Columbia University for Gateway National Recreation Area

Gateway National Recreation Area

Long-term Resource Management Under a Changing Climate

Prepared for:

The National Park Service:
Gateway National Recreation Area

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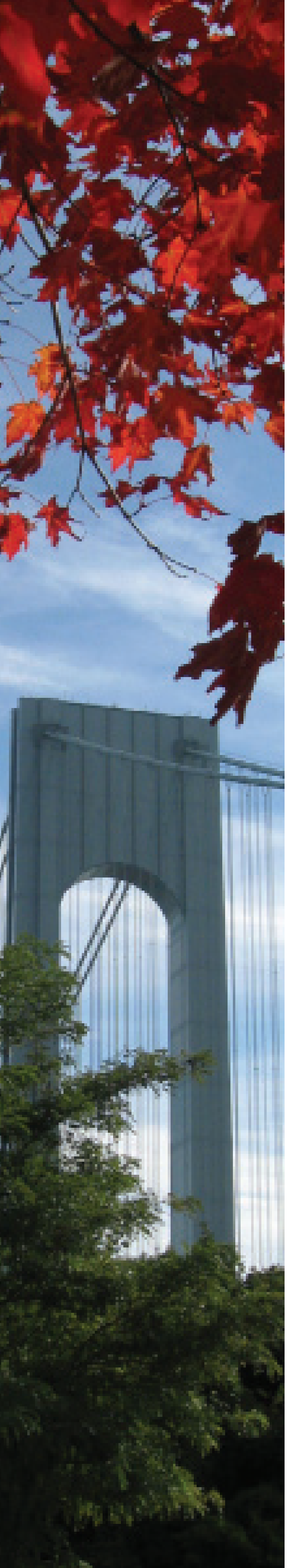


Executive Summary

Congress established Gateway National Recreation Area (Gateway) in 1972 as one of the first urban parks in the National Park System (NPS). A distinct, biologically diverse area on the footsteps of New York City, Gateway is home to many natural, cultural and recreational resources. Gateway's General Management Plan (GMP), written in 1979, acknowledges the need for a dynamic management strategy based on changing environmental and social conditions. Given the increased scientific knowledge on the likely impacts of climate change on the New York harbor, Gateway should consider incorporating climate change adaptation into its new GMP.

Climate change refers to a significant alteration of the average climate persisting for several decades or longer. Increased levels of greenhouse gases drive modern climate change, and changes in future human behavior will determine the extent of climatic changes. Globally, the evidence for climate change is strong; we are now beginning to understand local impacts. The Intergovernmental Panel on Climate Change (IPCC), the Metro East Coast (MEC) Assessment, and the New York City Panel on Climate Change (NPCC) provide data on likely local climate change impacts. This report identifies four climate change impacts that may significantly affect Gateway: sea level rise, precipitation changes, temperature changes and changes in extreme weather events' frequency or intensity.

These four, primary impacts will exert many secondary effects on Gateway, including coastal erosion, saltwater intrusion, species range shifts and mistimings between species migrations and their food sources. These secondary effects will overlap and interact, resulting in three combined impacts throughout the park: species composition changes, habitat loss and cultural resource damage and loss. Biodiversity loss and recreational infrastructure damage resulting from these combined effects would diminish Gateway's ability to fullfil its mandate to preserve and protect its resources.

Many opportunities exist for Gateway to incorporate climate change adaptation into long-term planning across its three park units at Sandy Hook, Staten Island and Jamaica Bay. This entails continuing to adopt an adaptive management approach in order to respond effectively to observed impacts and changing climate projections. Specific options to protect Gateway's resources include integrating long-term planning into park operations, monitoring climate sensitive species, implementing adaptive restoration and documenting resources. Implementing the options outlined within this report can help Gateway address the multiple effects of climate change on the park.

The information and recommendations presented in this report may prove useful in informing and shaping Gateway's approach to climate change adaptation and its new General Management Plan, 2009. While much of the information provided is specific to Gateway, the ideas and conceptual framework may also guide other NPS units as they incorporate climate change considerations into their own management plans.

By raising awareness and developing plans, our National Parks will have the best opportunity to adapt to the changing climate so that they may continue to serve this generation of Americans, as well as the next.

1 Introduction

1. Purpose of this paper

Congress established Gateway National Recreation Area (Gateway) in 1972 as one of the first urban parks in the National Park System (NPS). Gateway is a distinctive and biologically diverse area embedded within the New York-New Jersey Metropolitan Area, the largest metropolis in the United States. Gateway's annual visitation ranks third highest in the nation; in 2008, over 10 million visitors came to take advantage of the park's many natural and cultural resources.

Gateway consists of three units: the Sandy Hook Unit in New Jersey, the Staten Island Unit and the Jamaica bay Unit, both in New York. These three units are quite distinct, with different ecological and cultural resources.

Within this context, the park must balance ecosystem protection, historic monument preservation and provision of recreational activities. Gateway's urban context creates unique challenges for meeting these goals, including managing highly altered ecosystems and limited space. As such, successfully managing Gateway requires adapting to an ever-changing environment, finding creative solutions to new problems as they arise.

Gateway National Recreation Area. This map shows Gateway's three Units in relation to the larger New York-New Jersey Metropolitan Area.

Gateway management is currently creating a new General Management Plan (GMP). The General Management Plan serves as a guide for the park's management and development, outlining a strategy to fulfill the National Park Service's goals. The current GMP was written in 1979 with a 20-year outlook. While Gateway is long overdue for a new management plan, the 1979 GMP remains an important, forward-looking document, advocating for an adaptive management process at Gateway:

> *"It would plainly be a mistake to make a static plan, a confining plan, for Gateway. Because of the very complexity of its geography and structure, this multiple-purpose park will need additional management techniques and a more complex administrative philosophy than is commonly found in other parks"* (General Management Plan, 1979, p.ix).

The new GMP will follow in the spirit of the previous plan, acknowledging both the need for a dynamic management strategy based on changing environmental conditions, and Gateway's unique position among other National Park Service units.

Science is constantly developing, and since 1979 climate science has matured significantly. Climate change, also commonly called global warming, is a significant alteration of the average climate, or its variability, persisting for several decades or longer (IPCC 2007). Interactions between the atmosphere, hydrosphere and land surface create long-term, average weather patterns in a given area. Climate patterns determine what kinds of species can survive in a given location; thus, changes in the climate may heavily influence ecosystems at Gateway.

Given advances in climate forecasting since the previous GMP and the potential for profound changes at Gateway due to climate change, Gateway's management may consider incorporating climate change adaptation into its new General Management Plan.

In order to successfully incorporate resource management under changing climate conditions into the GMP, managers need reliable information on potential climate change impacts on the Park's ecological, cultural and recreational resources. Once impacts are established, the park will need strategies to respond to these effects.

The information in this white paper can assist Gateway's long-term investments and management decisions. It may also help educate the public about climate change, and eventually guide other NPS units in integrating climate change impacts into their own decision-making.

The key sections of this report include:

1. A summary of climate change science, including local projections relevant for planning at Gateway;

2. A focused assessment on how climate change impacts will affect Gateway's resources, both natural and cultural;

3. An overview of Gateway's guiding policies and how or whether these policies address adaptation to climate change;

4. Recommendations for a climate change adaptation strategy within the 2009 General Management Plan.

Responses to climate change include mitigation and adaptation; it is important to distinguish between the two. Mitigation refers to efforts to reduce greenhouse gas emissions. While global mitigation efforts are essential to ensure that greenhouse gas concentrations decline, lessening climate change's extent, this report will focus exclusively on adaptation measures. Adaptation is an attempt to respond to climatic changes. For a more detailed definition of adaptation, see Box 12. Defining Adaptation.

These analyses and recommendations are not intended to provide a comprehensive overview of all existing climate change adaptation options, nor does this report represent a complete plan, ready for implementation. Rather, this report is a guiding document, that can inform Gateway management's decisions relating to climate change. A climate adaptation strategy may become a core component of the new GMP. In the spirit of the 1979 Plan, Gateway management may also use these guidelines in an adaptive manner to best fulfill the National Park Service's mission.

2 Climate Change & Gateway

1. Literature Review

Three key resources describe the possible climate change effects relevant to Gateway:

1. The Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report is the most comprehensive and widely accepted report on global climate change; however, significant new scientific information has come to light since its publication in 2007.

2. The Metro East Coast (MEC) Assessment on Impacts of Potential Climate Variability and Change is one of eighteen regional components of the U.S. National Assessment of the Potential Consequences of Climate Variability and Change for the Nation, organized by the U.S. Global Change Research Program in 2000. This study examines the New York Metropolitan Region, supplementing the IPCC as a comprehensive guide to the response of regional wetlands, coasts and ecosystem functions.

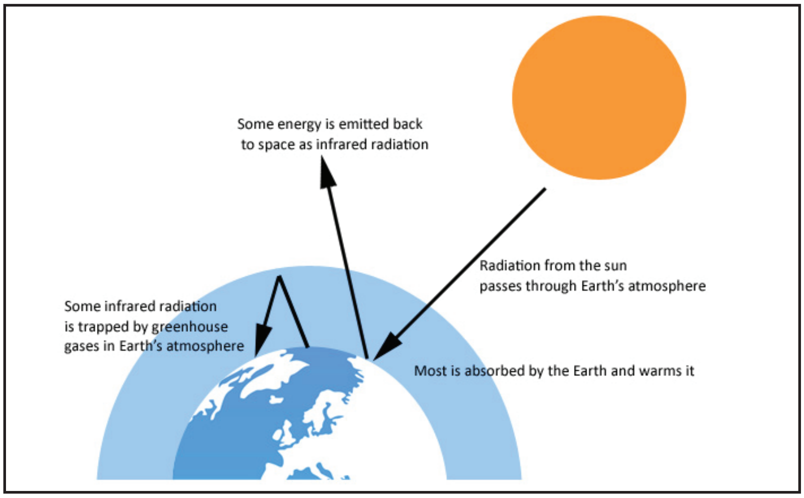


Figure 1. The Greenhouse Effect. The earth maintains a stable temperature by trapping a portion of incoming solar radiation and outgoing heat fluxes. Increased GHG concentrations will magnify this effect, resulting in higher temperatures and an unstable climate system.

3. The New York City Panel on Climate Change (NPCC) Assessment, published in 2009, which uses the same emissions scenarios as the IPCC but takes into account research published after 2007 (NPCC CRI, 2009).

2. What is Climate Change?

Climate change refers to a significant alteration of the average climate, or its variability, persisting for several decades. Climate change can occur as a result of natural processes and planetary cycles, as well as from human actions (IPCC, 2007). Modern climate change is very likely driven by increasing anthropogenic greenhouse gas (GHG) emissions. As Figure 1 illustrates, GHGs trap heat within Earth's atmosphere, causing the planet's overall average temperature to warm (IPCC, 2007). Human activities that emit these gases include burning fossil fuels, industrial and agricultural processes, and landfill decomposition. Some of the most important GHGs emitted into the atmosphere through human activities include methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2; EPA, 2009).

Carbon dioxide (CO_2) is considered the most prevalent anthropogenic greenhouse gas; atmospheric concentrations of CO_2 have increased dramatically since pre-industrial times. Global climate models predict the additional global warming effect resulting from these higher carbon dioxide concentrations (IPCC, 2007).

3. Uncertainty

Global climate models are a leading tool for understanding and predicting climate change (IPCC, 2007). However, explaining climate change to the public is often difficult due to the uncertainties inherent in climate change science (Budescu et al., 2008). There are three main sources of uncertainty in global climate model predictions:

1. ***Future greenhouse gas concentrations and mitigation efforts.*** It is presently unclear how much societies around the world will reduce their emissions over the next 50 years. Box 1. GHG Scenarios describes the projected future GHG concentration scenarios used by the IPCC.

2. ***The sensitivity of the climate system and environment to greenhouse gas concentrations*** (NPCC, 2009). GHG concentrations will continue to grow as long as emissions exceed the environment's capacity to absorb these gases. The extent of this capacity is unknown but being studied; according to one study by a Duke University professor and United States Department of Agriculture researchers, ecosystems may be close to reaching their capacity to absorb carbon dioxide (Meredith, 2002).

3. ***The role of positive feedbacks in future warming.*** The Earth's climate system is dynamic, containing a number of processes that help maintain equilibrium. There may be a GHG concentration threshold point beyond which the climate's equilibrium will be lost (IPCC, 2007). Climate change effects, such as GHGs released from melting permafrost and decreased ice reflectivity in the polar regions, may further destabilize the climate beyond recovery. Such consequences are termed 'positive feedbacks' because they are both caused by and contribute to climate change.

Greenhouse gas scenarios describe the possible future GHG concentrations based on three different emissions scenarios and observed trends. Figure 2 shows that atmospheric carbon dioxide concentrations will continue to increase into the future. Uncertainties surround the extent of GHG concentrations, not the increase itself. As time progresses and trends in emissions and climate are observed, future projections will become more certain.

Box 1. Greenhouse Gas (GHG) Scenarios

The IPCC outlines three climate change scenarios based on past and present atmospheric GHG concentrations, and predicted future emissions. Each scenario considers different future atmospheric carbon dioxide concentrations resulting from emissions reductions or increases over time (IPCC, 2007).

- A1B: assumes rapid increases in greenhouse gas emissions and the highest overall emissions during the beginning of the 21st century and declining emissions beginning in 2050;
- A2: assumes high greenhouse gas levels by the end of the 21st century and emissions growing throughout the century;
- B1: assumes the lowest greenhouse gas emissions, with decreases beginning by 2040.

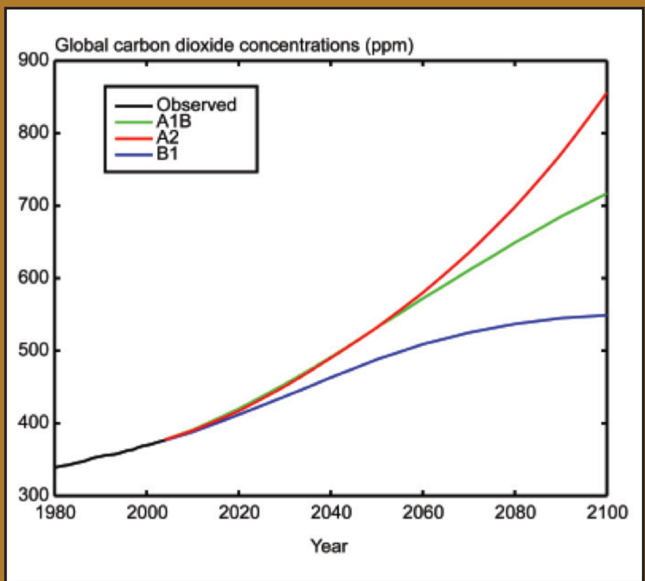


Figure 2. GHG Scenarios. Global CO_2 concentrations under different scenarios (Source: NPCC 2009; adapted from the IPCC.)

According to the NPCC, climate change projections impacting Gateway are considered at least 50% likely to be correct; some, such as temperature changes, are considered more than 90% likely to be correct. Thus, we consider these findings to be representative projections of the future conditions Gateway will face.

The IPCC uses the following terms to express uncertainty:

- "Virtually certain" (considered more than 99% likely to be correct)
- "Very likely" (more than 90%)
- "Likely" (more than 66%)
- "More likely than not" (more than 50%)

4. Local Climate Change Impacts

The findings of the three key reports mentioned above, as well as other published scientific papers, identify four climate change impacts relevant to Gateway:

- Sea level rise
- Temperature changes
- Precipitation changes
- Extreme weather events

Even if carbon dioxide emissions stopped today, warming effects would continue to persist.

Sea Level Rise

From 1932 until the present, the average rate of sea-level rise, as measured at Sandy Hook, was 3.9 cm (1.54 in) per decade (NOAA T&C, 2009). Climate change studies project rates of sea-level rise nearly doubling over the 21st century (Horton, 2007). New York City sea level rise projections expect waters to rise:

- 2 to 5 inches during the 2020s
- 7 to 12 inches by the 2050s
- 12 to 23 inches by the 2080s

Figure 6 shows the elevation of key resources at Gateway; this can be contrasted with projected sea level rise inland (see Section 4. Cultural Resources). The causes of sea-level rise that will affect Gateway include (NPCC, 2009):

- Global mean sea-level rise
- Thermal expansion of the ocean
- Melting ice-caps
- Changes in sea-ice area and volume
- Local water surface elevations
- Local subsidence

Sea-level rise is projected to increase, due to thermal expansion in the ocean, by 8 to 24 inches per 1.8°F of global warming. Sea levels will also rise 8 to 28 inches due to projected glacier and small ice cap losses. Additions to sea level rise due to melt of the Antarctic and Greenland ice sheets will be significant, although scientists still have difficulty characterizing the volume of this contribution, as well as its time scale (Solomon et al., 2009). Measurements of local subsidence and climate sensitivity are highly uncertain, as is the possibility of a "rapid ice melt" scenario (see Box 2. Subsidence).

Rapid Ice Melt Scenario

Under an extreme projection, the "rapid ice melt" scenario, both the Greenland and Antarctic ice sheets melt quickly, dramatically increasing sea level rise (Pfeffer et al., 2008). This increase would cause inundation of coastal lands amplifying coastal storm effects (NPCC, 2009 and Allison, 2009). Under this scenario, sea levels rise higher than IPCC predictions: about 5 to 10 inches by the 2020s, and 41 to 55 inches by the 2080s (NPCC, 2009). Another study estimates sea-level rise will increase by 39 to 79 inches in the 21st century, roughly 3.5 times higher than IPCC projections (Pfeffer et al., 2008). The large variation in seas level rise estimates reflect the uncertainty inherent in climate change models. Integrating the most up-to-date information into planning for climate change at Gateway will be a necessity.

Box 2. Subsidence

The Earth's surface is made up of tectonic plates that move in response to below-surface pressure and temperature changes. Natural, thermally-driven tectonic movements contribute to a majority of land subsidence in New York. Thermal subsidence is the result of thinning and cooling contractions of the Earth's lithosphere and crust (Steckler and Watts, 1979).

This natural phenomenon will compound sea level rise effects as subsidence vertically shifts the ocean floor downward (IPCC, 2007). While natural rates of sedimentation and accumulation of organic matter historically offset marsh loss, accelerated rates of sea level rise from climate change can potentially inundate Jamaica Bay salt marshes (Hartig et al., 2002).

Temperature Changes

In New York City, mean annual temperatures are "extremely likely" to increase from a baseline average temperature of 55°F (NPCC, 2009) by:

- 1.5 to 3°F by the 2020s
- 3 to 5°F by the 2050s
- 4 to 7.5°F by the 2080s

In addition to these mean annual changes, Gateway is "very likely" to experience an increase in extreme temperature events. The NPCC classifies high temperature extremes as days with maximum temperatures of 90°F or higher. Heat waves are periods of at least three consecutive days with temperatures of 90°F or higher. Low temperature extremes are days at or below 32°F (NPCC, 2009).

Precipitation Changes

Although predictions indicate only slight changes in mean annual precipitation, there may be large changes in the frequency, duration, and intensity of extreme precipitation (NPCC, 2009). Precipitation changes, relative to the baseline data from 1971 to 2000, include:

- Increases by up to 5% by the 2020s
- Increases by up to 10% by the 2050s
- Increases of 5 to 10% by the 2080s (NPCC, 2009)

While the predicted changes in yearly precipitation are relatively small, annual averages do not account for the possibility of heavy downpours followed by prolonged dry periods. The inter-annual variability of precipitation creates a significant amount of uncertainty in the direction of precipitation change.

