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

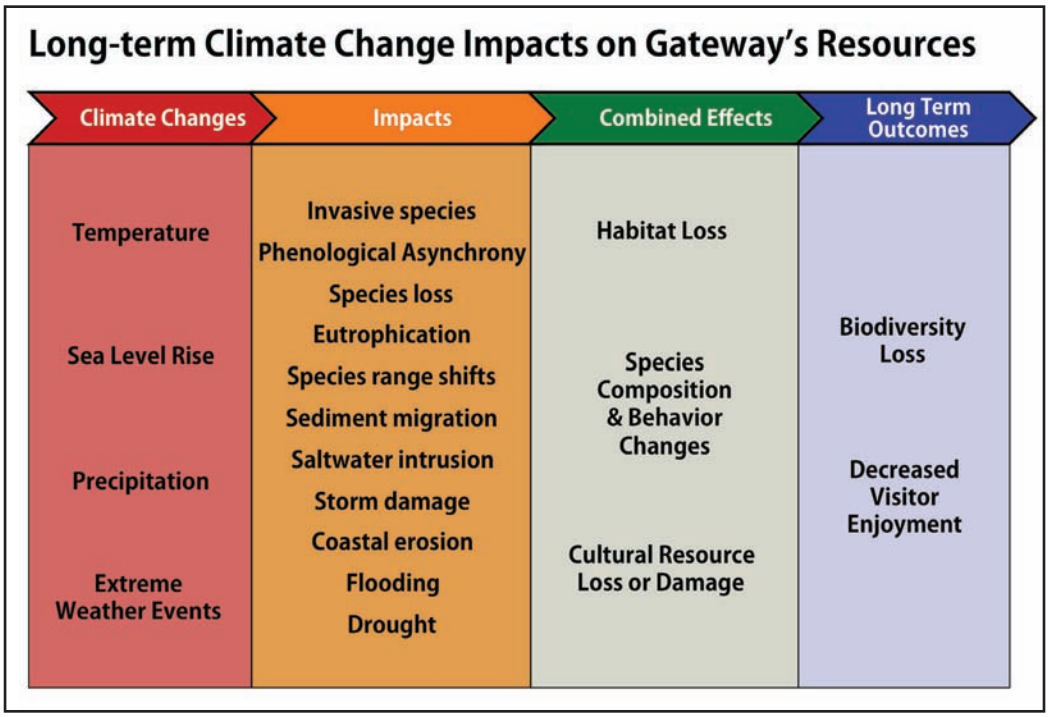
For greater detail, see Conceptual Model 1, which shows some of the combined climate change impacts at Gateway.

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).

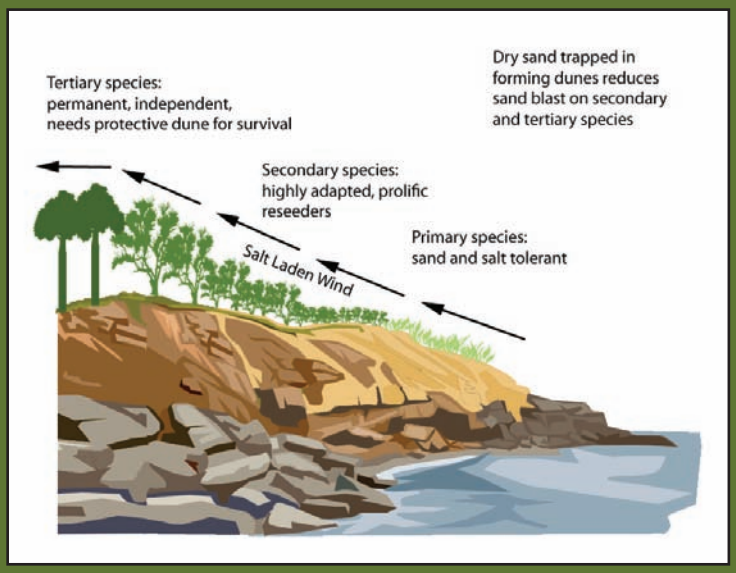


Figure 5. The Role of Coastal Vegetation. Adapted from Chapman (1989).

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.

