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# National Fish, Wildlife and Plants Climate Adaptation Strategy

## Coastal Ecosystems



*Photo: NOAA*

### Disclaimer

The information in this Coastal Ecosystems Background Paper was developed by the Coastal Technical Team of the National Fish, Wildlife and Plants Climate Adaptation Strategy (hereafter *Strategy*), and was used as source material for the full *Strategy* document. It was informally reviewed by a group of experts selected by the Team. While not an official report, this Coastal Ecosystems Background Paper is available as an additional resource that provides more detailed information regarding climate change impacts, adaptation strategies, and actions for U.S. coastal ecosystems and the species they support. These papers have been edited by the Management Team for length, style, and content, and the Management Team accepts responsibility for any omissions or errors.

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## Introduction

Over the past decade, there have been increasing calls for action by government and non-governmental entities to better understand and address the impacts of climate change on natural resources and the communities that depend on them. These calls helped lay the foundation for development of the National Fish, Wildlife and Plants Climate Adaptation Strategy (hereafter *Strategy*).

In 2009, Congress asked the Council on Environmental Quality (CEQ) and the Department of the Interior (DOI) to develop a national, government-wide climate adaptation strategy for fish, wildlife, plants, and related ecological processes. This request was included in the Fiscal Year 2010 Department of the Interior, Environment and Related Agencies Appropriations Act Conference Report. The U.S. Fish and Wildlife Service (FWS) and CEQ then invited the National Oceanic and Atmospheric Administration (NOAA) and state wildlife agencies, with the New York State Division of Fish, Wildlife, and Marine Resources as their lead representative, to co-lead the development of the *Strategy*.

A Steering Committee was established to lead this effort and it includes representatives from 16 federal agencies with management authorities for fish, wildlife, plants, or habitat as well as representatives from five state fish and wildlife agencies and two tribal commissions. The Steering Committee charged a small Management Team including representatives of the FWS, NOAA, Association of Fish and Wildlife Agencies (representing the states) and Great Lakes Indian Fish and Wildlife Commission to oversee the day-to-day development of the *Strategy*.

In March of 2011, the Management Team invited more than 90 natural resource professionals (both researchers and managers) from federal, state, and tribal agencies to form five Technical Teams centered around a major ecosystem type. These teams, which were co-chaired by federal, state, and in most instances, tribal representatives, worked over the next eight months to provide technical information on climate change impacts and to collectively develop the strategies and actions for adapting to climate change. The five ecosystem technical teams are: Inland Waters, Coastal, Marine, Forests, and a fifth team comprising four ecosystems: Grasslands, Shrublands, Deserts, and Arctic Tundra.

This Background Paper focuses on coastal systems, including information about these systems, existing stressors, impacts from climate change, and several case studies highlighting particular impacts or adaptation efforts. Information from this Background Paper informed discussion of coastal impacts and adaptation measures in the full *Strategy*, and was used to develop the Goals, Strategies, and Actions presented in that document and repeated here. This Background Paper is intended to provide additional background information and technical details relevant to coastal systems, and to summarize those approaches most relevant to managers of these areas and the species they support. Some of the material presented herein overlaps with that for other ecosystem types, particularly regarding cross-cutting issues.

The ultimate goal of the *Strategy* is to inspire and enable natural resource professionals, legislators, and other decision makers to take action to adapt to a changing climate. Those actions are vital to preserving the nation's ecosystems and natural resources—as well as the human uses and values that the natural world provides. The *Strategy* explains the challenges ahead and offers a guide to sensible actions that can be taken now, in spite of uncertainties over the precise impacts of climate change on living resources. It further provides guidance on longer-term actions most likely to promote natural resource adaptation to climate change. The *Strategy* also describes mechanisms to foster collaboration among all levels of government, conservation organizations, and private landowners.

Federal, state, and tribal governments and conservation partners are encouraged to look for areas of overlap between this Background Paper, the *Strategy* itself, and other planning and implementation

efforts. These groups are also encouraged to identify new efforts that are being planned by their respective agencies or organizations and to work collaboratively to reduce the impacts of climate change on coastal fish, wildlife, and plants.

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## Description of Coastal Ecosystems

The coastal system exists at the interface between land-based and oceanic influences (Archibold 1995, Mitsch and Gosselink 2000), creating an inherently dynamic environment that (with a few exceptions such as rocky shorelines) can be reformed under short and episodic timeframes (days to decades). As defined for the *Strategy*, the coastal system is bounded by physical conditions extending seaward to mean lower-low water and landward to all lands that drain directly into an estuary, ocean (including the entirety of off-shore islands), or Great Lake (i.e. estuarine, coastal, and Great Lakes drainage areas). The coastal system includes the waters and sub-tidal zones of estuaries, semi-enclosed bays, and lagoons, along with all habitats and zones contained therein (including freshwater lenses and groundwater in coastal areas). The upstream boundary of estuaries is the head of tide and the seaward boundary extends to include areas where brackish water is present at mean lower-low tide.

The coastal ecosystem can be broken into general subsystems as described in NOAA's Coastal Change Analysis Program including: emergent and wooded wetlands (estuarine and palustrine), open water and aquatic beds within the estuary, and unconsolidated and rocky shoreline. These subsystems serve as primary and secondary habitat for a vast variety of species. There are approximately 600 species or groupings of fish and shellfish that rely on estuaries during at least one life stage. This list includes commercially important species, with estuarine species representing 46 percent by weight and 68 percent by value (greater than \$11 billion) of commercial landings nationwide from 2000 to 2004 (Lellis-Dibble et al. 2008).