Extreme Weather Events

Extreme precipitation events occur when multiple factors of climate change combine, forming or increasing storms events including nor'easters and hurricanes. Measuring the probability of these events is difficult because they occur infrequently over long temporal scales (10, 50, or 100 years; NPCC, 2009). The most likely extreme events that Gateway will experience are increased droughts, wildland fires and coastal storms (see Box 3. Wildland Fire).

Higher temperatures may cause increased droughts during summer months, as evaporation increases at a faster rate than precipitation (NPCC, 2009). Although projections lack certainty, the effects of less snow and earlier snowmelt, combined with the changing precipitation frequency, will likely increase the probability of drought.

As temperatures rise, evaporation increases; this intensifies the hydrologic cycle, potentially increasing storm frequency and intensity (Hartig et al., 2002). However, increased storm frequency and intensity remains relatively uncertain (Mann & Emanuel, 2006).

Nor'easters are predicted to occur more frequently than hurricanes given projected higher winter precipitation levels and warmer temperatures (NPCC, 2009; McCabe, Clark, & Serreze, 2001). Nor'easters can be equally as damaging as a mild hurricane. On December 11, 1992, a Nor'easter with wind gusts of up to 90 miles per hour hit Gateway, causing tidewaters to rise 7.7 feet above normal. Sea level rise and coastal destabilization will further augment the effects of increased coastal storms, placing humans and the ecosystems closer to the impacts of coastal storms.

5. Other Stressors and Synergistic Impacts

Gateway's ecosystems face numerous stressors besides changing local climate conditions. Climate impacts will interact with, and in some cases exacerbate, existing pressures that threaten species, ecosystems and cultural resources. A successful adaptation plan will also consider other stressors that increase the park's vulnerability to climate change. Major stressors include:

- Land-use change and urbanization
- Invasive species
- Ocean acidification
- Nitrogen loading and eutrophication
- High visitation rates

Land-Use Change

Much of the land and waters comprising Gateway have a long history of human use and alteration. One example is Miller Field in the Staten Island Unit. Originally wetland, the area was farmland until it was converted to an airfield in 1919, and now consists of grass-covered sports fields. Species composition and ecosystem functions have changed to a significant extent in many areas. Land-use outside of the park boundary also influences Gateway. Species habitat fragments or shrinks as developers convert beaches, fields, and open spaces to built environment. Urban development, including new buildings and pavement with impervious materials, decreases groundwater recharge and accelerates water runoff into storm drains and streams. Replacing vegetation with pavement and other unreflective, impermeable surfaces increases urban air temperatures, known as the urban heat island effect (Rosenzweig et al., 2005.)

Invasive Species

Invasive plant and animal species are present throughout Gateway. These species can drastically reduce species diversity, disrupt food webs and suppress or prevent native plant growth. In many cases, invasive species are better able to adapt to changing temperatures or harsh environmental conditions, and therefore may pose an increasing threat under climate change (Neckles et al., 2001).

Box 3. Wildland Fire

Longer droughts, combined with increasing temperatures may lead to increased wildland fire events. Wildland fire consequences include greater demand on emergency services, disruption of recreation and outdoor activities, poor air quality and unplanned park expenditures (Maunsell Sustralia Pty Ltd, 2008).

Gateway already experiences relatively high numbers of small wildland fires; visitor and staff education and response plans can play a critical role in preventing an escalation in occurrence. Gateway may consider coordinating with adjoining counties to help educate neighboring residents on the dangers of wildland fires at Gateway. Further, the Gateway Fire Management Plan could be periodically reviewed to see if measures to prepare for and respond to "red flag" days continue to be appropriate, given climatic changes.

A common invasive species at Gateway is common reed (*Phragmites australis*), which chokes out other plant species, forming areas where common reed persists in isolation (mono-dominant stands). This greatly lowers the numbers and kinds of species present by eliminating both the native plant species and the faunal species that depend on native vegetation (Jodoin et al., 2008).

Feral and house cats pose a direct threat to Gateway's bird populations (NPS, 2000). Similarly, raccoons prey on the endangered Diamondback terrapins' eggs, consuming up to 92% of eggs laid (Feinberg & Burke, 2003). Competition with invasive species and non-native birds, such as the European mute swan (*Cynagus olor*) also threatens native waterfowl populations (NPS, 2000).

Ocean Acidification

Like climate change, rising ocean acidity results from high concentration of atmospheric carbon dioxide. The ocean absorbs a large proportion of the CO_2 emitted into the atmosphere; dissolved CO_2 lowers the ocean's pH, making the water more acidic (Caldeira & Wickett, 2003). One study estimates approximately 40% of CO_2 emitted in the past 200 years is now stored in the oceans, increasing acidity by a third (NPCC, 2009).

Nitrogen Pollution

Nitrogen pollution heavily impacts water quality within Gateway. Sources of excess nitrogen in Gateway's waters include:

- Residential development and the associated increase in wastewater.
- Water runoff containing fertilizer from lawns, golf courses, and ball fields.
- Nitrogen transfer from the atmosphere (Neckles et al., 2001).

The main nitrogen source in Jamaica Bay's estuaries are discharges from four nearby New York City waste treatment plants, especially during major storm events when the plants exceed their capacity to treat storm and sewer water. Pristine estuaries can absorb low levels of excess nutrients without major ecological consequences; however, excessive nutrient inputs will lead to dense algal growth and eutrophic conditions (See Box 4. Eutrophication).

Box 4. Eutrophication

Eutrophication occurs in water bodies loaded with high nutrient concentrations. These nurtrients trigger extreme algal growth, depleting oxygen availability in the aquatic habitat.

Extreme surface algal growth blocks sunlight from reaching algae and plants located at deeper depths, causing plants to die and decompose. Higher rates of decomposition deplete the oxygen supply and create an uninhabitable aquatic habitat (Smith & Smith, 2003).

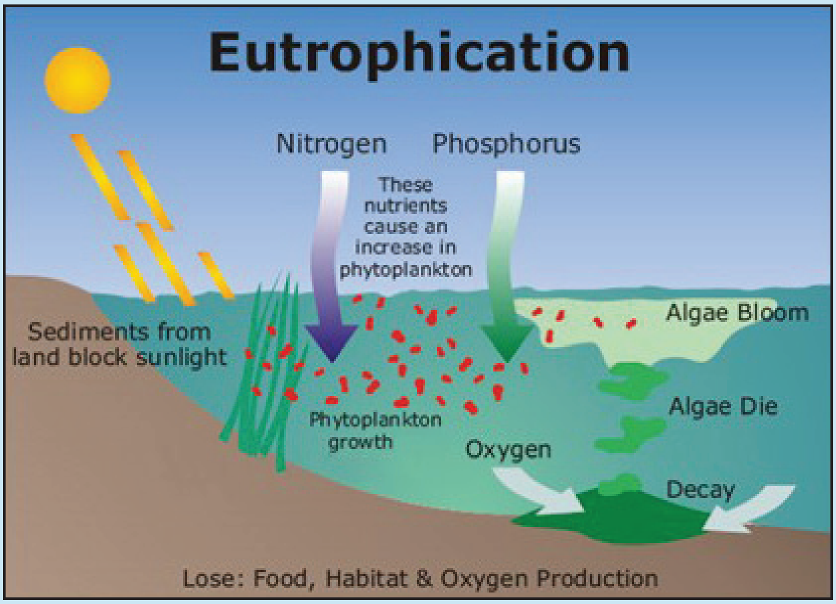


Figure 3. A Model of Eutrophication. (Source: City of Lincoln Watershed Management: Education Website)

Box 5. Public Opinion on Climate Change

Creating a climate change adaptation plan includes convincing the public that this is a wise investment in Gateway's future. The first challenge may be educating the visitor about climate change.

Many factors shape the public's understanding and interpretation of climate change, including political debates, the news, extreme weather events and natural disasters.

Some evidence suggests the public is increasingly understanding and accepting climate change realities. Figure 4 shows responses to three questions on climate change in 2008:

- Do you think that global warming is happening? (Yes, no, don't know.)
- If yes: How sure are you that global warming is happening?
- If no: How sure are you that global warming is not happening?

Part of Gateway's responsibility in creating a climate change adaptation is incorporating public education on climate change impacts.

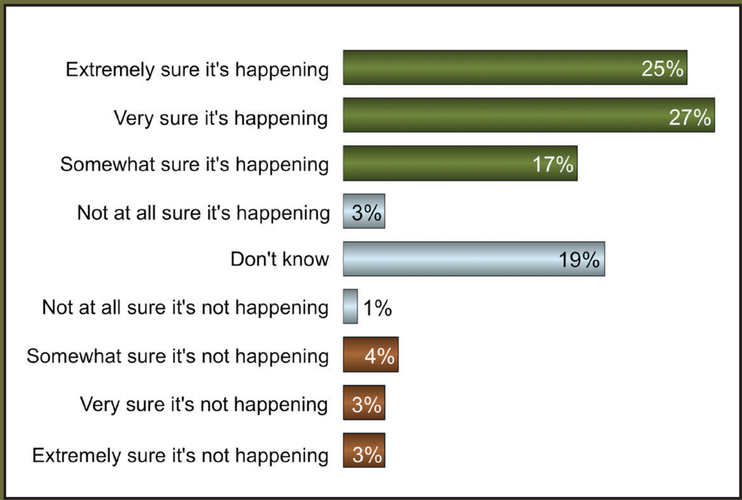


Figure 4. Public Perception of Climate Change. Adapted from "Climate Change in the American Mind" (2009).

High Visitation Rates

Gateway's mission includes providing opportunities for visitors to enjoy natural, cultural and recreational resources. However, visitors also constitute a stressor on park ecosystems. Visitors, if not properly informed and managed, may contribute to trash, remove individual plants or animals from the park, carelessly or accidentally damaging habitat. Gateway experiences the third-highest visitation of all NPS units, likely because it is located in a densely populated metropolitan region. Rising temperatures in and around the New York-New Jersey Metropolitan Area may lead to increasing use of Gateway for recreation, particularly during the summer, if increased heat waves lead to increased beach use. Milder winters could also increase year-round visitation.

3 Climate Change Impacts: Consequences for Ecological Resources

Climate change threatens the National Park Service's ability to carry out its mission at Gateway National Recreation Area by damaging the natural, cultural and recreational resources within the park's inventory. Sea level rise, precipitation changes, temperature increases and extreme weather events will adversely impact Gateway. These impacts can be categorized as:

- Habitat loss
- Species composition and behavior changes
- Cultural resource loss or damage

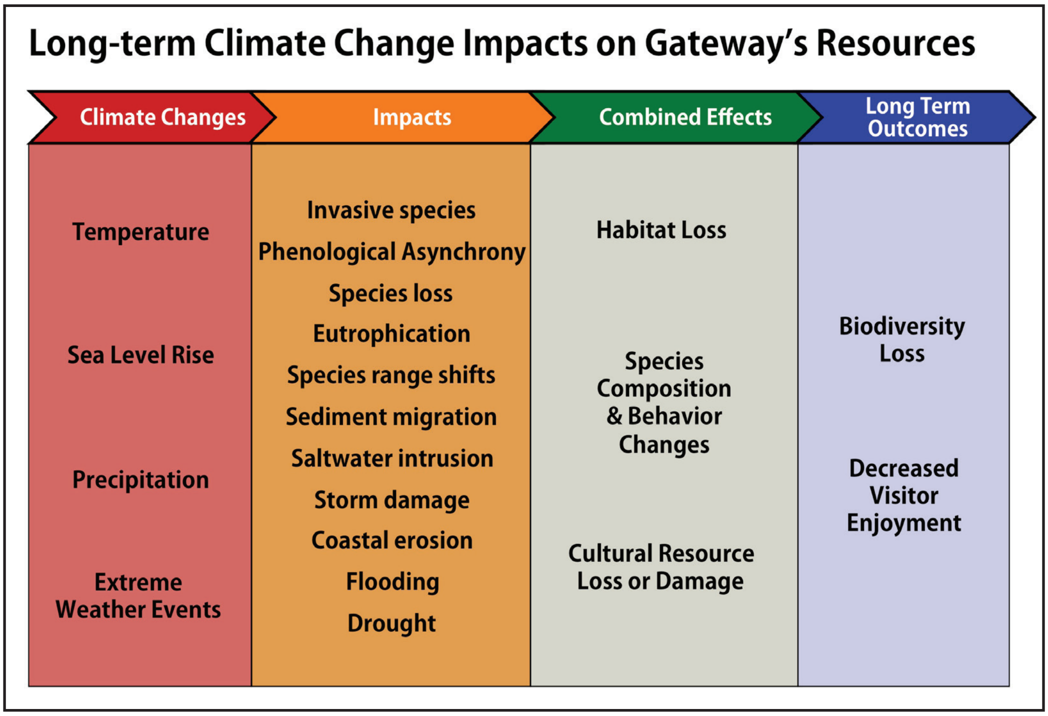
For greater detail, see Conceptual Model 1, which shows some of the combined climate change impacts at Gateway.

1. Habitat Loss

Sea Level Rise

Oceanic and maritime influences either create or maintain 20 out of the 35 ecosystems at Gateway (Edinger et al, 2008); climate change will likely threaten these ecosystems via sea-level rise. Shoreline erosion, saltwater intrusion and wetland and estuary inundation are significant threats from sea level rise (Pendleton et al., 2005).

Shoreline habitat is an acute problem at Jamaica Bay because it contains 28 miles of open-ocean shoreline at the NY Harbor entrance and 25 square miles of salt marsh estuary (Pendleton et al., 2005).



Conceptual Model 1. Sea level rise, temperature and precipitation changes create combined effects with long-term negative outcomes for Gateway's mandate.

Box 6. The Importance of Vegetation

Plants provide important ecosystem services; they buffer against extreme weather events, remove excessive nutrients from the water and prevent wind and rain erosion. Dune-habitat species are particularly tolerant to high winds, nutrient deprived soil, sea spray, and wave action during storms. These coastal plants trap sand and sediment to build up dunes and shoreline, protecting low lying areas on the inland side of the dunes (Department of the Environment, 1990).

Gateway contains many wetland plants like broadleaf cattail (*Typha latifolia*) and common reed (*Phragmites australis*) that directly contribute nitrogen and excess nutrient removal. Other plants like yellow flag (*Iris pseuducorus*) can also absorb heavy metals (Stalter, 1996). Bacteria and vegetation create a synergistic partnership to also remove excess nutrients from water (Wiesner, 1994).

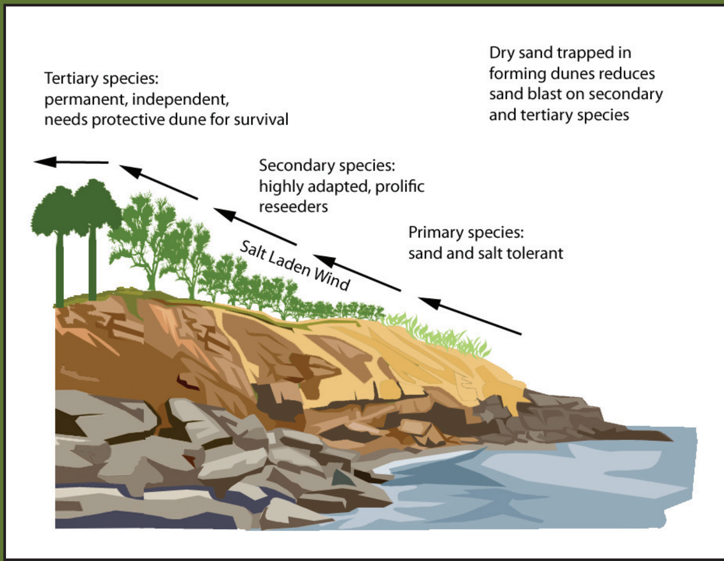


Figure 5. The Role of Coastal Vegetation. Adapted from Chapman (1989).

The coastal vulnerability index (CVI) compares coasts' relative vulnerability to sea level rise. Gateway's CVI, excluding the Jamaica Bay wetlands, shows high vulnerability to sea level rise in areas with frequent overwash and high shoreline change rates. A quarter of the shoreline throughout Gateway has "high" sea level rise vulnerability; an additional quarter of Gateway's shoreline, found exclusively in Sandy Hook, has "very high" vulnerability (Pendleton et al., 2005).

Sea level rise can potentially inundate low marshland ecosystems located on the shoreline and with significant biodiversity implications for Gateway, since marsh ecosystems provide valuable habitat for birds, fish and reptiles. Significantly, deep-water fish use marsh ecosystems as protective nurseries, while other species including weakfish and winter flounder use the low marsh vegetation for safe foraging. Additionally, birds such as the seaside sparrow exclusively nest in low marsh habitat (Anderson et al., 2009).

Extreme Weather Events

High frequency or intense extreme weather events might also drive habitat loss at Gateway because climate change may increase the frequency and magnitude of hurricanes along the Northeastern coast. However, this finding is uncertain and remains controversial (Mann & Emanuel, 2006; Michener, Blood, Bildstein Brinson, & Gardner, 1997).

While increased extreme weather event occurrence remains a scientifically uncertain, the impacts are well understood. Data collected from recent hurricanes show widespread mortality in numerous species that live in freshwater environments, particularly in freshwater estuaries through salt-water inundation.

Terrestrial animals such as mammals and small vertebrates living in coastal wetlands are particularly susceptible to drowning during hurricanes and severe storms (Michener et al., 1997). In South Carolina, Hurricane Hugo wiped out approximately a quarter of all un-hatched loggerhead turtle nests (Cely, 1991, cited in Michener et al., 1997). Extreme weather events can potentially push endangered species with low populations, such as the diamondback terrapin, closer towards extinction.

Increased hurricane and storm activity threatens avian species most dramatically (Michener et al., 1997); this presents serious economic and recreational implications for Gateway, a globally recognized Important Bird Area (NAS, 2009). Increased storm frequency during breeding season may severely harm bird populations in Jamaica Bay, especially ground-nesting birds that rely on habitats susceptible to damaging wind and wave action during storms. Hurricanes pose great danger to endemic, endangered bird species with fragile populations like the piping plover and least terns (Gardener et al. 1991 cited in Michener, 1997).

Intense storms also cause saltwater intrusion, which alters tidal marsh vegetation and damages freshwater wetlands and maritime forest ecosystems at Gateway. Typically, coastal dunes protect these ecosystems from seawater (see Box 6. The Importance of Vegetation); while the ocean side of the dune is subject to sea spray and intense winds, the opposite side of the dune protects plant species intolerant to saltwater. Salt water intrusion threatens previously dune-protected plants while saltwater inundation creates dead zones that further destabilize the coastal environment (NPCC, 2009). Storm tides threaten to over-top and erode away protective barriers between these separated ecosystems. Longer-term, saltwater can also penetrate through groundwater, up estuaries and through bays (NPCC, 2009).

2. Species Behavior & Composition

Climate change will also alter Gateway's species composition in terms of population abundance and distribution of different species. These changes may result from:

- Invasive species
- Migration due to range changes
- Species extinction

Invasive Species

As storms and saltwater intrusion damage and disrupt freshwater environments, they also weaken the threshold for native species to adapt. Invasive plant species can occupy these already fragile ecosystems, outcompeting native species for resources. Invasive species will become more problematic as climate change accelerates.

Since invasive species can reproduce and disperse efficiently, they are likely to gain competitive advantages under rising temperatures and increased extreme weather events that damage native populations (Markham and Malcom, 1996). Milder winters will allow non-native species that require warmer temperatures to expand their ranges and population sizes, which may allow for the spread of "pests" such as ticks, mosquitoes, and fire ants (see Box 7. Non-native Fire Ants; Menendez, 2009).

