The red line in the lower photo is the location of the oceanfront shore on June 12, 2010. A breach has been cut through the barrier island. Source of photographs: NOAA.[75]

Restoring the roads in Cape Hatteras NS after Isabel required major reconstruction. By contrast, reopening less-developed Cape Lookout was much easier, accomplished after rebuilding docks and remarking the unpaved road and beach-access ramps on top of the newly deposited sand.

Hurricane Irene in 2011, a Category 1 hurricane, also made landfall in **Cape Lookout NS,** again also affecting **Cape Hatteras NS[76].** The maximum storm surge along the ocean side of the barrier islands from Cape Lookout to Cape Hatteras was about six feet. After the storm crossed Pamlico Sound, the counterclockwise winds eventually blew from west to east, pushing onto the islands a second storm surge of six feet, this time of sound waters. Five breaches were made in the islands of the seashores, some of which on Hatteras Island severed NC Highway 12 (see page 39).

Figure 7 to the left includes before-and-after photographs showing a new breach opened by Hurricane Irene in Core Banks, within Cape Lookout NS. According to precise measurements prior to Irene, some of the area that was eroded away as the breach formed had an elevation of over one meter (39.4 inches).[77]

"There is some scientific opinion that barrier islands, wetlands, and other parts of coastal systems might have tipping points or thresholds, such that when limits are exceeded the landforms become unstable and undergo large irreversible changes. These changes are thought to occur rapidly and are thus far unpredictable."

U.S. Climate Change Science Program[78]

More powerful hurricanes can have much greater effects on barrier islands. Figure 8 on the next page shows the effects of Hurricane Katrina in 2005 on a group of barrier islands in Louisiana, the Northern Chandeleur Islands. The first image, before the hurricane, taken in July 2001, shows narrow sandy beaches, sand flats, low vegetated dunes, and marshes, and the second image shows the same site on August 31, 2005, two days after Hurricane Katrina made landfall on the Louisiana and Mississippi coastline.[79] The hurricane's storm surge was high enough and the islands were low enough that the islands were completely submerged, stripping the islands of sand; what remained after the storm was a discontinuous series of marsh fragments.[80] Follow-up aerial surveys by the U.S. Geological Survey (USGS) indicate that erosion has continued since 2005.[81] When the Chandeleur Islands were last mapped in the late 1980s and erosion rates were calculated from the 1850s, it was estimated that the Chandeleurs would last approximately 250 to 300 years. The results from post-Katrina studies suggest that a threshold has been crossed and natural processes may not contribute to the rebuilding of the barrier in the future.

Hurricane Katrina Effects on Louisiana Barrier Islands

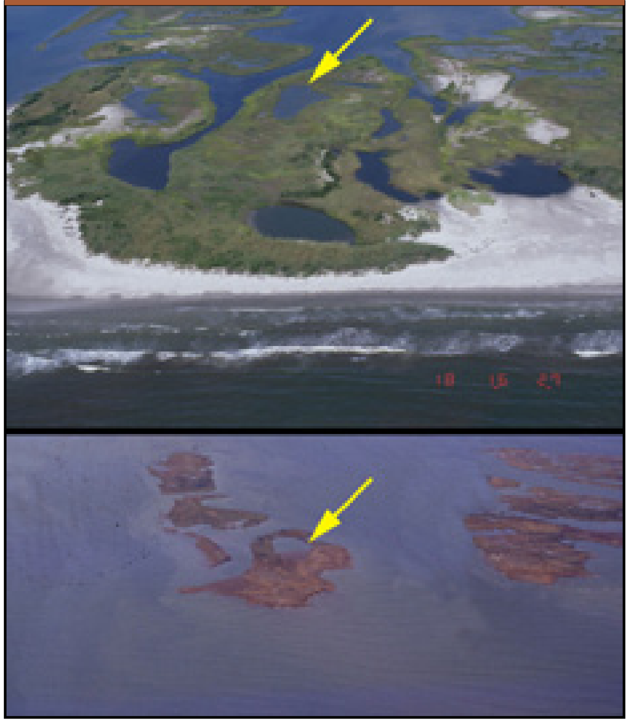


Figure 8. The Northern Chandeleur Islands before and after Hurricane Katrina, in photographs taken in July 2001 (top) and on August 31, 2005 (bottom). The yellow arrow indicates the same location in both photographs. Images source: USGS.[82]

To protect valuable property and navigation and transportation corridors, decisions have often been made to resist the forces of nature that reshape barrier islands, by fortifying particular areas, closing new inlets that open, and dredging old inlets that are filling. Perversely, the short-term protection of key social and economic resources usually comes at the long-term expense of the natural resources and systems on which they ultimately depend.[83] Blocking the natural movement of sand prevents the build-up of new land to replace that which has eroded elsewhere, leading to narrower, lower barrier islands that are more vulnerable to breaching and erosion.[84] "Armoring" shorelines eventually reduces beaches, wetlands, mudflats, and shallow open-water areas in an area, by blocking their landward migration to new locations.[85]

Reconciling competing social, economic, and natural values and visions has long been a struggle in policy and decision making about barrier islands. Striking the right balance will be more important than ever in the face of the new threats of climate change.

SEASHORE VULNERABILITIES

This portion of the report presents information on the particular vulnerabilities to sea-level rise and stronger coastal storms of each of the Atlantic Coast national seashores.

The authors of this report, interpreting a comparative assessment by the USGS of the relative vulnerabilities of different portions of the U.S. Atlantic Coast to sea-level rise based on six particular factors, suggest that **Assateague Island, Cape Hatteras, Cape Lookout, and Canaveral national seashores** are in a top tier of vulnerability based on those factors, followed in order by **Fire Island NS**, then **Cumberland Island NS**, then **Cape Cod NS**. This interpretation is summarized in Table 5 below.

This ranking is derived from an overall assessment of the relative vulnerability to sea-level of coastlines in the United States that was published 1999 in three preliminary reports by two USGS scientists.[86] (The reports separately covered the U.S. Atlantic, Pacific, and Gulf of Mexico coasts.) These reports were styled as preliminary because it was intended that the effort would be completed when a second phase of work was done; that additional work has not been done, but the results of the first phase of the project remain available online from the USGS as a

An Assessment of Relative Vulnerability Of Atlantic National Seashores

National Seashore	Summary of USGS Coastal Assessment
Cape Cod NS	Almost entirely low vulnerability.
Fire Island NS	Primarily high vulnerability. Less area of moderate vulnerability.
Assateague Island NS	Almost entirely very high vulnerability.
Cape Hatteras NS	Almost entirely very high vulnerability.
Cape Lookout NS	Almost entirely very high vulnerability.
Cumberland Island NS	Nearly equal areas of very high and moderate vulnerability. Less area of high vulnerability.
Canaveral NS	Entirely very high vulnerability.

Table 5. Summaries of vulnerability of ocean coastal areas of Atlantic national seashores to sea-level rise based on six factors (see text). Source: Based on USGS.[87]

national assessment of the relative vulnerability to sea-level rise of the coastlines of the contiguous United States.

The six factors on which the USGS vulnerability assessment summarized in Table 5 were based are tidal range, wave height, coastal slope, shoreline change, geomorphology (vulnerability to erosion), and historical rate of relative sea-level rise. Each stretch of coastline was assigned a numerical ranking for each factor as well as a cumulative ranking. The vulnerability rankings of individual stretches of coastline were not tabulated for larger areas such as an entire national seashore, so the summaries in Table 5 ultimately represent interpretations by the authors of this report, not the USGS ratings themselves.

Another factor of crucial importance in determining the vulnerability of the seashores to sea-level rise is the elevation of their lands above the sea, but that was not part of the USGS coastal assessment. However, this report presents new information on that measure of the vulnerability of the seashores, in Section 5 on pages 29–36.

Another source of information on the relative vulnerability of the Atlantic national seashores is their histories of hurricane frequency, as shown by information from the National Oceanic and Atmospheric Administration presented in Table 6 to the right. The past is no guarantee of the future, and whether and where hurricanes make landfall depend on a variety of factors, including large-scale steering winds, atmospheric stability, wind shear, and ocean heat content.[88] However, based on the high number of hurricanes that have historically passed within 65 miles of **Cape Hatteras NS** and **Cape Lookout NS**, it seems reasonable to consider that these seashores could continue to be particularly susceptible to hurricanes and other strong storms.

With respect to **Cape Cod, Fire Island, Assateague Island, Cape Hatteras, and Cumberland Island national seashores**, another source of information is detailed analyses of their vulnerabilities to shoreline changes driven by sea-level rise, prepared by the USGS Woods Hole Science Center for the NPS, part of a series that also analyzed some other coastal units of the national park system.[89] For the coastlines of the studied seashores, the USGS prepared a coastal vulnerability index, identifying the likelihood that physical changes will occur as sea-level rises, based on the same six factors used in the 1999 national coastline vulnerability assessment described above.

Because these seashore assessments were not intended for comparisons *among* different areas but instead to provide information to NPS managers on the relative vulnerability of different coastline stretches *within* a single seashore, cumulative ratings based on all six factors are not presented here. As the USGS emphasized in these reports, what is ranked as highly vulnerable in Cape Cod NS is not comparable to what is ranked as highly vulnerable in Cape Hatteras NS. For that kind of comparison, the USGS reports refer to the national assessment from which the information in Table 5 on the previous page is taken. In the accounts of the individual seashores that follow, maps from the USGS reports are provided, showing which factors are most important along the shoreline stretches of the five analyzed seashores.

One more major source of information for the following seashore accounts is another series of USGS assessments, of the vulnerability to hurricane-driven

Number of Hurricanes Within 65 Miles Since 1852

National Seashore	Hurricanes
Cape Cod NS	12
Fire Island NS	11
Assateague Island NS	13
Cape Hatteras NS	49
Cape Lookout NS	43
Cumberland Island NS	18
Canaveral NS	24

Table 6. Number of hurricanes passing within 65 miles of central features of the Atlantic Coast national seashores since 1852. Data source: NOAA.[90]

Summary of Vulnerability to Dune-Topping Flooding From Hurricanes

National Seashore	Median Height Seaside Dunes	Vulnerable Coastline: Category 1	Vulnerable Coastline: Category 4/5
Fire Island NS	17.8 Feet	1%	72%
Cape Lookout NS	9.2 Feet	11%	91%
Cumberland Island NS	13.7 Feet	10%	97%

Table 7. Heights of the seaside row of dunes and the percentage of seashore coastlines vulnerable to flooding that overtops those dunes, based on modeled worst-case storm surge levels at the center of landfalling Category 1 hurricanes (the least severe) on the Saffir-Simpson scale and Category 4 (for Fire Island NS) or Category 5 (Cape Lookout and Cumberland Island NS) hurricanes. Sources: USGS.[91]

flooding of the beach/dune systems of three Atlantic seashores: **Fire Island, Cape Lookout, and Cumberland Island national seashores**.[92] The USGS evaluated the extent to which the first (most seaward) row of sand dunes could be covered by the storm surges of hurricanes of different strength, using the commonly-used Saffir-Simpson system that ranks hurricanes from Category 1 (least severe) to Category 5 (most severe). Table 7 on the previous page shows some summary results. Maps from the individual analyses are presented in the seashore accounts that follow.

These analyses are important because when the initial row of dunes, which represents an island's first line of defense against a hurricane, is overtopped by water, large amounts of sand can be carried landward across the island and this sand typically is not naturally replaced in the years following storm landfall. Also, where beaches and dunes span the width of an island, storm surges above the height of the dunes can breach the island and open new inlets.[93] Figures 11, 15, and 17 below show for these three seashores where the dune row is low enough to be overtopped by the modeled maximum storm surge—that near the eye wall of a landfalling hurricane.

Cape Cod NS

Cape Cod NS is vulnerable to higher and stronger storms, but for the six factors assessed in the report summarized in Table 5 on page 19 it may be less at risk than the other Atlantic seashores. In that assessment, Cape Cod NS was rated as having primarily a low overall vulnerability to shoreline change from sea-level rise, compared to other locations on the U.S. Atlantic Coast. Importantly, Cape Cod, alone among these seashores, is primarily on a relatively stable peninsula, not on barrier islands.

As documented elsewhere in this report, Cape Cod NS has had fewer hurricanes than most other Atlantic national seashores (Table 6 on the previous page, but that does not include the frequency of nor'easters, the more common destructive storms of the Northeast); has relatively few lands one meter or less above sea level (Figure 18 on page 30); has had a local rate of sea-level rise higher than the global average (see Table App-2 on page 53); and is in a hotspot where sea-level rise is accelerating unusually rapidly (see page 54).

The USGS coastal vulnerability map in Figure 9 to the right shows that the factors that contribute most to the vulnerability of Cape Cod NS's coastline are wave height (band 5), which is consistently very high or high, and geomorphology (or susceptibility to erosion, shown by band 1), which in some places is very high.[94]

Another source of information on the vulnerability of Cape Cod NS is a 2011 consensus-based assessment among governmental and private experts who identified areas of Cape Cod they believed vulnerable to sea-level rise and coastal storms based on elevation, erosion, and exposure to storm surges and SLR.[95] This assessment was done as part of a broadly representative effort to consider how to meet future transportation needs on the

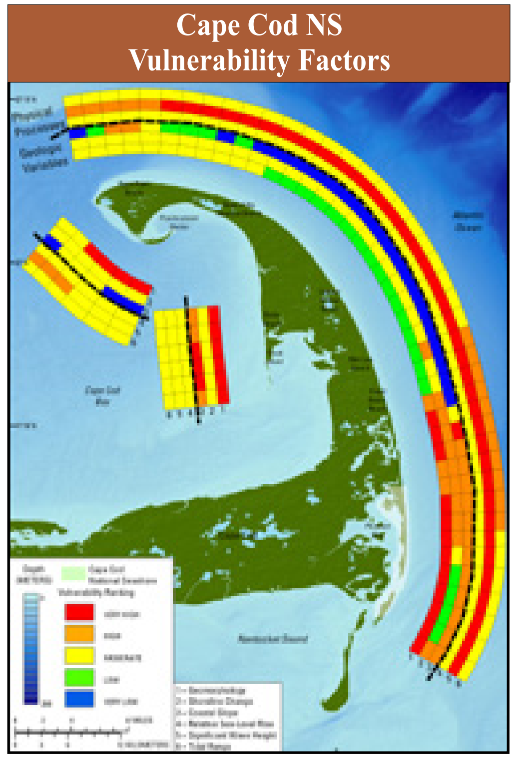


Figure 9. Vulnerability ranking of shorelines at the Cape Cod NS for each of the six factors identified in the legend: geomorphology, shoreline change, coastal surge, relative sea-level rise, significant wave height, and tidal range (see the text). Source: USGS.[96]

Cape in the face of climate change and other challenges (see page 37). Areas in the seashore identified as vulnerable include areas around Provincetown, variously described as "[v]ulnerable due to erosion" and "could be safe for 20 years or so but is likely vulnerable in any major storm."[97] Around Chatham, where what is known as the Patriot's Day Storm of April 2007 opened a new inlet in the barrier beach, the experts noted that the new island south of that inlet "is now dissipating fairly rapidly" and "presumably there will [be] rapid erosion as that island continues to dissipate."[98] Within 10 years, the experts continued, what is now the landward side of the island will instead be the beach on the seaward side. "The harbor will likely be closed as the beach washes in. The entire area is vulnerable to SLR impacts and changes that will result [when] the beach is gone."

Fire Island NS

For the six factors assessed in the report summarized in Table 5 on page 19, Fire Island NS may be less vulnerable than Assateague Island, Cape Hatteras, Cape Lookout, and Canaveral national seashores, but more than the two other Atlantic seashores. In that assessment, Fire Island NS was rated as having primarily a high vulnerability to shoreline change from sea-level rise, with lesser stretches of moderate vulnerability, compared to other

Fire Island NS Vulnerability Factors

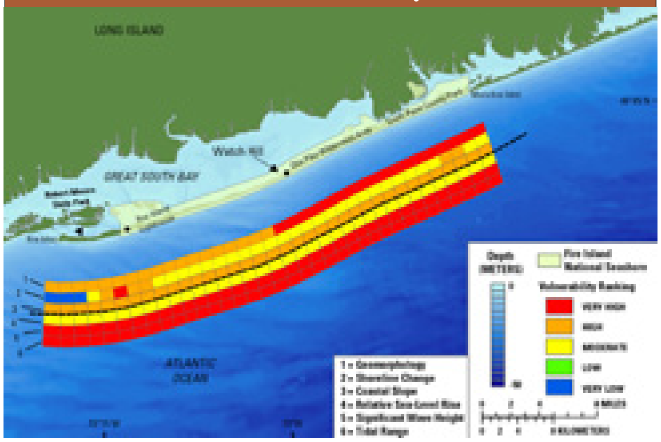


Figure 10. Same as Figure 9, except with respect to Fire Island NS. Source: USGS.99

locations on the U.S. Atlantic Coast.

As documented elsewhere in this report, Fire Island NS has had fewer hurricanes than most other Atlantic national seashores (Table 6 on page 20, but that does not include nor'easters); has much of its land one meter or less above sea level (Figure 19 on page 31); has had a local rate of sea-level rise higher than the global average (see Table App-2 on page 54); and is in a hotspot where sea-level rise is accelerating unusually rapidly (see page 54).