Migratory and non-migratory birds, estuarine fish and shellfish, marine and terrestrial mammals, and reptiles (especially turtles) are among the fauna that reside within the coastal ecosystem. The coastal system includes important parts of bird migratory pathways (Pacific flyway, central, and Atlantic) comprising some of the most important wintering, breeding, or stop-over habitat for many migratory species. The residents often use both terrestrial and aquatic environments and many of the resident species are rare, threatened, or endangered due to human impacts on the coast. Coastal ecosystems also provide important environments for many fish species, many of which spend some portion of their lifecycle in the estuary.

Coastal ecosystems are typically dominated by plants that have varying tolerances of salinity, temperature, water level, and storm stress, resulting in discrete zonation of vegetation along the coastlines due to local site conditions and tolerance levels (Mancera et al. 2005). Often, vegetation in coastal ecosystems creates unique habitat for fauna, as with submerged aquatic vegetation, emergent wetlands, and mangroves.

Human settlement is one significant driver of change in coastal ecosystems. Globally, at least 600 million people, or 10 percent of the world's population, lives between zero and 10 meters elevation along coastlines (McGranahan et al. 2007), and in the United States, an estimated 53 percent of the population lives in coastal counties (Crossett et al. 2004). Developed areas include recreational, residential, commercial, industrial, and agricultural uses and critical infrastructure such as roads and bridges. In addition many coastal areas are used for marine commerce such as commercial fishing and shipping. In 2004, the coastal zone was responsible for nearly half of the national gross domestic product and coastal tourism contributed over \$69 billion to the U.S. economy (OCRM 2010). Development and its associated impacts (e.g. polluted runoff) are already stressing coastal ecosystems, impacts which will likely be exacerbated by climate variation and change.

The coastal ecosystem also provides many different types of ecosystem services, including controlling shoreline erosion, providing habitat for both aquatic and terrestrial animals and plants, improving water quality, providing storm protection, eco-tourism and recreation, and carbon sequestration (VIMS 2009).

Since the coastal ecosystem lies within the transition zone between marine and other inland ecosystems there are many possible areas of linkage and overlap when evaluating adaptation strategies for climate change impacts. In addition, many coastal areas have freshwater input, forming various size estuaries with saline and brackish waters, for example the Mississippi Delta area and the San Francisco Bay. Strategies addressing changes in freshwater inflow to estuaries resulting from climate change will need to be integrated.

## Impacts of Climate Change on Coastal Systems

Since 1900, global average temperature has risen approximately 1.5 °F and is projected to rise between 2 and 11.5 °F more by 2100 (USGCRP 2009). Global ocean temperatures rose 0.2 °F between 1961 and 2003 (IPCC AR4 2007). In addition to increases in air and water temperature, coastal ecosystems will experience climate impacts that include: sea and lake level changes; alterations in precipitation patterns and subsequent delivery of freshwater, nutrients, and sediment; changes in intensity of coastal storms; changes in water chemistry; and changes in sea ice. Fish, wildlife, and plants, including juvenile and adult fish and shellfish, sea turtles, and migratory birds, rely on coastal habitats and vegetation (such as mangroves, marsh plants, and submerged aquatic vegetation) for critical refuge and foraging opportunities (Shellenbarger Jones et al. 2009). These species and habitats will respond differently to climate change, with some becoming increasingly vulnerable in the future (Table 1).

**Table 1: Examples of Observed and Projected Ecological Changes Associated with Increasing Levels of Greenhouse Gases on Coastal Ecosystems (USGCRP 2009, IPCC AR4 2007)**

Major Changes Associated With Increasing Levels of GHGs	Major Impact on Coastal Systems
<b>Increased atmospheric CO<sub>2</sub>:</b>	Increased growth of algae and other plants, changes in species composition and dominance
<b>Ocean acidification:</b>	Declines in shellfish and other species, impacts on early life stages
<b>Increased temperatures:</b>	Growth of salt marshes and forested wetlands, distribution shifts, phenology changes (e.g., phytoplankton blooms), altered ocean currents and larval transport into/out of estuaries, stronger estuarine stratification, lower dissolved oxygen levels
<b>Melting ice/snow:</b>	Loss of anchor ice and shoreline protection from storms/waves, loss of ice habitat, changes in ocean carbon cycle, salinity shifts, increased shoreline erosion
<b>Rising sea levels:</b>	Inundation of coastal marshes/low islands, higher tidal surges, geomorphology changes, loss of nesting habitat, beach erosion, saltwater intrusion
<b>Changing precipitation patterns:</b>	Altered productivity, survival and/or distribution of fish and other estuarine dependent species, changes in salinity gradients, reduced Great Lake levels
<b>Drying conditions/drought:</b>	Changes in salinity, nutrients, sediment flows, and freshwater input, changing estuarine conditions may lead to hypoxia/anoxia, new productivity patterns
<b>More extreme rain/weather events:</b>	Higher wave heights and storm surges, loss of barrier islands, beach erosion, new nutrient and sediment flows, salinity shifts, increased physical disturbance

It is important to note that climate impacts will vary regionally. For example, different rates of sea level rise are projected for different regions, because the rate is determined not only by global rates of sea level change, but also by changes in coastal elevation associated with local vertical movement of the land, and by atmospheric circulation patterns (CCSP 2009). Understanding the regional variation of impacts and ecosystem response is critical to developing successful adaptation strategies.