Range Changes: Sea Level Rise Induced

Sea level rise, already occurring along North America's Atlantic coast as a result of climate change and subsidence, has led to observable changes in vegetation composition in salt marsh and tidal flat ecosystems (Warren, 1993). Historic records from the late 1940s and peat core samples indicate that black grass rush (*Juncus gerardi*) and salt meadow cordgrass (*Spartina patens*) once dominated Northeastern marshes, but these areas are now dominated by forbs, non-grassy plants such as seaside arrowgrass (*Triglochin maritime*) and saltgrass (*Distichlis spicata*).

Ecosystems that maintain their historic vegetation composition have higher elevation than ecosystems dominated by new species. Accretion is a naturally occuring process that counters erosion by replenishing lost sediment. Vegetation forms natural sediment traps that catch wind-blown and water transported sediment. Sea level rise and extreme storm events may increase coastal land loss if erosion rates exceed accretion rates (Twilley, 2007). Stable, unchanged marsh ecosystems accrete at the rate of local sea-level rise, while ecosystems with altered vegetation have slower accretion rates. A low accretion rate exposes plants to longer and more frequent tidal inundation, increasing salinity. These new conditions favor species that tolerate wetter, more saline environments, often resulting in two new communities: smooth cordgrass and forbs (non-grassy plants; Warren, 1993).

Jamaica Bay provides important stopover grounds for shorebirds as they migrate between wintering and breeding grounds (Mizrahi, 2006). The park has recorded 331 species of birds within Jamaica Bay – nearly half of all bird species in North America. Sandy Hook's maritime forest and dune habitats are also a refuge for spring and fall migratory songbirds and raptors.

The Jamaica Bay salt marshes and tidal flats serve as breeding grounds for horseshoe crabs, which are an important food source for migratory birds. High-priority species such as red knots (*Calidris canutus*) and semipalmated sandpipers (*Caldris Pusilla*) depend on horseshoe crab eggs for the energy reserves needed to complete their migration to Arctic breeding grounds (Mizrahi, 2006). Loss of beach and marsh habitat due to sea-level rise can interfere with horseshoe crab spawning, which in turn will make it difficult for migratory birds to meet their energy needs (NJAS, 2009).

Sea level rise can also inundate tidal flats, reducing the overall exposed habitat available as refuge for migratory shorebirds, especially during high tide; rising seas will eventually make flats unavailable for foraging short-legged shorebirds (Erwin et al., 2004 in Anderson et al., 2009).

Box 7. Non-native Fire Ants

Since its introduction in the U.S. in the 1930s, the fire ant, which is a native to South America, has spread to 13 states and continues to expand its range (Morrison et al., 2005). Fire ants thrive in warm climates and will continue to expand northward as global temperatures increase. Based on climate change predictions from the National Oceanic and Atmospheric Administration (NOAA), Morrison et al. (2005) mapped a potential distribution of fire ants based on global warming predictions. Like other pests, fire ants may be able to survive farther north than expected, including areas with artificial heat sources like Manhattan (Morrison et al, 2005). The potential intrusion of fire ants threatens survival of least tern chicks (Lockley, 1995; Krogh & Schweitzer, 1999 cited in Allen & Garmestani, 2004).

Box 8. Endangered & Threatened Vegetation Species

Gateway is home to several state, federal, and globally listed endangered and threatened plant species. Seabeach amaranth (*Amaranthus pumilus*) is perhaps the rarest plant found at Gateway (Stalter, 1996). Amaranth disappeared from the park in 1950, but reappeared during the 1990s. It now occurs among sparsely vegetated American beachgrass (*Ammophila breviligulata*) stands, which lie on flat or gently sloped sands at West Beach, Breezy Point.

Other listed species include Schweinitz flatsedge (*Cyperus schweinitzii*), an endangered species in New York that grows on sands and sparsely vegetated areas in Jamaica Bay and Breezy Point.

Other notable coastal species include coast flatsedge (*Cyperus polystachyos texensis*), seabeach sandwort (*Honckenya peploides*), and fewflowered panic grass (*Panicum oligosunthes*), which can be found on the ocean side of sparsely vegetated dunes in Sandy Hook's coastal area (littoral zone). Similarly, seabeach knotweed (*Polygonum glaucum*) is extremely rare in the Sandy Hook unit but is also found on the New York side in Breezy Point.

Range Changes: Temperature Induced

Amphibians and reptiles are highly vulnerable to warmer temperatures and drought. These species, already persisting in low population sizes at Gateway, may be particularly vulnerable to drier, warmer temperatures. Such stressors could drive populations towards extinction (R. Burke, personal communication, March 27, 2009).

In 2007, the United Nations declared climate change will severely impact over 84% of the Conservation of Migratory Species listed species (World Migratory Bird Day, 2007). Migratory birds will not be able to adapt to rapid environmental changes, such as earlier spring seasons and increased storms. Mistimings between food sources and migrating species are already evident in some populations, such as the pied flycatcher (see Box 10. Phenological Asyncrony, and Box 9. NAO & Migration Patterns; Both et al., 2006).

Extinctions: Endangered & Threatened Species

Endangered and threatened species are already susceptible to stressors including urban development, ship traffic and invasive species. Threatened populations may be unable to adapt to rapidly changing climatic conditions at Gateway. For example, a temperature increase of 1.5–2.5°C, in the moderate range for climate projections, may increase extinction risk 20–30% for at risk species (IPCC, 2007). A heat wave, defined as three consecutive days with temperatures 90°F or higher, has the potential to harm Gateway's ecosystems. Mature plants and animals can recover from individual days of extreme heat, but face greater difficulty if heat waves increase in frequency and duration (Huey, et al., 2002).

For example, the diamondback terrapin (*Malacylemys terrapin*) is extremely vulnerable to warmer temperatures because drier summers reduce nesting success. Data collected over a two year period shows a dramatic decline in the hatching success of the terrapin during a hot and dry year (R. Burke, personal communication, March 27, 2009).

Threatened and Endangered Species at Gateway include birds and turtles (USFWS, 2007):

- Piping plover (*Charadrius melodus*)
- Least terns (*Sterna antillarum*)
- Roseate tern (*Sterna dougallii*)
- Peregrine falcon (*Falco peregrinus*)
- Ridley sea turtle (*Lepidochelys kempii*)

- American oystercatcher (*Haematopus palliatus*)
- Black skimmers (*Rynchops niger*)

Other species of conservation concern include birds such as (National Audubon Society, 2009):

- Barred owl (*Strix varia*)
- American woodcock (*Scolopax minor*)
- Osprey (*Pandion haliatus*)
- Willet (*Tringa semipalmata*)
- Clapper rail (Rallus longirostris)
- Marsh wren (*Cistothorus palustris*)
- Seaside sparrow (*Ammodramus maritimus*)

Extinctions: Declining Keystone Species

Species on lower levels of the food chain like crustaceans and bivalves play a critical role in Gateway's estuarine ecosystem because they support the park's extensive food web (Franz, 2006). These benthic invertebrates are primary consumers of planktonic algae and detritus, and are a food source for many other species (Franz, 2006). Shorebirds, such as the endangered piping plover, thrive in habitats rich with invertebrates (Haig et al., 2005). Horseshoe crabs (*Limulus polyphemus*) and oysters (*Crassostrea Virginica*) are two significant keystone species at Gateway (see Species Case Study 1. Horseshoe Crabs and Climate Change.)

Box 9. North Atlantic Oscillation (NAO) & Migration Patterns

The North Atlantic Oscillation (NAO) is a climatic phenomenon caused by fluctuations in atmospheric pressure differences at sea level between the Icelandic Low and the Azores high. The NAO is responsible for the strength and direction of westerly winds and storm tracks across the North Atlantic. Similar to the El Niño phenomenon in the Pacific Ocean, the NAO is one of the most important drivers of climate fluctuations in the North Atlantic and surrounding humid climates. Higher NAO indices mean an earlier seasonal warming, changing vegetation growth patterns and making food available earlier.

Climate change has led to changes in the North Atlantic Oscillation (NAO) index. In the last four decades, researchers recorded an increase in winters with a positive NAO index associated with an increase in the Northern hemispheres' surface temperatures (Huppop and Huppop, 2003). This change will cause seasonal mistimings with implications for migratory birds at Gateway, including a temporal mismatch between avian predators and prey (Both et al., 2006). Changing conditions will also affect butterflies' activities. In the summertime, monarch butterflies stopover at Gateway to refuel on native seaside goldenrod nectar. Changes in seasonal seaside goldenrod growth would have detrimental effects on monarch migration.

Box 10. Phenological Asynchrony

Climate change is expected to disrupt plants and animals' seasonal activities (phenology) because flowering, breeding, and migration departure dates depend on specific, time sensitive conditions. Climate change will reduce ecosystem resilience by affecting different species at different rates of change (asynchrony; Both et al., 2006). Some species are adaptable to temperature changes while others cannot respond as readily; these differences disrupt ecosystems.

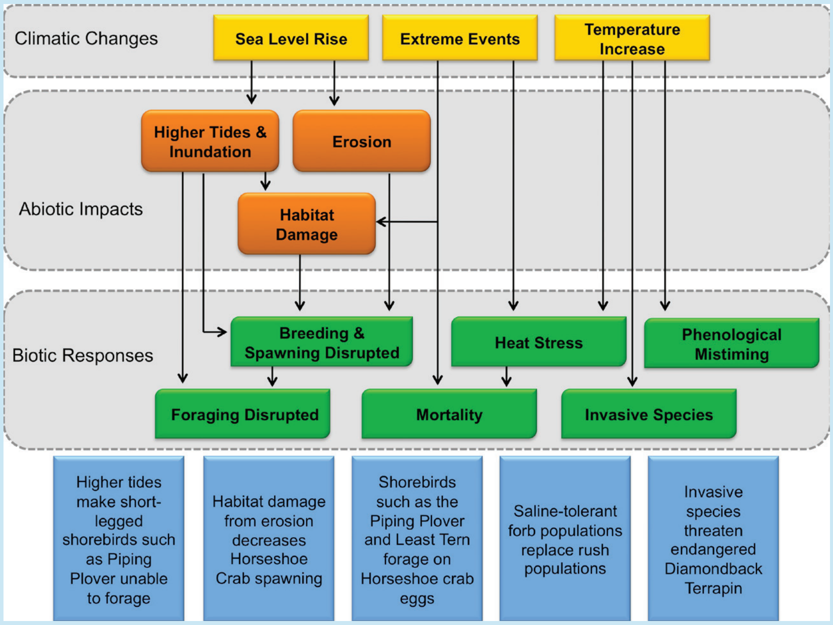
Migratory birds and butterflies are subject to the greatest harm from phenological asynchrony because of their inability to adapt to rapid environmental changes (Both et al., 2006); birds, for example, often migrate based on light cues, while their food sources may develop as a function of temperature. These differences lead to mistimings. During the last 20 years, the average egg laying date for the migratory pied flycatcher has advanced due to an earlier spring arrival. In areas where food for nestlings was mistimed, it has resulted in a 90% population decline (Copack and Both, 2002). It is critical that food sources are available to match the birds' dietary requirements since Gateway is an important migratory bird stopover site.

Significant Ecosystems and Climate Change

The most prominent and characteristic ecosystems at Gateway include intertidal mudflats, salt marsh, maritime forests and dune shrublands (see Figures 7, 8 & 9 in the Appendix for a visual representation of all the ecosystems across the park). Climate change threatens all three of these ecosystems, as well as the many other ecosystems throughout the park (see Conceptual Models 2, 3, and 4).

1. Intertidal Mudflats

Intertidal mudflats, also known as tidal flats and North Atlantic Coastal Estuarine Mudflats, are the most prominent ecosystem within Gateway constituting about 60% of the mapped area in 2006 (3,912.87 hectares; Edinger et al., 2008). Saline silt and mud, rich with organic matter, characterize these flats, which become completely exposed at low tide and flooded twice daily with high tide. Tidal Flats occur within Gateway's Great Kills section of the Staten Island Unit, as well as Jamaica Bay's Floyd Bennett Field and Wildlife Refuge.



Conceptual Model 2. Ecosystem Responses: Intertidal Mudflats
Of the three climate change drivers, sea level rise may pose the biggest threat to tidal flats. An increase in sea level will reduce shoreline habitat and lead to higher tides. This in turn will reduce spawning grounds available for horseshoe crabs, resulting in fewer eggs available for migratory birds to forage on. Higher tides will also affect short-legged shore birds that can only forage during low tides. Because migratory birds and shorebirds nest and breed in this ecosystem, extreme events such as storms and wave frequencies, will damage and destroy nests and juvenile birds. Increased temperatures may also allow invasive species to enter, threatening native species.

Species Case Study 1. Horseshoe Crabs & Climate Change

Horseshoe crabs are an integral part of the Jamaica bay ecosystem, supplying critical forage for shorebirds (Anderson et al., 2009). Horseshoe crab populations at Gateway have decreased as a result of over-harvesting from the bait industry (Sclafani, 2006). As of 2008, the horseshoe crab harvest quota for New York waters was approximately 350,000 individuals/year (Fishery Management Plan for Horseshoe Crab Addendum III, 2004, cited in Mizrahi, 2006). In the spring of 2008 however, NPS started enforcing a "no harvest rule" that became fully enforced in February 2009. This new mandate prohibits taking horseshoe crabs anywhere within the Park (National Park Service, 2007).

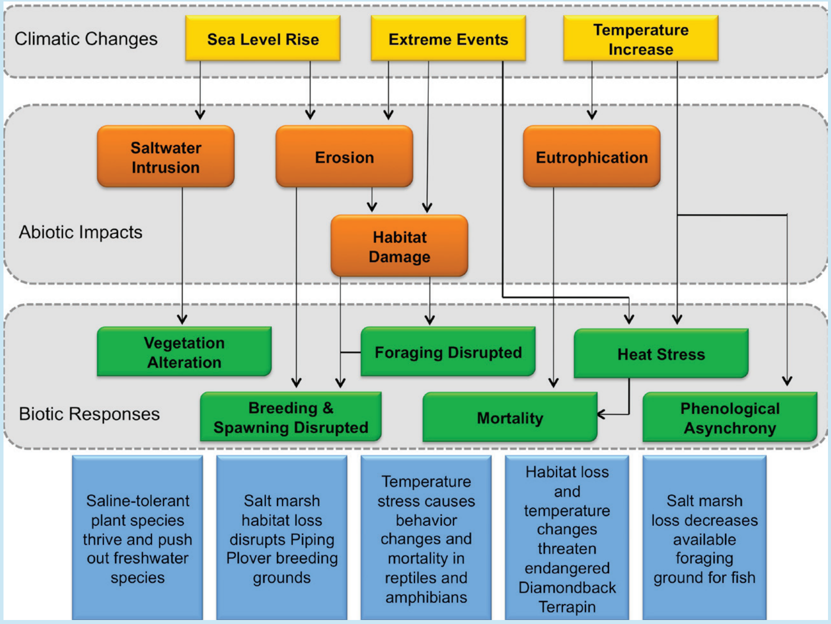
Habitat loss from sea level rise is also responsible for fewer horseshoe crabs at Jamaica Bay. The crabs depend on narrow sandy beaches and the alluvial and sand bar deposits for spawning grounds. These

sandy beaches at Gateway are diminishing at alarming rates (Anderson et al., 2009). Horseshoe crabs require sand at least deep enough to nearly cover their bodies, about 10 cm, to spawn (Weber, 2001 cited in Anderson et al., 2009). A loss of horseshoe crabs as a result of sea level rise will adversely affect migratory birds. For example, red knot (*Calidris canutus*) populations have dramatically declined due to the decline in horseshoe crab eggs during their spring migration (Mizrahi, 2006).

2. Salt Marsh

The second most prominent ecosystem within Gateway is salt marsh. Salt marshes occur in the regularly flooded intertidal zones, from mean high tide to mean sea level. These ecosystems are found in all three Gateway units, but are most predominant in Jamaica Bay (Edinger et al., 2008). Jamaica Bay is one of the largest, most productive ecosystems in the northern US. The Bay provides important habitat for more than eighty fish species, and nearly 20% of North America's bird species visit the bay during migration. These wetlands also mitigate flooding and erosion in Brooklyn and Queens and act as organic matter sinks. Salt marshes have extremely high primary productivity, and their algae and phytoplankton communities contribute to carbon fixation (reducing carbon dioxide in the atmosphere). Finally, the marshes serve as important recreation and educational centers at Gateway (see Figure 9).

Despite these important functions, the Jamaica Bay wetlands are rapidly disappearing. Aerial photography interpretation has shown total vegetated marshland decreased from 2,347 acres in 1951 to 876 acres in 2003; this is a total loss of almost two-thirds of all marshland since 1951 (Gateway, 2003). Although climate change may contribute to marsh loss, it does not completely explain the accelerating trend since sea level rise has remained relatively constant throughout the 20th century. Human disruptions (filling, dredging, urbanization, waves from boating, construction) and biological factors (die-off of smooth *Spartina alternaflora*) are likely fueling accelerated salt marsh land loss. In addition, the natural replenishment of sediments in Jamaica Bay may be insufficient to compensate for losses due to erosion and other stresses (accretion rates; Hartig, Gornitz, Kolker, Mushacke, and Fall, 2002). In the future, if new wetland growth is significantly slower than losses, and sea level rise erodes new growth, the salt marshes may be lost entirely.



Conceptual Model 3. Ecosystem Responses: Salt Marsh
In salt marsh ecosystems, sea level rise will lead to saltwater intrusion in freshwater ponds adjacent to the marshes. This in turn will alter salt marsh vegetation, making conditions more habitable for saline-tolerant species. The rate of sea level rise is currently increasing faster than accretion rates, resulting in habitat loss for wildlife that utilize the marshes for foraging and breeding. Extreme events such as increased storms and wave frequencies, will lead to habitat loss and adversely affect migratory and shorebirds at Gateway. Warmer temperatures will also affect wildlife intolerant to hot and dry temperatures such as reptiles and amphibians. Finally, increased sea surface temperatures will exacerbate existing eutrophication, leading to dead zones.