The USGS coastal vulnerability map in Figure 10 above shows that the factors that contribute most to the vulnerability of Fire Island coastline are wave height and tidal range (bands 5 and 6), which are consistently very high, and geomorphology (or susceptibility to erosion, shown by band 1), which in some places is very high.[100]

As shown in Table 7 (see page 20), 1% of the shoreline of Fire Island NS is vulnerable to overtopping floods from a Category 1 hurricane and 72% to a Category 4 hurricane. The part of the seashore most vulnerable to this flooding is the Otis Pike Wilderness section at the seashore's east end, as shown by Figure 11 below, which includes the USGS map from this analysis.[101]

An additional source of information on Fire Island's vulnerability is a USGS report recommending to the NPS a science-based approach for determining when new storm-caused breaches in Fire Island should be closed.[102] This report details that some structures to protect the shoreline, including stone jetties and armoring and stabilization of headlands, as well as dredging to maintain navigation have actually compounded the island's vulnerability by interfering with the natural processes that maintain the barrier island and increasing the odds of new breaches and other disruptions of the island.

"The Fire Island barrier islands, a sand-starved system dominated by highly dynamic processes, are struggling to maintain their integrity in the face of sea-level rise and storms. Adding to the dilemma is that development on the barriers and the mainland has increased greatly during the past 50 years."

Northeast Region, NPS[103]

Fire Island NS: Vulnerability to Flooding by Hurricane

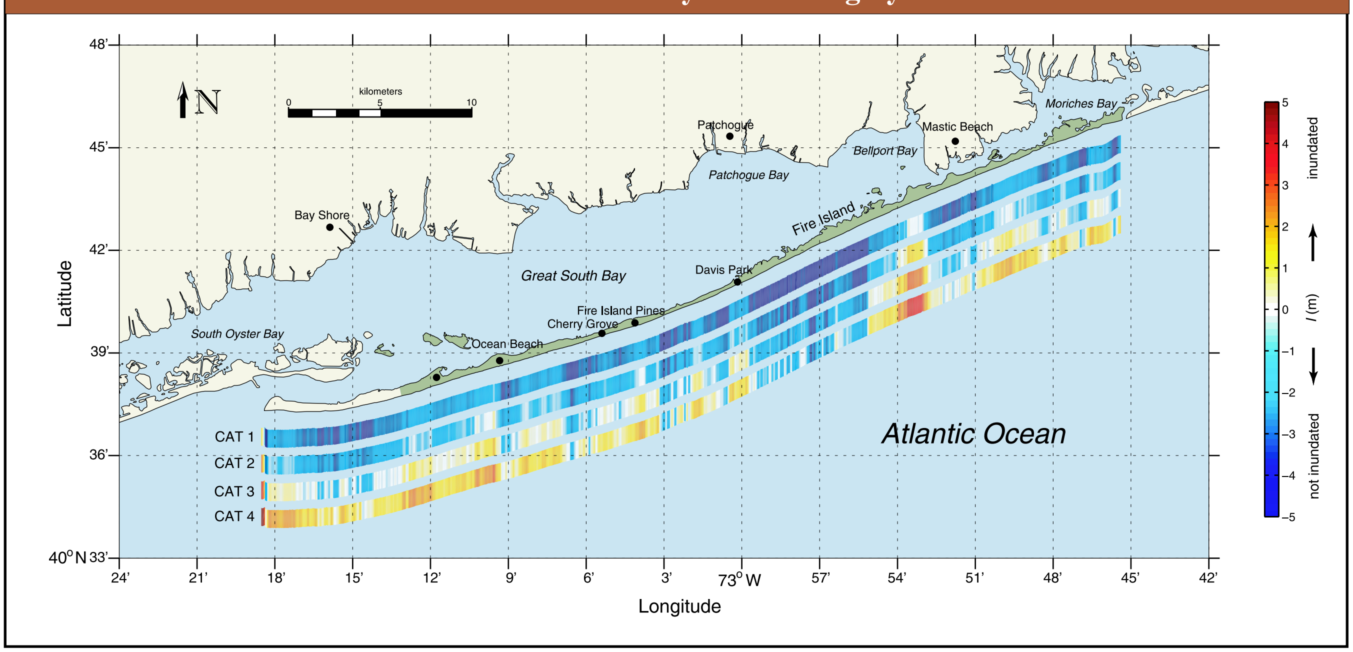


Figure 11. Areas potentially subject to flooding overtopping the seaward dunes at Fire Island NS, corresponding to the expected storm surge from hurricanes in categories 1-4 of the Saffir-Simpson scale. Source: USGS.[104]

Assateague Island NS

For the factors in the report summarized in Table 5 on page 19, Assateague Island NS appears to share with Cape Hatteras, Cape Lookout, and Canaveral national seashores the highest vulnerability to climate-change-driven shoreline change of the Atlantic seashores. In that assessment, Assateague Island was rated as having an almost entirely very high overall vulnerability to sea level rise, compared to other Atlantic Coast locations.

As documented elsewhere in this report, Assateague Island NS has had fewer hurricanes in the past than the Atlantic national seashores to its south (Table 6 on page 20, but that does not include the frequency of nor'easters); has most of its land is one meter or less above sea level (see Figure 20 on page 32); has had a local rate of sea-level rise much higher than the global average (see Table App-2 on page 54); and is in a hotspot where sea-level rise is accelerating unusually rapidly (see page 54).

The USGS coastal vulnerability map in Figure 12 to the right shows that past sea-level rise and wave height (bands 5 and 6) contribute most to the vulnerability of Assateague Island NS coastline, and that its risks based on geomorphology (or susceptibility to erosion, shown by band 1) are very high in some places.[105]

A 2009 U.S. government report on sea-level rise in the Mid-Atlantic region identified northern Assateague Islands NS along with Cape Hatteras NS as two areas where almost any increase in the rate of sea-level rise will ultimately lead to "the degradation" of their barrier islands.[106] The report says that a substantial portion of Assateague Island, having been breached and segmented by recent sea-level rise and storms, may already be at a threshold of permanent geological change, and that much of Cape Hatteras NS may also be at a similar threshold. For both seashores, with any increase in the current rate of sea-level rise, it is "virtually certain" that they will experience large changes and degradation. With even a modest increase of an additional inch of sea-level rise every dozen years, it is "very likely"—at least a two-thirds chance—that their islands will be broken apart.

"The natural environment of Assateague Island National Seashore is expected to become less stable under most climate change projections. Driven by increasing rates of sea level rise, more intense and possibly more frequent storms, the island will experience an increased likelihood for erosion, overwash, inlet breaching, shoreline retreat and island narrowing. Should the highest rates of projected sea level rise occur, the island may exceed stability thresholds, resulting in rapid migration landward, segmentation, and possibly disintegration."

Assateague Island NS, NPS[107]

Assateague Island NS Vulnerabilty Factors

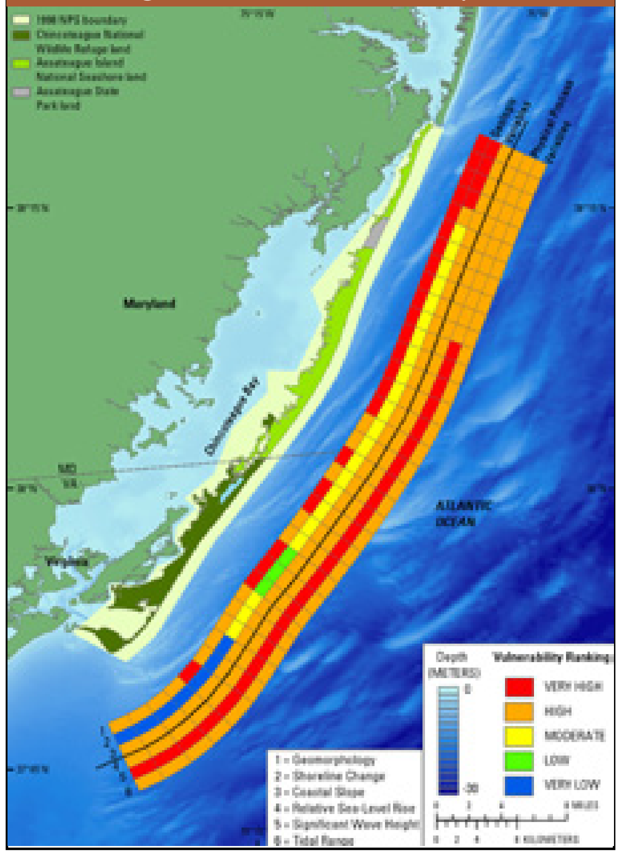


Figure 12. Same as Figure 9, except with respect to Assateague Island NS. Source: USGS.[108]

In 2009, the U.S. Fish and Wildlife Service, in charge of Chincoteague NWR, which overlays the southern part of Assateague Island NS, used a modeling program (Sea Level Affecting Marshes Model, or SLAMM) to project the ecosystem effects of sea-level rise on Assateague Island.[109] When the refuge manager got the results, "It hit me like a ton of bricks and took my breath away," he said.[110] No wonder—as the FWS has summarized it, what the model predicts is:

> nothing less than a wholesale transformation of the refuge. Vast swaths of wetlands, and the precious shorebird habitats contained within, would likely be radically altered—or even under water—in 2100. According to the model, rising sea levels over the next 100 years will flood coastal marshlands and transform inland habitats at Chincoteague NWR—producing a cascade effect on the refuge's habitats.[111]

The model results for Assateague Island are shown in Figure 13 on the next page.

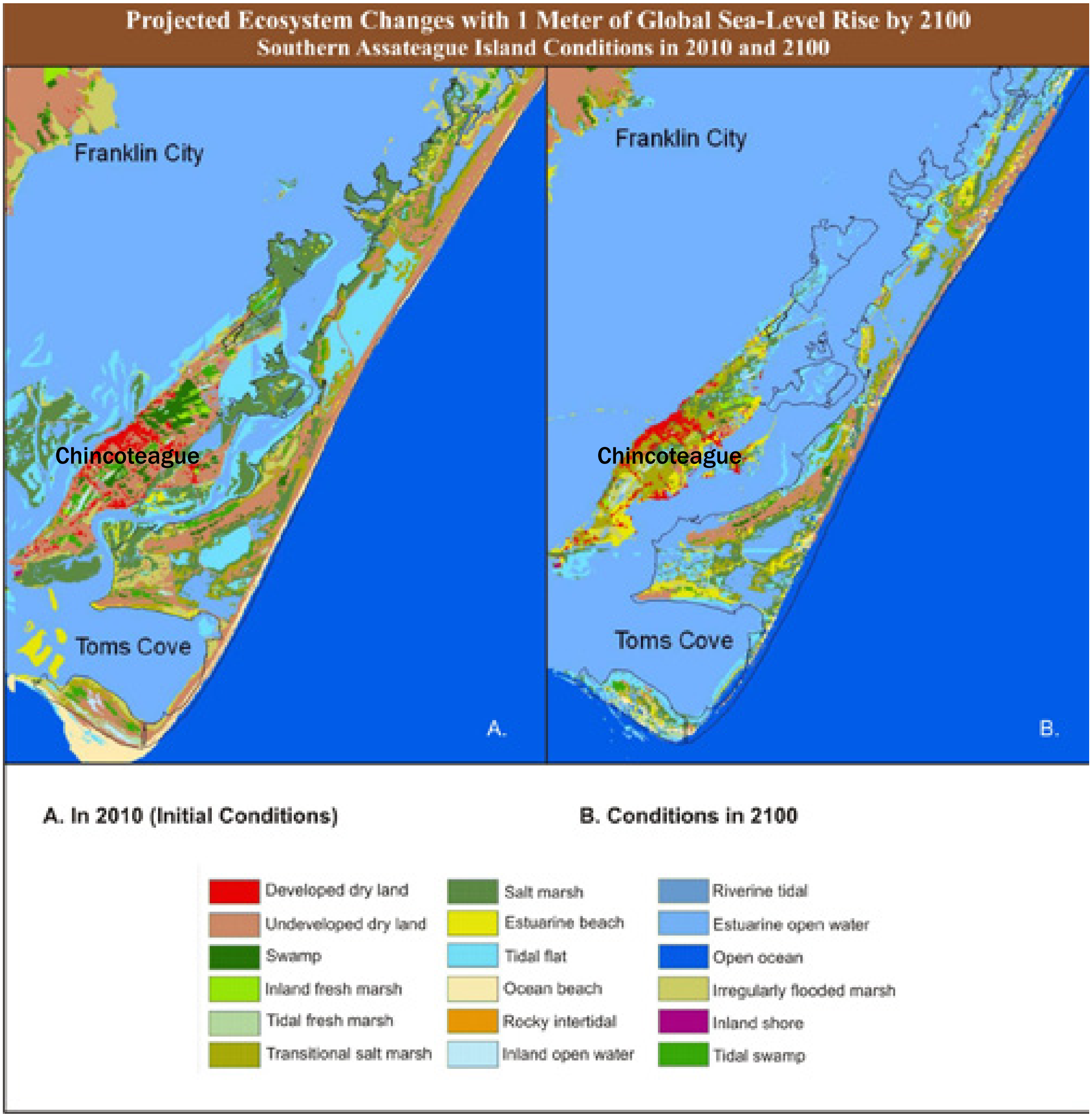


Figure 13. Results of modeling showing projected changes in ecosystems (including inundation by the ocean) at southern Assateague Island and surrounding area if seas rise at a local rate consistent with a 1 meter rise in global sea level by 2100. Figure 13A on the left shows initial conditions in 2010 and 13B on the right projections for 2100. The land boundaries of Chincoteague National Wildlife Refuge on Assateague Island are outlined faintly in black; Assateague Island NS overlaps the refuge on the main, outer, barrier island shown in these figures, from the southern end of the refuge (south of Tom's Cove) and extending northward beyond this map. The Town of Chincoteague, Virginia, is on the next island inland. Source: FWS.[112].

Across the broader region of the lower Delmarva Peninsula analyzed in the SLAMM modeling, the change in ecosystem types would be sweeping.[113] As shown in Table 8 on the next page, with one meter of global sea-level rise by century's end, dry land in the region is projected to decline by 18%, ocean beaches by 80%, and brackish marshes by 82%. (Within the seashore itself, as opposed to the entire region, the loss of dry land clearly would exceed the regional average of 18%, as illustrated by Figure 13 above.)

Changes in Ecosystems with Sea-Level Rise Lower Delmarva Peninsula			
Ecosystem Type	Current Conditions (percentage of area)	Projected Changes From Current Conditions With 1 Meter of Global Sea Level Rise by 2100	
		In 2050	In 2100
Dry Land	29%	-9%	-18%
Swamp	10%	+18%	+14%
Salt Marsh	5%	-5%	-57%
Tidal Flat	7%	-21%	-24%
Open Beach	0.3%	-11%	-80%
Estuarine Open Water	22%	+16%	+49%
Brackish Marsh	3%	-27%	-82%

Table 8. Projections from the Sea Level Affecting Marshes Model (SLAMM) for changes across modeled portions of the Lower Delmarva Peninsula (of which the modeled portion of Assateague Island NS comprises less than 10%). Data source: FWS.[114]

Cape Hatteras NS

For the six factors assessed in the report summarized in Table 5 on page 19, Cape Hatteras NS appears to share with Assateague Island, Cape Lookout, and Canaveral national seashores the highest vulnerability to climate-change-driven shoreline change of all the Atlantic Coast seashores. In that assessment, Cape Hatteras NS was rated as having an almost entirely very high overall vulnerability to sea level rise, compared to other locations on the U.S. Atlantic Coast, with some short stretches of the seashore assessed as having high or moderate vulnerability.

As documented elsewhere in this report,Cape Hatteras NS has had more hurricanes in the past than any of the other Atlantic national seashores having had 49 hurricanes pass within 65 miles of the cape since 1842, the largest such total of the seashores (Table 6 on page 20);has most of its land one meter or less above sea level (Figure 21 on page 33); and has had a local rate of sea-level rise much higher than the global average (see Table App-2 on page 54).

Figure 14 on the right shows that the seashore's primary risk factors include all six of the assessed factors for at least some stretches of the seashore, with past sea-level rise (band 5) and tidal range (band 6) rated as very high for the entire seashore.[115]

Cape Hatteras NS Vulnerability Factors

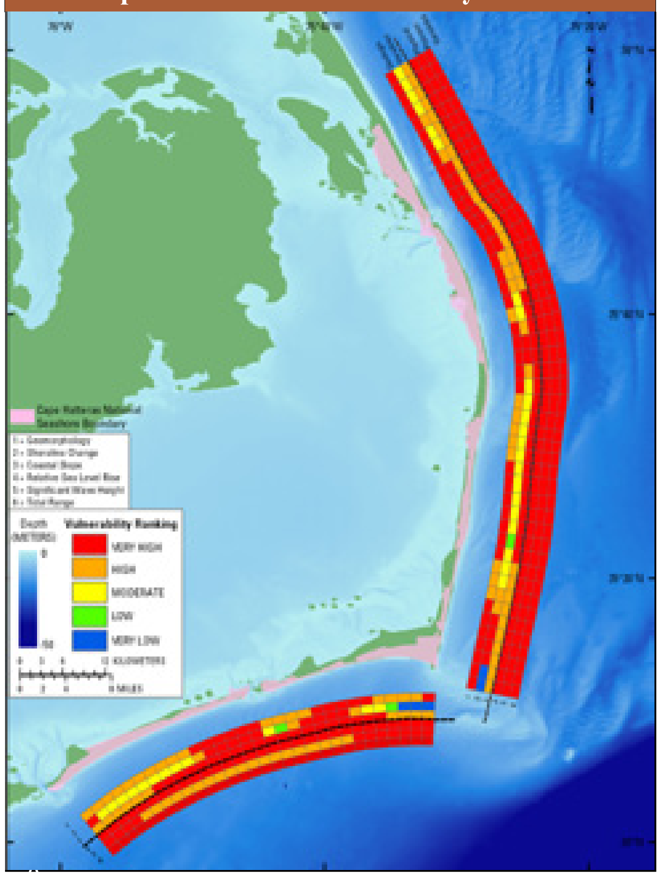


Figure 14. As Figure 9, except with respect to Cape Hatteras NS. Source: USGS.[116]

A 2009 U.S. government report on sea-level rise in the Mid-Atlantic region identified Hatteras Island in the seashore and northern Assateague Island as the region's two areas where almost any increase in the previous rate of sea-level rise will lead to large changes and ultimately to "the degradation" of the seashore's islands.[117]

Cape Lookout NS

For the six factors assessed in the report summarized in Table 5 on page 19,Cape Lookout NS appears to share with Assateague Island, Cape Hatteras, and Canaveral national seashores the highest vulnerability of the Atlantic Coast seashores. In that assessment, Cape Lookout was rated as having an almost entirely very high overall vulnerability to sea level rise, compared to other locations on the U.S. Atlantic Coast. Only the tip of Core Banks, just south of the Ocracoke Inlet, has less than a very high vulnerability; that area is ranked with moderate vulnerability.[118]

As documented elsewhere in this report, Cape Lookout also has a history of very high hurricane frequency, having had 43 hurricanes pass within 65 miles of the cape since 1842, second only to Cape Hatteras NS among the Atlantic national seashores (Table 6 on page 20); has most of its land one meter or less above sea level, primarily on the sound side of the islands (Figure 22 on page 34); and has had a local rate of sea-level rise at least as high as the global average (see Table App-2 on page 54).