**Changes in Temperature:**

Climate induced changes in air, water, and soil temperatures include both changes to average seasonal temperatures as well as changes in temperature minima/maxima and variability. Temperature changes affect flora and fauna phenology, including key events such as the spring phytoplankton bloom, plant germination, turtle nesting, and species range shifts. (Harley et al. 2006, Hoegh-Guldberg and Bruno 2010). Extreme changes may also stress organisms to the point of mortality. In estuarine environments, increased water temperature will affect water column stratification and eutrophication; and could cause range shifts in coastal organisms, including commercially important species, with cascading effects on predators and prey. While warmer temperatures might be an opportunity for increased growth and distribution of coastal salt marshes and forested wetlands, they might also allow for expansion of exotic, invasive species to the detriment of native species, and spread of disease pathogens. In addition, warmer water temperatures will exacerbate low summer oxygen levels (such as those in mid-Atlantic estuaries and the Gulf of Mexico) due to increased oxygen demand and decreased oxygen solubility (Najjar et al. 2000).

In Alaska, for example, the annual average temperature has increased at more than twice the rate of the national average over the last 50 years (USGCRP 2009). Impacts due to this increase have been substantial, and include earlier spring snowmelt, reduced sea ice, widespread glacier retreat, and permafrost warming (USGCRP 2009). These impacts have had dramatic negative effects on coastal ecosystems, such as rapid shoreline erosion (e.g. at rates of 36-83 feet per year (USGCRP 2009)) due to longer seasons without ice cover and thus, greater coastal vulnerability to wind and wave damage, and land subsidence due to permafrost melt and sea level rise (Larsen and Goldsmith 2007). For high islands, such as those in Hawaii, warmer temperatures will increase stress on forest species, including birds, plants, and insects, which need cool, moist conditions to survive.

**Sea Level Rise:**

Sea level rise is caused by both the thermal expansion of sea water and water mass input from land ice melt. The immediate effects of sea level rise are the submergence and increased inundation of coastal land at higher elevations and increased salinity in estuaries. Additional physical effects include increased erosion and changes in geomorphology, and saltwater intrusion in groundwater. Sea level change is highly variable regionally, as it depends on the relative increase in water levels as well as local land elevation changes (e.g., subsidence or uplift), and rates of sediment accumulation. Relative sea level rise refers to a local increase in the level of the ocean due to the interaction of these factors. For example, in some regions, such as the Gulf of Mexico, the projected rates of sea level rise for this century are dramatic (Anderson et al. 2010). Coastal habitats and wildlife will respond to these changes in different ways. For instance, marsh islands are already being lost in the Mid-Atlantic due to sea level rise-related flooding and erosion, which threatens island nesting bird species such as gull-billed terns (*Gelochelidon nilotica*), common terns (*Sterna hirundo*), American oystercatchers (*Haematopus palliatus*), and black skimmers (*Rynchops niger*) (Shellenbarger Jones et al. 2009). In addition, the degradation and loss of tidal marshes affect fish and shellfish production and flood attenuation, key ecosystem services for coastal communities.

Sea level rise is a key driver of coastal geomorphologic change. For example, in barrier island systems, impacts include changes in size and location of islands and lagoons which affect their ability to attenuate incoming wave energy or that affect tidal flow regimes. These impacts result in subsequent changes in hydrodynamic characteristics, and energy or sediment-supply regimes that, in part, dictate the distribution of coastal intertidal habitats such as marshes and mangroves, which need sufficient sediment supply to keep pace with sea level rise. Alternatively, tidal wetlands need space to migrate inland. The success of inland migration is dependent both on the availability and slope of an upland corridor, as well as the pace

of sea level rise and erosion, and the potential for wetland accretion (CCSP 2009). In populated coastal areas, wetland migration is often constrained by land development and shoreline stabilization measures, which can result in the crowding of foraging and bank-nesting birds and the loss of critical coastal habitat for certain species, such as the Diamondback terrapin which relies on both marsh habitat and beaches for nesting purposes (Shellenbarger Jones et al. 2009).

Sea level rise also may exacerbate flooding events ranging from spring tides to tropical or extratropical storms. Sea level rise will cause inland penetration of storm surge into areas not accustomed to inundation, and these areas will likely experience flooding more often. While sea level changes have occurred repeatedly in the geologic past, the accelerated pace of sea level rise in the 20th and 21st centuries raises questions as to how coastal ecosystems will respond to new rates of change (USGCRP 2009).

Sea level rise may also result in the inland movement of seawater, shifting the tidal influence zone of streams and rivers upstream and permanently inundating downstream riparian/coastal portions with brackish water (Riggs and Ames 2003). In the United States, these impacts are already apparent in freshwater swamps along Louisiana and Florida (IPCC 1997, Bowman et al. 2010, Migeot and Imbert 2011). In Florida, mangroves have advanced 0.93 miles inland over the last 50 years (Rivera-Monroy et al. 2011), and another 10 to 50 percent of the freshwater sawgrass prairie will be transformed to salt marsh or mangroves by 2100 (Kimball 2007). Salinity increases in formerly fresh or brackish surface waters and saltwater intrusion of shallow coastal groundwater aquifers will also be a result of sea level rise. Habitats and species that are not tolerant of extreme and/or extended changes in salinity will be particularly vulnerable. For example, tidal freshwater forested wetlands support a variety of wildlife including songbirds, small mammals, and amphibians, and currently are considered globally imperiled. Sea level rise and a sustained upstream shift in the salinity gradient in estuarine rivers may potentially cause tree mortality and degradation of these vulnerable systems (Fleming et al. 2006). Changes in salinity regimes will also cause shifts in marsh vegetation composition and in associated wildlife ranges.

Small and low-lying islands are particularly vulnerable to climate impacts such as sea level rise, erosion, and saltwater intrusion (Baker et al. 2006, Church et al. 2006, USGCP 2009). Many islands are home to high concentrations of rare, threatened, and endangered species (in many cases endemic to that area only), which could be particularly vulnerable to climate change impacts such as sea level rise and loss of habitat (Baker et al. 2006). Saltwater intrusion into groundwater and changes in precipitation that impact recharge of the freshwater lens will also have implications for the availability of fresh water for fish, wildlife, and plants on islands.