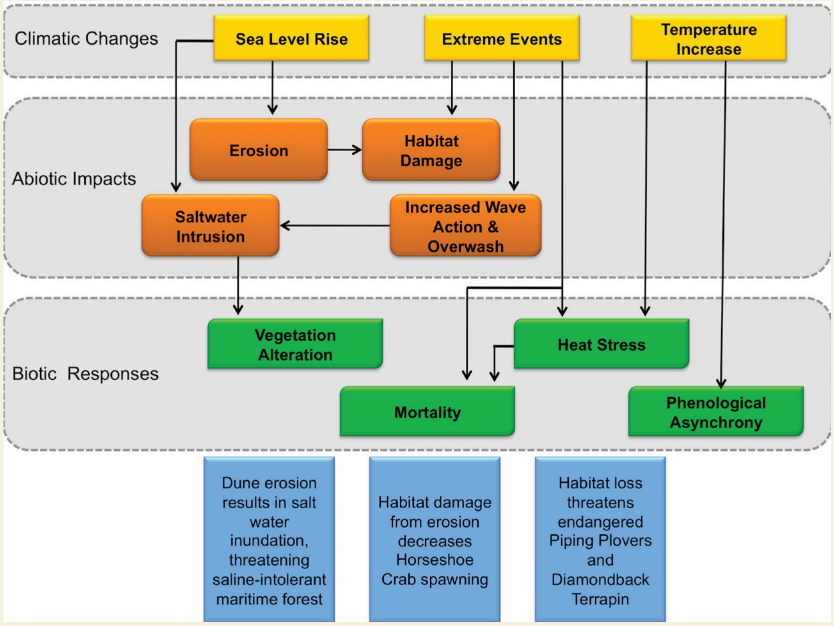
Species Case Study 2. Diamondback Terrapin

The diamondback terrapin (*Malacylemys terrapin*) lives along the Atlantic and Gulf coasts, and is the only turtle species known to occur in brackish water (Anderson et al., 2009). The terrapin's preferred nesting habitat is shrubland, dune, and mixed-grassland near brackish water (Feinberg & Burke, 2003). While information on the status of terrapin populations in New York is limited, the threats to this species at Gateway are evident. Red foxes (*Vulpes vulpes*) and raccoons (*Procyon lotor*) consume terrapin eggs and hatchlings, while the roots from beachgrass (*Ammophila breviligulata*) and codgrass invade terrapin nests. Abiotic factors such as flooding and wind erosion also contribute to high mortality rates that further reduce nest survivorship (Feinberg & Burke, 2003). Diamondback terrapins depend on salt marsh habitat for survival, thus a decrease in marsh habitat directly threatens this already endangered reptile. Burke suggests that, among competing hypotheses, the marsh loss is likely caused by sea level rise. In order to sustain terrapin populations against the irreversible damage from sea level rise, marsh restoration is necessary.

3. Maritime Forests and Dune Shrublands

Northern Tall Maritime Shrublands are a prominent ecosystem located on all Gateway units. Locally rare willow oaks (*Quercus phellos*) grow in woodlands and shrublands in Floyd Bennett Field's northern portion. Willow oaks often occur in stands dominated by poplars, birches, and black cherry (*Populus spp.*, *Betula populifolia*, *Prunus serotina*) on sandy or gravelly soils. Rare wild wormwood (*Artemisio campestris caudata*), closely related to common wormwood (*Artemisia vulgaris*), grows only in Sandy Hook (common wormwood occurs throughout the park). Gateway also serves as the northern extent of the Sweetbay's (*Magnolia virginiana*) range due to warmer temperatures up the coast, caused by the Gulf Stream (Figures 7, 8 & 9).

Red cedar woodlands and unique holly forests can be found on the west shore of Sandy Hook, inland from the low salt marshes. While maritime forest habitat is present on all three Gateway units, Sandy Hook is the only portion that contains holly forest and red cedar woodlands. The holly forest (107 ha) is dominated by American holly (Ilex opaca) species, which persist on inactive sand dunes (Edinger et al., 2008). The red cedar woodlands (119 ha) are characterized by both American holly and Easter red cedar (*Juniperus virginian*; Edinger et al., 2008).



Conceptual Model 4. Ecosystem Responses: Dunes

Dune ecosystems provide an important buffer between freshwater and saline-tolerant ecosystems; climate drivers that erode away these dunes will affect freshwater ecosystems. For instance, sea level rise will increase dune erosion and saltwater inundation threatening maritime forest vegetation behind the dunes. Sea level rise will also lead to habitat loss for species that nest on dune habitats, including piping plovers and diamondback terrapins. Extreme events will increase wave action and overwash rates, which further expose saline-intolerant forest ecosystems to saltwater. Extreme events can also destroy nests and increase shoreline erosion. Increased temperatures and droughts will adversely affect species sensitive to heat stress such as the diamondback terrapin. As with all the models, these are only some of the potential ecosystem effects imposed by climate change.

Species Case Study 3. Piping Plover

Piping plovers are one of only 50 North American breeding shorebird species. Piping plovers are listed under the Endangered Species Act (Haig et al., 2005). The National Audubon Society recognizes Sandy Hook as a globally significant Important Bird Area for its ability to support this species, which nests on high beach and dune ecosystems (NJAS, 2009). A recent piping plover census confirms that wintering birds prefer sand/mud/salt flat habitat (Haig et al. 2005).

Biologist Scott Barnes has identified five beach-nesting colonies for over 600 least terns and 60 piping plovers within the Sandy Hook region (NPS, 2006; NJAS, 2009). Sea level rise may reduce nesting and breeding habitat for these birds. The availability of adequate shoreline for breeding has already declined as a result of non-climate related activities (NRDC, 2009). For example, an oil spill in New Jersey reduced a 5-year net population increase of piping plovers within the New York/New Jersey population by 11% from 1996 to 1998 (Haig et al., 2005). Biologists are concerned that Gateway's population will fall below a viable level due to long-term habitat loss or alteration, leading to inadequate remaining local habitats (Haig et al., 2005).

4 Climate Change Impacts: Consequences for Cultural & Recreational Resources

While ecosystem and species protection are essential to Gateway, the many cultural, historic and recreational resources also provide important resources within the park. These resources exhibit vulnerabilities to climate change impacts.

Rapid and extreme changes between high and low temperature and humidity, termed "shocks," can cause materials and surfaces to split, crackle, flake or dust. For example, the number of freeze-thaw cycles in a season puts pressure on outdoor structures (Colette, 2007). Temperature shocks may cause significant damage to historic buildings and paved recreational trails. While warmer average temperatures may mean milder winters, there may be a greater potential for sudden temperature increases leading to rapid thawing; these events would stress cultural resources.

Flooding creates rapidly moving waters which may damage buildings. At Gateway, severe flooding from extreme storm events will combine with sewage overflow. Due to poor water quality during post-flood drying, micro-organisms such as molds and fungi may thrive, causing building damage, stains and health hazards (Colette, 2007).

Weathering may also increase building damage. In the past, acid rain caused significant weathering to stone structures, such as statues, in New York City; some studies predict higher atmospheric CO_2 concentrations will result in even greater weathering to stone structures (Brimblecombe et al., 2008). This is especially threatening to Gateway's historic forts.

Climate change threatens all units at Gateway; however, management will have to evaluate each resource individually to determine how to best protect resources from these threats.

1. Sandy Hook

Within the Sandy Hook Unit, major structures include Sandy Hook Light and Fort Hancock, including its gun batteries and Officer's Row.

Sandy Hook Light House

Sandy Hook Light House is the oldest operating lighthouse in the United States. Sandy Hook Light was built on a stone foundation and has a brick exterior. Next to the lighthouse is the original keeper's quarters building, a wood house (Maritime Heritage Program, 2007). Constructed in 1764, it was originally built 500 feet inland from the tip of Sandy Hook. Due to littoral drift, the peninsula has grown and the tip is now 1.5 miles from the shore. The fact that sediment deposits have enlarged the tip of Sandy Hook, effectively "moving" the Light inland, bodes well for this structure, and should protect it against sea level rise in the immediate future.

Fort Hancock

Fort Hancock is a major cultural and historical resource at the Sandy Hook Unit. Fort Hancock is listed on the National Register of Historic Landmarks and is home to a host of historic structures. Fort Hancock was an active military installation until 1974. The gun batteries, constructed between 1890 and 1945, attract significant visitor interest.

Updated continuously with the latest weapons throughout their active life, these batteries reflect developments in military technology during the 20th century. The public can also tour Battery Potter, built in 1895.

Officer's Row is a row of Colonial Revival style homes where military personnel lived while stationed at Fort Hancock. While not open for public visit, these homes can be viewed from the road as visitors drive, bike, or walk by. One home, the History House, has been restored for visitors.

Recreational Resources at Sandy Hook

Apart from the rich cultural resources available at the Sandy Hook Unit, visitors also enjoy the recreational resources available on the site. Visitors can enjoy fishing, swimming, sunbathing and water sports on Sandy Hook's beaches. Sandy Hook also offers excellent locations for bird watching, including prime spots on Plum Island, the Spermaceti Cove boardwalk, the North Pond, the Horseshoe Cove salt marsh and the fields at Fort Hancock. Beach access on Sandy Hook offers swimming, fishing and boating. Visitors also enjoy hiking, walking and biking along Sandy Hook's trails and a 5-mile multi-use path.

Impacts on the Sandy Hook Unit's Cultural Resources

Climate change impacts will primarily affect the cultural resources on Sandy Hook through sea level rise. The batteries and homes of Fort Hancock exhibit the greatest vulnerability to sea level rise, due to their location on the coast. In the long-run the ocean may inundate these historical resources. Extreme weather events also threaten Fort Hancock's Officer's Row; some of these buildings are already deteriorating due to the harsh, humid coastal climate and the effects of past storms (National Historic Landmarks Program website). Without proper maintenance and preparation, storm damage could speed up the deterioration of these structures. Due to its distance

from the coast, extreme storm events present the most likely environmental threat to Sandy Hook Light.

Sea level rise, storm events and associated increases in coastal erosion may also impact recreational resources located close to the water. Hartshorne Drive, the main access roadway to the Park, is particularly vulnerable due to its close proximity to the waterfront on both sides of the peninsula. Increased precipitation, particularly heavy rainfall events, may result in increased occurrences of flooding, which may damage pathways and building foundations. Further, more humid conditions caused by increased precipitation and warmer temperatures will likely accelerate damage to Sandy Hook's wooden structures. Finally, any impacts to Sandy Hook's ecosystems that result in species change or habitat loss may negatively impact visitors' enjoyment of bird watching opportunities.

2. Staten Island

Major cultural resources within the Staten Island unit include Fort Wadsworth, Miller Field and Hoffman and Swinburne Islands.

Fort Wadsworth

Fort Wadsworth includes Battery Weed, located directly on the waterfront at the Verrazano Narrows, and Fort Tompkins, constructed on the bluff above the Battery. Constructed during the Civil War, this historic military site never came under attack. Today, the historic stone structures fascinate visitors and rank among the best-preserved military forts of the nineteenth century.

Miller Field

Miller Field, located southwest of Fort Wadsworth, is a major recreational resource at Gateway. Originally a wetland, the area was converted to farmland before being transformed into a military air base. The National Park Service extensively renovated the area when it acquired Miller Field in 1974. Today, Miller Field primarily hosts recreational sports. Approximately 80 leagues and 2,000 teams take advantage of the 187 acres of open space, sports fields, playgrounds and picnic areas, making it an important recreation resource within Gateway (NPNYHC, 2008) and New York City. Great Kills Park, on the Eastern shore of Staten Island, also offers a variety of recreational activities including swimming, fishing, boating, bird watching and a multi-use path for biking, walking and hiking.

Hoffman and Swinburne Islands

Hoffman and Swinburne Islands are artificial islands built out of landfill on top of Orchard Shoals, located about one mile south of Fort Wadsworth and two miles east of Miller Field. Swinburne Island, currently home to migrating harbor seals, as well as wading birds, gulls and cormorants, still bears the ruins of buildings used by the Merchant Marine during World War II. Both islands formerly housed quarantined immigrants carrying infectious diseases during the nineteenth and early twentieth centuries. Today, Hoffman Island is home to large colonies of egrets and herons. Gateway restricts the general public from accessing the islands; however, researchers and scientists may coordinate trips in order to monitor the islands' many species.

Impacts on the Staten Island Unit's Cultural Resources

Rising seas, and their resulting impact on Battery Weed, present the greatest concerns from climate change. The sea walls originally constructed to protect the fort area are already insufficient against the rising ocean. The potential for increased severe weather events, including storm surge and waves, also poses a threat to Battery Weed. Fort Thompson, located high on the bluff, is not threatened by sea level rise and is better protected from waves; nevertheless, it could still be damaged by extreme weather events.

Sea level rise will also affect Swinburne and Hoffman Islands; Gateway may wish to monitor the impact of rising seas on the islands' artificial walls and on the current species occupying the island. Miller Field, located immediately on Staten Island's eastern coast, may also face inundation from sea level rise and extreme storm events, damaging the sports facilities and recreational resources located there.

3. Jamaica Bay

Within Jamaica Bay, Floyd Bennett Field and Fort Tilden are important cultural resources.

Floyd Bennet Field

Floyd Bennett Field is both a historical landmark and an important recreational resource. The airfield, which opened in 1931, served as New York City's first municipal airport. Many famous pilots broke records from or passed through Floyd Bennett Field, including Charles Lindbergh, John Glenn Jr. and Amelia Earhart. Today, Floyd Bennett Field offers a large variety of recreational activities, including fishing, biking, bird watching and boating. The field also has educational facilities, a working hangar, a community garden and the "Ecology Village" camping program and facilities are located at the site.

Fort Tilden

Fort Tilden is the third in the series of forts constructed to protect the New York Harbor. Built in 1917, Fort Tilden first protected the city from naval attack during the two World Wars, prior to serving as a Nike nuclear missile site. Today, most of the military buildings have been stabilized or converted to other uses, but the Fort Tilden Historic District now offers opportunities for hiking, fishing and bird watching.

Other Jamaica Bay Cultural Resources

Jacob Riis Park is located on the former site of Naval Air Station Rockaway, adjacent to Fort Tilden. The Art Deco bath house at Riis Park is listed on the National Register of Historic Buildings and serves as an important example of the public works projects of the 1930s. Although strong, the building's brickwork has suffered extensive weathering due to gypsum formation and the harsh coastal conditions (Stokowski and Berkowitz, 1997).

Riis Park is an important recreation beach for the residents of New York City due to its close proximity to the city and easy accessibility by public transportation and car. Other resources in the Jamaica Bay unit include fishing at Canarsie Pier, as well as biking, horseback riding and nature study and bird watching at the Jamaica Bay Wildlife Refuge.

Impacts on the Jamaica Bay Unit's Cultural Resources

Sea level rise presents a significant threat to Floyd Bennett Field. The airfield was constructed on a small marsh island filled in and artificially raised 16 feet above high tide (Blakemore, 1981). Gateway has already improved the barrier surrounding Floyd Bennett Field to protect against erosion. While not immediately endangered, Gateway may wish to closely monitor sea level rise forecasts, to determine if protecting the field should have greater priority. Sea level rise, coastal erosion, and severe weather will also threaten Riis Park beach, necessitating greater expenditures in the future to maintain the current recreation area.

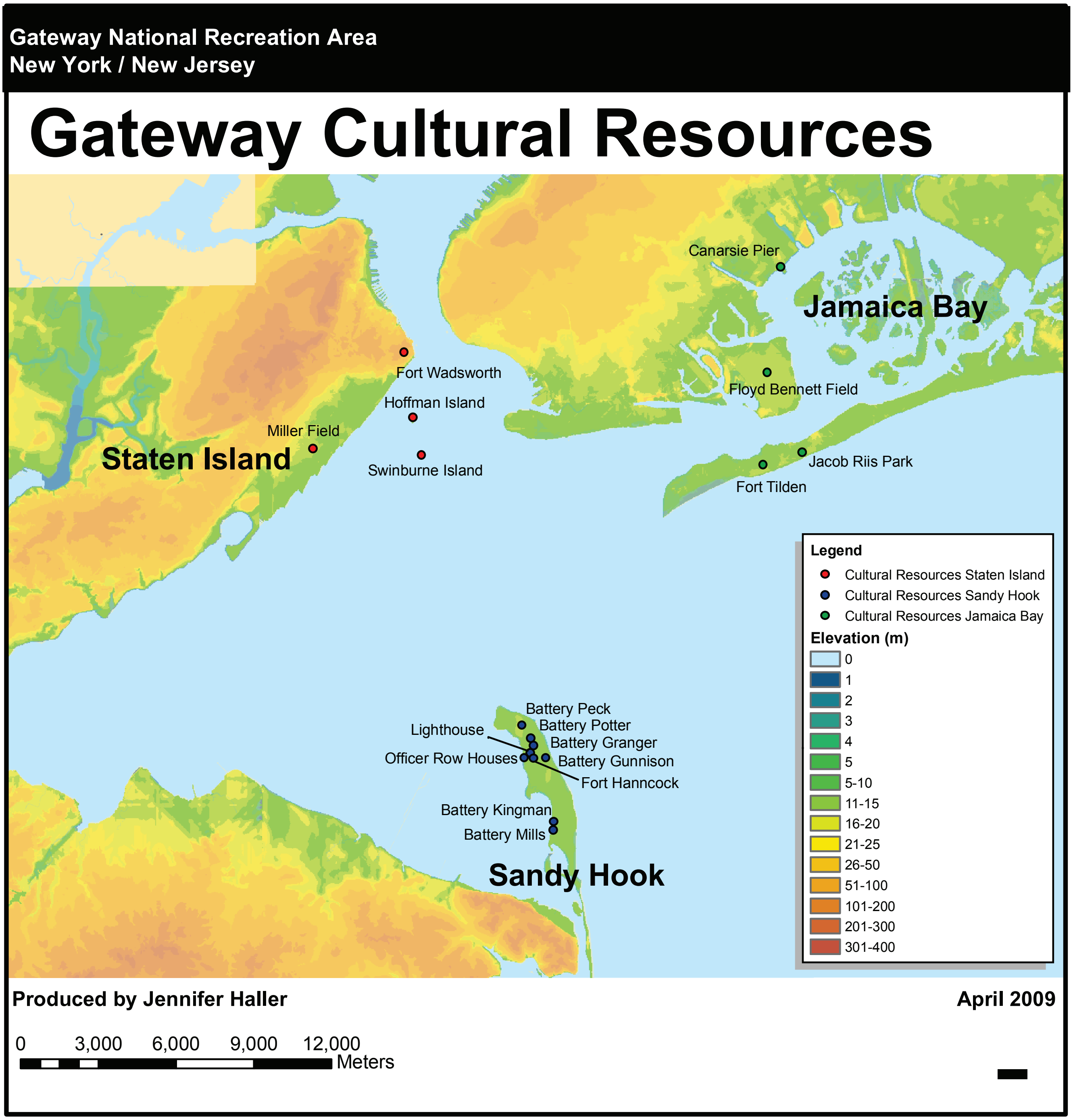


Figure 6. Elevation for key Cultural Resources at Gateway

This map shows potential impacts from sea level rise. As discussed in Section 2. Climate Change & Gateway, sea level rise may increase by 2 to 6.5 feet over the next century; these estimates remain uncertain. Nevertheless, Gateway's important cultural resources could be severely threatened by rising seas. Continuing to incorporate new climate science into planning at Gateway will help protect and preserve these resources over the long-term.

5 Guiding Policy and Climate Change Adaptation

The overarching policy framework under which Gateway operates provides critical guidance in understanding both the need and options for a climate change adaptation strategy for the Park. Four main documents direct Gateway NRA's management and each offers insight on how the park can or should approach the challenges posed by climate change:

- The Organic Act of 1916
- Public Law 92-592 of 1972 (the Enabling Legislation)
- National Park Service Management Policies 2006
- Secretary of the Interior Amendment 1 to Secretarial Order 3326, January 16, 2009

1. The Organic Act of 1916

The National Park Service Organic Act established the National Park Service (NPS) in 1916. This law outlines the mission of the organization, describing the principal purpose of the service:

> *…to conserve the scenery and the natural and historic objects and the wild life 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.*

While the NPS' purpose is to protect the United States' vast natural and historical resources, the organization also serves US citizens, ensuring people are able to enjoy these resources, unimpaired for future generations.

While this goal may seem straightforward, the Organic Act does not include specific directions on how to carry out the legislation's intent, giving the NPS and individual units some discretion in achieving these goals (Doremus, 1999). Moreover, since the legislation dates to 1916, it offers no direct guidance on how to respond to climate change. While the principles outlined in the Organic Act must be a core influence in Gateway's adaptation strategy, it is unclear how the NPS should interpret and apply these principles to climate change.