As shown in Table 7 on page 20, 11% of the shoreline of Cape Lookout NS is vulnerable to overtopping floods from a Category 1 hurricane and 91% to a Category 5 hurricane. Figure 15 below includes the map from that USGS assessment, which indicates that it is the eastern half and westernmost portions of Shackleford Banks, areas around inlets, and the beaches on either side of New Drum Inlet and south of Ocracoke Inlet that are most vulnerable.[119]

One factor that may reduce the vulnerability of Cape Lookout NS to higher seas and stronger storms compared to neighboring Cape Hatteras NS is that the former seashore largely has been left in a natural condition, without human actions to close new inlets as they open and install structures to protect human developments in place. While providing protection to human developments, particularly in the short term, these actions can disrupt the natural processes that enable a barrier island to survive by building up in one place and thereby compensating for erosion in another. Especially with sea-level rise, the consequences over time can be losses of ocean beaches, estuarine beaches, wetlands, mudflats, and very shallow open water areas.[120] In 2006, a USGS report documented a 72% increase between 1961 and 2001 in the average elevation of Core Banks in Cape Lookout NS, and suggested that the elevation gain results from the natural

Cape Lookout NS: Vulnerability to Flooding by Hurricane

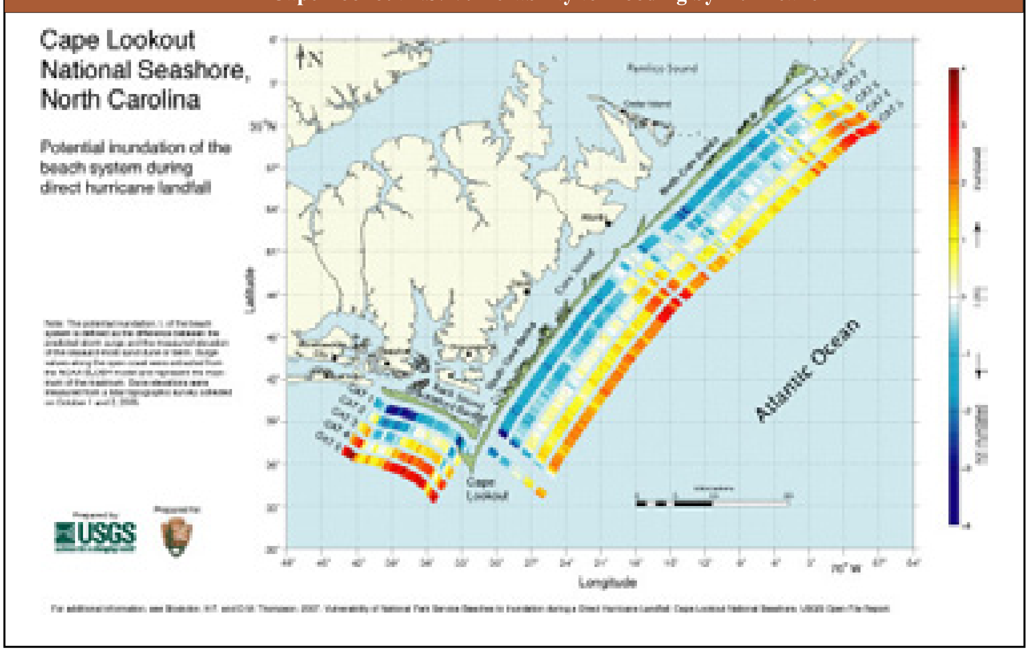


Figure 15. Same as Figure 11, except for Cape Lookout NS and assessing hurricanes through Category 5. Source: USGS.[121]

dynamics of a barrier island—erosion of the shoreline "but also major overwash events that move sand onto and across the island; this process is critical for island building and migration."[122] The authors stated, "the deposition of frequent storm-driven, cross-island overwash fans through time . . . can only happen on an undeveloped barrier island with a general absence of constructed barrier dune ridges, maintained roads, and structural developments along the oceanfront."

Cumberland Island NS

For the six factors assessed in the report summarized in Table 5 on page 19, Cumberland Island appears to rank ahead of Cape Cod but behind the other national seashores in its overall vulnerability. In that assessment, Cumberland Island NS was rated as having nearly equal coastline stretches with very high and with moderate overall vulnerability to sea-level rise, with lesser areas of high vulnerability, compared to other locations on the U.S. Atlantic Coast. Importantly, Cumberland Island is a relatively wide, stable barrier island.

As documented elsewhere in this report, Cumberland Island has had a moderate number of hurricanes (18) since 1852 (Table 6 on page 20); has relatively few lands one meter or less above sea level (Figure 23 on page 35); and has had a local rate of sea-level rise approximately equal to the global average (see Table App-2 on page 54)

According to the USGS assessment of the seashore, the results of which are shown in Figure 16 below, the primary local risk factor is the geomorphology (susceptibility to erosion, shown in band 1 in the figure) of some stretches of the coastline.[124] The seashore's areas with the high geomorphology risk are washover-dominated or low discontinuous dune areas.[125]

The USGS also assessed the vulnerability of Cumberland Island NS to hurricane-driven flooding. As shown in Table 7 on page 20, 10% of the seashore is vulnerable to dune-overtopping flooding from a Category 1 hurricane and 97% is from a Category 5 hurricane. As shown in Figure 17 below, which contains the map from that USGS analysis, the greatest vulnerabilities are where there are lower-elevation dunes on the northern end and central third of the seashore.[126]

Cumberland Island NS Vulnerability Factors

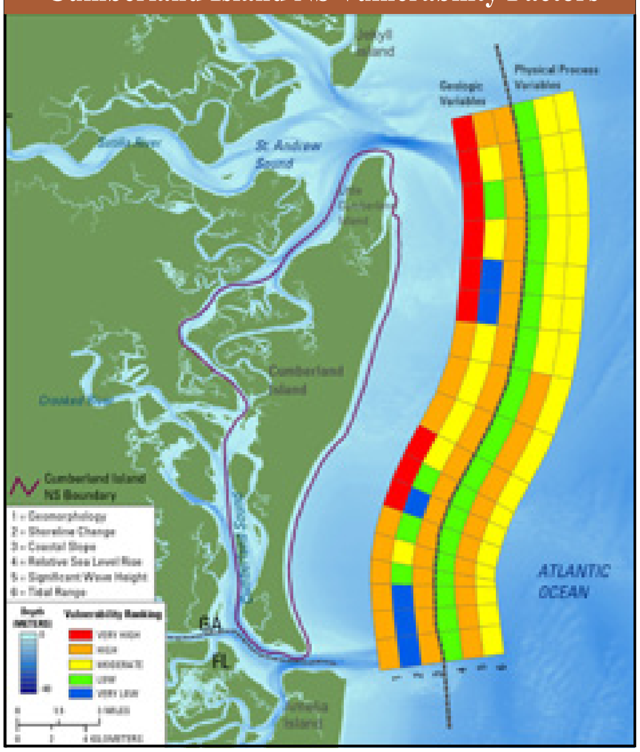


Figure 16. Same as Figure 9, except with respect to Cumberland Island NS. Source: USGS.[123]

Cumberland Island NS: Vulnerability to Flooding by Hurricane

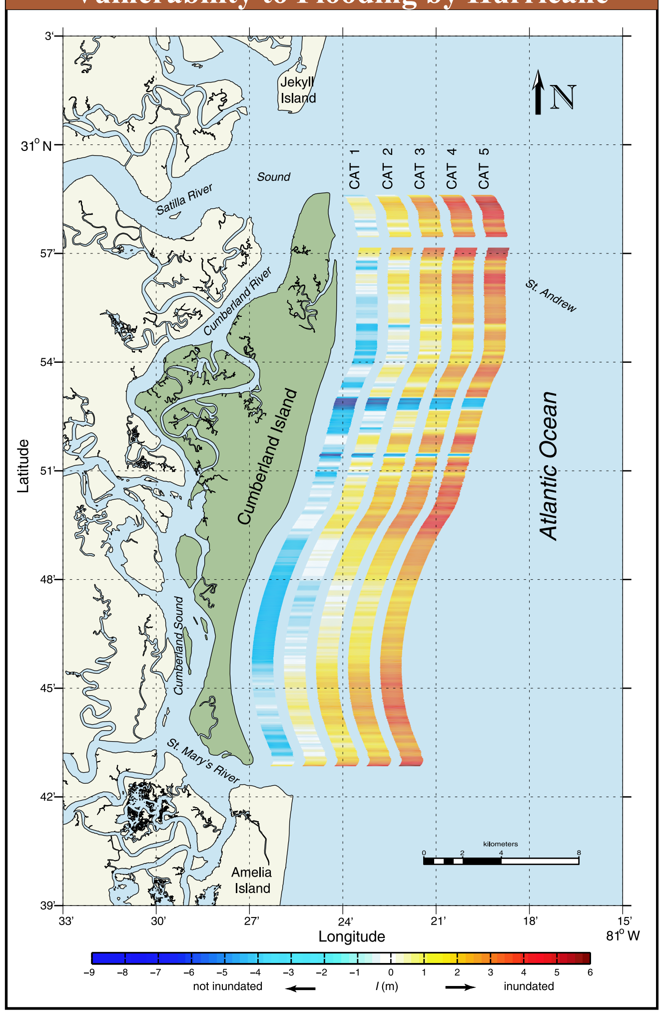


Figure 17. As Figure 15, except with respect to Cumberland Island NS. Source: USGS.[127]

Canaveral NS

For the six factors assessed in the report summarized in Table 5 on page 19, Canaveral NS appears to share with Assateague Island, Cape Hatteras, and Cape Lookout national seashores the highest vulnerability of the Atlantic Coast seashores. In that assessment, Canaveral NS, alone among the Atlantic seashores, was rated as having entirely a very high overall vulnerability to sea-level rise, compared to other locations on the U.S. Atlantic Coast.

As documented elsewhere in this report, Canaveral has had a moderately high number of hurricanes (24) since 1852 (Table 6 on page 20); has most of its land one meter or less above sea level (Figure 24 on page 36); and has had a local rate of sea-level rise approximately equal to the global average (see Table App-2 on page 54).

Canaveral NS has two particular risks different from the other Atlantic seashores, because of the nature of its barrier island. First, its 24-mile barrier island is such a thin ribbon of sand that in some places it is no more than 100 yards wide, with obvious risks of segmentation. Second, unlike many barrier islands with both primary and secondary rows of dunes, which afford additional protection from storm surges and overwash, Canaveral has only a single dune row.[128]

5

Low-Elevation Seashore Lands

New maps show the lands of the Atlantic seashores that are of such low elevation that they are at particular risk of inundation and, prior to that, storm surges. Most lands in Fire Island, Assateague Island, Cape Hatteras, Cape Lookout, and Canaveral are low-lying enough to be at great risk of being submerged in this century.

Assateague Island NS
James Fair, FWS

The greatest threat to the seashores is that human-caused climate change could raise the level of the Atlantic Ocean so much that major portions of the seashores, or even entire seashores, could be permanently covered by the ocean. The elevation of coastal lands above the sea level obviously is an important factor in determining their vulnerability to inundation as the sea rises. (Other factors are also relevant, including those covered in Section 4.)

This section presents new maps of the Atlantic Coast national seashores showing lands that are less than one meter (39.4 inches) above the current sea level. This is the first set of maps showing for the Atlantic national seashores their lands that are low-lying enough to be at particular risk of inundation by higher seas. Prior to that, these are the lands that are also at particular risk of storm surges, erosion, infrastructure damage, and disintegration of barrier islands and landforms.

One meter is widely accepted as a reasonable possibility for how much the global average sea level might rise in this century, depending in part on the levels of future emissions of heat-trapping pollution (see pages 53-56 for background on sea-level rise, globally and at the Atlantic seashores). As a U.S. government interagency report in 2009 stated, "thoughtful precaution suggests that a global sea-level rise of one meter to the year 2100 should be considered for future planning and policy discussions."[129]

The maps in this section show lands that are less than one meter above the current local sea level and are potentially connected to ocean waters. The maps were created for this report from a database created by scientists at the University of Arizona of low-elevation coastal lands.[130] The elevation data for that database are from the National Elevation Dataset maintained by the U.S. Geological Survey (USGS), which incorporates the best available elevation data for each coastline area.[131] The elevations shown in the University of Arizona database are above the current mean high water levels, reflecting average high-tide levels.[132]

Importantly, the elevation maps below show only what now is land and do not include any projections for buildup of new land. Barrier islands typically migrate landward as sand and other material is eroded from their seaward side, is carried by overwashing waves or currents to their landward side, and deposited there (see page 15). Some low-lying lands, rather than being inundated, could gain in elevation and persist despite a higher sea. What actually happens to the low-lying lands depends on many factors, including the rates of future global and local sea-level rise—which, it deserves emphasizing, depend in part on the levels of future emissions of heat-trapping gases.

In the maps on the following pages, the areas indicated in red are lands with an elevation of one meter or less above current high tides and with a potential connection to ocean waters. These are the lands of the Atlantic seashores that are most vulnerable to higher seas and stronger coastal storms. The maps show that in each of **Fire Island, Assateague Island, Cape Hatteras, Cape Lookout, and Canaveral national seashores** a majority of the seashore land is in this category of highest risk. Important lands in the other seashores are also in this highest-risk category.

In **Cape Cod NS**, most of the seashore lands are more than one meter above sea level. Figure 18A below shows one of the two seashore areas with the most low-lying land. In the figure, the areas marked in red include most of the landward sides of the barrier spits and island that comprise the popular Orleans (or Nauset) Beach. The other seashore area with a major concentration of low-lying land (not shown here) is the Provincetown area, at the very end of the Cape Cod peninsula.[133]

Cape Cod NS: Lowest Lands

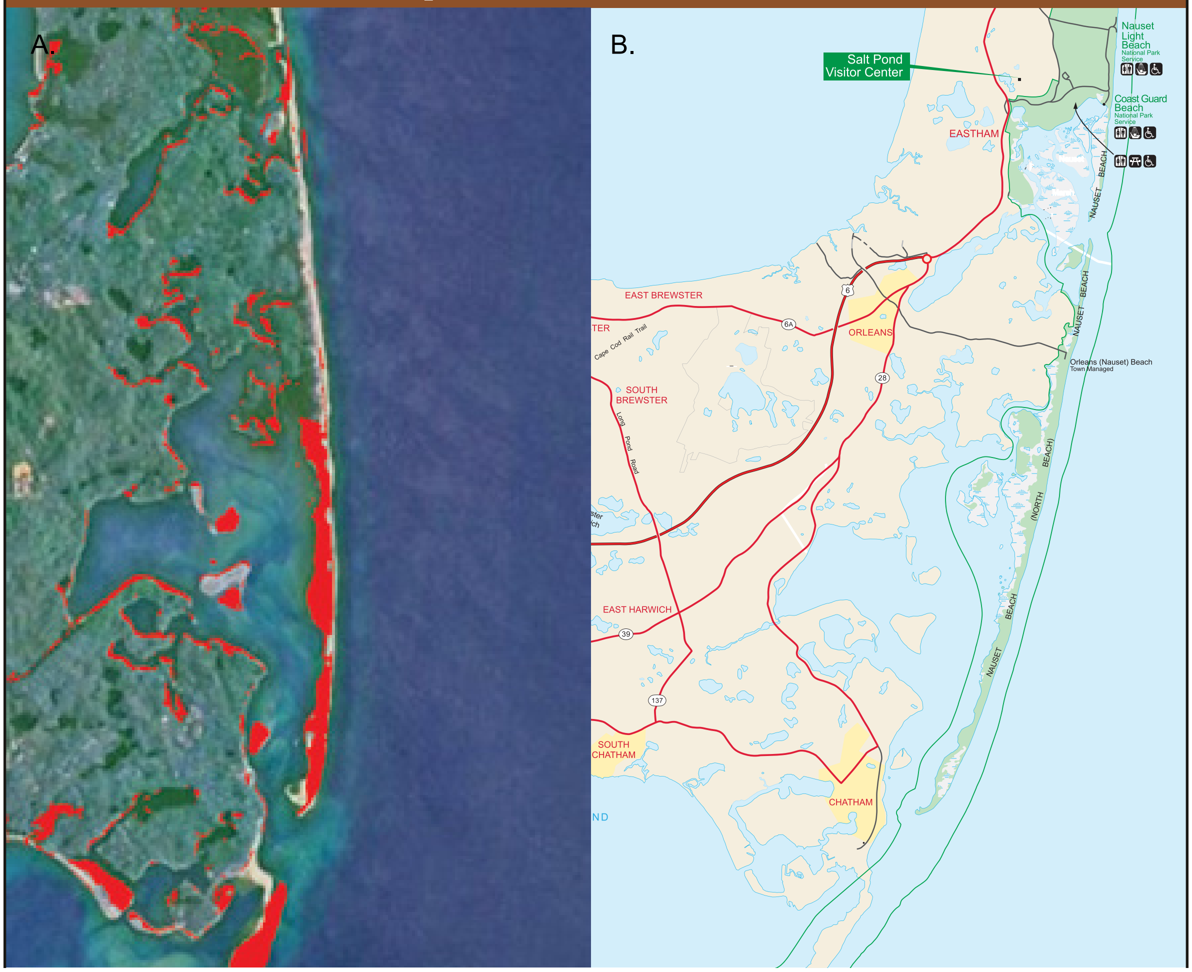


Figure18. Cape Cod NS and surrounding area showing those lands that are one meter or less in elevation, indicated in red in Figure 18A, and a reference map showing seashore boundaries and selected features, in Figure 18B. Sources: 18A, Weiss and Overpeck; 18B, based on NPS.[134]

For **Fire Island NS**, Figure 19A below shows the eastern half of the seashore, including the road and highway that provide vehicle access to the eastern end of the seashore. Most of the seashore lands shown in the figure are less than one meter of land, including a large majority of lands on the landward side of the island. The western half of the seashore (not shown) has a similar preponderance of low-lying lands.