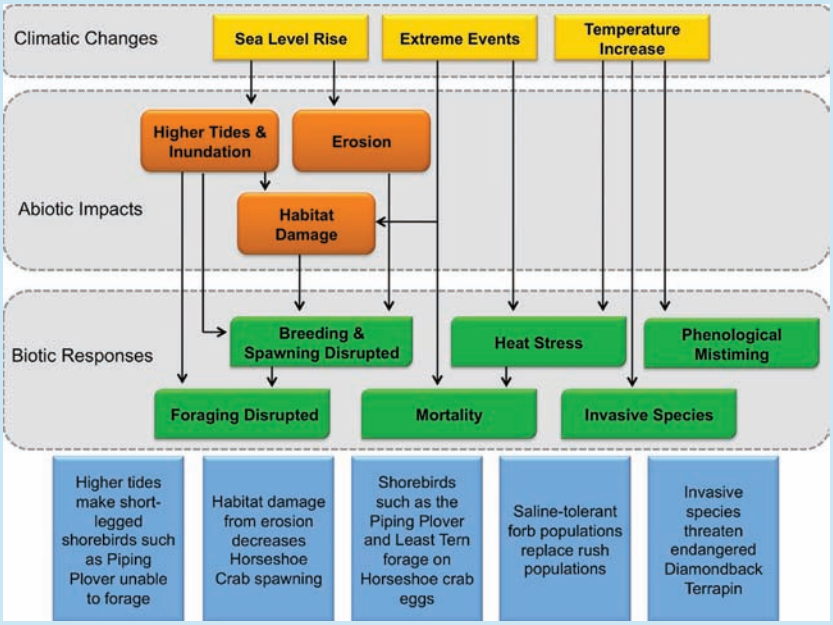
Migratory birds and butterflies are subject to the greatest harm from phenological asynchrony because of their inability to adapt to rapid environmental changes (Both et al., 2006); birds, for example, often migrate based on light cues, while their food sources may develop as a function of temperature. 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).

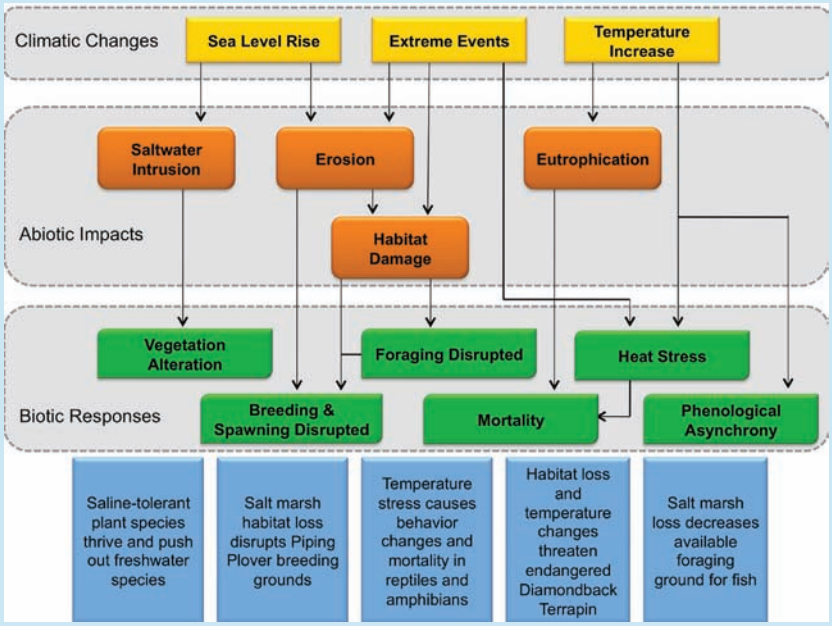
Habitat loss from sea level rise is also responsible for fewer horseshoe crabs at Jamaica Bay. The crabs depend on narrow sandy beaches and the alluvial and sand bar deposits for spawning grounds. These

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.

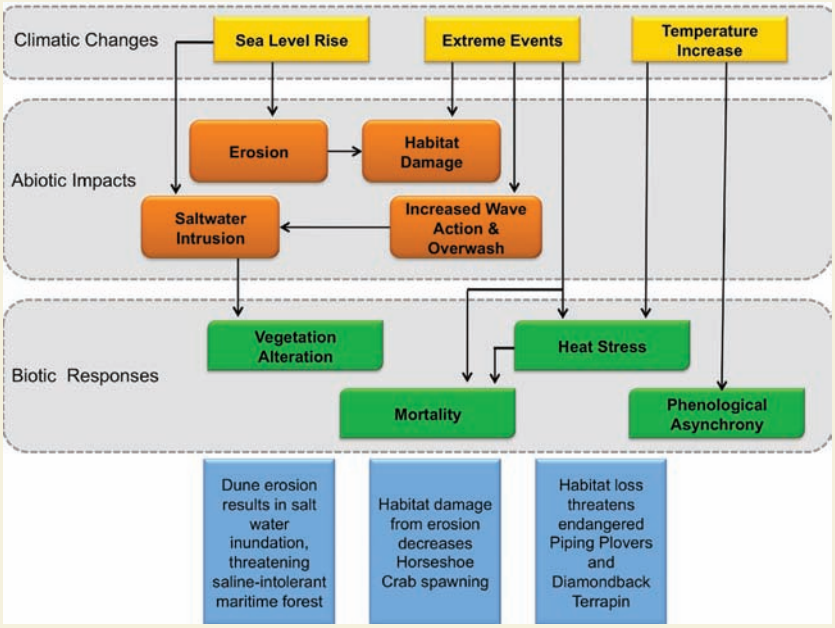
Species Case Study 2. Diamondback Terrapin

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 Sweet-bay'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).