What is evident is that changing climate conditions may complicate the NPS' core mission established in the Organic Act. For example, conserving dynamic resources, such as ecosystems, in an unimpaired state is increasingly difficult as the environment around these resources changes. The NPS needs to consider how climate change will affect its mission

2. Public Law 92-592 of 1972; Gateway's Enabling Legislation

Congress established Gateway NRA though Public Law 92-592, the Enabling Legislation (1972). Congress sought to "preserve and protect for the use and enjoyment of present and future generations an area possessing outstanding natural and recreational features."

The Enabling Legislation establishes the park territory, including the three main operational units at Jamaica Bay, Sandy Hook and Staten Island. Since Gateway is a coastal park, the legislation also includes Hoffman and Swinburne islands and "all submerged lands, islands, and waters within one-fourth of a mile of the mean low water line of any waterfront area" within the park's boundaries (Public Law 92-592, 1972). This provision is relevant when considering climate change since sea level rise may change park boundaries.

While the Enabling Legislation does not address climate change directly, its mandates require the park to protect resources that are directly threatened by climate change impacts. For instance, Section 3a notes:

> *The Secretary shall administer and protect the islands and waters within the Jamaica Bay Unit with the primary aim of conserving the natural resources, fish and wildlife located therein and shall permit no development or use of this area which is incompatible with this purpose* (Public Law 92-592, 1972).

The express language to protect the islands presents a significant challenge under sea level rise and subsidence in Jamaica Bay. Climate change may also endanger cultural and historic resources. Section 3g requires the Secretary to:

> *…inventory and evaluate" sites having "historical, cultural, or architectural significance" and … provide for appropriate programs for the preservation, restoration, interpretation, and utilization of them* (Public Law 92-592, 1972).

The NPS is clearly required to preserve or restore such buildings or sites, a task made more difficult by increased storm events or sea level rise. Climate change impacts present new challenges to achieving these goals; challenges without precedence in the NPS' long history.

3. National Park Service Management Policies 2006

The National Park Service's Management Policies 2006 governs NPS operations and provides the broad direction for developing and adopting new procedures. Management Policies 2006 does not provide direction for addressing and adapting to climate change; however, it does provide support for initiatives related to climate change measurement, adaptation planning, and adaptation.

Section 2.1.2, "Scientific, Technical and Scholarly Analysis," requires management plans be based upon "the best available scientific and technical information and scholarly analysis to identify appropriate management actions for protection and use of park resources" (Management Policies, 2006, p 22). New findings in climate change science have implications for the park's ecosystems. In order to fulfill this provision, climate change science must be considered in park operations.

Section 4.7.2, "Weather and Climate" explicitly refers to climate change. This section acknowledges the climate's dynamic and changing nature:

> *Although national parks are intended to be naturally evolving places that conserve our natural and cultural heritage for generations to come, accelerated climate change may significantly alter park ecosystems. Thus, parks containing significant natural resources will gather and maintain baseline climatological data for reference.*

This section acknowledges the evolving nature of parks and park ecosystems, providing for the possibility that some aspects of a National Park might not be strictly "preserved." This acknowledgement could have wide-reaching implications in interpreting the original NPS mandate.

The Management Policies 2006 also includes a provision that the NPS use its natural resources and facilities to educate visitors about global climate change. This is an important task, both in the global fight against climate change and in the context of Gateway. For Gateway to incorporate climate change adaptation into its new GMP, the public must understand and accept this choice. Education about climate change will assist Gateway in justifying and explaining investment and management decisions related to its new adaptation plan.

4. Department of Interior Secretarial Order on Climate Change, 2009

On January 16, 2009, Secretary of the Interior Dirk Kempthorn signed Secretarial Order no. 3326A1, "Climate Change and the Department of the Interior." Amendment 1 to the Secretarial Order provides the most important and relevant instruction on addressing climate change adaptation and mitigation for the entire NPS. This order provides guidance to each bureau and division within the Department of the Interior on "how to provide leadership by developing timely responses to emerging climate change issues" (Sec O #3326A1, 2009).

In cooperation with other federal agencies, local governments, private landowners, and Tribes, DOI agencies should "develop adaptation strategies for managing natural and cultural resources affected by such changes" (Sec O #3326A1, 2009). More specifically, Sections 2 and 4 provide direction to bureaus and offices within DOI to undertake 14 measures related to ecosystems and climate change (see Box 11. Secretarial Order no. 3326A1).

The order is directive in nature; although produced by the outgoing Secretary of the Interior, it is authoritative for bureaus within the Department, and provides legal guidance for taking appropriate action to identify and plan adaptive responses to climate change. While deadlines are not provided, the language is clear that these efforts should commence immediately.

The new office within DOI overseeing climate change adaptation and mitigation issues may assist Gateway in with budgetary, legal issues, and coordination with other agencies already undertaking climate change work. Most importantly, the order clearly mandates that all National Park Service units begin to address climate change and adaptation in their management strategies. As Gateway forms its new General Management Plan, this order can provide direction.

Box 11. Secretarial Order no. 3326A1 (Adapted)
Climate Change and the Department of the Interior

1. Identify changes in (the Park's) landscape which may result from climate change.
2. Develop adaptation strategies for managing natural and cultural resources affected by such changes.
3. Provide geologic and terrestrial carbon sequestration alternatives. Section 4 states that these measures should be undertaken by Gateway in "a manner consistent and compatible with (its) respective missions. "
4. Consider and analyze potential climate change impacts when undertaking long-range planning exercises.
5. Consider and analyze potential climate change impacts when setting priorities for scientific research.
6. Consider and analyze potential climate change impacts when making major decisions affecting DOI resources.
7. Review all existing programs, facilities, boundaries, policies, and authorities (in Gateway NRA) to identify potential impacts of climate change on its areas of responsibility and to recommend a set of response actions.
8. Identify to the Assistant Secretary - Policy, Management and Budget through the annual budget process all issue areas where action is needed to make budget adjustments necessary to carry out the actions identified in #7 above (Section 4C in the Order).
9. Identify for the Solicitor's office all issue areas where legal analysis is needed to make the adjustments necessary to carry out the actions identified in #7 (Section 4C in the Order).
10. Ensure that any policy review or guidance with a major focus on climate change, is coordinated with the Climate Change Coordinator within the Office of Environmental Policy and Compliance (OEPC).
11. Partner, consistent with existing policies, authorities and programs, with state, local, and private bodies and individuals in support of projects and activities that contribute to the conservation of species, natural communities, and lands and waters placed at risk by changing climate conditions.
12. Provide incentives for activities to encourage GHG emissions sequestration, including carbon dioxide.
13. Work with USGS on DOI's Climate Effects Network to integrate science, monitoring, and modeling information.
14. Work with USGS on the National Climate Change and Wildlife Science Center to develop effective resource management adaptation strategies related to climate change impacts on fish and wildlife.

6 Adapting to Climate Change at Gateway

As the previous sections illustrate, climate change could severely impact Gateway's ecological and cultural resources. Moreover, Section 5 highlights Gateway's authority and mandate to incorporate climate adaptation into its management of park resources. The following section will outline a number of strategies that Gateway management could adopt to lessen the severity of climate change impacts.

Climate adaptation, although defined variously by different organizations (see Box 12. Defining Adaptation), generally encompasses three concepts:

- Responsiveness to climate change rather than an attempt to lessen climatic changes.
- Responsiveness to both observed changes and expected changes that are projected yet uncertain.
- Both reactive and preventive measures; actions may try to repair climate change damage or prevent potential future damages.

Any adaptation strategy that Gateway chooses to implement will require normal management procedures undertaken in any park program: from project development to program implementation, and monitoring results. The options we outline here focus primarily on program implementation. Conceptual Model 5 displays the planning and implementation process involved in developing an adaptation project. The operational approaches show categories of adaptation approaches that could be used.

Adaptation Options

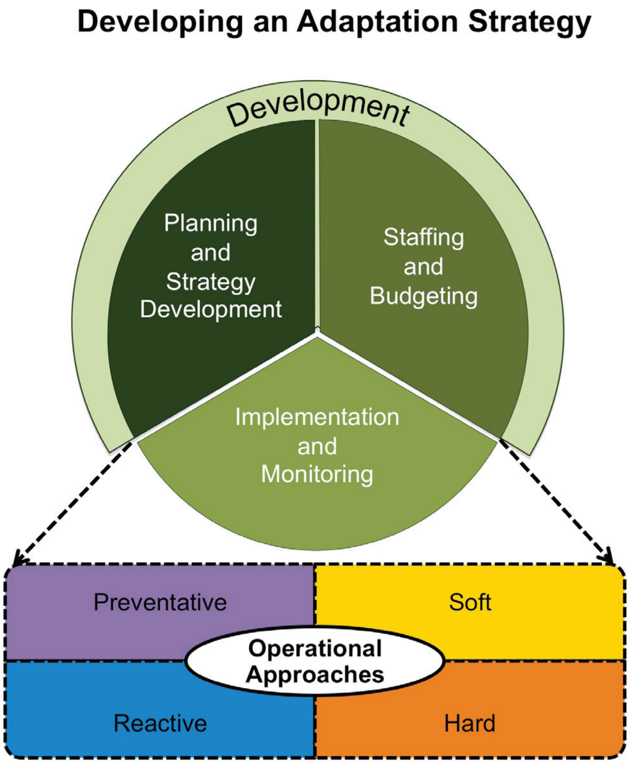
To craft adaptation options for Gateway, we drew upon existing adaptation strategies in the US and abroad (see Appendix C. Global Overview of Adaptation Strategies). We used this information in conjunction with Gateway's existing management strategies and guiding legislation to propose climate change adaptation initiatives.

The adaptation options outlined below constitute an initial framework for forming a complete climate change adaptation strategy at Gateway. These options may form individual elements of such a strategy, or serve to inspire

Box 12. Defining Adaptation

To understand the principles guiding climate change adaptation, it is helpful to examine how relevant institutions define 'adaptation':

- **The United Nations Framework Convention on Climate Change (UNFCCC):** "Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects" (UNFCCC online glossary).
- **The Intergovernmental Panel on Climate Change (IPCC):** "Actual adjustments, or changes in decision environments, which might ultimately enhance resilience or reduce vulnerability to observed or expected changes in climate" (Adger et al., 2007, p. 720).
- **The US Climate Change Science Program and the Subcommittee on Global Change Research:** "Planned adaptation […] refers to strategies adopted by society to manage systems based on an awareness that conditions are about to change or have changed, such that action is required to meet management goals" (Baron et al., 2008, p. 1).



Conceptual Model 5. Developing an Adaptation Strategy

This report describes the implementation and monitoring elements of climate change planning. These operational approaches are categorized as hard, soft, preventative or reactive.

Hard approaches are engineering-intensive solutions that have a permanent, engineering component. These approaches require more administrative and budgetary resources than soft approaches, which are less technical and often entail strengthening a natural system. Preventative operations are intended to protect against climate change impacts before they are observed, while reactive operations are designed to ameliorate adverse ecosystem responses that are already occurring.

other adaptation projects. Overall, these options address a wide variety of possible adaptation strategies. The strategies identified below address crosscutting climate impacts throughout the park as well as specific impacts on individual ecosystems.

Each of the following options attempts to address the climate change impacts that make park resources vulnerable (see Sections 3 & 4. Climate Change Impacts). In order to logically connect this section to the previous, each strategy is categorized by major combined effect. The options address each combined effect, aiming to reduce impacts (see Conceptual Model 6. Adaptation Options). Addressing each one of these stressors will prove crucial to adapting park resources to furthest extent possible. The strategies are:

Park-wide Capacity Building for Climate Adaptation:

- Long-range Ecosystem Planning
- Task Force to Monitor Sea Level Rise

Reducing Changes in Species Composition:

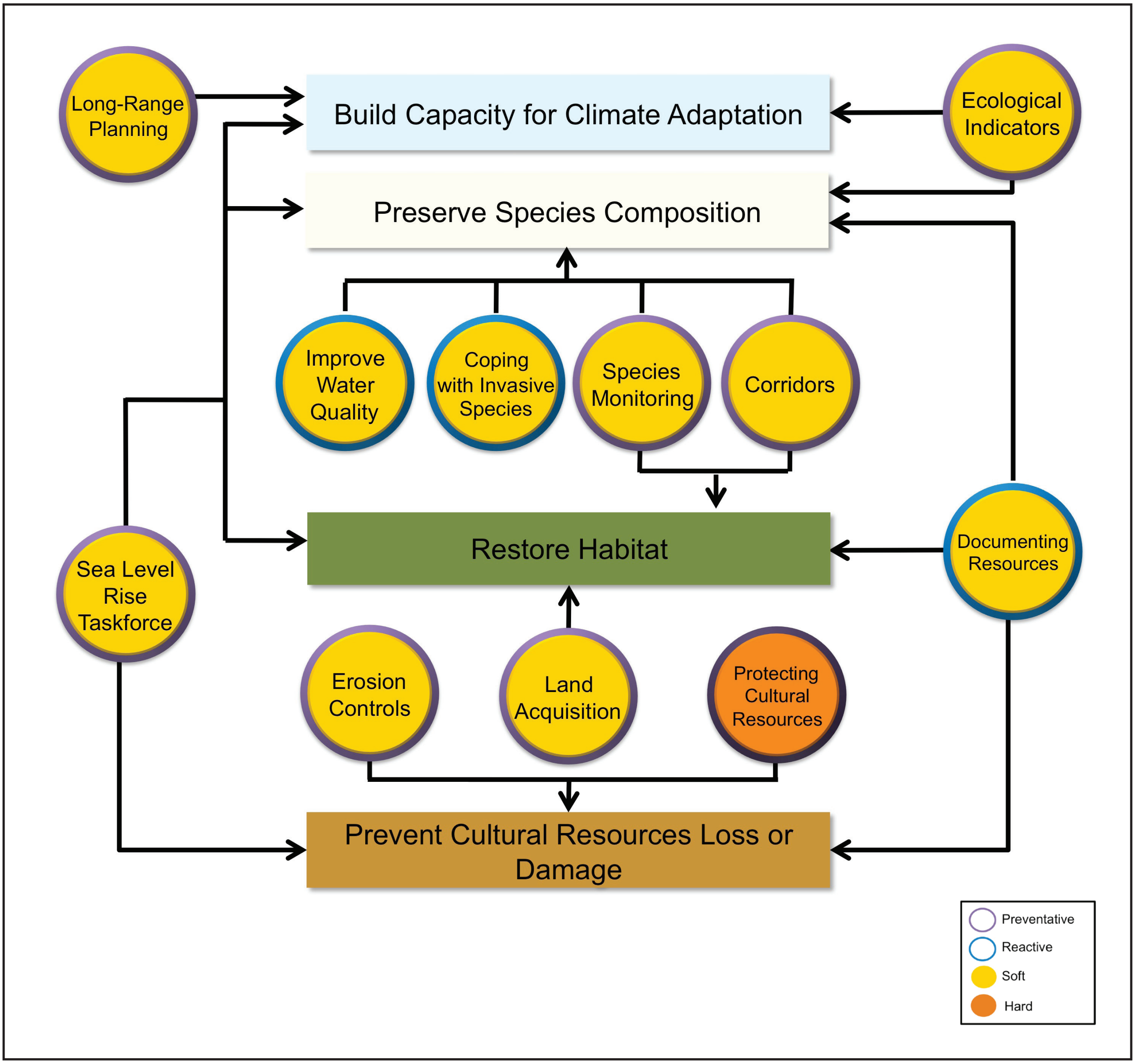
- Ecological Indicators to Monitor Climate Change Impacts
- Keystone Species Monitoring and Management; Horseshoe Crab
- Coping with Invasive Species and Range Shifts

Reducing Habitat Loss:

- Sediment Trapping to Control Coastal Erosion
- Strategic Land Acquisition & Partnerships
- Increasing Habitat Connectivity with Corridors
- Reducing Nitrogen Loading
- Adaptive Restoration

Reducing Cultural Resource Damage and Loss:

- Protecting Cultural Resources
- Documenting Resources & Climate Change Education



Conceptual Model 6. Proposed Adaptation Strategies

The adaptation strategies we have developed for Gateway are designed to direct park-wide management towards climate change adaptation, preserve species composition, restore habitat loss, and prevent cultural resources from loss or damage. The adaptation strategies are described as hard, soft, preventative and reactive. While the options are organized by the topic they most closely address, the model shows how most options can influence multiple aspects of climate change adaptation.

1a Long-range Ecosystem Planning

Strategy

In order to effectively prepare for climate change, Gateway should consider incorporating climate change mitigation and adaptation into all long-range planning decisions.

Description

Climate change impacts will increase in severity over time. Therefore, climate change planning should occur on a long-term timescale. The 2009 General Management Plan is an opportunity for Gateway to ensure that climate change is a core component of all long-term planning decisions across the park. Management decisions could take into account IPCC predictions and new climate science when making priorities and developing projects across all park units.

Gateway could require all new park projects to consider incorporating both climate change mitigation and adaptation strategies in the planning phase, including projects not responding directly to climate change. Within all initiatives, Gateway can look for opportunities to lessen GHG emissions, to educate visitors about climate change, or implement adaptation, buffering resources against future climate change impacts.

Along with long-term adaptation planning, Gateway can be a leader in climate change mitigation efforts. To set an example for other NPS units and visitors, Gateway can strive to adopt climate-friendly practices in park operations. Gateway can target:

- ***Building practices:*** Gateway can continue to incorporate Leadership in Energy and Environmental Design (LEED) certification into its construction and renovation plans, as exemplified by the Jamaica Bay Visitor Contact Station.
- ***Vehicle improvements:*** Gateway can pledge to replace old vehicles with hybrid or alternative fuel vehicles.
- ***Carbon sequestration:*** Gateway can preserve vegetation, possibly creating a net carbon sink; however this depends on many factors, including decomposition.
- ***Eco-friendly products:*** Gateway can supply its offices, visitor centers, cafeterias and other facilities with products containing recycled and biodegradable content.

Incorporating climate change into all park actions will ensure that Gateway is able to make informed investments and management decisions, fulfilling its long-term goals, continuing to protect park resources and serving visitors even as it responds to climatic changes. Considering climate change in all planning is in line with the 16 January 2009 Secretarial Order on Climate Change (see Box 11. Secretarial Order no. 3326A1).

Benefits

- Coordinating with the DOI offices established by the Secretarial Order.
- Building capacity to respond to future impacts proactively.

Challenges

- Incorporating climate change into all park operations will require additional coordination, staffing and research.
- Allocating funds based on uncertain future conditions may be controversial.

1b Task Force to Monitor Sea Level Rise

Strategy

Gateway could create and implement a Sea Level Rise Adaptation Strategy presided over by a Sea Level Rise Adaptation Task Force. Focusing on sea-level rise could help Gateway adopt adaptive management practices to continuously monitor, plan, and manage climate change adaptation.

Description

While gradual sea level rise contributes to habitat loss, the greatest damage from extremely high sea levels will be to cultural resources and infrastructure (Bindoff et al., 2007, 414). Gateway or the broader Northeast Coastal and Barrier Network, a monitoring and inventorying program within the NPS, could identify a team of employees who would remain up-to-date on potential sea level rise conditions and their likely effects on the region. This team would meet regularly to review climate change monitoring information, discuss impacts and oversee adaptation planning. In addition, this team would develop a Sea Level Rise Adaptation Strategy, identifying specific sea level rise threats and adaptation measures, including specific timelines to deal with these threats.