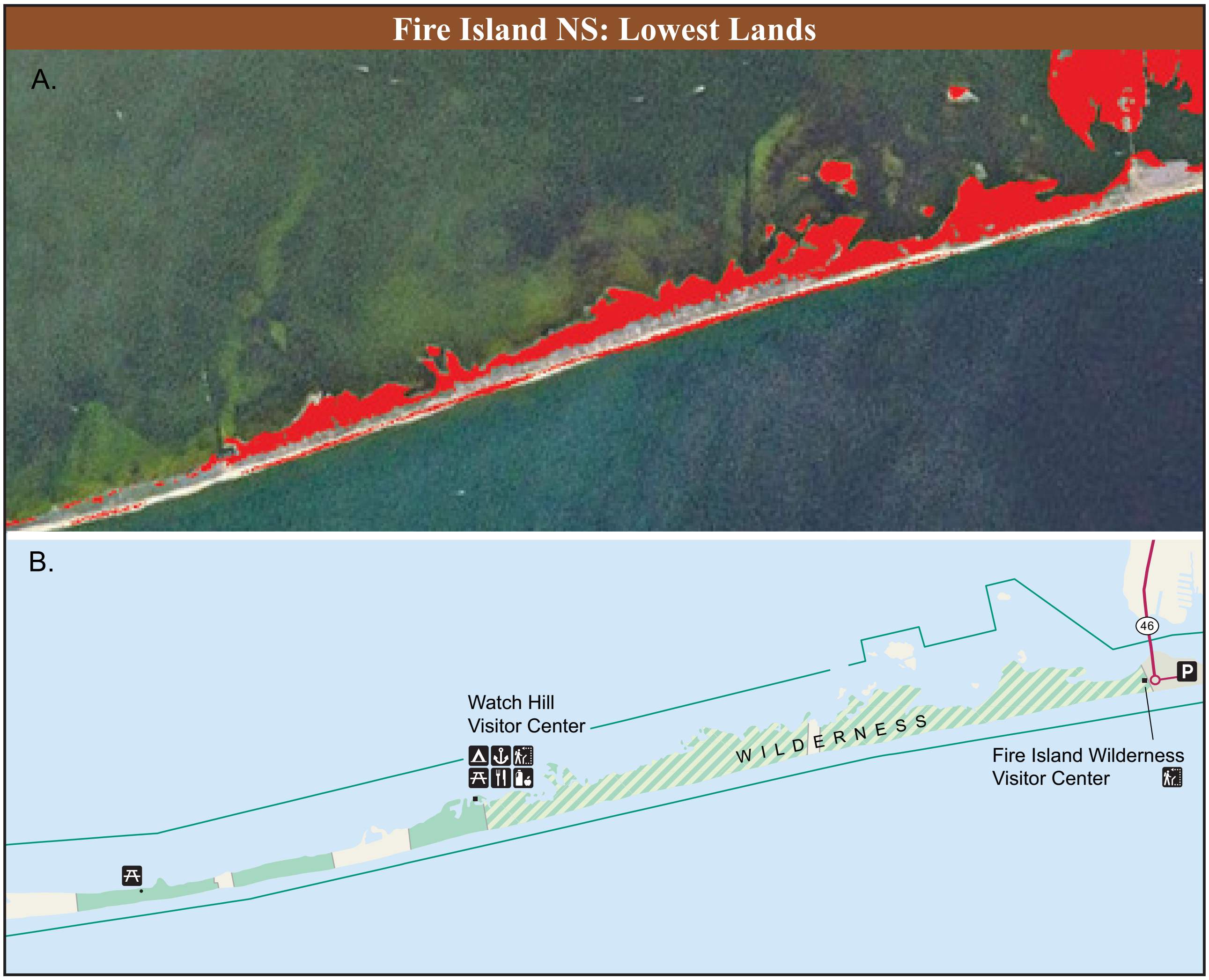


Figure 19. As Figure 18, except with respect to Fire Island NS. Sources: 19A, Weiss and Overpeck; 19B, based on NPS.[135]

For **Assateague Island NS**, Figure 20 below shows separate elevation and reference maps for the most visited portions of the Maryland (Figure 20A) and Virginia (Figure 20C) units of the seashore. In both units, most lands shown in the figures are less than one meter above sea level. The low-lying areas include visitor centers, campgrounds, and other heavily visited areas. The remainder of the seashore also has a majority of its lands below one meter.

Figure 20. As Figure 18, except with respect to Assateague Island NS, Maryland unit (Figure 20A) and Virginia unit (Figure 20C). Sources: 20A and 20C, Weiss and Overpeck; 20B and 20D, based on NPS.[136]

For **Cape Hatteras NS**, Figure 21 below shows the southern portion of the seashore, covering much of Hatteras Island and all of Ocracoke Island, including the ferry landing area, visitor center, and Ocracoke Village at the southern end of the latter island. Most of the seashore lands shown in the figure, especially those on the landward (western and northern) sides of the barrier islands are less than one meter above sea level. The elevations of the seashore lands farther to the north (not shown) are similar.

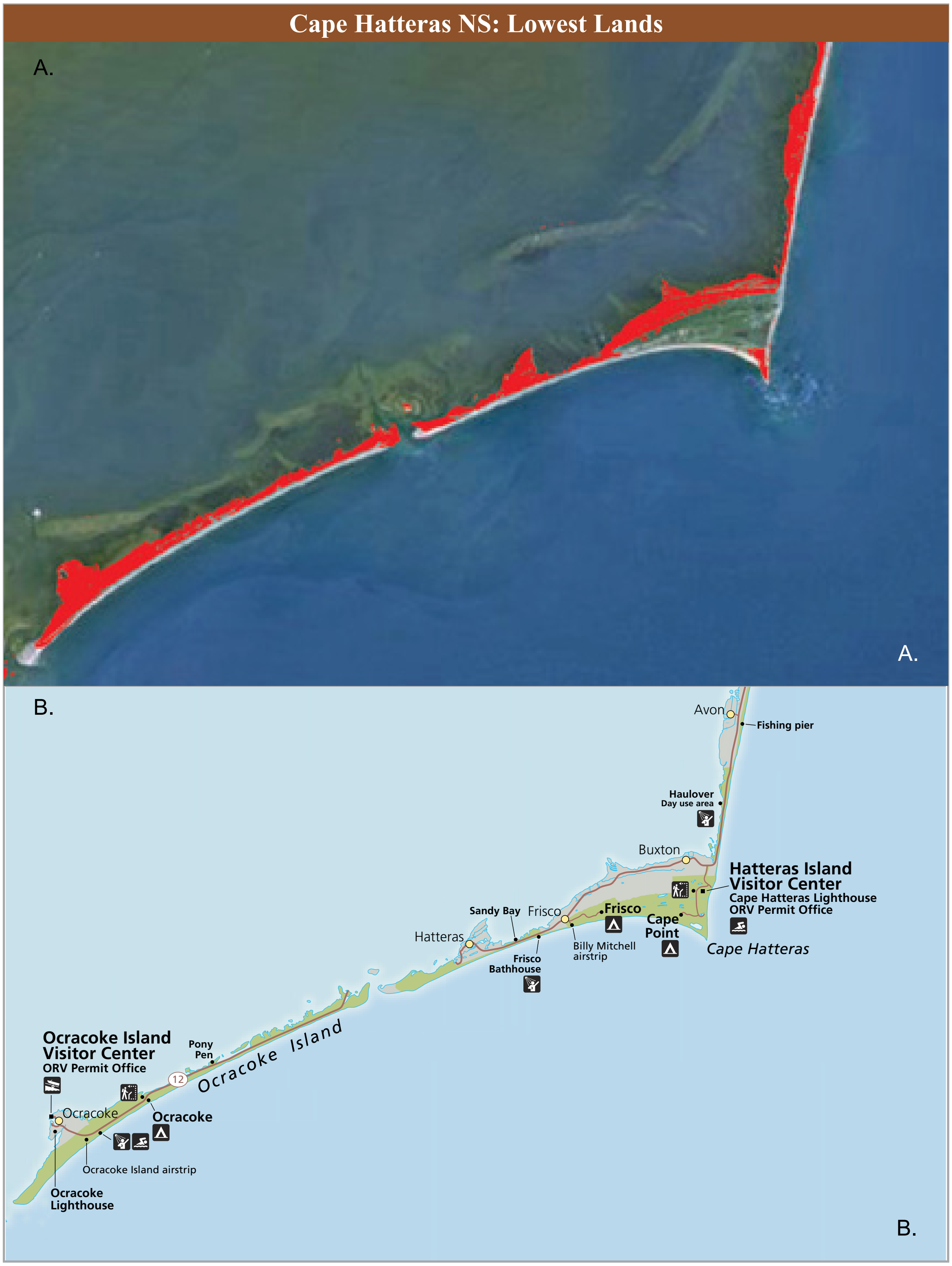


Figure 21. As Figure 18, except with respect to Cape Hatteras NS. Sources: 21A, Weiss and Overpeck; 21B, based on NPS.[137]

Figure 22 below shows the southern portion of **Cape Lookout NS**, including Shackleford Banks, Cape Lookout, and the southern stretch of the Core Banks. Most of the seashore lands shown in the Figure are less than one meter above sea level. This includes a large majority of the lands on the landward sides of the islands. Elevations in the remainder of the seashore are similar.

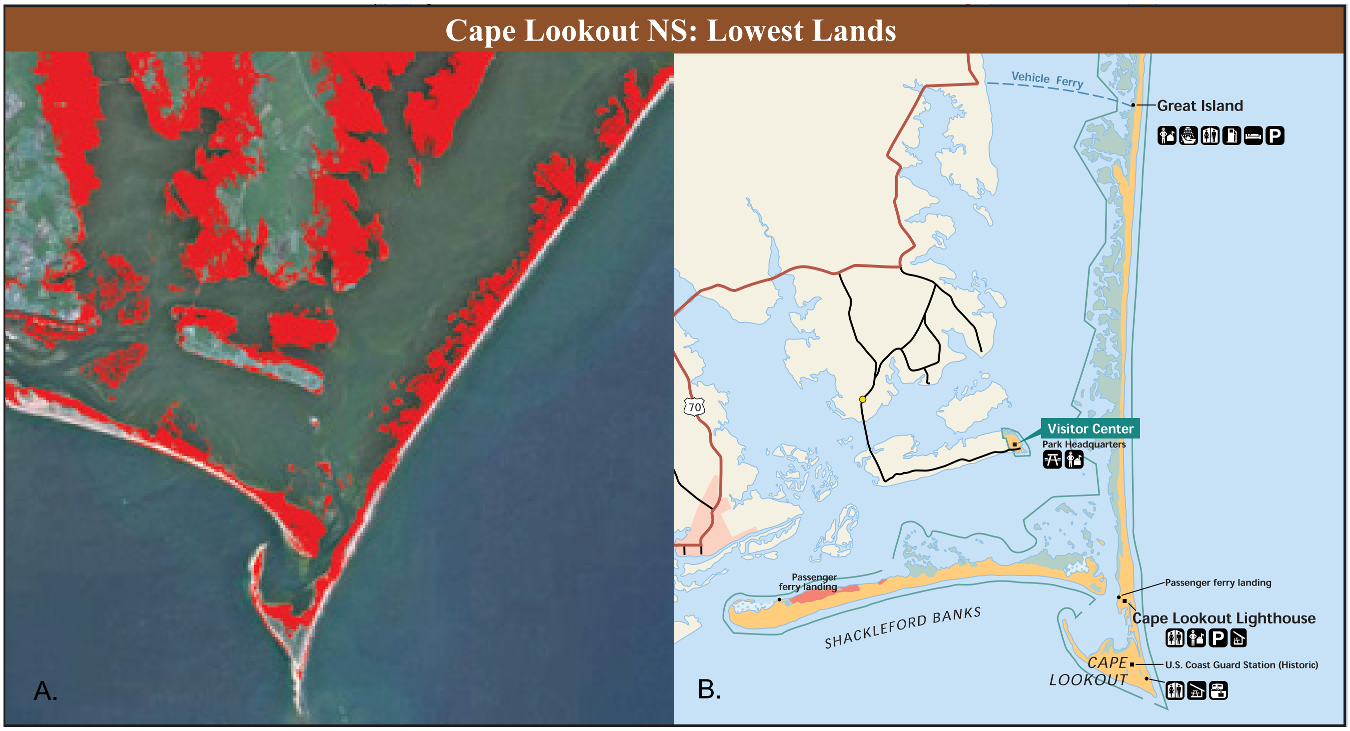


Figure 22. As Figure 18, except with respect to Cape Lookout NS. Sources: 22A, Weiss and Overpeck; 22B, based on NPS.[138]

Figure 23 below shows that the southern two-thirds or so of **Cumberland Island NS**. Most seashore land shown in the figure is more than one meter above sea level. The low-lying lands are primarily salt marsh and beach areas. Elevations on the northern end of Cumberland Island are similar.

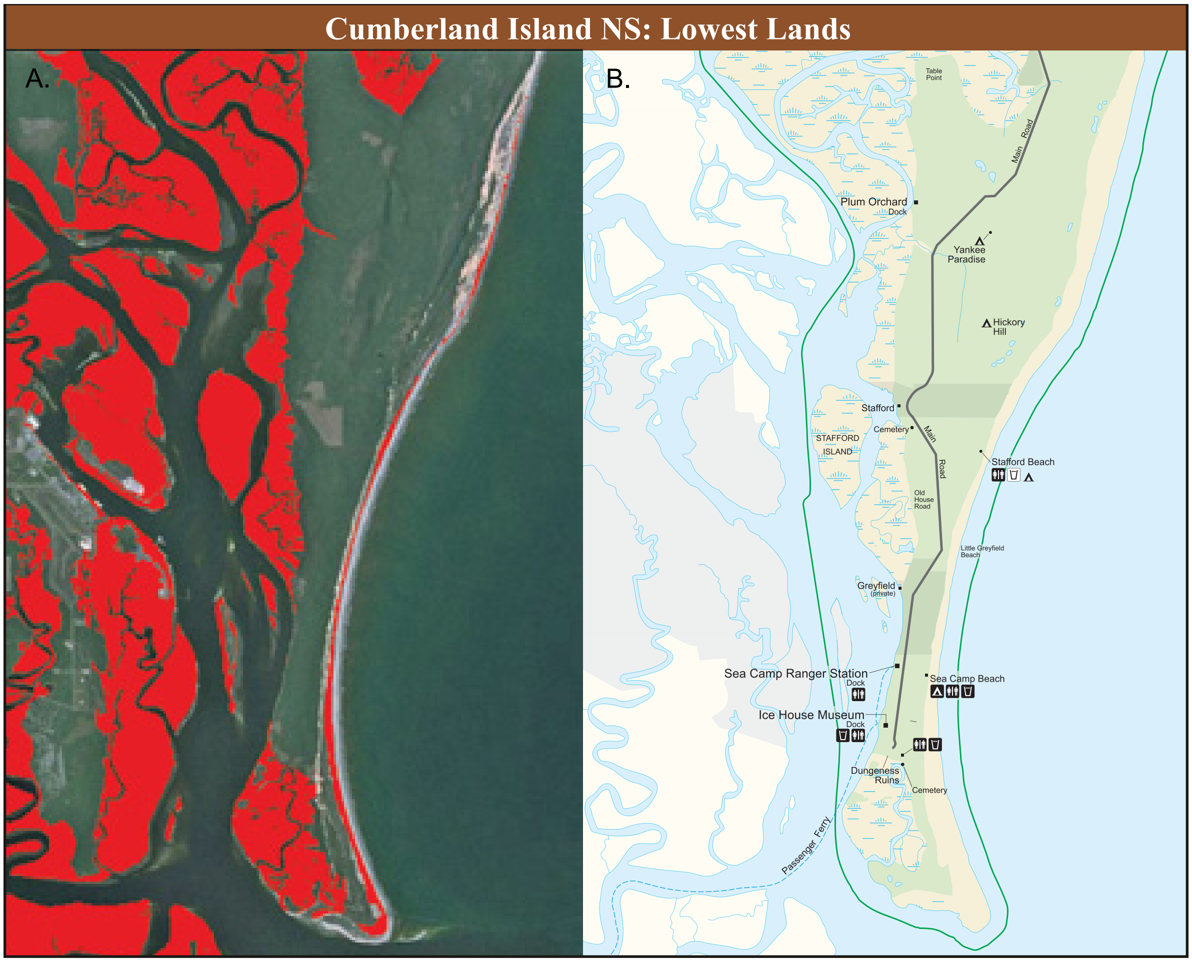


Figure 23. As Figure 18, except with respect to Cape Lookout NS. Sources: 23A, Weiss and Overpeck; 23B, based on NPS.[139]

Figure 24 below shows **Canaveral NS**. Most of the seashore lands are less than one meter above sea level. Notably, the vast majority of the lands behind the seashore's beaches are less than one meter high, and only thin strips of lands are higher. This seashore's beaches already are particularly vulnerable because of how narrow they are (see page 28).