### ATLANTIC COAST PIPING PLOVER HABITAT CONSERVATION

Decisions regarding coastal management, such as stabilization, retreat, and beach nourishment will strongly influence the effects of sea level rise on the Atlantic Coast piping plover (*Charadrius melodus*), a threatened beach-nesting bird protected under the ESA. Piping plovers breed from Maine to North Carolina, and favor wide, gently sloping ocean beaches with blowouts, washovers, ephemeral pools, and sparse vegetation.

Federal and state agencies, nongovernmental organizations, and academic institutions are collaborating to couple a model of piping



Photo: Bill Byrne, MassWildlife

plover habitat evolution with a model of piping plover nest density and distribution. The habitat evolution model relates changes in physical habitat, such as topography, shoreline position, and vegetation, to changes in sea level and storminess (Gutierrez et al. 2011). A Bayesian approach is particularly well-suited to understanding and responding to climate change because future conditions, including results of habitat management experiments, are uncertain. Empirical data will be used to update and improve model forecasts. Model predictions will be used to develop sea level rise-related piping plover habitat conservation recommendations that can be implemented by land managers and inform regulatory authorities. Case studies incorporating explicit measures to preserve resilience of piping plover habitat to sea level rise into management plans for specific locations will demonstrate potential applications. Collaborators anticipate that model results may be readily translated to inform habitat management for other sensitive beach-strand species, such as least terns, American oystercatchers, Wilson's plovers, and seabeach amaranth (a federally threatened plant species).

### Lake Level Change:

Great Lakes water levels are expected to decrease significantly due to climate-driven changes in precipitation and evapotranspiration due to higher temperatures (USGCRP 2009, Angel and Kunkel 2010). Water-level decrease will lead to desiccation of coastal habitats that do not (or cannot) migrate with retreating shoreline. This loss of habitat will likely stress fish species that rely on wetlands as nursery habitat. Shorebirds may also experience a loss of nesting habitat as existing and newly formed beach habitats may become overrun by opportunistic invasive species (e.g., *Phragmites* species). While a loss of existing habitat is expected in some areas, new wetlands may be formed as a result of accretion in other areas. In these new habitats, invasive species will be a concern and dictate what type of



Photo: USGS

habitat is formed and what species find the new habitat suitable.

A decrease in the extent and duration of lake ice will affect organisms within the lakes and the habitats surrounding the lakes. Lake ice enhances the overwinter survival of fish eggs and protects shoreline habitat from erosion during winter storms. Longer periods without lake ice cause greater evaporation and can increase lake-effect snows if air temperature is favorable for snow (Lofgren et al. 2002).

### Changes in Precipitation:

Changes in precipitation will primarily impact coastal systems through changes in quantity, timing, intensity, and quality of freshwater flow into estuarine systems. The quantity of freshwater will affect salinity gradients, which can have profound impacts on distribution and survival of flora and fauna. Changes in peak flow timing could affect phenology and migration cues (e.g., species accustomed to gradual delivery of snowpack melt versus rapid influx from rainstorms). More infrequent but intense precipitation events can lead to scouring of sediment and vegetation during peak flows, redistribution of sediment, as well as increased pollutants compromising water quality (for example, more frequent sewer overflows delivering pollutants to coastal aquatic systems).

Changes in the timing and amount of freshwater, nutrient, and sediment delivery will impact estuarine productivity. For example, changes in flow regimes will affect the abundance and distribution of

suspension feeders, such as mussels, clams, and oysters, which will in turn alter food web dynamics (e.g. phytoplankton abundance) as well as water clarity. Increases in flow, and associated increases in turbidity and eutrophication, will also impact submerged aquatic vegetation (SAV) due to reduced light penetration and thus, reduced photosynthesis (Najjar et al. 2000). Degradation or loss of SAV will in turn affect organisms that rely on the habitat for food and shelter. Decreases in freshwater flow (drought) in estuaries result in higher salinities and lower inputs of nutrients. These impacts of precipitation changes in estuaries will likely be exacerbated by non-climate stressors such as freshwater demand and extraction, eutrophication, and hypoxia.

#### **Changes in Storm Intensity:**

Improving our understanding of the impacts of climate change on tropical and extratropical cyclone activity, including discerning climate-related changes from natural variability, is an active area of research. There is potential for increased storm wind strength due to elevated sea surface temperatures, which would lead to increases in wave height and storm surge (Scavia et al. 2002). These changes would also be magnified by a higher sea level. In a comprehensive review of recent studies, Knutson et al reported a mean change in tropical storm intensity for the Northern Hemisphere of +9 percent by 2100 (+8 percent for the North Atlantic basin) (Knutson et al. 2010). For extratropical storms, current research suggests a decrease in the total number of events, but an increase in the number of intense events within the next century (Lambert and Fyfe 2006, Bengtsson et al. 2009).

The primary impacts associated with more intense tropical or extratropical storm systems include increased storm surge and flooding and increased wave energy leading to erosion. For example, barrier islands naturally respond to coastal storms by migrating landward via erosion and overwash, followed by the rebuilding of beach and dune systems and other habitats during fair-weather conditions. Beaches depend on their ability to migrate and the availability of sediment to replenish eroded sands (CCSP 2009). More intense storms, coupled with common manmade ecosystem alterations such as shoreline stabilization structures that impede or eliminate long-shore transport, could lead certain barrier islands (and their habitats) to cross a threshold condition where the islands are fragmented and disappear instead of migrating and rebuilding. Impacts to coastal and estuarine beaches would affect biota such as microscopic invertebrates that are critical to the food web; shorebirds such as the piping plover and horseshoe crab (*Limulus polyphemus*) that rely on beaches for egg deposition; and migratory shorebirds that feed on the eggs, such as the red knot (*Calidris canutus*) (Shellenbarger Jones et al. 2009).