This strategy would help Gateway adapt to climate change impacts through:

- Periodic revisions of predictions on expected sea level rise.
- Monitoring storm and tidal surge impacts from nor'easters and hurricanes as their impacts will likely result in more significant damage.
- Engage in analysis of threats to both ecosystems and cultural resources.

A team responsible for the continuous study of sea level rise could serve to revise the adaptation strategy when necessary. This decision informs all other planning decisions and could operate through a combination of National and State parks and other bodies with vested interest. Melbourne, Australia is one example of a city that includes the task force model in its adaptation planning (Maunsell Sustralia Pty, Ltd, 2008, 78-83). Key components of their plan suggest that an effective strategy should:

- Begin active planning immediately with ongoing planning in the future.
- Develop suitable planning guidelines for different sea levels based on model results.
- Model the altered flood risk and impacts to coastal infrastructure.
- Establish a strategy to communicate adaptation decisions to stakeholders.
- Identify appropriate adaptation measures for distinct geographic areas or features.

A Sea Level Rise Adaptation Task Force could aid other plans for adaptation measures throughout the park and with other invested bodies. Establishing a dedicated team in the near future to address this encroaching issue will help Gateway lessen or even avoid significant long-term risks and costs.

Benefits	Challenges
• Providing a framework for adaptive management and decision-making in response to new information on sea level rise (Maunsell Sustralia Pty, Ltd, 2008, 78). • Establishing a forum for discussing current knowledge about climate change and impacts. • Integrating climate change adaptation across multiple parks' departments. • Requiring minimal additional funding.	• Adding to existing staff's workload beyond capacity. • Requiring additional technical knowledge which current staff members may not possess. • Focusing too heavily on sea level rise, possibly to the exclusion of other climate change impacts.

2a Ecological Indicators to Monitor Climate Change Impacts

Strategy

Gateway could devise and implement a monitoring system that accurately identifies climate change impacts within the park, a prerequisite for an effective response to these changes. Utilizing existing or new datasets could establish this new monitoring system.

Establishing baseline climate information and tracking future measurements would allow Gateway management to identify deviations from normal readings, as well as their statistical relevance. Creating a monitoring network across the park would also provide better information to decision-makers, allowing for adaptive management.

Description

First, critical indictors could be identified. The Northeast Coastal and Barrier Network, an NPS monitoring program, currently monitors "vital signs" to track ecosystem health. The concept of ecological indicators is similar, but would specifically measure climate change impacts; indicators from this program could be adapted or filtered through a climatic change lens.

For example, Pukaskwa National Park in Canada, along Lake Superior, uses specific ecological indicators to monitor climate change. Pukaskwa's park biologists selected ten ecological indicators, including songbirds, several rare plants, caribou and, more broadly, forest health to monitor the park's health (Taylor et al., 2006, 69). While climate change adaptation plans typically include water and air temperature as indicators, using key species or ecosystems as biological climate change indicators offers an innovative and useful approach for parks.

The second step in setting up this program is identifying the necessary information Gateway is already collecting through other monitoring programs and understanding what data is missing. Gateway can begin to populate the climate change indicator datasets with existing data while beginning to collect new data as necessary.

The final step in creating an ecosystem indicator program is database analysis. Once the relevant data is collected in an indicator database, managers can use this information to track climate change impacts at Gateway. Creating a scoring tool to understand and track climate change impacts may prove useful in understanding different ecosystem impacts. Descriptions would accompany the score to add context for the rating. For instance, average monthly sea level could be used as an example indicator:

- Current levels could be given a 'green' level.
- An increase of 15 cm might trigger an "alert, area subject to flooding during storms or high seas."
- A further increase to 40 cm might trigger an alert level of "danger, coastal erosion ongoing, infrastructure threatened during storms."

Benefits

- Building upon preexisting information.
- Improving decision-making.
- Offering a starting point for interactive dialogue with other parks in the Northeast.
- Offering a platform for regional collaboration on climate change monitoring with neighboring organizations and stakeholders.
- Aiding parks in the Northeast region in planning for climate change impacts.

Challenges

- Picking the right biological indicators could be difficult.
- Gathering the data could be time consuming and expensive.
- Managing extensive data could require specialized personnel.
- Discerning which changes are meaningful could be ambiguous.

Proposed Monitoring Network

We recommend Gateway consider selecting indicator species for a proposed climate change monitoring network. Initial ideas for possible indicators are listed below.

Possible Abiotic Indicators

1) **Water levels:** A successful monitoring network at Gateway could include tracking data from the following NOAA tidal stations:

- The Battery, Station ID 8518750
- Sandy Hook, Station ID 8531680
- Bergen Point West Reach, Station ID 8519483

This data can be used to track water levels over time. Due to the high potential for storm damage, Gateway should also consider monitoring average high water levels (see Appendix A. Water Levels at Sandy Hook).

2) **Water temperature:** Some aquatic species are particularly sensitive to changes in water temperature. Tracking temperature, particularly in Jamaica Bay, would alert park staff to anomalies. Currently installed monitoring systems do not sufficiently track temperatures in Jamaica Bay and around Sandy Hook.

3) **Air temperature:** Temperature data stations at sites adjacent to known temperature-sensitive species would enable park staff to compare changes in species behavior with recorded air temperatures. Current systems focus on either weather information or a specific species and lack an integrated systems approach.

Possible biotic indicators:

1) **American eel:** This is the only fish found in Jamaica Bay that lives in freshwater but moves to saltwater in order to breed. Despite declining numbers in North American waters, their ease of identification by amateurs make them convenient indicators (Waldman, 2008). Eels are sensitive to climatic changes, specifically the strength and position of the Gulf Stream which transports young eels (Wirth, 2003). Eels may also be subject to environmental sex determination (see Box 13. Environmental Sex Determination & Climate Change; Waldman, 2008). Monitoring and analysis of eel gender and eel biology in the Jamaica Bay watershed could provide critical information on the significance of changes in water temperature in the bay and in the Atlantic Ocean.

2) **American horseshoe crab:** These crabs play a critical role in the food chain, as their eggs are important dietary components for migratory birds (Waldman, 2008). Understanding if their reproduction period is shifting due to climatic changes is critical information for Gateway management. Horseshoe crabs could prove an important climate change indicator if, for example, warmer water temperatures lead crabs to lay eggs earlier during full and new moon tides.

3) **Monarch butterfly:** Monarch butterflies exhibit particular sensitivity to temperature. In a dramatic and well-known event, monarch butterflies migrate through Jamaica Bay in autumn (Waldman, 2008). Geographic or temporal shifts in migration patterns could indicate changes in climate.

4) **Migratory birds:** Gateway could track the arrival and departure dates of key bird species to better identify changes in climate. Ideal bird species include those common to Jamaica Bay, well-documented in historical records and easily recognizable. Linking this data to horseshoe crab information could help uncover whether mistimings (phenological asynchrony) are occurring. Two suggested species are:

- Common tern: A migratory shorebird which occupies seven colonies totaling more than 1000 individuals in Jamaica Bay (Waldman, 2008).
- Barn swallow: The most numerous neotropical migrant (Waldman, 2008).

5) **Mosquitoes:** Indicators could include species not currently existing within Gateway. New species typically found south of Gateway could indicate a warming climate, possibly forecasting species range shifts. Howard Ginsberg, an entomologist, surveyed Gateway in 2001 and did not find a specific mosquito species in the park (*Anopheles atropos;* Lussier et al. 2006). This species thrives in coastal salt marsh and rock pools in the south; Maryland is the current northern extent. Dr. Ginsberg notes that, if this species was recorded in Gateway, climate change could be a contributing factor (H. Ginsberg, personal communication, 27 March 2009).

Box 13. Environmental Sex Determination & Climate Change

Some species do not undergo sex determination until after conception; these species are at greater risk of extinction, because environmental factors such as temperature and humidity influence the sex of the offspring (Hulin et al., 2009). Climate change increases vulnerability in these populations, disrupting sex ratios in offspring.

Fish and reptiles are temperature-dependent sex determination (TSD) species, since external temperatures determine the sex of the embryo. For turtles, low temperatures produce males and high temperatures produce females (Hulin et al., 2009). Gateway supports a wide array of fish species and the endangered diamondback terrapin; warmer temperatures can potentially alter sex ratios and reduce population growth in these species.

2b Keystone Species Monitoring and Management; Horseshoe Crab

Strategy

Gateway is home to a rich number of ecosystems, with complex food webs. Keystone species, which maintain other species, may be especially important to monitor for responses to changing climate conditions, to prevent loss or extinction in other populations. Gateway may consider continuing to monitor the horseshoe crab, due to its central importance in the park's food web.

Description

Gateway collects data on many species within its boundaries. Gateway could use new and existing monitoring programs to track keystone species' responses to climate change, protecting them from adverse affects. For instance, a Horseshoe Crab Monitoring and Management program could build upon the NPS' current program by continuing to utilize GIS to periodically track and map horsehoe crab population densities. Migratory bird species dependent on horseshoe crab eggs could be identified and monitored in order to analyze the relationships between the horseshoe crab and these charismatic populations. Specifically, migratory birds' weight gain could be monitored to establish whether the birds are gaining sufficient fat reserves to complete migration (Mizrahi, 2006). If horseshoe crab populations do not rebound to appropriate levels, the program could also investigate captive breeding programs and expanding sandy beach habitats.

The program could include provisions to prevent crab harvesting and maintain suitable horseshoe crab populations. Until the spring of 2008, the horseshoe crab harvest quota for New York was approximately 350,000 individuals per year; this quota was voluntary. Starting in February 2009, however, the quota became fully enforced within Gateway.

Goals

Researchers have observed declines in horseshoe crab abundance at Gateway (Sclafani, 2006). Climate change will likely cause horseshoe crab populations to decline more rapidly in the future, through damaged salt marsh and tidal flat habitats. Monitoring and managing these populations would help maintain horseshoe crab populations, as well as the species that depend on them, preserving this species as a key component of Gateway's Jamaica Bay ecosystem.

Benefits

- Protecting an endangered species that depend on critical food sources.
- Interacting with existing data collection activities.
- Using student volunteers can decrease costs.

Challenges

- Challenging enforcement due do staffing and budgetary limitations.

2c Coping with Invasive Species and Species Range Shifts

Strategy

Establish a research, monitoring and control program, in coordination with partners, to cope with species range shifts and invasive species under climate change.

Description

Gateway will need to plan and respond to species range shifts due to changing climatic conditions. A rise in mean minimum temperatures will assist the northward expansion of many species (Parmesan et al. 1999), and species currently limited by cold weather will be more difficult to control (Hellmann et al., 2008). As some native species migrate out of the park, new, non-native species may arrive in their place.

In some cases, non-native species may be benign or could prove beneficial, helping to stabilize ecosystem functions. Other non-native species may expand rapidly, encroaching on other species' habitats and threatening the ecosystem's biodiversity. Species that are disturbance-adapted may thrive as a result of disruptions associated with climate change, including vegetation loss and changes in species diversity (Zabaleta & Royal, 2001). Gateway management will face the challenge of distinguishing between non-native and invasive species, which is often a difficult task. Understanding what new species may arrive in Gateway due to climate change impacts, and how these new species will interact with Gateway's ecosystems, can help managers prepare for these changes.

As well as determining what species are likely to arrive in Gateway, the park could organize a conference to discuss what might constitute a harmful invasive species as opposed to a non-native species pressured to migrate by climate change. This may involve ethical dimensions, including species valuation and discussions on appropriate control mechanisms. Once a list of likely invasive species is established, Gateway can develop research, monitoring and control programs.

Potential participants in a discussion of what species should be considered invasive include the NPS Washington Office, NPS Northeast Region units, Greenbelt Native Plant Center, New York City Parks and Recreation and New York City Botanical Gardens.

Benefits

- Sharing information among parks may lead to more effective regional collaboration.
- Anticipating species changes proactively may reduce costs.
- Providing a framework for devising strategies to address unexpected species that appear in the park.

Challenges

- Navigating uncertainty on what species may arrive at Gateway and how they may interact with existing species.
- Navigating internal debates over valuation and ethical control approaches.

3a Sediment Trapping to Control Coastal Erosion

Strategy

Erosion threatens critical habitat and cultural resources. Although erosion is a natural process, climate change impacts are likely to increase erosion rates. Installing small-scale sediment traps in erosion-prone areas could increase accretion rates and slow erosion. This option considers techniques to address erosion in tidal wetlands and sandy beaches.

Tidal Wetlands

Gateway has used large-scale permeable fabrics (geotextiles) to rebuild wetlands; these techniques have proven successful yet costly (Vadino, 2006). In the Jamaica Bay Watershed Protection Plan (2007), the New York City Department of Environmental Protection (DEP) proposes using sediment-filled biodegradable geotextile tubes filled with sand or dredge material to continue preserving wetlands (DEP, 2009).

Gateway could use small, biodegradable pre-seeded geotextile tubes, as well as filtration enhanced devices (FEDs) to recreate wetland and eroded coast. FEDs are similar to geotextile tubes, but are generally filled with straw instead of sand. This makes FEDs easier to transport and install, but less resistant to wave action. FEDs and geotextile tubes enhance wetland development by increasing accretion rates, slowing erosion and spurring plant colonization. Both of these techniques have proven more useful when pre-seeded or plugged with seedlings; the most common plant for seeding is smooth cordgrass (*Spartina alterniflora*; Marterne, 2006).

Certain strategies can improve sediment traps' success rate, lowering costs. Strategically placing sediment traps reduces labor and capital costs. Using sediment mapping tools or observation can determine optimal locations. Utilizing stone anchors, rather than stakes, can help increase strength, ensuring installations can withstand wave and tidal actions. Using recycled burlap bags made from natural fiber can also reduce costs; fibers such as kenaf or jute may prove more durable (DEP, 2009).

Sandy Beach

Using scrap brushwood can help create erosion barriers around dunes. Partnerships with New York City could potentially provide a low-cost source for materials such as discarded Christmas trees and brush. This technique involves constructing low fences of brush in rows, or shaving and burying portions of Christmas tree trunks in the ground. Sediment builds up until it eventually buries the treetop or brush fence. In washed-out areas, the trees are laid horizontally and the branches cause sediment to deposit. The accumulated sediment provides footholds for re-vegetation. Overtime, the scrap brushwood becomes part of the re-vegetation process, leaving behind nutrients as it decays (EURIS, 2009).

Benefits

- Using natural and biodegradable materials contributes to sustainability.
- Small geotextile and FED tubes are easier to install than large tubes.

Challenges

- Projects may require review from the Army Corps of Engineers and/or the USGS.
- Materials may weather quickly.

3b Strategic Land Acquisition & Partnerships

Strategy
Gateway can expand habitat and buffer zones through strategic land acquisition and partnerships.

Description
Expanding Gateway's buffer zones through strategic land acquisition and partnerships could help relieve some of the pressure on Gateway's ecological resources. Unlike many National Parks, Gateway lacks the necessary buffer zones to lessen the impacts of climate change, particularly sea level rise. Unbounded beaches are able to adapt to storms, waves and currents by going through natural regeneration cycles. However, urban development confines Gateway's coastline (Schlacher, 2007). Small increases in sea levels typically result in increased erosion, decreasing available habitat (Voice, Harvey and Walsh, 2006, 45-46). Purchasing adjoining lands and critical habitat areas, and building partnerships focused on land management and conservation can provide additional buffer space to Gateway's ecosystems and species.

As the current General Management Plan notes, Congress permits acquisition of prime shoreline areas using federal funds (Gateway National Recreation Area, 1979). Many NPS parks have recently proposed legislation to expand their boundaries (Holleman, 2009; Duffy, 2009). Gateway currently has a map of available areas bordering park lands. Gateway could examine any changes to land ownership or availability in the area, update the map, and begin to identify and prioritize those parcels which offer the greatest potential benefits to reduce ecosystem vulnerability. Gateway could then coordinate land acquisitions with partners and with the National Park Service. For natural areas not available for purchase, Gateway can partner with land owners to create conservation programs and corridors between core areas owned by different parties.

Goals
- Lessen coastal habitat loss from sea-level rise.
- Buffer existing park areas, offsetting the effects of fragmentation.
- Expand coastal habitat, allowing for natural coastal migration.
- Link natural areas, aiding species through migration corridors and providing footholds for some species.

Benefits

- Halting development on land adjacent to the park through conservation partnerships.
- Converting marginal land in the New York Harbor area into valuable, usable park space.
- Building upon existing core missions of groups such as Sustainable South Bronx, Hudson River Park Alliance, and Environmental Defense Fund.
- Preserving or reclaiming non-federal lands in coordination with NPS and in support of Gateway needs via non-traditional land partnerships (Hamin, 2001).

Challenges

- Much land available for acquisition is altered and may be degraded requiring expensive restoration.
- Roads and parkways encircle much of Gateway, presenting hard barriers to expansion.
- Adjacent land is either private property or property of New York City. The City may be reluctant to cede developed land to Gateway.
- High land value in New York City area presents high cost of acquisition.
- Acquisition of land not immediately adjoining parkland may present further management and maintenance challenges given limited resources.

Current Efforts

Multiple state and city agencies are currently working to preserve open space in and around Gateway. Two examples include the New York State Open Space Conservation Plan (OSCP) and the Environmental Protection Fund (EPF) Local Waterfront Revitalization Program. The EPF Local Waterfront Revitalization Program goals include:

- Identifying areas in danger of flood impacts.
- Establishing zoning laws to protect these areas from development.
- Aiding local government and non-profit acquisition of priority coastal properties.

The OSCP actively supports climate change adaptation by:

- Facilitating intergovernmental land transfers and connections between urban greenways and parks.
- Developing tools with NYS Department of Transportation (DOT) that aid in integrating aquatic conservation objectives into road planning, which could also benefit in creating corridors.

Gateway could work with OSCP and EPF, as well as other partners, to identify land it wishes to acquire, prioritize lands that the EPF may not conserve on its own, and/or suggest lands for the EPF to protect. See Appendix D. Land Acquisition & Partnerships for a list of potential organizational partners.

3c Increasing Habitat Connectivity

Strategy
Increasing connectivity in Gateway through wildlife corridors can assist wildlife in adapting to climate change. Gateway can focus on both increasing connectivity within the park and identifying partners to increase regional connectivity.

Description
Wildlife corridors are strips of land linking intact patches of core habitat to one another. Corridors allow plant and animal species to travel between habitat patches, assisting gene flow and new site colonization (Primack, 2004). Wildlife corridors should be robust in order to buffer climatic impacts and provide sufficient habitat for species survival (BRANCH, 2007).

Developing successful corridors programs typically involves:

- Planting diverse vegetation to provide shelter and food for animals.
- Restoring core habitat, as corridors cannot substitute for core habitats.
- Selecting indicator species that share characteristics with many other species moving through the corridor.
- Monitoring new colonization to measure the corridor's effectiveness (Queensland, 2002, p. 16-17).

Goals
This strategy can help species adapt to climate change impacts including:

- Range shifts due to temperature and precipitation changes.
- Habitat alteration as a result of sea level rise.
- Combined effects from climate change impacts and anthropogenic habitat fragmentation and deterioration.

Within Gateway, managers can evaluate the current use of available land to identify potential areas where habitat connectivity could be increased. While there is not a lot of unused land at Gateway, corridors can be creatively developed along roads or through other developed areas. In Gateway, the species that are likely to become isolated include turtles and amphibians. Even species with low mobility, such as salamanders, are able to use natural corridors, such as wet fissures, during severe droughts to reach other suitable habitats. Human-made corridors that provide suitable habitat are likely to be effective in supporting species' adaptation under climate change (Tumlison et al., 1997). Wildlife corridors can ease movement of Gateway's reptiles and amphibians by providing critical habitat connections.