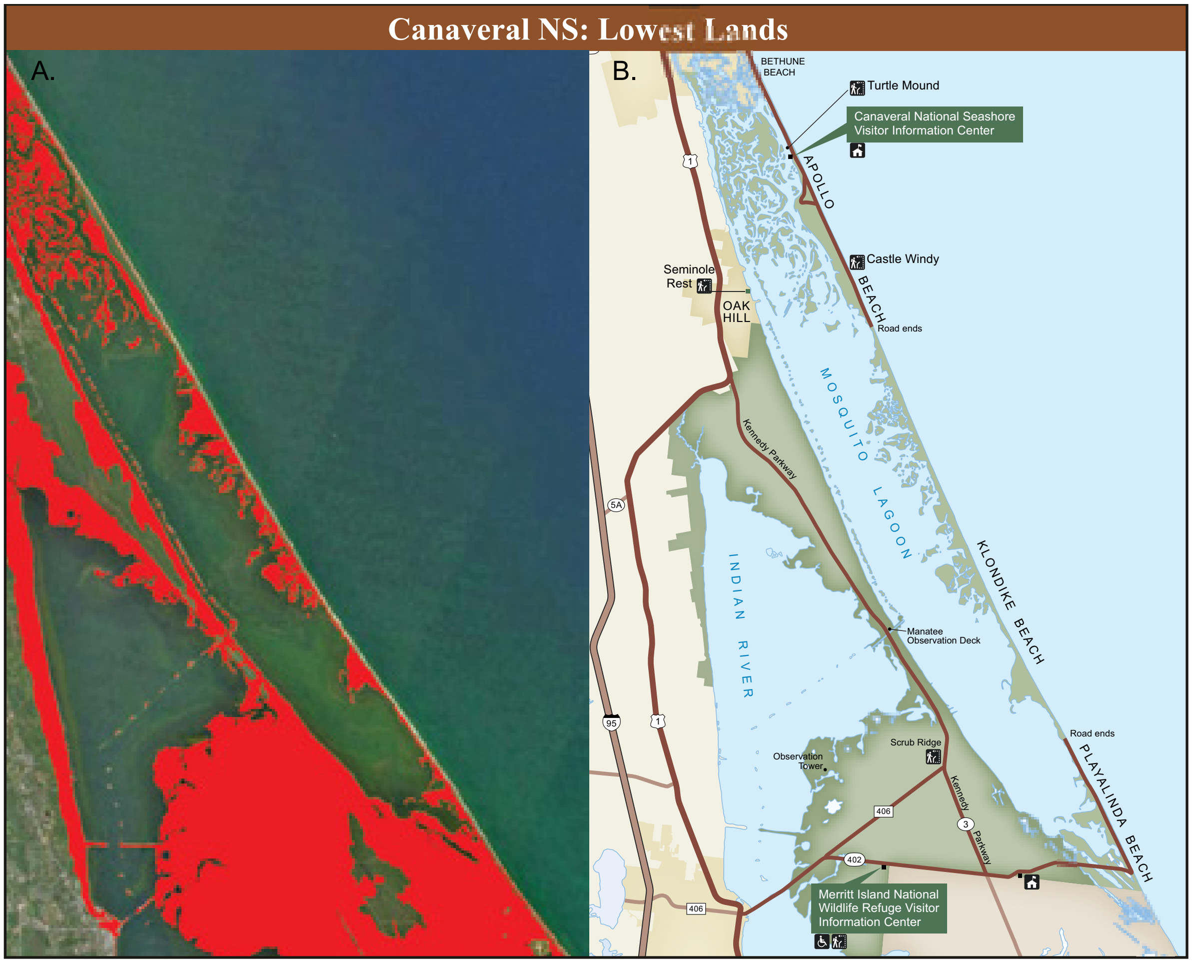


Figure 24. As Figure 18, except with respect to Canaveral NS. Sources: 24A, Weiss and Overpeck; 24B, based on NPS.[140]

6

VISITOR ACCESS

Assateague Island NS. Photo: FWS.

Getting to the seashores may become harder for visitors, as current roads and parking lots may not be able to withstand higher seas and stronger storms. New, sustainable transportation alternatives may be needed. Assateague Island and Cape Hatteras are especially vulnerable.

As seas rise and coastal storms become stronger, some Atlantic seashores face a potential loss of the bridges and roads that now provide most visitor access to them.

The vulnerability of the roads depends on their elevation above sea level, their exposure to erosion, and other factors. The most vulnerable roads are those that already have been periodically subject to overwash and washout, necessitating expensive repairs and rebuilding, especially in **Assateague Island and Cape Hatteras national seashores**. The frequency of these events is likely to increase with rising seas and stronger storms.

In the near term, the threats primarily are of more frequent and long-lasting temporary closures of key bridges and roads that provide visitor access to those seashores. In the long term, the current transportation infrastructure may not be adequate, forcing permanent closures of the current roads and their replacement with alternative methods of access. At some point, the decisive factor in whether to continue maintaining current roads or to provide alternative access likely will be the relative governmental expenses in either repeatedly repairing them or replacing them with alternative transportation.

Ultimately, **Fire Island, Assateague Island, Cape Hatteras, Cumberland Island and Canaveral national seashores** face the risk of inundation of most of their land, depending on future rates of sea-level rise (see Section 5). If extensive lands and bridges, roads, and other visitor-access facilities were to be lost, there would be obvious consequences for both visitor access to and visitation levels at the seashores. But so long as substantial land remains above the sea, the seashores doubtless will remain attractive to visitors even if the methods of access may change, as demonstrated at **Cape Lookout and Cumberland Island national seashores**, reachable only by boat.

Continuing to provide visitor access will require new planning and funding—and a clear-eyed vision of how the future could be different from the past.

Cape Cod NS

At Cape Cod NS, several short roads from the main highway along the cape lead to beaches and other seashore locations. In 2011 a consensus-based approach among experts was used to identify areas of Cape Cod vulnerable to SLR based on elevation, erosion, and exposure to storm surges and SLR, as part of a multi-governmental and stakeholder effort to consider transportation and land-use needs on the cape in the face of climate change (see page 21). The experts identified a stretch of Highway 6 near Provincetown at the tip of the Cape as a roadway:

> vulnerable to erosion and SLR impacts. The road is currently maintained through replacement of sand. Without continued replacement, the road would likely be lost.[141]

The broad-based effort to begin considering sustainable transportation methods for Cape Cod is an example of the work that must be done to continue visitor access to the seashores in the face of climate change impacts.

Fire Island NS

At Fire Island, methods of transportation are quite varied. What warrants consideration at this seashore is not just how higher seas and stronger storms may affect road access but also how ferry service to the island, walking and cycling on it, and other methods of transportation may be affected.

Assateague Island NS

At Assateague Island NS, in both the Maryland and the Virginia units, bridges and roads provide access to central developed areas, with short side roads within those areas. In the Virginia portion, a beach road, four parking lots, and other infrastructure that are regularly overwashed and damaged as a result of the forces that drive the landward movement of the barrier island.[142] From 2007 through 2011, the costs to maintain the parking lots have averaged about $560,000 per year, with over 70% of that going to repairing storm damage.[143] Repairing damage from Hurricane Irene in 2011 cost about $700,000.[144] Storm repairs typically take two weeks to three months, and have ranged from fixing washed-out parking lots and roads to total relocation of parking lots and roads slightly to the west.[145] The Maryland unit's roads, parking lots, and other infrastructure are similarly vulnerable.

Describing the impacts on visitor use and the NPS's response, the national seashore staff has written:

> From a visitor use perspective, the more dynamic barrier island landform expected under most climate change projections will challenge the ability of the NPS to provide recreational access and opportunities in traditional ways. Rapid rates of shore retreat and storm-driven overwash will make fixed location infrastructure such as roads, parking lots and visitor use facilities increasingly more difficult and costly to maintain. New ways of providing sustainable access and infrastructure are needed to protect visitor use opportunities in the face of climate change. Some of these adaptive measures are currently being demonstrated at [Assateague Island NS], including low impact road and parking lot construction techniques, and mobile visitor use facilities that can be easily removed from harm's way prior to storms. Other potential options include the relocation of infrastructure such as parking lots and campgrounds to the adjacent mainland, and the use of alternative transportation systems.[146]

In developing a draft of a new general management plan (GMP) to guide management of the seashore for the next 20 years or so, Assateague Island has begun the

Management Alternatives for Visitor Experiences and Access at Assateague Island NS

	Continued Current Management	Traditional Beach Recreation	Sustainable Recreation and Climate Change Adaptation	Natural Island Evolution and a Primitive Island Experience
Type of Visitor Use and Experience	Focus on traditional beach recreation as long as access is maintained and facilities are sustained given available funds.	Focus on traditional beach recreation within a high-density visitor use area; recreational use would become concentrated within a smaller space, increasing crowding and potentially leading to visitor use limits and increased fees.	Focus on maintaining most recreational uses and activities; over time facilities supporting uses would likely move to more sustainable locations on the island; some recreational activities relocated to the mainland.	Focus on traditional beach recreation with a shift over time to increasingly primitive day-use-only experiences; some recreational activities eliminated.
Long-Term Visitor Access to Seashore	No planning for if and when bridge access is lost; seashore access could be lost for months to years following major storm events.	No planning for if and when bridge access is lost; seashore access could be lost for months to years following major storm events.	If and when bridge access is lost, access would transition to all-water access via new passenger ferry service and a new network of public-access sites.	If and when bridge access is lost, access would transition to all-water access via new passenger ferry service and by commercial service providers operating from existing mainland access sites.

Table 9. Summary of alternatives under consideration for a new draft general management plan at Assateague Island NS. Source: Assateague Island NS, NPS.[147]

process of addressing visitor access to the seashore in a pioneering way. Four preliminary management alternatives have been outlined at the outset of the planning process.[148] They differ on several points, including approaches to the types of visitor experience that will be the primary management focus and long-term visitor access to the seashore, as summarized in Table 9 on the previous page. Importantly, the NPS has pointed out that attempting to maintain the current bridges, roads, and other infrastructure to support motor vehicles on the island could actually halt future visitor access for the months or years needed to reopen that access after storm-related closures. To sustain visitor access, the seashore is considering a new management approach: recognizing that bridge access will be lost at some point, and planning now to replace it with commercial ferry service of the kind that provides most access to Fire Island, Cape Lookout, and Cumberland Island national seashores.

This forthright consideration of climate change impacts and new management options based on them is a fundamentally different and encouraging step by the NPS. The public also seems ready to embrace this new approach. In comments on the GMP alternatives, the most support was expressed for the Sustainable Recreation and Climate Change Adaptation alternative.[149] Next steps in the planning process will include the preparation of a full draft GMP for public review.

The options the National Park Service is considering for the future of Assateague Island National Seashore well illustrate how climate change will affect the national seashores and how new management approaches are needed.

Cape Hatteras NS

At Cape Hatteras NS, a highway runs the full length of the seashore's three major barrier islands. On Hatteras and Ocracoke islands, it is North Carolina Highway 12, which is highly vulnerable to rising seas and stronger storms. This vulnerability is well illustrated by the effects on the road of hurricanes Isabel, which hit this coast as a Category 2 hurricane in September 2003, and Irene, which made landfall as a Category 1 (minimal) hurricane in August 2011 (see pages 17–18). Both hurricanes breached Hatteras Island and severed NC 12 in two places. After Isabel, the U.S. Army Corps of Engineers and the North Carolina Department of Transportation closed the inlet and reconstructed the highway by November of 2003. After Irene, temporary road repairs at one new inlet consisted of building a temporary bridge and at the other breach using sand to close the breach and rebuilding the road. The highway reopened in early October 2011, after about $12 million in highway repair costs.

Over the past 10 years, the N.C. Department of Transportation has spent about $100 million maintaining

NC Highway 12, Hatteras Island. Photo: FWS.

NC 12, mostly south of Oregon Inlet (which separates Bodie Island and Hatteras Island).[150] Repair costs related to hurricanes Dennis, Bonnie, and Floyd in 1999 were $1.7 million and to Hurricane Isabel in 2003 were $1.2 million.[151] Over that period, there were six hurricanes, one tropical storm and 13 nor'easters that required cleanups.[152] So far, the Federal Highway Administration and the state government have remained committed to rebuilding the highway as needed, although others have suggested that it is time to switch to other alternatives, such as new bridges or ferry service to provide direct access from the mainland to points on the barrier islands.[153]

The N.C. Department of Transportation is currently embarking on a replacement of the bridge over Oregon Inlet, and with others is beginning a process of assessing potential long-term transportation options in the area.[154]

"Six locations in and around the national seashore have been identified by the Outer Banks Task Force as erosional hot spots, or sections of coast where the dunes are frequently destroyed by storms. Sections of North Carolina highway 12 have been relocated in these hot spot areas, and when breaks form in the dunes they are immediately filled, which may interfere with natural barrier overwash processes. Some scientists suggest that storms and overwash processes are essential to the evolution of these barriers, and human interference through dune building, road maintenance, and breach filling only ensures an increase in vulnerability of these islands. Park managers, charged with resource preservation for future generations, are faced with a difficult task along the Outer Banks."

U.S. Geological Survey[155]

Cape Lookout and Cumberland Island NSs

Cape Lookout and Cumberland Island national seashores, unlike the five other Atlantic seashores, have no roads from the mainland to be overwashed, eroded, or inundated; the public access to these seashores is by commercial ferries. Continued visitor access to these seashores is easier to maintain than in seashores dependent on more transportation infrastructure (see page 18). As with Fire Island NS, consideration of future transportation needs to begin with an assessment of possible climate-change-driven effects on the current systems.

Canaveral NS

At Canaveral NS, roads provide access to the mainland portion of the seashore and to the northern and southern stretches of beach. These roads can be overwashed by coastal storms, causing temporary closures.[156] The seashore has a draft of a new general management plan, but it does not really address the transportation or other impacts of climate change (see page 49).

Another Example: Gulf Islands NS

The Atlantic Coast national seashores are not alone in facing new challenges about providing continued visitor access in the face of climate change-impacts, as illustrated by NPS travails with the road in Gulf Islands NS (in Florida and Mississippi) that provides access to Fort Pickens, a historic fort at the western end of Santa Rosa Island, a barrier island, which guarded the entrance to Pensacola Bay. When the road was destroyed in 2004 by Hurricane Ivan and again in 2005 by Hurricane Dennis just two weeks before it was to have reopened, the reconstruction of the road was put on hold while alternatives could be evaluated.[157] In part, the U.S. Department of Transportation and the Federal Highway Administration questioned spending another $10-11 million to rebuild the road again. They evaluated alternatives including an "armored" road that could better withstand intense storm activity, a less expensive road that would be considered expendable, or not rebuilding the road at all. A decision was made to build the less expensive road, which now has been done.

Local officials and residents have expressed concern about whether the NPS will continue after future major storms rebuilding the Fort Pickens Road, which carries 800,000 visitors a year. In a draft of a new general management plan for the seashore, the NPS stated, "The intent of the national seashore is to rebuild the road after storms, if feasible . . . but there are situations that may arise in the future where conditions become so altered that it is no longer feasible to build or maintain the road."[158]

The seashore superintendent explains that this is a reference to another possible future storm-caused breach of the island and road.[159] He points out that if federal transportation agencies have expressed reluctance to repeatedly rebuilding a road that costs $10-11 million, it is unlikely given the current budget climate that there would be support for constructing a sustainable elevated road or bridge that could cost hundreds of millions of dollars.

> *"[N]oticeable trends include an increase in the intensity and frequency of storms in the Gulf of Mexico. This has accelerated the rate of repair on national seashore infrastructure resulting from storm damage. Climate change forecasts reinforce the likelihood that this trend will continue into the foreseeable future."*
>
> Gulf Islands National Seashore[160]

7

WILDLIFE AND ECOSYSTEM IMPACTS

Climate disruption threatens wildlife and ecosystems in all the Atlantic seashores.

Piping plover on eggs. Photo:NPS.

Hotter temperatures, stronger storms, rising seas, and other manifestations of a changing climate are affecting the wildlife and ecosystems of the Atlantic seashores. Greater impacts are expected in the future as the climate continues being altered.