#### **Changes in Carbon Dioxide (CO<sub>2</sub>) and Water Chemistry:**

While not a climate change impact per se, atmospheric concentrations of CO<sub>2</sub> will continue to increase, which will increase CO<sub>2</sub> in the oceans and estuaries. The reaction of CO<sub>2</sub> and seawater results in a reduction in pH, also known as “ocean acidification,” as well as changes to other key nutrients and biological processes. For example, increased acidity in estuaries will affect shellfish species that use carbonate minerals to build their shells, as these minerals are more readily dissolved (more difficult to extract) in lower pH environments (USGCRP 2009). Elevated carbon dioxide concentrations are expected to increase photosynthesis and productivity for many plants such as mangroves and emergent and submerged vegetation. The increased growth rates will be reduced in areas that experience additional stress due to coastal pollution, which can also exacerbate the effects of ocean acidification. These changes in water chemistry could have significant impacts on estuarine organisms, but currently the range and severity of impacts to estuarine systems is not well understood.

#### **Changes in Sea Ice:**

Changes in the extent, thickness, condition, and duration of sea ice are a direct impact of changes in global temperature. Warming triggers loss of sea ice, creating open water conditions. These in turn allow

higher wave energy to reach the shoreline (particularly during storms), accelerating the rate of coastal erosion (USGCRP 2009). Changes in extent and duration of sea ice will result in loss of critical habitat for species that depend on the ice, such as polar bears (*Ursus maritimus*) and walrus (*Odobenus rosmarus*). Similarly, the timing of the spring phytoplankton bloom is directly tied to the location of the sea ice edge over the Bering Sea shelf (Stabeno et al. 2001). In addition, warmer temperatures could change food web dynamics by allowing for the migration of different predator and prey species in the Arctic, and may also affect benthic resources (Forbes 2011). Changing ice conditions are threatening indigenous lifestyles and subsistence economics as well. For instance, the deterioration of ice conditions makes trips to hunting grounds more hazardous, so there is more hunting from open water, which requires larger and more expensive vessels and motors (Forbes 2011). Warmer temperatures could also extend the growing season, increasing primary production in the summer.

### STORMWATER RUNOFF

A major nonpoint source of pollution related to development along the coastline is stormwater runoff. Runoff degrades water quality, making it an important stressor affecting resilience and sustainability of coastal habitats and species. As a result of increasing development, impervious surfaces that do not allow rain to penetrate the soils (such as parking lots, roads, and rooftops) increase the amount and peak flow of stormwater runoff. Changing precipitation patterns, especially increased frequency and intensity of heavy rains, will have a compounding effect on the amount of stormwater released into surrounding ecosystems.

NOAA's National Centers for Coastal Ocean Science at Hollings Marine Laboratory has developed a stormwater runoff-modeling tool to project the local impacts of development in a changing climate (Blair et al. 2011). Urbanized watersheds were compared with less-developed suburban and undeveloped forested watersheds to examine the relationship between land-use change and stormwater runoff and how this will be amplified under climate change.

This user-friendly and flexible tool provides a mechanism to quantify the volume of runoff and peak flow estimates under different land-use and climate change scenarios. It provides an improved understanding of the impacts of development on stormwater runoff as well as the potential impacts associated with climate change in urbanized communities. Moreover, this research provides coastal resource managers with a tool to protect coastal habitat resiliency from both non-climatic stressors such as development as well as climate-associated stressors such as changing patterns of precipitation.

### Coastal Climate Change Impacts in the Context of Existing Stressors:

Coastal resource managers in particular must consider climate impacts in the context of multiple natural and human-induced changes. As noted throughout this discussion, climate change will likely exacerbate many existing, and primarily human-induced, stressors faced by coastal ecosystems. These include: pollution, habitat loss and fragmentation, invasive species, changes in water availability and quality, and changes in geomorphology. Sometimes the most successful strategy for increasing the resilience of fish, wildlife, and plants in a changing climate is to reduce the impact of non-climate stressors to the ecosystem.

Climate change can cause ecological and economic damage to coastal ecosystems and communities, particularly if important ecosystem processes are affected through the destruction of coastal habitats. These impacts can, in turn, affect the ecosystems services valued by humans. For instance, marshes and

mangroves provide natural buffers against storms, absorbing floodwaters and providing erosion control with vegetation that stabilize shorelines and absorbs wave energy. If those habitats are degraded and/or destroyed, then adjacent inland communities will have less protection from sea level rise, and may experience more direct storm energy and flooding (NC NERR 2007, VIMS 2009, Christian 2009). Tidal marshes and associated submerged aquatic plant beds are important spawning, nursery, and shelter areas for fish and shellfish, including commercially important species like blue crab (*Callinectes sapidus*), nesting habitat for bird species, and invertebrate food for shorebirds. All coastal ecosystems provide important habitat (both food and shelter) for aquatic and terrestrial fish, wildlife, and plants, which in turn, benefit humans and coastal communities through their many services (such as improving water quality and providing a source of food and recreational opportunities for those communities).

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## Climate Adaptation Strategies and Actions for Coastal Systems

The *Strategy* identifies seven primary Goals to help fish, wildlife, plants, and ecosystems cope with the impacts of climate change. As discussed in the Introduction, these Goals were developed collectively by diverse teams of federal, state, and tribal technical experts, based on existing research and understanding regarding the needs of fish, wildlife, and plants in the face of climate change. Each Goal identifies a set of initial Strategies and Actions that should be taken or initiated over the next five to ten years.