Benefits

- Enhancing genetic diversity, thereby increasing species resilience.
- Preventing species isolation as habitat space decreases and becomes fragmented.
- Increasing food availability.
- Assisting low mobility and extremely climate sensitive species.
- Providing natural spaces and easing animal sightings for park visitors.

Challenges

- Requires monitoring the movement of species throughout the park.
- Determining whether movements are due to climate change or other factors will be difficult.
- Expanding corridors and habitat connectivity beyond Gateway boundaries will be crucial for long-term species migration but is dependent on the participation of other land-holding organizations.

In the long term, climate change will force species to migrate beyond the boundaries of Gateway. Because the heavily developed landscape surrounding Gateway does not allow for easy migration through the region, habitat connectivity outside of Gateway is a major challenge. While Gateway cannot influence the potential corridors outside of the park, it can consider partnering with other public and private organizations to try to increase regional habitat connectivity or promote the protection of lands that do or could serve as corridors (see Adaptation Strategy 3b. Strategic Land Acquisition & Partnerships).

3d Improving Water Quality

Strategy

Gateway could establish a water quality program in conjunction with its long term climate change planning initiatives, with a focus on Jamaica Bay. Water quality relates to climate change adaptation because poor water quality reduces ecosystem resilience. Climate change will also worsen the drivers behind water quality problems at the park.

Description

Pollution is the major source of water quality problems at Gateway. Gateway can address pollution in three ways: reducing pollution within the park, working with New York to reduce external pollution and implementing projects to improve the water quality.

1. Reducing Pollution within the Park

To address water quality internally, Gateway could focus on decreasing runoff from paved surfaces within park boundaries. Precipitation runoff from paved surfaces carries pollutants such as heavy metals, chemicals and motor oil into open water sources (EPA, 2008). Creating vegetation buffer zones that slow water and collect polluted sediments before they reach the Bay can help reduce runoff from the many paved surfaces in and around Gateway. Where buffer strips are not an option, Gateway could consider infrastructure changes such as pervious pavements on parking lots. This pavement allows water to flow into the ground (Hirschman et al., 2007). Areas where Gateway can focus to reduce runoff include the parking lot near Jacob Riis Beach and Canarsie Pier. Gateway can also consider partnering with landowners adjacent to the Bay to reduce runoff, including the US Coast Guard, US Navy Reserve and JFK Airport.

Benefits

- Gateway can improve corridors within park boundaries, or can attempt to involve outside partners.
- Buffer strips that slow and filter runoff might also serve as habitat.

Challenges

- Many areas where buffer strips might be most useful are outside of NPS jurisdiction.
- Replacing concrete with pervious pavement can be expensive.

2. Reducing External Water Quality Problems

Nitrogen pollution from the New York City wastewater system is a second target area to reduce water quality problems. Approximately 70% of New York's sewer network is part of a Combined Sewage Overflow (CSO) system that frequently discharges untreated waste into Jamaica Bay (NYC DEP, 2007). The Bay relies on treated wastewater effluent for freshwater, but excessive nutrients in untreated water undermine efforts to restore the Bay. The Jamaica Bay task force is currently working with New York to address nitrogen pollution. Gateway could bring a new focus to this partnership, emphasizing how sewage overflows into the Bay are also a climate change issue because:

- Climate change will likely cause an increase in extreme precipitation events, exacerbating the current wastewater overflow problem.

- Nitrogen pollution could decrease the success of other climate change adaptation measures.
- Temperature increases could increase the likelihood and size of algae blooms, worsening eutrophication events.

Benefits	Challenges
• The relationship between Gateway and the New York is already established. • Reducing nitrogen pollution will have significant benefits to ecosystems.	• The scale and cost of reducing sewage overflow makes progress difficult and unlikely to occur quickly.

3. Implementing Projects to Improve Water Quality

In addition to reducing water pollution, Gateway can take actions to remedy some of the existing pollution. One option is restoring oyster beds in Jamaica Bay. Oysters naturally filter water sediment and micro-algae, and eastern oysters (*Crassostrea virginica*) are native to New York's waters (see Box 14. The Importance of Oysters). Gateway is currently exploring options for eastern oyster restoration in Jamaica Bay (Frame, 2008); these projects can be continued as part of a climate change adaptation strategy.

Benefits	Challenges
• Gateway may act internally or work with partners such as the NY/NJ Baykeepers. • Oysters also provide food for other aquatic species (Frame, 2008).	• Diseases limited past restoration projects and will likely threaten future attempts (Frame, 2008). • Large-scale oyster bed projects might maximize filtration capacity, but could be considered aquaculture which is contrary to NPS policy.

Box 14. The Importance of Oysters

Oyster reefs extended 350 miles from Sandy Hook northward when Henry Hudson first arrived in 1609, but populations declined dramatically around the turn of the 19th Century due to overharvesting, pollution, disease and siltation (NY/NJ Baykeeper, 2005). Oysters are keystone species that cleanse the water. Oysters, such as the native eastern oyster (*Crassostrea virginica*), play a vital role in maintaining a healthy estuary ecosystem. The New York Department of Environmental Protection (2007) notes that a single mature oyster can filter approximately 2.5 gallons of water per hour (35 gallons a day) and can remove approximately 20% of the nitrogen it consumes.

Oysters grow in colonies forming reefs, which provides important habitat for fish and other aquatic species. Oysters provide habitat for biofoulers, which cling to the hard shells of oysters or surrounding substrate to make up a uniquely rich microecosystem (Raj, 2008). The realization that oysters are vital to ecosystem function has led to a series of oyster restoration programs. In 2005, volunteers with the New York/New Jersey Baykeeper participated in oyster gardening, using remote sensing to restore oyster populations near the Sandy Hook Unit. The Department of Environmental Protection has also implemented the Oyster and Eel Grass Restoration Pilot Study (DEP, 2007).

3e Adaptive Restoration

Strategy
Gateway is currently implementing salt marsh restoration projects. Climate change will further damage salt marsh habitat; as a result, restoration is a major adaptation effort. In addition to current projects, Gateway can consider focusing on several smaller, modular projects. The smaller sites are essentially tests sites to attempt a variety of techniques, in order to understand best practices.

Description
Climate change will make Gateway's ecosystems, particularly salt marshes, increasingly vulnerable. Salt marshes provide a wide range of environmental services, including water filtration, storm surge protection and critical habitat. Salt marshes are one of the most difficult ecosystems to protect in the face of climate change for many reasons:

- Salt marsh is highly vulnerable to sea level rise.
- Nitrogen loading and turbidity hinder salt marsh vegetation development.
- Salt marsh is already disappearing and is difficult to recreate once lost.

Salt marsh is integral to coastal adaptation. Without maintaining salt marsh ecosystems, protecting many species that inhabit Gateway, either permanently or during migration, may be impossible. In the face of human stressors and sea level rise, Gateway's inter-tidal wetlands will vanish by 2025 without drastic human intervention (Lloyd, 2006).

In partnership with USACE, NYCDEP and NYDEC, Gateway has restored 40 acres of salt marsh at Elders Point East using dredge material. Gateway is duplicating this successful project to restore 25 acres at Elders Point West and 30 acres at Yellow Bar Hassock. Given the rapid rate of salt marsh loss, totaling 63% since 1951, these projects are essential for maintaining this critical habitat but may not be able to keep up with loss (Gateway et at., 2007).

An option for Gateway as they continue salt marsh restoration in the future is an adaptive restoration, taking the following approach to uncover best practices:

- Creating small, test project sites to pilot different techniques.
- Inter-planting a variety of native species to improve mature wetland habitat formation.
- Monitoring and recording how and why different methods work to improve future projects' success.
- Using larger upfront costs to decrease costs in the long term, when projects are expanded.
- Collaborating with other restoration projects to understand new techniques and best practices (Zedler, 2003).

Benefits

- Building upon previous success; past projects indicate that this is a feasible option for adapting to climate change.
- Decreasing costs through best practice utilization.
- Preserving salt marsh not only improves habitat but is also a more cost-effective barrier to storm events than "hard" engineered solutions.

Challenges

- Increasing maintenance costs due to sea level rise acceleration if more efficient restoration techniques are not found.
- Restoring sites may eventually prove futile due to sea level rise and other stressors.
- Funding may become more difficulut to access since project funding often require a life span of 30 years (USEPA, 2009).

4a Protecting Cultural Resources

Strategy

Physically reinforce cultural resources to protect them against sea level rise, saltwater incursion, and erosion. Where reinforcements are impractical, consider relocation.

Description

Climate change threatens the long-term viability of some of Gateway's important cultural resources through increases in erosion, saltwater incursion, and sea level rise. Unlike the 'soft approaches' available for ecosystem adaptation, cultural resources may require hard, or more engineering-intensive, solutions such as building sea walls and protecting buildings from increased weathering through building alterations.

In some cases, historic buildings and objects may need to be moved to higher ground. As in adaptation planning for ecosystems, adaptation planning for cultural and recreational resources may require new management strategies, and will depend heavily on physical adaptation of landscapes and structures. In addition, implementing hard approaches will likely vary from unit to unit at Gateway, since the cultural resources are quite different from site to site. Any changes must be in collaboration with the State Historic Preservation Officers in New York and New Jersey. For further information on non-climate factors affecting this approach, it may be helpful to consult two Department of the Interior publications: Moving Historic Buildings, by John Obed Curtis (1991) and the Historic Lighthouse Preservation Handbook (1997).

Goals

- Provide long-term physical protection for threatened cultural resources.
- Identify those resources most at-risk to changes in climate and sea level.
- Prioritize cultural resources requiring relocation.
- Identify potential sites for receiving relocated structures and landmarks.
- Avoid long-term recurring costs from insufficient soft measures (Schneiderman, 2003, 215-216).

Benefits

- Providing long-term physical protection of important historical and cultural landmarks. Properly planned and executed projects could last hundreds of years.

Challenges

- Requiring significant financial resources and long-term budgeting, planning and construction.
- Identifying suitable sites for relocating cultural buildings. Parkland is already at a premium; most potential sites will present some disadvantages.
- Significantly impacting the environment at both the new and old sites.

1. Sandy Hook Unit

From an adaptation perspective, maintaining Officer's Row may require relocating buildings or erecting sea walls. In the near-term, erosion control measures described previously can help slow the impacts of sea level rise. Documenting Fort Hancock, including its batteries, may be the only way to provide a historical record of these resources; full physical protection of the site may not be possible given the high cost. At this point, many of the guns and historic components associated with Fort Hancock have already been moved from the site; this may need to continue into the future.

A second possibility is to consider some of the harder options mentioned in Maryland Shorelines Online (2009). Projects in and around the Chesapeake Bay employ artificial barrier reefs and oyster reefs and shoreline sills to slow water energy impacting beach areas, thereby slowing erosion. Similar measures could be adopted off of Sandy Hook or Rockaway point. Artificial reefs offer additional benefits as aids to marine ecosystem development (Urbina, 2008).

2. Staten Island Unit

From an adaptation perspective, Battery Weed's sea walls could be improved, but this strategy is likely limited. Given current projected sea level rise within the next 40-90 years, this fortification is likely to face increasing inundation (see Figure 6. Elevation for Cultural Resources). Moving Battery Weed would be very expensive and logistically challenging. More feasible options would include careful documentation of the Battery or removal of a small section of the structure for preservation. Given the Battery's sturdy construction, it is also possible to leave it as is, and dedicate it as a monument to measure and teach sea level rise, as noted in the "Documenting Resources" option. The Battery would likely survive sustained saltwater incursion, and could be viewed from above as waters rise.

At Miller Field, sea walls could prevent erosion and guard against sea level rise. Since most of Miller Field is grassy land used for sports and recreation, there is also the potential for increasing the actual height of the area by adding more land. Due to the high costs associated with these measures, adopting soft erosion controls may present more economically viable options. Storm damage to Miller Field, while costly, can be repaired relatively simply, thus favoring the employment of softer measures.

3. Jamaica Bay Unit

Floyd Bennett Field faces similar problems of coastal erosion and sea level rise. It would be harder to re-elevate this field, due to historic buildings and runways as well as the grassland habitat. Efforts to protect against sea level rise and erosion are already being implemented. Gateway should consider incorporating sea level rise projections into planning long-term solutions for the field's waterfront.

4b Documenting Resources & Climate Change Education

Strategy

Gateway could design educational programs and tours in impacted sites to illustrate climate change impacts and inform visitors about actions they can take to mitigate climate change.

Description

In areas where Gateway can not feasibly protect resources from climate change impacts the park could create "living museums" as examples of local climate change effects. First-hand observations may provide a meaningful and intense exhibit of climate change and other synergistic stressors on the park. This may encourage visitors to make changes in their lifestyle, helping to reduce emissions.

An example site for this type of educational tourism is Battery Weed, where the original sea-wall and lower portions of the waterfront exterior are already threatened by rising sea levels, erosion and other factors. Adaptation options to preserve the Battery may be too costly, leaving it vulnerable to the rising sea.

In the development of this option, historical sites may play an important role as they are a significant cultural resource for Gateway. However, this idea is also applicable to natural resources. Gateway could document and share species and ecosystems that may no longer exist at Gateway in the future.

In order to educate visitors, Gateway could create an exhibit at the park devoted to climate change. This could help raise awareness on local climate change, and could be a destination for school field trips. The exhibit could include:

- Explanations of why climate change is occurring, how species react and Gateway's adaptation and mitigation efforts.
- Maps and photographs documenting changes around the park including "before and after photographs" of original sites.
- A display of past and present species occupying Gateway's ecosystems.
- Ideas to help households and individuals help fight climate change.

Benefits

- Extending Gateway's climate change adaptation initiatives beyond the park through educational programs.
- Using funds more effectively through targeted adaptation.
- Ensuring preservation through documentation and display.

Challenges

- Making the difficult decision that a resource or species can not be saved.
- The NPS may not consider this adequately fulfilling the obligations under the Organic Act.

Conclusion

Over the next century, climate change will significantly affect human and ecological systems. In the past few decades, climate change science has grown in certainty. While attention has historically focused on mitigation efforts, adaptation is beginning to emerge as an important area. Climate adaptation is critical, since current GHG concentrations will already cause climate change impacts in the next few decades. As a result, society must begin to take steps to prepare for and buffer against climate change impacts. At Gateway National Recreation Area, climate change adaptation means increasing ecosystem resilience and protecting cultural and recreational resources from damage or loss.

Gateway does not currently have a climate change adaptation plan in place. The development of a new General Management Plan this year is the ideal opportunity to incorporate climate change considerations into planning and decision-making across all three park units. A comprehensive climate change adaptation strategy may include both reactive and preventive responses to both observed and projected impacts. It may also include broad management responses, such as forming task groups and partnerships and specific physical responses such as fortification technologies. Finally, a successful climate change adaptation strategy will include adaptive management. Strategies will need to be revised as new climate change projections from the IPCC and other sources come to light.

The options for an adaptation strategy outlined in this report are an initial framework from which Gateway can build an adaptation strategy. It is not a complete plan, but rather a starting point intended to provide ideas and suggestions to develop further. The findings in the climate change impacts sections may help guide Gateway in making the case for proactive planning, incorporating climate change into its General Management Plan, as well as educating visitors about climate change and its impacts.

These suggestions are specific to Gateway, but climate change will impact all National Park System units. As is clear from the recent Secretarial Order, climate change will exert significant stress on Department of the Interior resources; the National Park System, in particular, can act proactively to stem these effects. Climate change adaptation is critical for Gateway National Recreation Area and fellow NPS units. Implementing an adaptation strategy can help Gateway fulfill its mandate to continue to preserve and protect the park's natural and cultural resources for future generations.

Appendices

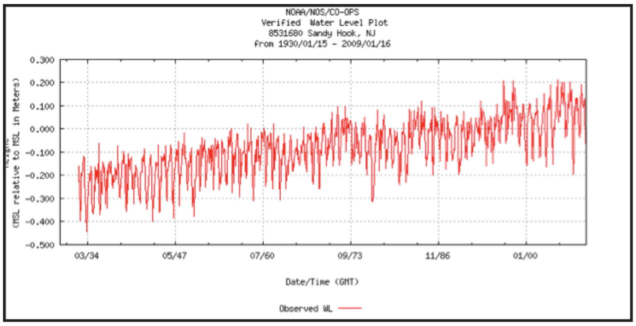
Appendix A. Water level monitoring at Gateway; Example, Sandy Hook

Water level monitoring at Gateway; Example, Sandy Hook

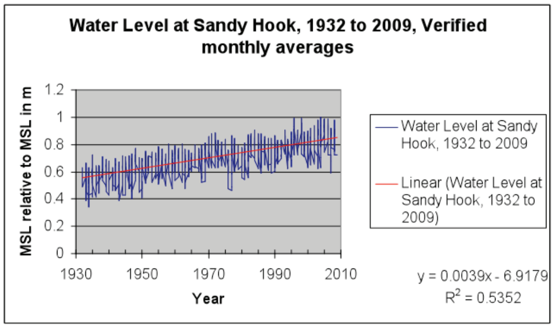
A successful monitoring network at Gateway could include tracking data from the following NOAA tidal stations:

- The Battery, Station ID 8518750
- Sandy Hook, Station ID 8531680
- Bergen Point West Reach, Station ID 8519483

This data can be used to track verified water levels over time, as well as high water levels (see Appendix: Water Level at Sandy Hook). For instance, verified mean sea level water levels at Sandy Hook from 1930 to 2009 are shown in Graph 1. Reconfiguring the data and adding a trend-line we can translate this data into Graph 2.



Graph 1. Sandy Hook sea level from 1930-2009



Graph 2. Sandy Hook trend 1930-2009

In conducting an analysis of the data trends, one finds a 3.9 mm average annual increase in sea level at Sandy Hook over 77 years. Based solely on current trends, this suggests an increase in sea level of 35.5 cm at Sandy Hook by 2100. By continuing to monitor these trends for sharp or sudden increases (outliers from the above data set), GNRA will be alerted to heightened threats of erosion or beach-loss.

Mean sea level relative to mean sea level is the most common statistic for measuring water level. However, due to the high-cost in potential damages caused by extreme water levels, Gateway should also monitor "monthly highest sea level." This data is available from NOAA tidal stations and would allow Gateway to understand the frequency and level of extreme high waters. The IPCC emphasizes the need for this data, noting that "extra-tropical storms… are likely to become more intense, but perhaps less frequent, leading to extreme wave heights in the mid latitudes" (Meehl et al., 2007, Section 10.3.6.4). Taylor et al. argue that "preparing for such events should be a priority" for all communities, and suggest appropriate preparatory actions, including "updating and revising (as required) design criteria, codes and standards for structures and facilities such as culverts, bridges, and water treatment plants as well as community disaster management planning" (2006, iii). These intense weather events will surge water levels, so tracking water level highs is crucial information in adaptation planning.