IMPACTS TO WILDLIFE

Climate change is expected to drive some wildlife species into extinction. The Intergovernmental Panel on Climate Change warns that just 4°F to 5°F of higher temperatures could leave 20 to 30 percent of plant and animal species in climatic conditions far outside those of their current ranges, making them "likely to be at increasingly high risk of extinction."[161] One reason this percentage is so high is that stresses resulting from climate change would come atop others such as habitat loss.[162] Even if species do not become extinct everywhere, they may be eliminated from places where they now are found by changed conditions there. Also, new species likely will move into an area as they search out suitable habitats as their home ecosystems change. These new immigrants would compete with existing species for habitat and food, potentially driving further changes in wildlife populations. Already, the ranges of many wildlife species in the United States have shifted northward.[163]

Sea Turtles

Sea turtles, all of which are endangered species, can be found in all the Atlantic seashores and nest in seashores from Assateague Island NS (where they are uncommon) to Canaveral NS (where 3,000-4,000 loggerheads, up to 300 green sea turtles, and a few leatherbacks nest annually). These sea turtles are vulnerable to climate change in several ways.

First, coastal storms can destroy sea turtle nests before the new turtles can hatch. At Assateague Island NS in 2006, Tropical Storm Ernesto washed out six of the seven nests discovered that year.[164] In 2011, Hurricane Irene washed away 32 of 147 sea turtle nests at Cape Hatteras NS and 58 out of 157 at Cape Lookout NS.[165] In 2004, Canaveral NS had more than 1,000 nests washed away by four hurricanes.[166] If coastal storms become stronger as expected, more nesting failures could be expected.

A hotter climate threatens sea turtles in another, particularly insidious way.[167] The sex of their young is controlled by temperature, with more females hatched from eggs incubating at higher nest temperatures. Already, populations of turtles in southern parts of the United States are currently heavily skewed toward females and are likely to become much more so with even slight further increases in temperature. One study suggests that if air temperatures increased by 13.5ºF, all hatchlings would be females.

Also, a hotter climate could push sand temperatures above the upper limit for successful egg incubation, about 93ºF.[168]

Later in their lives, sea turtles are vulnerable to climate-change-driven disruptions of their feeding grounds, including sea grass beds and coral reefs, both of which are vulnerable habitats.[169]

Birds

The Atlantic seashores, preserving some of the most diverse undeveloped coastal habitats along the eastern seaboard, sustain astonishing numbers of birds. Species that have been sighted in the seashores number more than 330 at Fire Island NS, 324 at Assateague Island NS, over 360 at Cape Hatteras NS, more than 250 at Cape Lookout NS, and 310 at Canaveral NS. Each of the seven seashores has been designated as a Globally Important

Bird Area.[170]

Birds in every terrestrial and aquatic habitat will be affected by climate change.[171] Coastal species are particularly at risk, with the great majority of them having been identified as having medium or high vulnerability to climate change. This high degree of risk is largely based on climate-change-driven impacts described throughout this report, including potential inundation or fragmentation of low-lying habitats such as sand beaches, salt marshes, and mudflats by rising seas and more severe coastal storms.

Nesting Sea Turtles

The only time adult sea turtles come ashore is when the females nest.[172] It is exhausting work for them to drag their heavy bodies onto the beach to lay their eggs. Loggerheads and greens weigh between 200-350 pounds, while leatherbacks range from 700 pounds to a ton.

The different crawl marks they leave can be used to identify the species of turtle. Loggerheads leave alternating flipper marks, since they move like lizards, simultaneously moving a front flipper on one side and the rear flipper on the other. Greens and leatherbacks leave opposing flipper marks, as they move both front flippers at the same time, then both rear flippers. The crawl marks of greens are smaller than those of leatherbacks, which are about six feet across.

Although most females mate only once a season, they may nest several times—three times on average—at intervals of about 10 days for leatherbacks and 13 or 14 days for loggerheads and greens. The mothers dig their nests with the hind flippers, so they cannot see what they are doing. They then pack sand over the nest, first with their rear flippers and then with all four as they gradually move away. Loggerheads lay an average of 100 to 120 eggs in a nest, greens 100 to 140, and leatherbacks 60 to 100. Loggerhead and green eggs are the size and shape of a ping-pong ball, while leatherback eggs are larger. Loggerhead nests are about two feet deep, and those of greens and leatherbacks are deeper and under conspicuous mounds.

Kemp's Ridley sea turtle hatchling, Cape Lookout NS. Photo: NPS.

Loggerhead crawl tracks, Cape Lookout NS. Photo: NPS.

Eggs generally hatch in 50 to 60 days. As the hatchlings emerge from the eggshells they move about, gradually working their way towards the surface. The movement of one hatchling will generate movement in others. As they near the surface, they will become still if they sense high temperatures outside. When temperatures cool at night, the hatchlings emerge. They are genetically programmed to move towards light, since normally the dune behind the nest is dark, and the horizon over the ocean is relatively lighter. During their journey to the water, they are vulnerable to crabs, raccoons, birds, and other predators. This may also be when they become imprinted to their nesting beach, helping to guide them back as reproducing adults many years later. Hatchlings which make it to the ocean then must elude offshore predators. They head straight out to sea at about one mile per hour until they reach rafts of floating seaweed that may be 20 or 30 miles offshore. There they hide and feed on tiny plant and animal matter. Ultimately, perhaps only one hatchling out of 100 or 1,000 survives to maturity.

Canaveral NS and Cape Lookout NS offer popular turtle-watch programs for people to observe loggerhead nesting and hatching.

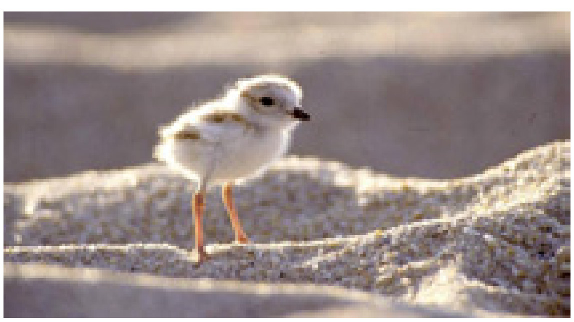
"The quality and quantity of coastal habitats is likely to decrease as a result of sea-level rise, increased storm damage, and effects on marine productivity. Losses of habitat and food sources due to climate change are the largest concerns for coastal birds."

State of the Birds 2010 Report on Climate Change [173]

At especially high risk in the seashores are beach-nesting species, such as piping plovers and least terns, because of the possibility of loss of beach habitat (see the next page). The Atlantic Coast piping plover is listed as threatened under the Endangered Species Act. Once plentiful along the Atlantic coast, the species nearly disappeared due to excessive hunting for their feathers.[174] Under protections put in place under the federal Migratory Bird Treaty Act, numbers recovered by the 1940s, but have declined since due to degradation of habitat, human disturbances, and intensified predation pressures. Recent surveys suggest the Atlantic population is less than 1,800 pairs. The undeveloped sand beaches of Cape Cod, Fire Island, Assateague Island, Cape Hatteras, and Cape Lookout national seashores provide crucial nesting habitat for the plovers, with the further protection that in the seashores their nesting areas are closed to public use during the nesting season. But if the key remaining undeveloped beaches on the Atlantic Coast are diminished and disrupted by rising seas and stronger coastal storms (see page XX), piping plovers would be pushed closer toward extinction.

"Piping plovers and least terns need beach habitat that is not vulnerable to erosion or flooding given sea-level predictions. Further loss of habitat for these and other rare species would make their continued survival questionable."

Defenders of Wildlife[175]



Piping plover. Photo: NPS.

Climate change is also expected to lead to changes in the breeding and wintering ranges of birds and of their migration timing and patterns.[176] Warmer winters in recent decades have already led birds to shift their winter ranges to the north. According to Christmas Bird Count data compiled annually by thousands of volunteer birders, over half of the 305 most widespread, regularly occurring winter species in the contiguous United States now winter farther to the north than before, moving their ranges by an average distance of 35 miles over 40 years.[177] On Cape Cod, there have been clear shifts in the populations of wintering birds, with southern species becoming relatively more common and northern species less so, which researchers have identified as more linked to milder winter temperatures than to habitat changes on the cape.[178]

Manatees

Endangered Florida manatees, a subspecies of the West Indian manatee which is the state mammal of Florida, can be regularly found in summer in the lagoon in Canaveral NS, and less frequently in Cumberland Island NS. In either seashore, a sighting of these gentle creatures is a highlight of any visit. Among the many threats to manatees, at least two could be increased by climate change. First, hotter waters are likely to promote the spread of toxic algae, particularly those that cause red tides, which produce a poison that can affect manatees; red tides were associated with deaths of 39 manatees in 1982 and 149 in 1996.[179] Second, manatees depend on sea grass as a primary food source, and sea-level rise may lead to fewer areas with sea grass.[180]

"Sensitive species such as the manatee, which already has a reduced habitat range, are especially vulnerable to the impacts of climate change."

Canaveral National Seashore[181]

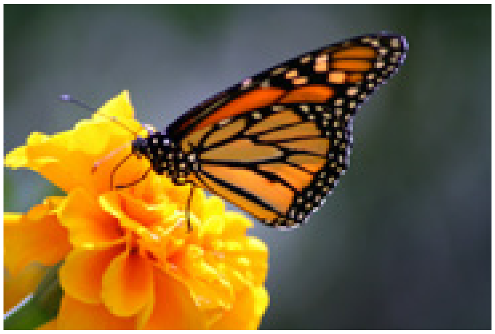
Alligators

Alligators are found at Cumberland Island NS and Canaveral NS. As with sea turtles, the sex of alligator hatchlings is determined by temperature. At incubation temperatures of 90 to 93 ºF, males are produced; at 82 to 86 ºF, females; at intermediate temperatures, a mix of males and females.[182] Again, higher temperatures could dangerously skew the makeup of the population.

Butterflies

Butterflies are particularly sensitive to temperature and so are vulnerable to a changed climate. Monarch butterflies illustrate the risks. They make one of the most amazing migrations of all wildlife, taking several generations to complete a round trip thousands of miles long to return to particular wintering grounds. Scientists do not even know how the great-great-great grandchildren find the winter roosting sites. But scientists project that an altered climate will make the wintering grounds wetter, causing problems for the monarchs, which cannot survive the area's occasional freezing temperatures if they are wet.[183]

Monarchs migrate through and to all 48 contiguous states. If their populations drop, though, that would be



Monarch butterfly.

felt particularly at Assateague Island NS. Many monarchs migrate along the Atlantic Coast in the fall; on Assateague Island, a monitoring project has recorded more than 900 migrating monarchs per hour during peak flights.[184]

> *"For butterflies, birds, and other species, one of the concerns with such changes in geographic range and timing of migration is the potential for mismatches between species and the resources they need to survive."*
>
> U.S. Global Change Research Program[185]

IMPACTS TO ECOSYSTEMS

All ecosystems in the Atlantic national seashores face potential alterations driven by climate change.

The effects on salt marshes, in particular, warrant attention, both as an illustration of ecosystem change and because salt marshes themselves are "among the most productive systems in the world"—or, as the NPS has called them, "hot spots for biodiversity."[186] They harbor large amounts of plant matter and nourish animals from insects to crabs, shrimp, other fish, birds, and mammals. One climate-change-driven threat to salt marshes is the possibility that seas may rise faster than deposits of sediment can keep marsh waters from becoming too deep for marsh plants to grow, or than marshes themselves can migrate inland or to areas of higher elevation. A federal report suggests that salt marshes may be able to survive rates of sea-level rise as high as about 20 inches in 50 years, but sea levels may rise faster than that (see pages 53–56).[187]

In 2002, the NPS began monitoring salt marshes at **Fire Island NS** to determine how they fare as the local sea level rises. In the first five years (through 2007), the researchers found that the three monitored marshes are not keeping pace with the regional level of sea-level rise over the past 60 to 100 years.[188] They observed that the loss of marshes could continue for the long run, future storms could deliver new sediment so marsh levels keep up with sea level, or periods of low sea-level rise could enable the marshes to adjust. If the observed elevation deficit continues, it is likely that the Fire Island marshes will become wetter, types of marsh vegetation may change, and open waters may replace marshes.

There could also be a migration of marshes to current upland areas, a natural process of marsh development in response to sea level rise, if bulkheads or other structures do not impede this migration.

> *"Assateague's other dominant wetland habitat, tidal salt marsh, is also at significant risk from the effects of climate change. Increased rates of sea level rise coupled with a more dynamic landform has the potential to overwhelm the ability of intertidal marshes to maintain surface elevations and keep pace with rising seas. Significant loss of salt marsh will decrease primary productivity and reduce habitat availability for both terrestrial and aquatic species; some of which are important to regional commercial fisheries."*
>
> Assateague Island NS [189]

Salt Marsh, Assateague Island NS. Photo: NPS.

Sandy beaches also are vulnerable. Strong coastal storms can strip sand from beaches, which might not be naturally replaced (see pages 17–19). The impacts of higher seas and stronger storms on barrier islands depend in part on the local availability of sediment, with a local shortage of sediment generally leading to a landward retreat of islands.[190] The Mid-Atlantic coast is considered to be "sediment-deprived," which increases the odds of a loss of beaches and shoreline change.[191] There are indications that as sea-level rises sandy beaches may be lost at a far greater rate than the rate of SLR.[192] A reduction in beaches at the seashores would affect not only wildlife (see above) but also the millions of visitors who come to the seashores in large part to enjoy their undeveloped beaches (see pages 2–3).

Freshwater wetlands, too, are at risk. **Cape Cod NS** has hundreds of freshwater wetlands and numerous kettle ponds, which serve as critical habitat for a multitude of species and are vulnerable to climate-related changes in air temperature, precipitation, and sea level.[193] At other Atlantic seashores freshwater tidal marshes occur at the upper reaches of tributaries of estuaries and support a more diverse vegetation community than more saline marshes.[194]

At **Assateague Island NS**, the limited freshwater wetlands and aquifers are threatened by saltwater inundation from rising seas and from summer droughts, and may affect drinking water for the island's famous wild horses and the stability of the island's maritime forests.[195]

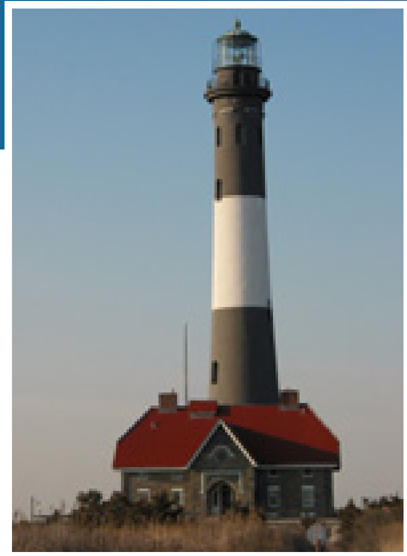
Ocean waters are already being affected by climate change. Globally, sea surface temperatures rose by approximately 0.5°F during the past 10 years.[196] Rising temperatures may increase stresses on organisms, reducing growth, slowing metabolism, and weakening immune systems to marine diseases, which favor hotter waters. Oceans also take carbon dioxide out of the atmosphere, making ocean waters more acidic. Since the Industrial Revolution, the ocean has become about 30% more acidic.[197] The effects include a decrease in the calcium carbonate that clams, oysters, starfish, and other animals use to form skeletons. Other adverse effects on marine wildlife may include harm to metabolism, reproduction, development, and resistance to predators and diseases.[198]

Assateague Island NS. Photo: NPS.

8

Other Impacts

Climate disruption could lead to overcrowding, loss of historical resources, and more air pollution in the seashores.



Fire Island NS. Photo: USGS.

An altered climate will affect many resources and values of the Atlantic seashores, including the enjoyment of visitors, historical and cultural resources, and even the health of visitors.

OVERCROWDING

Retreating to the beach is a popular way to escape summer heat, and as summers get hotter so many people may flock to the national seashores that overcrowding becomes a serious problem. (When temperatures reach extremes, though, being outdoors even at the beach may be too uncomfortable, and visitation may drop—see pages 11–14).[199] So far, there has been surprisingly little research done, by the National Park Service or others, on how higher temperatures may increase visitation to cooler parks, national seashores, and national lakeshores—or on how that increased visitation can be accommodated. Researchers in a study of Canadian national parks, which also offer escapes from hot summers, even suggested that to keep those parks from being overrun in a hotter climate "de-marketing" or visitor quotas could be required.[200]

Overcrowding is most likely to become a significant problem for those national seashores that can readily be reached from major population centers, which is the case for nearly all of the Atlantic seashores:

- **Cape Cod NS**, which in its 1998 general management plan noted that the seashore's 4.5 million annual visitors bring "traffic jams, crowded beaches, growing demands on water resources, and the fragmentation of woodlands and waterfront . . that threaten the very elements most residents and visitors seek."[201]
- **Fire Island NS**, already facing challenges in its high natural resource and aesthetic values so near to the most populous metropolitan area in the country, with 19 million residents.[202]
- **Assateague Island NS**, which already gets 2.1 annual million visitors, and is near the Norfolk-Newport News-Virginia Beach area (1.7 million people) and not far from Washington, DC, which at 5.6 million people is the seventh largest metropolitan area in the country.
- **Cape Hatteras NS**, which now has 2.2 million visitors a year, "[l]ocated within a day's drive of several urban centers," from Washington, DC, south through the Carolinas.[203]
- **Canaveral NS**, a short drive from Orlando and not much farther from other Florida population centers.

LOSS OF CULTURAL RESOURCES

Higher seas and stronger coastal storms threaten many of the cultural resources of the national seashores, which help keep us connected to our national story of who we were, who we are, and who we will be.

Iconic lighthouses are among the seashore resources at risk. Spurred by local organizations, the U.S. government in 1996 moved two lighthouses in **Cape Cod NS**, Highland Light (built in 1857) and Nauset Light (1923), to protect them from erosion of the coastal bluffs on which they had long stood and the new threat of a rising sea.[204] Highland had barely 110 feet to spare from the edge of the cliff by the time it was moved, and Nauset just 37 feet.