Actions listed here were derived from those Technical Team submissions determined to be most applicable to coastal systems. Numbers that correspond to the full *Strategy* document are designated by *Strategy* (S) and the Action number (e.g., 1.1.1).

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### **GOAL 1: Conserve habitat to support healthy fish, wildlife and plant populations and ecosystem functions in a changing climate.**

**Strategy 1.1: Identify areas for an ecologically-connected network of terrestrial, freshwater, coastal, and marine conservation areas that are likely to be resilient to climate change and to support a broad range of fish, wildlife, and plants under changed conditions.**

**Actions:**

- A: Identify and map high priority areas for conservation using information on species distributions (current and projected), habitat classification, land cover, and geophysical settings (including areas of rapid change and slow change). (**S 1.1.1**)
- B: Identify and prioritize groundwater sources, recharge and discharge sites, and areas that provide sediment resources necessary for coastal ecosystem processes.
- C: Assess the migration potential of coastal habitats and species and prioritize areas for highest migration potential, considering ecosystem functions and existing and future physical barriers.

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**Strategy 1.2: Secure appropriate conservation status on areas identified in Action 1.1.1 to complete an ecologically-connected network of public and private conservation areas that will be resilient to climate change and support a broad range of species under changed conditions.**

**Actions:**

- A: Protect coastal wetlands including those that may function for relatively short periods during species and ecosystem transition and migration.
- B: Incorporate climate change into land acquisition plans (e.g., Coastal and Estuarine Land Conservation Program, state acquisition plans) and prioritize projects whose conservation targets are resilient in a changing climate.
- C: Capitalize on unique opportunities and funding sources (e.g., the Federal Emergency Management Agency's Repetitive Loss and Severe Repetitive Loss programs) to acquire coastal lands.

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**Strategy 1.3: Restore habitat features where necessary and practicable to maintain ecosystem function and processes and resiliency to climate change.**

**Actions:**

- A: Restore degraded habitats as appropriate to support diversity of species assemblages and ecosystem structure and function. (**S 1.3.2**)
- B: Consider climate change impacts when prioritizing coastal ecosystem restoration activities.

- C: Explore alternative environmental engineering options (e.g., dredged material as wetland fill, beach re-nourishment) to restore or enhance coastal habitats.

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**Strategy 1.4: Conserve, restore, and as appropriate and practicable, establish new ecological connections among conservation areas to facilitate fish, wildlife, and plant migration, range shifts, and other transitions caused by climate change.**

**Actions:**

- A: Assess and prioritize critical connectivity gaps and needs across current conservation areas, including areas likely to serve as refugia in a changing climate. (**S 1.4.2**)
- B: Assess existing barriers or structures that impede movement and dispersal within and among habitats to increase natural ecosystem resilience to climate change, and where necessary consider the redesign or mitigation of these structures
- C: Restore coastal habitats in replication along a depth and elevation gradient

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**GOAL 2: Manage species and habitats to protect ecosystem functions and provide sustainable cultural, subsistence, recreational, and commercial use in a changing climate.**

**Strategy 2.1: Update current or develop new species, habitat, and land and water management plans, programs and practices to consider climate change and support adaptation.**

**Actions:**

- A: Incorporate climate change considerations into existing and new management plans and practices using the best available science regarding projected climate changes and trends, vulnerability and risk assessments, and scenario planning. (**S 2.1.1**)
- B: Develop basin-specific integrated water management plans that address in-stream flows, inter-basin water transfers, and surface and groundwater withdrawals while promoting water conservation and ecosystem function.
- C: Develop strategic protection, retreat, and abandonment plans for areas currently experiencing rapid coastal climate change impacts (e.g., coastline of Alaska and low-lying islands).

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**Strategy 2.2: Develop and apply species-specific management approaches to address critical climate change impacts where necessary.**

**Actions:**

- A: Use vulnerability and risk assessments to design and implement management actions at species to ecosystem scales. (**S 2.2.1**)
- B: Develop criteria and guidelines for the use of translocation, assisted migration, and captive breeding as climate adaptation strategies. (**S 2.2.2**)
- C: Where appropriate, actively manage populations (e.g., using harvest limits, seasons, translocation, captive breeding, and supplementation) of vulnerable species to ensure sustainability and maintain biodiversity, human use, and other ecological functions. (**S 2.2.3**)

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**Strategy 2.3: Conserve genetic diversity by protecting diverse populations and genetic material across the full range of species occurrences.**

## SEA LEVEL RISE IN DELAWARE

A rising sea combined with sinking land creates a watery future. The state of Delaware is experiencing both, with relative sea levels to rise at the rapid rate of one inch every eight years (NOAA 2009). That is a big problem in a state where more than 10 percent of the land lies less than eight feet above sea level and no spot is farther than 35 miles from the Atlantic Ocean, Delaware Bay, or Delaware River. Residences, communities, and industries are at risk. In fact, the state is already experiencing worrisome coastal flooding. Breaches in the sandy shoreline at Prime



*Photo: NOAA*

Hook National Wildlife Refuge, for instance, have allowed saltwater into freshwater marshes that provide important waterfowl habitat.

Keenly aware of the threat, the state of Delaware has created a Sea-Level Rise Initiative to understand the impacts of sea-level rise, prepare for inundation, respond where necessary, and keep the public informed. Prime Hook National Wildlife Refuge is collaborating with the state of Delaware to implement short-term adaptation strategies to address inundation and saltwater intrusion into freshwater impoundments by stabilizing the shoreline.

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### GOAL 3: Enhance capacity for effective management in a changing climate.