Appendix B. Gateway Ecosystem Maps

- Figure 7. Ecosystems at Sandy Hook Unit
- Figure 8. Ecosystems at Staten Island Unit
- Figure 9. Ecosystems at Jamaica Bay Unit

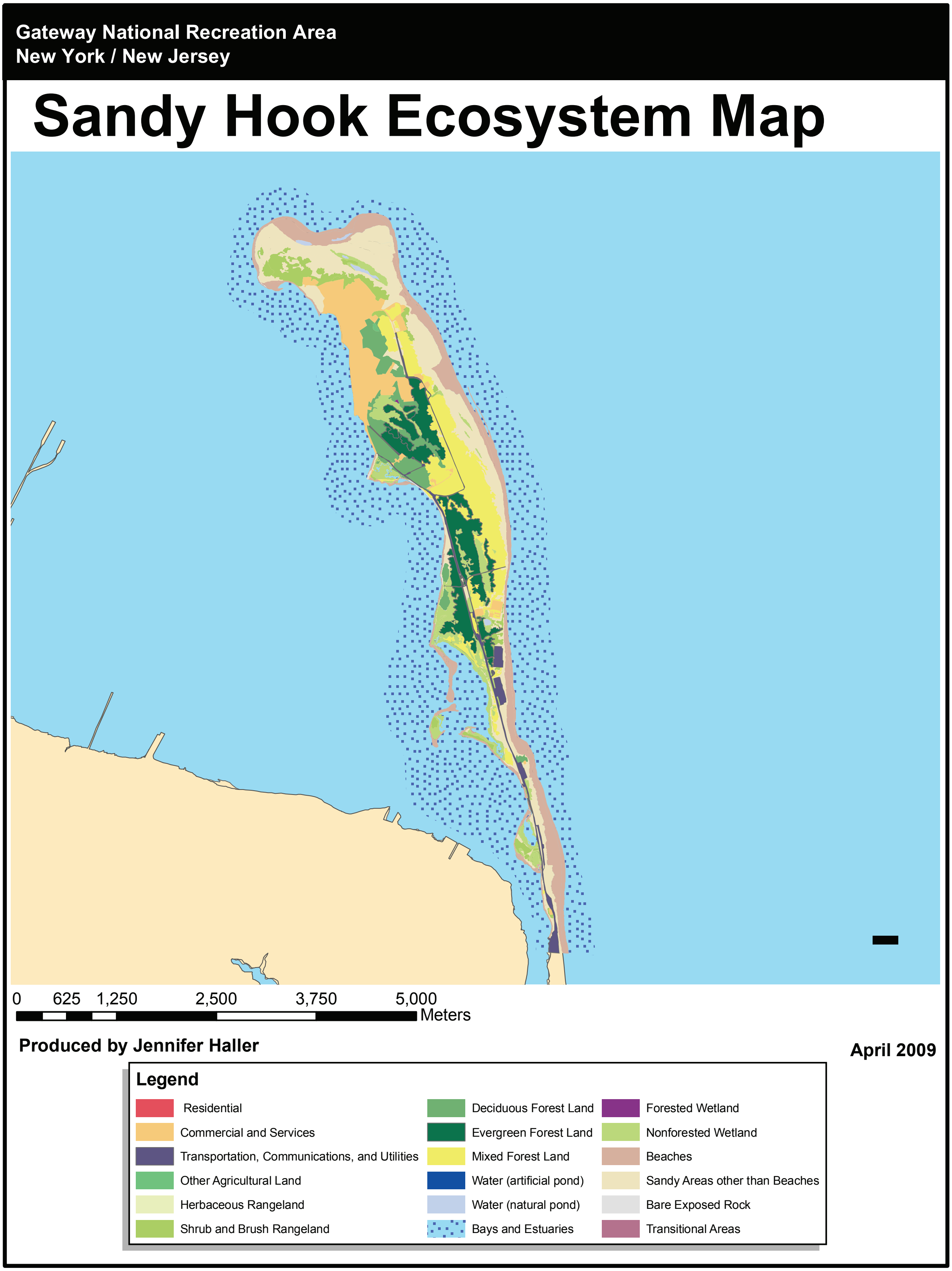


Figure 7. Ecosystems at Sandy Hook Unit

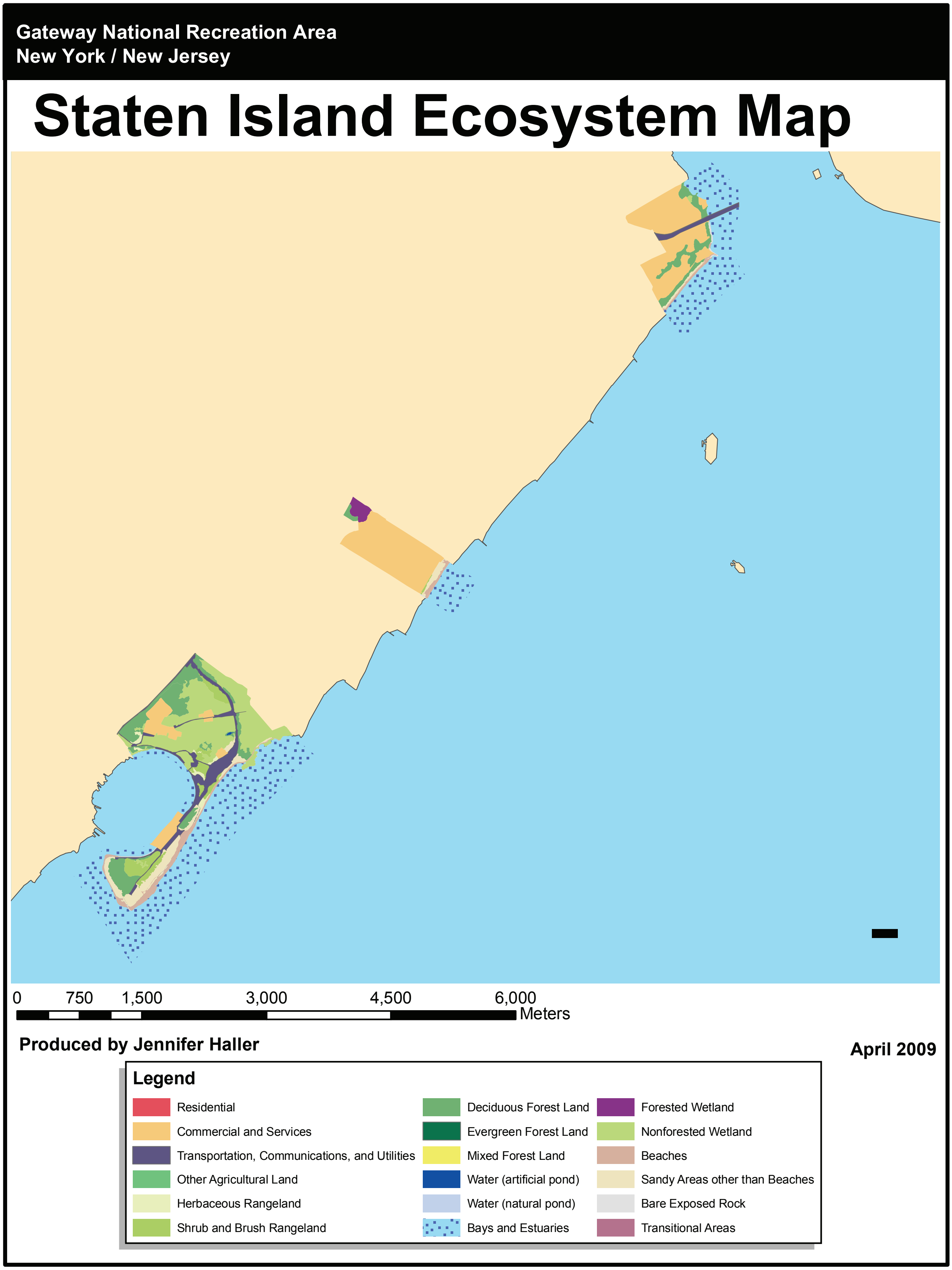


Figure 8. Ecosystems at Staten Island Unit

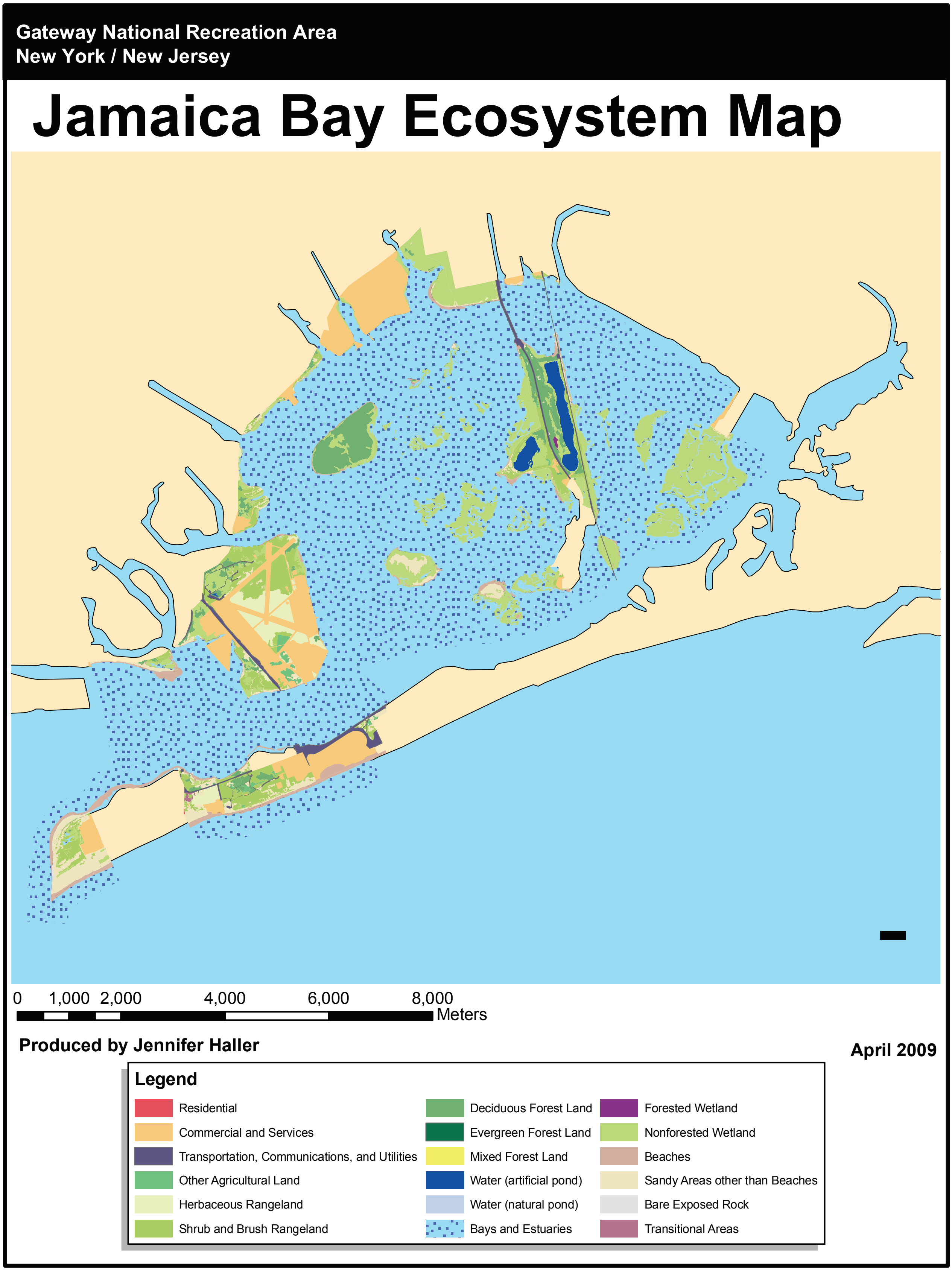


Figure 9. Ecosystems at Jamaica Bay Unit

Appendix C. Overview of Climate Change Adaptation Best Practices

In response to warming temperatures and extreme weather events, cities, states and countries realize the need to plan for climate change. Across the globe, community leaders are developing and implementing climate change adaptation plans. The overview of global adaptation plans provided here focuses on policies with elements relevant to Gateway, including ecosystem management and habitat, wetlands and coastline protection. Identifying climate change adaptation best-practices can assist Gateway in developing a sound adaptation strategy.

Australia: City of Melbourne

The City of Melbourne, Australia Climate Change Adaptation Strategy addresses climate change impacts on the city. Melbourne's plan identifies four key climate change risks, along with adaptation strategies to counter each risk. These risks are: drought and reduced rainfall; intense rainfall and wind events; extreme heat wave and bushfire; and sea level rise.

Strategies are divided into short term and long-term measures. Understanding climate change risks, then implementing response strategies and measuring their results, provides a useful format for an overall adaptation strategy. The report notes that all stakeholders have a shared responsibility, and that cooperation is critical. Many adaptation options address multiple risks, generating synergies. Some of the specific adaptation strategies proposed are:

- Develop stormwater harvesting and re-use to counter more frequent drought.
- Develop and Implement a Heatwave Response Action Plan.
- Future proof planning, incorporate sensible precautions and contingencies for proposed future developments, or potentially restricting certain types of development in areas with a high risk of natural attrition due to sea level rise.
- Better protection for existing, low-lying developments.
- Better flood control through revised drainage planning.
- Measures to improve resilience to exposed infrastructure.

The Melbourne Plan uses a detailed planning model called 'the concentric circles of consequences.' This tool enables managers to visualize links between cause and effect, ensuring that critical climate change impacts are not overlooked. This tool could prove useful to Gateway planners in identifying climate change risks and corresponding impacts upon the park.

Canada: The Great Lakes

The Natural Resources Canada report, entitled *Coastal Zone and Climate Change on the Great Lakes* focuses on the impacts of climate change on the Great Lakes region, to include analysis of impacts on national and provincial parks. Long Point Biosphere Reserve, along Lake Erie, is especially relevant to Gateway since it is a major staging area for waterfowl and has extensive submerged wetland vegetation. The report contains innovative options that could be applied at Gateway, including:

- Using ecological indicators to monitor overall park health and ecosystems' responses to climatic changes (Example from Pukaskwa National Park).
- Recognizing the Great Lakes as a unified watershed comprised of many different political and social actors, species and ecosystems. This approach helps foster broad, coordinated planning.
- Considering multiple climate change impacts facing the Great Lakes communities. These impacts are traced out into their second, third, and fourth order effects.

European Union: Project Safecoast: A Collaboration of Five North Sea Countries

Five North Sea countries established Project Safecoast to share knowledge and information on coastal flood and erosion risk management. Through this process, two types of coastal protection measures were identified: soft and hard measures. According to this report, hard protection strategies:

- Often disrupt ecosystems.
- Require extensive planning, coordination, and financial resources.
- May ultimately provide the only suitable measure to protect coastal resources.

According to this report, soft protection strategies:

- Can be applied faster, usually with more cost-effective results.
- Act like buffer zones to protect the land from the sea.
- Support natural dune formation through passive drainage (Ash, Baarse, Roode and Salado, 2008).

European Union: Natura 2000 and the BRANCH Project

Communication on Halting the Loss of Biodiversity by 2010 – and Beyond delineates key policy areas, including ecosystem conservation and biodiversity protection, in a changing climate. The report recommends adopting policy measures to:

- Ensure adequate financing.
- Strengthen decision-making.
- Increase partnerships and public education.

The Natura 2000 Network is the world's largest network of protected areas. The Network attempts to implement sustainable management, share best practices, provide information to government agencies, and support conservation programs.

To assist species in climate change adaptation, Nature 2000 endeavors to foster ecosystem resilience and to enhance the connectivity among core biodiversity areas (Jones, Silva, Eldridge, Murphy & Goss, 2008). This issue is being handled by the BRANCH (Biodiversity Requires Adaptation in Northwest under a Changing Climate) project. The BRANCH project has developed research and best practices experiments on wildlife climate change, making use of spatial planning and land-use systems. Some of these best practices could be implemented at Gateway.

United States: Maryland

The Living Shores Program, adopted by Maryland and replicated in Virginia and North Carolina, addresses erosion, coastal flooding and bluff failure. This program combines soft and hard measures to protect coastlines. Living Shores projects pay particular attention to wave energy along the coast. High wave energy coastal areas may require harder measures to prevent erosion, or offshore reefs to slow waves.

The Living Shores project introduces several innovative coastal protection measures which may be useful at Gateway, including:

- Emplace rock fill below mean sea level to provide a stable foundation for coastline reconstruction. These rock fills are built upon using natural vegetation, sand fill and other natural materials to reconstruct a natural habitat and coast.
- Partially connect marshy island systems to the mainland, creating a series of protected coves. These areas of low wave energy provide ideal habitat for terrapin nesting and promote the growth of submerged aquatic plants. (See the Horsehead Wetlands shoreline restoration project in Queen Anne's County).

Reduce wave energy further away from the shore by creating a system of offshore oyster bars using stone rumble. Use barrier rings or "stone sills." Moderate wave energy gradually eroded a high bank shoreline. In response, coastal managers constructed a stone sill in a semi-circle around the eroded area, filling the ring's interior with a fringe marsh habitat. The sill reshaped the shoreline's contours, improving protection against wave action while still allowing water flow to the marsh (See the London Town Public House and Garden in Anne Arundel County).

The Living Shores program can potentially be replicated at Gateway because of its emphasis on using natural material and barriers to protect the coast. The design measures and principles of this traditional coastal management program should serve equally well as climate adaptation measures.

Appendix D: Land Acquisition and Partnerships

Gateway's location within the New York harbor area creates a complicated land-use dynamic. The city's air, noise, and water pollution have real and significant impacts upon the park. The park lacks a substantial buffer zone between its natural systems and urban areas. Partnerships with neighboring stakeholders and agencies could be developed to address land use of adjacent areas in order to reduce negative impacts on the park. Under ideal conditions, these partnerships could present options to acquire land to expand the park or create a suitable buffer zone.

Key Potential Partners for Gateway could be:

Federal:
- Army Corps of Engineers (responsible for major habitat restoration)
- U.S. Coast Guard (possesses neighboring facilities)
- U.S. Navy (possesses neighboring facilities)
- U.S. Fish and Wildlife Service

State:
- New York Department of Environmental Conservation
- New Jersey Department of Environmental Protection
- New York, New Jersey Port Authority

City:
- New York City Department of Parks and Recreation (possesses neighboring facilities)

The following legislation could support the land acquisition program:

Federal Level:
- Section 404 of the Clean Water Act (CWA): Federal wetland credit program to convert acquired sub-prime land into functioning wetland (Shabman, Leonard and Scodari, Paul 2004), and enhance state level legislations (Zinn and Copeland, 2001).
- NOAA Coastal and Estuarine Land Conservation Program (CELCP): To support state preservation through federal Coastal Zone Management Program (CZMP).
- Coastal Zone Management Act (CZMA): To fund state restoration and protection efforts of coastal lands.
- Water Resource Development Act (WRDA): To regulate dredging and landfill projects as well as restoration and protection of aquatic habitats by the USACE.

State level:

- New Jersey Freshwater Wetlands Protection Act, N.J.S.A. 13:9B: To preserve wetlands from unnecessary disturbance.
- New Jersey Coastal Management Program (NJCMP): To ensure that coastal resources are conserved though cooperation with other state programs and nonprofit organizations (NJCMP, 2009).
- The New Jersey Wildlife Action Plan (WAP) : To coordinate wildlife research and management and provide for research into climate change impacts on wildlife and adaptation strategies (Division of Fish and Wildlife, 2008).
- The NJ Landscape Project: to protect the habitats and imperiled species on ecosystem level.

Municipal level:

- New York City Administrative Code - Title 24 (PlaNYC 2030): To open 90% of waterways for recreation by reducing water pollution and to preserve natural areas (City of New York, 2007).
- Waterfront Revitalization Program (WRP): Designates "Special Natural Waterfront Areas" as natural areas having connection with any waterfront activity.
- NYC Local Law 83: Inventories City-owned wetlands located within New York boundaries and looks at transferring these properties to the protection and jurisdiction of the NYDPR (New York City, 2005).

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