Cape Lookout NS has identified for some of the seashore's cultural resources their current elevation above mean sea level, including the Portsmouth life-saving station, 3.1 feet; the Portsmouth Village Church, 3.8 feet; and the Portsmouth Village post office and store,

Moving the Cape Hatteras Lighthouse

At Cape Hatteras NS, the NPS in 1999 moved the Cape Hatteras Lighthouse, the tallest brick lighthouse in the United States, to keep ahead of a rising sea.[205] The lighthouse is culturally important because of the engineering feat it represented when it was built and its role in preventing shipwrecks, and it also has been called by the NPS "one of the most striking and beautiful structures on the Atlantic Coast."[206]

When built in 1870 it was 1,500 feet from the shoreline; by 1970, after the natural erosion of the barrier island's beachfront and landward migration of the island, only 120 feet separated the lighthouse from the Atlantic Ocean. After the National Academy of Sciences (NAS) confirmed in 1988 that the lighthouse was in danger of being lost to the continued rise of the Atlantic and that moving it was the most cost-effective option, Congress eventually appropriated funds to move the lighthouse 2,900 feet inland.

The principal lighthouse keeper's quarters being moved at Cape Hatteras NS, in advance of the move of the lighthouse itself.

Moving the lighthouse consisted of using hydraulic jacks to raise the 4,400-ton structure, inserting roll beams and rollers under it, transporting it along a pathway of steel track beams, and installing it on a new foundation. The lighthouse was started on its journey on June 17, 1999, and was settled into its new location on July 9. The principal lighthouse keeper's quarters and other associated structures had already been moved, and the light station is now again matched up with its supporting cast in the same relative positions as before, at a total cost of $11.8 million.

Knowing that this relocation may prove inadequate in the face of rising seas and stronger storms, the National Park Service left steel beams under the lighthouse to make the next move easier.[207]

"The measures used to protect the lighthouse represent some of the more drastic (and costly) responses possible for resource managers. While a number of measures were employed over the years to protect the structure, ultimately the lighthouse had to be moved away from the receding shoreline. However, this type of action would not be available to many cultural resources, such as cemeteries, eroding battlegrounds, or historic forts."

Maria Caffrey and Rebecca Beavers [208]

3.0 feet.[209] All obviously are vulnerable to inundation if the local sea level were to rise by four feet, and prior to that are vulnerable to damage or destruction from storm-surge flooding.

"Many of the resources at Cape Lookout lie near or slightly above current sea level. Threats from storm surge and flooding due to storm events will only be exacerbated by potential sea-level rise in the future."

Cape Lookout National Seashore[210]

MORE AIR POLLUTION

Cape Cod NS and Assateague Island NS are the only two Atlantic national seashores where air quality is monitored, and both have experienced high concentrations of ground-level ozone, the key component of smog. Ground level ozone harms people's health—through increased asthma attacks, cases of chronic bronchitis and visits to the emergency room. The young and elderly are particularly vulnerable because of their more fragile respiratory systems. Smog also obscures visibility and damages plants and other natural resources. (Naturally occurring ozone higher in the atmosphere is a different thing and has the positive effect of filtering the sun's ultraviolet rays.) In 2010, the last year for which the NPS has reported air quality data on a nationwide basis, Cape Cod NS exceeded the air quality standard for ozone, and Assateague Island NS just missed exceeding it, with the highest possible reading that does not constitute a violation.[211] Heat contributes to the formation of ground-level ozone, and a hotter climate is expected to lead to more of it, with future climate-change-driven increases in ozone levels expected to be greatest where ozone levels already are high.[212] As a result, visitors to these seashores, at least, likely will face increased risks to their health, requiring more air-pollution control efforts to protect them.

"Because ground-level ozone is related to temperature, air quality is projected to become worse with human-induced climate change."

U.S. Global Change Research Program [213]

9

Tackling Climate Disruption

The good news is that climate disruption can be reduced and its worst effects avoided, through national actions and within the seashores, where threatened resources can be protected and visitors can learn about climate change.

As the risks of a changed climate dwarf all previous threats to our national seashores and other units of the national park system, new actions to face these new risks must also be on an unprecedented scale.

To protect our parks for the enjoyment of this and future generations, we need to act now to reduce emissions of climate-changing pollutants, which come mostly from the burning of fossil fuels like coal and gasoline. If we continue with a business-as-usual approach into a high-emission future, our country could heat up another 7° to 11°F, which would have extraordinarily severe effects on national parks, as well as on other resources. The most important step we can take to protect parks is to reduce those impacts by beginning to cut heat-trapping emissions to a level that would stabilize further warming at about an additional 2°F. That would minimize impacts on national parks, other ecosystems, and other resources. But even an additional 2°F of warming would increase the harm that is already being done to parks by the climate changes that are already underway. So we also need bold, visionary actions to protect our national parks in the face of whatever climate changes we end up causing. Both these types of actions—cutting emissions and ensuring our parks are prepared for the impacts of a changing climate—need to be driven by the federal government, primarily the Congress and the National Park Service.

Actions Specific to the National Park System

The mission of the National Park Service, defined by the 1916 Organic Act for the NPS, is "to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."[214] Beginning in September 2010, when it released a *Climate Change Response Strategy*, the NPS has begun to apply this strong mandate to the threats of climate change, which NPS Director Jonathan Jarvis in that document identified as "fundamentally the greatest threat to the integrity of our national parks that we have ever experienced."[215] NPS reinforced this in 2011 with its strategy for the Service's upcoming second century, stating in its first resource-protection goal that, "To preserve America's special places in the next century, the NPS must manage the natural and cultural resources of the National Park System to increase resilience in the face of climate change and other stressors."[216]

The *Climate Change Response Strategy* provides an excellent road map for NPS actions to address climate change, pledging to take many of the steps that are needed and are within the Service's control. Among the goals and objectives in the strategy are pledges that the NPS will:

- "Incorporate climate change considerations and responses in all levels of NPS planning."
- "Use the best available scientific data and knowledge to inform decision making about climate change."
- "Identify and evaluate greenhouse gas reduction options in general management plans and other planning and environmental compliance documents and processes."
- "Create interpretive products and programs that educate general audiences about the impacts of climate change and climate-friendly technologies and practices."

Taking these steps will go a long way toward addressing climate change in the national parks. And significant progress is being made in implementing the strategy. A major step was NPS adoption in April 2012 of a Green Parks Plan to guide the operation in a sustainable manner of what is the largest number of constructed assets of any federal civilian agency.[217] Importantly, a central part of plan of the plan is "informing and engaging park staff, visitors, and community partners about climate change and sustainability to broaden opportunities to foster change."[218] Another example is that the NPS's Inventory and Monitoring Networks are undertaking new, critical monitoring needs and enhancing the understanding of park staffs of the effects of climate change, including specifically in coastal ecosystems.[219]

Timely NPS action is of the essence. A U.S. government report on addressing climate-change impacts in the national park system and other key protected ecosystems emphasized, "it is prudent to begin to implement adaptation strategies as soon as possible."[220]

An example of appropriate NPS action is the importance being given at Assateague Island NS to addressing climate change impacts in the development of a new general management plan (GMP) for the seashore, which will guide the management of it for 20 years or more. At the beginning of this effort, the seashore developed overview documents of climate change projections for the seashore and the implications of those changes for seashore resources and visitors.[221] One of the four preliminary management alternatives identified at the outset of the planning process is an alternative based on sustainable recreation and adaptation to climate change, which includes (among others) these elements:

- Climate change adaptation—letting the island evolve naturally and relocating/ designing new facilities to be more sustainable.
- Allowing breaches and new inlets to evolve naturally.
- Maintaining most recreational uses and activities; over time facilities supporting uses would likely move to new, more sustainable locations on the island; some recreational activities relocated to the mainland;
- If and when bridge access is lost, transitioning to all-water access via new passenger ferry service and a new network of public access sites; and
- Changing the scope of some natural resource programs change to address issues created by climate change.[222]

In comments on the GMP alternatives, the public expressed the most support for the "sustainable recreation and climate change adaptation" alternative.[223] The American people seem ready to support NPS in addressing climate change. Next steps in the planning process will include the preparation of a full draft GMP for public review.

"In developing the GMP, we have chosen to consider climate change and sea level rise as key factors influencing the future of the seashore. While there is uncertainty about the future pace of climate change and sea level rise, there is near consensus among the scientific community that change is underway. Barrier islands such as Assateague will be especially vulnerable to the effects of climate change and sea level rise, and we must be able to respond effectively. Although major impacts are not expected in the near term, now is the time to set the stage so that future managers have the options available when conditions and circumstances do change."

Patricia Kicklighter, superintendent, Assateague Island NS[224]

But implementation of the NPS *Climate Change Response Strategy* is not yet consistent across the national park system. Since the NPS put climate change atop its official priority list in 2010, only one of the Atlantic Coast national seashores—Canaveral NS—has released a new, full draft general management plan.[225] Unfortunately, that draft still reflects the old, pre-strategy approach, not the principles stated in the strategy:

- Although most seashore lands are so low-lying that they are at great risk of inundation by a rising sea in this century (see Figure 24 on page 36), the draft GMP merely says, "Climate change is expected to increase the extent and frequency of coastal flooding." (Hardly a full consideration of the effect of most seashore lands being under the ocean.)[226]
- For this and other considerations of climate-change impacts on the seashore, the draft GMP relies on a single source—a set of NPS "talking points" on climate change--although 155 other references are cited on other matters.[227]
- The draft GMP does not identify a single action to assess or address climate change impacts in the seashore.
- The draft GMP states that the operation of the national seashore for 20 years or more "would only emit a negligible amount of greenhouse gases that contribute to climate change; therefore, this impact topic has been dismissed from detailed analysis in this plan."[228]
- The draft GMP identifies themes for interpretive actions in the seashore; none address climate change.[229]

The NPS has an important opportunity to improve the draft Canaveral GMP before it is finalized to consider and address climate change in the manner promised in the *Climate Change Response Strategy*. If the strategy really is going to make a difference, this is an obvious opportunity—and also a test. The draft GMP was prepared before the NPS's new policy of giving priority to climate change had taken hold. The decisions on a final GMP will come well after the strategy has been adopted.

In addition to full NPS implementation of the Strategy, other actions will also be important to address climate change threats to the national park system, including the following:

- The Congress and the Administration should adequately fund NPS actions to address a changing climate. The Rocky Mountain Climate Organization and the Natural Resources Defense Council recommend that Congress let NPS and other land-management agencies use funds from entrance and recreation fees to address climate change and its impacts, by both reducing emissions and protecting resources. Congress previously allowed NPS to use visitor fees for what was then seen as the greatest threat to national parks—a backlog of unmet maintenance needs. Now, climate change is seen as the greatest threat to the parks. The use of visitor and recreation fees should be broadened to cover this threat, so long as visitor education efforts explain the ways the fees are being spent and the reasons for those actions.
- NPS should reduce emissions in their own operations, and provide information to visitors on those actions to inspire them to undertake their own emission reduction actions. Much has been done on this front, and continued progress is essential.
- Service officials and managers should speak out publicly about how climate change and its impacts threaten the areas for which they are responsible and the broader ecosystems on which they depend.
- In addition to the NPS using environmental education programs to inform visitors about a changed climate and its impacts and about what is being done to address climate change and those impacts, the NPS should also require concessionaires to do so, too.

"The breath-taking scenery in national parks itself conveys a message of wonder and hope. That hope an inspire action on climate change rather than despair."

Brian Ettling, ranger, NPS[230]

NATIONAL ACTIONS

Contributed by Theo Spencer, NRDC

Ultimately, to protect the Atlantic Coast national seashores for the enjoyment of this and future generations, it will take actions by all of us to reduce emissions of heat-trapping pollutants enough so that climate disruption does not overwhelm these seashores, or any other special places. The federal government must lead the way, with broad, aggressive actions on four essential fronts:

- Establishing comprehensive mandatory limits on carbon pollution to reduce emissions by at least 20% below current levels by 2020 and 80% by 2050. This will deliver the reductions that scientists currently believe are the minimum necessary, and provide businesses the economic certainty needed to make capital investments to achieve those reductions.
- Protecting the current Clean Air Act authority of the U.S. Environmental Protection Agency (EPA). This includes current authority under the Clean Air Act to set standards to curb carbon pollution from vehicles, power plants, and large industrial sources. EPA authority must also be maintained to institute the tightest pollution controls necessary to protect public health and the environment. That includes standards for the pollution that causes smog and other dangerous and fatal respiratory ailments, pollution of hazardous materials like mercury and dioxin, and dangerous waste from power plants and other industrial facilities.
- Overcoming barriers to investment in energy efficiency to lower emission-reduction costs, starting now. To fully harness energy efficiency potential, many opportunities require additional federal, state, or local policies to unleash investments that are already cost-effective even without a price on greenhouse gas emissions. Policies include building, industry, and appliance efficiency (standard) upgrades, as well as incentives for "smart" transportation and growth and for advanced vehicles. Standards for more efficient lighting technologies, now under attack, should be enforced.
- Accelerating the development and deployment of emerging technologies to lower long-term emission reduction costs. That means incentives and investments in appropriately-sited renewable electricity, low carbon fuels, and carbon capture and storage; a federal renewable energy standard; and infrastructure upgrades to support transmission capacity for these renewable assets.

With respect to natural gas use, updated, comprehensive regulation (from wellhead to end-use/site remediation), and proper transparency are essential to reducing public safety threats and environmental impacts. In addition, technologies to economically and effectively capture and store greenhouse gas emissions resulting from natural gas use will be needed if the full potential of this resource is to be delivered in an environmentally sound fashion.

National climate preparedness actions also are needed.

The National Ocean Council, a consortium of federal agencies recently established by the landmark National Ocean Policy, has called for immediate action to help states defend themselves against the effects of climate change and ocean acidification. Among the priority items in the Council's draft *National Ocean Policy*

Implementation Plan are a series of efforts to improve coordination and advancement of climate change and ocean acidification predictions, and to identify the impact that such changes will have on coastal communities and their economies. The plan, for example, calls on the federal government to develop and share sea-level rise estimates with states so that they can better visualize, map and communicate the key areas that are expected to experience flooding so that homeowners, businesses and regular citizens know what to expect and how to prepare. The plan also calls for agencies to design and implement best practices for the coming risks.

APPENDIX

NEW RMCO CLIMATE ANALYSES

This portion of the Appendix describes the methodology used by the Rocky Mountain Climate Organization (RMCO) in analyzing climate data and projecting future temperatures for this report.

Figure 3: Trends in Seashore Temperatures

For the analysis presented in figure 3, the weather stations in or near the seashores are: for Cape Cod NS, Provincetown, MA; for Fire Island NS, Bridgehampton, NY; for Assateague Island NS, Wallops Island Flight Facility, VA; for Cape Hatteras NS, Cape Hatteras, NC; for Cape Lookout NS, Morehead City, NC; for Cumberland Island NS, Brunswick Malcolm McKinnon Airport, GA; and for Canaveral NS, Titusville, FL.

For all but Wallops Island and Brunswick Malcolm McKinnon Airport, which are not in the U.S. Historical Climatology Network (USHCN), monthly data from the USHCN database were used for the analysis. The USHCN is a high-quality data set of daily and monthly records of basic meteorological variables from 1218 observing stations across the 48 contiguous United States.[231] Most of these stations are COOP stations located generally in rural locations, while some are National Weather Service first-order stations that are often located in more urbanized environments. The USHCN has been developed over the years by the National Climatic Data Center (NCDC), National Oceanic and Atmospheric Administration (NOAA), to assist in the detection of regional climate change. The period of record varies for each station. The stations in the USHCN were chosen using a number of criteria including length of record, percent of missing data, number of station moves and other station changes that may affect data homogeneity, and resulting network spatial coverage.

The USHCN data used for those five stations have been reviewed by the NCDC and adjusted as necessary for reliable long-term analysis—such as by adjusting data to compensate for movements of weather stations over time so that the data can be reliably compared; by including estimated values, based on measurements elsewhere from surrounding areas, to fill in gaps when actual measurements are missing; and by excluding daily data that fail data-quality tests.

For Assateague Island and Cumberland Island NSs, no USHCN stations with sufficient periods of record are close enough to the seashores to be representative of conditions there, and the stations indicated above were used for the analysis. As these are not USHCN stations, the data have not been reviewed for quality by the NCDC.

Table 2: Projected annual temperatures

The data for Table 2 were obtained by RMCO from the World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset of climate models developed for the Intergovernmental Panel on Climate Change's Fourth Assessment Report (released in 2007).[232] The WCRP's Working Group on Climate Modeling helped to coordinate these modeling efforts and enable their location in a single database archive, available online and hosted by the Program for Climate Model Diagnosis and Intercomparison at the Lawrence Livermore National Laboratory (LLNL). The conversion of all simulation results to a common data format has made probabilistic, multi-model projections and impacts assessments practical. To enable local projections from these models, the larger-scale outputs from the models have been combined with local historical climate observations to produce finer-scale projections. This particular approach, originally developed for hydrological analysis, has compared favorably to other downscaling techniques. The U.S. Bureau of Reclamation's Research and Development Office and LLNL, through support from the U.S. Department of Energy's National Energy Technology Laboratory and the U.S. Army Corps of Engineers Institute for Water Resources, have teamed with Reclamation's Technical Service Center, Santa Clara University Civil Engineering Department, Climate Central, and The Institute for Research on Climate Change and its Societal Impacts to develop this public-access archive.