**Strategy 3.1: Increase the climate change awareness and capacity of natural resource managers and enhance their professional capacity to design, implement, and evaluate fish, wildlife, and plant adaptation programs.**

**Actions:**

- A: Develop training on the use of existing and emerging tools for managing under uncertainty (e.g., vulnerability and risk assessments, scenario planning, decision support tools, and adaptive management). (S 3.1.3)
- B: Develop a web-based clearinghouse of training opportunities and materials addressing climate change impacts on natural resource management. (S 3.1.4)
- C: Encourage use of interagency personnel agreements and interagency (state, federal, and tribal) joint training programs as a way to disperse knowledge, share experience and develop interagency communities of practice about climate change adaptation. (S 3.1.5)

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**Strategy 3.2: Facilitate a coordinated response to climate change at landscape, regional, national, and international scales across state, federal, and tribal natural resource agencies and private conservation organizations.**

**Actions:**

- A: Identify and address conflicting management objectives within and among federal, state, and tribal conservation agencies and private landowners, and seek to align policies and approaches wherever possible. (S 3.2.2)

- B: Integrate individual agency and state climate change adaptation programs and State Wildlife Action Plans with other regional conservation efforts such as the National Fish Habitat Action Plan, Landscape Conservation Cooperatives (LCCs), Migratory Bird Joint Ventures (JVs), and the Northeast Association of Fish and Wildlife Agencies regional application of State Wildlife Grant funds to foster collaboration. (**S 3.2.3**)
- C: Engage with international neighbors, including Canada, Mexico, Russia, and nations in the Caribbean Basin, Arctic Circle, and Pacific Ocean to help adapt to and mitigate climate change impacts in shared trans-boundary areas and for common migratory species. (**S 3.2.5**)

**Strategy 3.3: Review existing federal, state and tribal legal, regulatory and policy frameworks that provide the jurisdictional framework for conservation of fish, wildlife, and plants to identify opportunities to improve, where appropriate, their utility to address climate change impacts.**

**Actions:**

- A: Initiate a dialogue among all affected interests about opportunities to improve the utility of existing legal, regulatory and policy frameworks to address impacts of sea level rise on coastal habitats. (**S 3.3.7**)
- B: Modify policies and programs to create and strengthen incentives for reducing/removing shoreline armoring and for increasing climate-smart coastal development.
- C: Alter current policy and zoning in coastal areas to anticipate migratory nature of coastal habitats and prevent development in potential refugia and corridors critical to fish, wildlife and plant adaptation.
- D: Clarify legal authority to manage new and future habitat areas, particularly in areas where jurisdiction migrates with landscape features (e.g., shorelines).

**Strategy 3.4: Optimize use of existing fish, wildlife, and plant conservation funding sources to design, deliver, and evaluate climate adaptation programs.**

**Actions:**

- A: Prioritize funding for land and water protection programs that incorporate climate change considerations. (**S 3.4.1**)
- B: Review existing federal, state, and tribal grant programs and revise as necessary to support funding of climate change adaptation and include climate change considerations in the evaluation and ranking process of grant selection and awards. (**S 3.4.2**)
- C: Develop a web-based clearinghouse of funding opportunities available to support climate adaptation efforts. (**S 3.4.6**)

**GOAL 4: Support adaptive management in a changing climate through integrated observation and monitoring and use of decision support tools.**

**Strategy 4.1: Support, coordinate, and where necessary develop distributed but integrated inventory, monitoring, observation, and information systems to detect and describe climate impacts on fish, wildlife, plants, and ecosystems.**

**Actions:**

- A: Develop consensus standards and protocols that enable multi-partner use and data discovery, as well as interoperability of databases and analysis tools related to fish, wildlife, and plant observation, inventory, and monitoring. (**S 4.1.2**)
- B: Work through existing distributed efforts (e.g., National Climate Assessment (NCA), National Estuarine Research Reserve System -wide monitoring program, State Natural Heritage Programs, National Wildlife Refuge System, National Park Service) to support integrated national observation and information systems that inform climate adaptation. (**S 4.1.4**)

- C: Monitor and assess water levels in shallow coastal aquifers that support freshwater-dependent ecosystems.

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**Strategy 4.2: Identify, develop, and employ decision support tools for managing under uncertainty (e.g., vulnerability and risk assessments, scenario planning, strategic habitat conservation approaches, and adaptive management evaluation systems) via dialogue with scientists, managers (of natural resources and other sectors), and stakeholders.**

**Actions:**

- A: Develop regional downscaling of Global Climate models to conduct vulnerability assessments of living resources. (**S 4.2.1**)
- B: Engage scientists, resource managers, and stakeholders in climate change scenario planning processes, including identification of a set of plausible future scenarios associated with climate phenomena likely to significantly impact fish, wildlife, and plants. (**S 4.2.2**)
- C: Conduct vulnerability and risk assessments for priority species (threatened and endangered species, species of greatest conservation need, species of socioeconomic and cultural significance). (**S 4.2.4**)
- D: Ensure the availability of and provide guidance for decision support tools (e.g., NOAA's Digital Coast, etc.) that assist federal, state, local, and tribal resource managers and planners in effectively managing coastal fish, wildlife, and plants in a changing climate. (**S 4.2.7**)

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**GOAL 5: Increase knowledge and information on impacts and responses of fish, wildlife and plants to a changing climate.**

**Strategy 5.1: Identify knowledge gaps and define research priorities via a collaborative process among federal, state, and tribal resource managers and research scientists working with the National Science Foundation (NSF), USGCRP, NCA, USDA Extension, Cooperative Ecosystem Study Units (CESUs), Climate Science Centers (CSCs), LCCs, JVs, and Regional Integrated Sciences and Assessments (RISAs).**

**Actions:**

- A: Increase coordination and communication between resource managers and researchers through existing forums (e.g., NSF, USGCRP, NCA, USDA, CESUs, CSCs, LCCs, JVs, RISAs, Sea Grant and others to ensure research is connected to management needs. (**S 5.1.1**)
- B: Bring managers and scientists together to prioritize research needs that address resource management objectives under climate change. (**S 5.1.2**)
- C: Prioritize research on questions relevant to managers of near-term risk environments (e.g., low-lying islands and glaciated areas) or highly vulnerable species. (**S 5.1.6**)

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**Strategy 5.2: Conduct research into ecological aspects of climate change, including likely impacts and the adaptive capacity of species, communities and ecosystems, working through existing partnerships or new collaborations as needed (e.g., USGCRP, NCA, CSCs, RISAs, and others).**

**Actions:**

- A: Support basic research on life histories and food web dynamics of fish, wildlife, and plants to increase understanding of how species are likely to respond to changing climate conditions and identify survival thresholds. (**S 5.2.2**)
- B: Conduct research to determine flows required to support sustainable populations of vulnerable species, such as during prolonged drought.
- C: Conduct research to better understand fish, wildlife, plant, and ecosystem responses to ocean acidification and saltwater intrusion.

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**Strategy 5.3: Advance understanding of climate change impacts and species and ecosystem responses through modeling.****Actions:**

- A: Develop and use models of climate-impacted physical and biological variables and ecological processes at temporal and spatial scales relevant to conservation.
- B: Model sea level rise and physical and biological responses at relevant scales.

**SENTINEL SITE MONITORING**

Crafting an effective climate adaptation strategy is difficult without having good data on the impacts of climate change. Collecting that vital information, in turn, requires observing and measuring what is happening at specific locations over many years. In 2008, the National Estuarine Research Reserve System (NERRS) began establishing such so-called “sentinel sites” to learn how estuarine habitats respond to sea level change.

One of those sentinel sites is the Elkhorn Slough Reserve in California’s Monterey Bay. The area began losing some of its tidal wetlands more than 50 years ago after an inlet was built to Moss Landing harbor, creating a permanent connection to the open ocean. Now, sea level rise is further threatening this valuable estuarine ecosystem. At the same time, the Reserve is under stress from eutrophication, groundwater withdrawals, and other factors.

To understand the complex effects of these stressors, the NERRS is intensely monitoring the ecosystem. Researchers are recording surface and groundwater levels, testing water quality, and measuring changes occurring in tidal marsh plants, and submerged aquatic vegetation. They are also monitoring the amounts of sediment in the wetlands and changes in land elevation.

So far, the project has documented a worrisome trend. The combination of rising sea levels and the loss of marshes is increasing the vulnerability of a railroad line, a power plant, and a number of adjacent farms to flooding and coastal erosion. The monitoring data will be informing the adaptation measures that are taken to reduce vulnerability.

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**GOAL 6: Increase awareness and motivate action to safeguard fish, wildlife and plants in a changing climate.**

**Strategy 6.1: Increase public awareness and understanding of climate impacts to natural resources and ecosystem services and the principles of climate adaptation at regionally- and culturally-appropriate scales.**

**Strategy 6.2: Engage the public through targeted education and outreach efforts and stewardship opportunities.**

**Strategy 6.3: Coordinate climate change communication efforts across jurisdictions.**

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**GOAL 7: Reduce non-climate stressors to help fish, wildlife, plants, and ecosystems adapt to a changing climate.**

**Strategy 7.1: Slow and reverse habitat loss and fragmentation.**

**Actions:**

- A: Work with local and regional water management agencies to evaluate historical water quantities and base flows and develop water management options to protect or restore aquatic habitats. (**S 7.1.4**)
- B: Conserve natural dunes and dune vegetation from removal and trampling.
- C: Identify options for redesign and removal of existing structures/barriers where there is the greatest potential to restore natural processes. (**S 7.1.8**)
- D: Evaluate how to best incorporate risks associated with coastal development into insurance rates to enlist market forces in the effort to minimize loss of coastal habitat in a changing climate.
- E: Support the development of tidal wetland greenhouse gas offset protocols for use in voluntary carbon markets to enable private investment in coastal wetland protection and restoration.

**Strategy 7.2: Slow, mitigate, and reverse where feasible ecosystem degradation from anthropogenic sources through land/ocean-use planning, water resource planning, pollution abatement, and the implementation of best management practices.**

**Actions:**

- A: Work with water resource managers to identify, upgrade, or remove outdated sewer and stormwater infrastructure to reduce water contamination. (**S 7.2.4**)
- B: Increase restoration, enhancement, and conservation of riparian zones and buffers in agricultural and urban areas to minimize nonpoint source pollution. (**S 7.2.5**)
- C: Reduce impacts of impervious surfaces and stormwater runoff in urban areas to improve water quality, groundwater recharge, and hydrologic function. (**S 7.2.6**)
- D: Investigate mechanisms for including carbon sequestration in ecosystem service assessments for coastal wetlands to require mitigation for lost carbon storage/sequestration when wetlands are damaged or destroyed.

**Strategy 7.3: Use, evaluate, and as necessary, improve existing programs to prevent, control, and eradicate invasive species and manage pathogens.**

**Actions:**

- A: Employ a multiple barriers approach to detect and contain incoming and established invasive species, including monitoring at points of origin and points of entry for shipments of goods and materials into the United States and for trans-shipment within the country. Utilize education, regulation, and risk management tools (e.g., the Hazard Analysis and Critical Control Point process) to address. (**S 7.3.1**)
- B: Apply risk assessment and scenario planning to identify actions and prioritize responses to invasive species that pose the greatest threats to natural ecosystems. (**S 7.3.3**)
- C: Implement best management practices to reduce the spread of invasive species through ballast water.

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