The projections made by RMCO using this database were focused for each national seashore on a grid of 1/8 of a degree of longitude by 1/8 of a degree of latitude, chosen to be as representative as possible of the entire seashore, with boundaries as shown in the following table.

Seashore	Latitude	Longitude
Cape Cod	41.625 to 41.75	-70.0 to -70.125
Fire Island	40.75 to 40.875	-72.875 to -73.0
Assateague Island	38.25 to 38.375	-75.125 to -75.25
Cape Hatteras	35.625 to 35.75	-75.75 to -75.875
Cape Lookout	34.75 to 34.875	-76.625 to -76.5
Cumberland Island	30.75 to 30.875	-81.5 to -81.625
Canaveral	28.5 to 28.62	-80.625 to -80.75

Table App-1 (previous page). Latitude/longitude grids used for climate projections for the national seashores.

Projections of surface temperature were obtained from the first listed model run for each of the 16 climate models in the CMIP3 dataset for each of the scenarios

B1 (identified in this report as "lower-emissions") and A2 ("medium-high emissions"). Each model's projection for a future period with a particular scenario was compared to that model's projection with the same scenario for the historical base period of 1981–2010. For each combination of emissions scenario and climate model, the projection for the average temperature for a future period (2051–2060 or 2081–2090) was compared to the modeled result using that scenario and climate model for the baseline period of 1981–2020, yielding a projected increase in the average temperature for the future period compared to the baseline period.

Climate projections using these scenarios and climate models yield precise-appearing numbers, but they should be taken as indications of how the future could unfold, not as predictions of what is most likely to happen. The current state of scientific knowledge is probably best reflected not by any one scenario or modeled projection, but by paying attention to the average of results from multiple scenarios and models, the range of those results, and the degree of agreement or disagreement among them.

Table 3: Projected National Seashore Summer Temperatures

Projected differences in June-July-August temperatures were obtained from the CMIP3 dataset referred to above, using the same models and model runs identified above, for 2051–2060 (not shown in the report) and 2081–2090, both compared to modeled 1981–2010 levels, but in this case using only the medium-high emissions scenario (A2). The projected differences were added to the measured 1981–2010 June-July-August average maximum temperatures for the same weather stations used for the analysis of past year-round (or annual) temperature trends in and near the seashores. Those summer temperatures were taken from the NCDC's climate normals dataset for 1981–2010. Note that the projections of changes in future summer temperatures are for *mean* temperatures, and that those projected differences were added to the measured *maximum* temperatures for the weather stations. There is no certainty that maximum temperatures will increase to the same extent as mean temperatures (which represent the daily averages between maximum and minimum temperatures), and this extrapolation adds an additional, undefined degree of uncertainty to these projections.

In Table 3, the weather station identified as "Long Island, NY" is the Islip Long Island MacArthur Airport station and the weather station identified as Charleston, SC, is the Charleston City weather station.

SEA-LEVEL RISE BACKGROUND

This portion of the Appendix provides additional background on sea-level rise, as a broader context for the information in sections 4 and 5 of the report.

Observed Sea-Level Rise

A hotter climate is already leading to sea-level rise (SLR), in two ways.[233] First, water expands when it is warmer, so thermal expansion pushes sea levels higher. Second, a hotter climate is melting land-based ice, with some of that meltwater flowing into the oceans.

From 1900 through 2009, the average global sea level rose, with a slightly higher rate in recent decades (1961–2009) (see Table App-2 on the next page).[234] From 1992–2011, as shown both by new, more accurate satellite measurements and by tide gauges, the average global rate of sea-level rise (SLR) increased to 1.05 feet per century, nearly double the 20th century rate.[235] It is not yet clear whether the faster rate of SLR since 1992 reflects decadal variability or an increase in the longer-term trend, but there is evidence of a recently accelerating contribution to SLR from a loss of the Greenland and Antarctica ice sheets.[236]

There are local variations in SLR, based on changes in ocean density, currents, and other factors, and the local vertical (up or down) movements of the underlying land.[237] Along the Atlantic Coast, local rates of sea-level rise have generally exceeded the national average, as shown in Figure App-1 below. The especially higher rate in the Mid-Atlantic has been attributed to subsidence of the underlying coastal land, which is adjusting to the loss of heavy inland ice during the Ice Age.[238] Inland, where heavy ice cover used to weigh down the land, the crust has rebounded; in coastal areas, the reverse

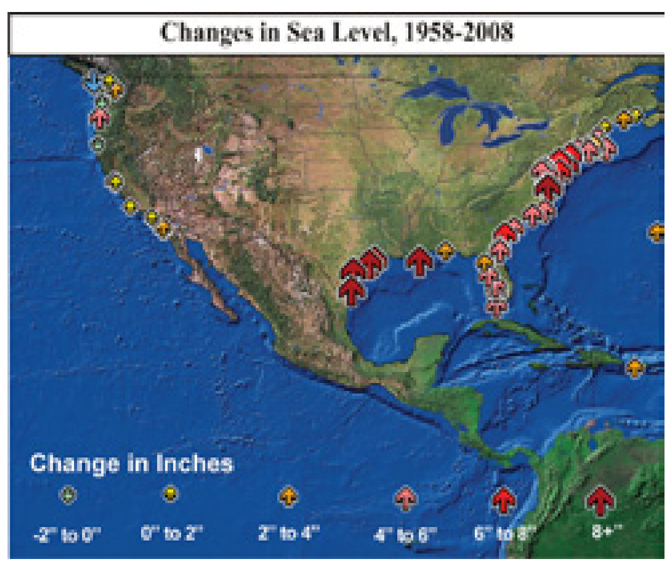


Figure 5. Changes in sea level from 1958 to 2008, as measured by tide gauges. Figure source: U.S. Global Change Research Program.[239]

is happening, and land previously forced upward by the subsidence of adjacent inland areas now is settling back down.

As shown in Table App-2 below, with careful attention to the different periods of record shown in the table, local rates of SLR at or near the Atlantic seashores have generally at least equaled the global rate of SLR.

Past Sea-Level Rise: Global and Near Atlantic Seashores Trends in Feet per Century			
	Nearby Tide Gauge	Period of Record	Trend Over Period
Global average	N/A	1900-2009	0.56
Global average	N/A	1961-2009	0.63
Cape Cod NS	Woods Hole, MA	1932–2011	0.91
Fire Island NS	Montauk, NY	1947–2011	1.02
Assateague Island NS	Ocean City, MD	1977–2011	1.85
Cape Hatteras NS	Oregon Inlet, NC	1975–2011	1.12
Cape Lookout NS	Beaufort, NC	1953–2001	0.68
Cumberland Island NS	Fernandina Beach, FL	1897–2011	0.66
Canaveral NS	Mayport, FL	1928–2011	0.78
Canaveral NS	Daytona Beach, FL	1925–1983	0.76

Table App-2. Trends in sea-level rise. Top rows: global mean sea level. Bottom rows: local sea-level rise at tidal gauges with at least 30 years of records located closest to the Atlantic national seashores, plus for Canaveral NS a closer gauge with a shorter period of record. Sources: Church and White (global trends) and NOAA.[240]

Northeast "hotspot" of sea-level rise

As noted above, since 1992 the global average sea level has increased at about twice the 20th century rate. As with long-term trends in SLR itself, there have been regional variations in whether and how much SLR has accelerated in recent decades. In June 2012, scientists at the U.S. Geological Survey (USGS) identified a 600-mile stretch of the Atlantic Coast from north of Cape Hatteras through Massachusetts as a "northeast hotspot" of accelerated sea-level rise.[241] They found that in this region over the last 40 years, local rates of SLR accelerated at about three to four times the global rate of acceleration, with the change in the rate beginning around 1990. By contrast, they found that from southern North Carolina through Florida local rates of SLR have not changed.

After considering several possible reasons for the accelerated SLR in the Northeast, the USGS scientists found it most consistent with a change in ocean currents in the North Atlantic, potentially driven by climate change. Close to the Atlantic Coast, the Gulf Stream and its continuation to the northeast, the North Atlantic Current, are powerful enough to create differences in water pressures that keep coastal sea levels lower than those offshore. Scientists previously had projected that climate change could lead to a slowing of these currents and a resulting rise in sea levels along the coast. In their 2012 study, the USGS scientists found that the best explanation for the accelerated SLR in the northeast hotspot is that this change is already underway.

Projected Future SLR

Scientists project that continued human-caused climate change will increase the rate of SLR in this century, although there continue to be uncertainties about the extent. Table App-3 shows projections from three sources: a June 2012 report by the National Academy of Sciences (NAS), which includes new, independent projections of future global sea-level rise; a study by two scientists, Martin Vermeer and Stefan Rahmstorf, whose projections were also included in the NAS report; and projections made by the Intergovernmental Panel on Climate Change (IPCC) in 2007.

The NAS projections are the most recent ones by an authoritative scientific body.[242] Like the earlier projections made by the IPCC, they were made using a "process-based" approach, used in most SLR projections—separately estimating and then adding together the possible contributions to SLR from the processes of thermal expansion of ocean waters and melting of land-based ice.

For comparison with its projections, the NAS included in its report projections made by Vermeer and Rahmstorf (in 2009) using a different, "semi-empirical" approach to projecting SLR.[243] This approach is based on a central assumption that future sea levels will rise in relationship to higher global temperatures as past sea levels did, and approach avoids the difficulties of accurately estimating the individual contributions to future sea-level rise from different factors (in a process-based approach); several

Projections of Global Mean Sea-Level Rise (In Inches)									
	2030			2050			2100		
	Low End	Central Projection	High End	Low End	Central Projection	High End	Low End	Central Projection	High End
National Academy of Sciences (2012)	3.3	5.3	9.1	6.9	11.0	19.0	19.8	32.6	55.2
Vermeer and Rahmstorf (2009)	5.5	7.1	8.7	11.0	14.6	18.5	30.7	47.6	68.9
IPCC (2007)	N/A	N/A	N/A	N/A	N/A	N/A	7-15	N/A	10-23

Table App-3. Three recent sets of projections of global mean sea-level rise: top row, projections by the National Academy of Sciences (NAS) in a June 2012 report; by Vermeer and Rahmstorf, as presented in that NAS report; and by the Intergovernmental Panel on Climate Change (IPCC). Comparisons are to a 2000 baseline in the case of the NAS and Vermeer and Rahmstorf and to 1980-1999 in the case of the IPCC projections. The IPCC projections are for 2090-2099 not 2100 as the two other projections are. For the central NAS projections, a scenario of a medium level of future emissions of heat-trapping gases was used to project the contribution to sea-level rise from the expansion of ocean water as it warms. For each of the three sets of projections, the "low end" shown in this table is the average projection (or range of projections in the case of the IPCC) using a common scenario with a lower level of emissions and the "high end" using a common scenario (the same in each case) with higher emissions. Data sources: NAS and IPCC.[245]

of those estimates are subject to uncertainties.[244] The semi-empirical approach instead uses the simple concept of physics that sea level rises faster as the Earth gets hotter—a concept supported by observations on long time scales. As is typical of a semi-empirical approach, Vermeer and Rahmstorf projected more future SLR than the process-based projections by the NAS and others. In presenting the Vermeer and Rahmstorf projections in its report, the NAS adjusted them to use a 2000 baseline, the same baseline used by the NAS for its own new projections, to better enable ready comparison between them. Table App-3 presents the Vermeer and Rahmstorf values with this NAS adjustment.

Table App-3 also includes projections made by the IPCC in 2007, using a process-based approach. The IPCC projected SLR by 2090–2099 compared to 1980–1999, using six emissions scenarios, producing a range of possible results.[246] For simplicity and to present the IPCC projections in parallel to those made by the National Academy of Sciences in 2012 (see below), Table App-3 presents the IPCC projections for only two of those scenarios, those which yielded the lowest and highest ranges of future SLR of the six scenarios. The IPCC's projections are now generally regarded as identifying less SLR than most scientists now expect. The IPCC acknowledged that its projections did not factor in any contribution to SLR from changes in the flow of ice sheets (primarily those of Greenland and Antarctica), which, if they move more rapidly to the sea as they melt, could contribute "substantially" more to SLR, as the IPCC noted.[247] Commenting on this, the U.S. government's 2009 national assessment stated:

> More recent research [since 2007] has attempted to quantify the potential contribution to sea-level rise from the accelerated flow of ice sheets to the sea or to estimate future sea level based on its observed relationship to temperature. The resulting estimates exceed those of the IPCC, and the average estimates under higher emissions scenarios are for sea-level rise between 3 and 4 feet by the end of this century.[248]

The national assessment also stated that even with lower emissions, seas could rise about 2.3 feet.[249]

An interagency U.S. government report on sea-level rise published in 2009 noted, "Recent studies suggest the potential for a meter or more of global sea-level rise by the year 2100, and possibly several meters within the next several centuries."[250] That report did not include any new forecasts of future SLR, but evaluated the impacts of three possible future levels of SLR along the U.S. mid-Atlantic coast by the end of this century: 12 inches of additional sea-level rise, which would be a continuation of the 20th-century rate for that region; 20 to 24 inches; and 40 to 44 inches.[251] The report did not make any judgment about which future level is more likely, but as quoted in the main body of this report (see page 29) said, "thoughtful precaution suggests that a global sea-level rise of 1 meter [39.37 inches] to the year 2100 should be considered for future planning and policy discussions."[252]

The USGS scientists who identified a northeast "hotspot" of accelerated SLR (see above) also suggested that future SLR from north of Cape Hatteras through Massachusetts will continue accelerating at more than the global rate.[253] Other studies also have projected above-average increases in sea-level rise along the U.S. northeast coast.[254]

The state governments of four of the states containing the Atlantic national seashores have developed projections of sea-level rise along their coasts.

- In Massachusetts, a state climate change adaptation report published in 2011 identified potential inundation of areas of East Boston by 2100 under a low SLR scenario of two feet and a high scenario of three feet, with both scenarios based on local land subsidence plus global sea-level rise.[255]
- A New York State Sea Level Rise Task Force reported in 2010 that sea-level rise affecting the Lower Hudson Valley and Long Island is projected to be 12 to 23 inches by the end of this century, but with rapid melt of land-based ice could reach up to 55 inches.[256]
- In Maryland, a state climate change adaptation report includes what it calls "a conservative estimate" that by the end of this century the state may experience a relative sea-level rise of 2.7 feet under a lower-emission scenario, and as much as 3.4 feet under the higher-emission scenario.[257]
- In North Carolina, the N.C. Coastal Resources Commission's Science Panel on Coastal Hazards reported in 2010 that the most likely scenario is for SLR in a range from a low of 15 inches to "a reasonable upper limit" of 55 inches by 2100.[258]

Scientists tell us that sea levels will continue rising after 2100 because of the very slow processes involved in spreading heat through ocean waters.[259] Even if atmospheric concentrations of heat-trapping gases are stabilized in this century, SLR will continue for additional centuries.[260]

NOTES

1. The declaration that climate change poses the greatest threat ever to U.S. national parks was first made in S. Saunders and T. Easley, Losing Ground: Western National Parks Endangered by Climate Disruption, report of the Rocky Mountain Climate Organization (RMCO) and Natural Resources Defense Council (NRDC) (New York: NRDC, 2006), http://www.rockymountainclimate.org/website%20 pictures/Losing%20Ground.pdf, and further supported in S. Saunders and T. Easley, National Parks in Peril: The Threats of Climate Disruption, report of RMCO and NRDC, Denver, CO (2009), http://www.rockymountainclimate.org/ programs_7.htm. The same conclusion was subsequently stated by the National Park Service (NPS) in NPS, National Park Service Climate Change Response Strategy, Climate Change Response Program (Fort Collins, CO: NPS, 2010), http://www.nature.nps.gov/climatechange/docs/NPS_CCRS. pdf.

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4. All facts in this paragraph are from PB Americas, Inc., NC 12 Replacement of Herbert C. Bonner Bridge: Final Environmental Impact Statement and Section 4(f) Evaluation, Volume 1, report for the North Carolina Department of Transportation, 2008, p. 1-3, available at http://www.ncdot. gov/projects/bonnerbridgerepairs/.

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9. C. Vaughn, "Supervisors support beach parking," delmarvanow.com, July 29, 2010, http://www.delmarvanow. com/apps/pbcs.dll/article?AID=20107290304.

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12. Title 16, U.S. Code, section 1.

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21. All facts in this paragraph are from NCDC, NOAA, "The annual global (land and ocean combined) anomalies (degrees C)," ftp://ftp.ncdc.noaa.gov/pub/data/anomalies/monthly.land_ocean.90S.90N.df_1901-2000mean.dat; see also NCDC, NOAA, "Global surface anomalies" (see previous note).

22. IPCC, "Summary for policymakers" (see note 17), p. 5 (comparing 2001-2005 global temperatures to 1850-1899 temperatures). Average global temperatures for 2001-2005 were virtually identical to those for 2001-2011, according to the NCDC database referred to in note 22, so the IPCC comparison also holds true for that recent period.

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24. UNFCCC, "Conference of the Parties: The Cancun Agreements" (see previous note).

25. USGCRP, Climate Change Impacts (see note 15), p. 28.

26. USGCRP, Climate Change Impacts (see note 15), p. 22.

27. USGCRP, Climate Change Impacts (see note 15), p. 22.

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29. USGCRP, Climate Change Impacts (see note 15), p. 22.

30. See, for example, USGCRP, Climate Change Impacts (see note 15), pp. 107, 111; Northeast Climate Impact Assessment (NECIA), Climate Change in the U.S. Northeast, P. C. Frumhoff and others, authors (Cambridge, MA: Union of Concerned Scientists, 2006), p. 6, http://www.northeastclimateimpacts.org.

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