Coasts

More than one-third of all Americans live in counties immediately bordering the nation's ocean coasts[1]. In addition to accommodating major cities, the coasts and the exclusive economic zone extending 200 miles offshore provide enjoyment, recreation, seafood, transportation of goods, and energy. Coastal and ocean activities contribute more than $1 trillion to the nation's gross domestic product and the ecosystems hold rich biodiversity and provide invaluable services[2]. However, intense human uses have taken a toll on coastal environments and their resources. Up to 38 percent of all fish stocks have been diminished by over-fishing, large "dead zones" depleted of oxygen have developed as a result of pollution by excess nitrogen runoff, toxic blooms of algae are increasingly frequent, coral reefs are badly damaged or becoming overgrown with algae, and about half of the nation's coastal wetlands have been lost—and most of this loss has occurred during the past 50 years.

Global climate change imposes additional stresses on coastal environments. Rising sea level is already eroding shorelines, drowning wetlands, and threatening the built environment[3]. The destructive potential of Atlantic tropical storms and hurricanes has increased since 1970 in association with increasing Atlantic sea surface temperatures, and it is likely that hurricane rainfall and wind speeds will increase in response to global warming[4]. Coastal water temperatures have risen by about 2°F in several regions, and the geographic distributions of marine species have shifted[5-7]. Precipitation increases on land have increased river runoff, polluting coastal waters with more nitrogen and phosphorous, sediments, and other contaminants. Furthermore, increasing acidification resulting from the uptake of carbon dioxide by ocean waters threatens corals, shellfish, and other living things that form their shells and skeletons from calcium carbonate[8] (see *Ecosystems* sector). All of these forces converge and interact at the coasts, making these areas particularly sensitive to the impacts of climate change.

Significant sea-level rise and storm surge will affect coastal cities and ecosystems around the nation; low-lying and subsiding areas are most vulnerable.

During the past century, sea level relative to the land ranged from falling several inches to rising up to 2 feet, depending on whether and how fast the land was rising or falling[10]. High rates of relative sea-level rise, coupled with cutting off the supply of sediments from the Mississippi River and other human alterations, have resulted in the loss of 1,900 square miles of Louisiana's coastal wetlands during the past century, weakening their capacity to absorb the storm surge of hurricanes such as Katrina[11]. Shoreline retreat is occurring along most of the nation's exposed shores.

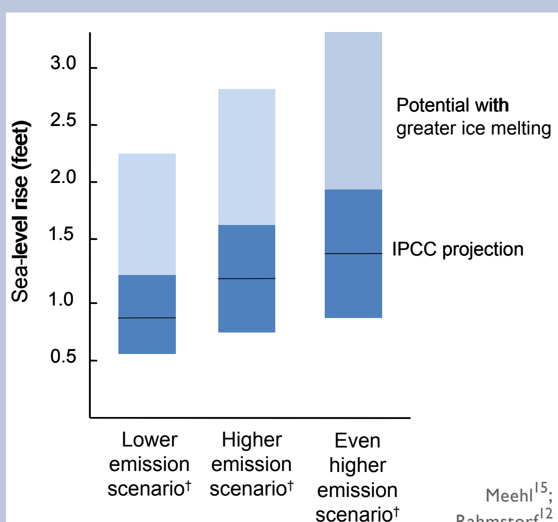
Multiple Stresses Confront Coastal Regions

Various forces of climate change at the coasts pose a complex array of management challenges and adaptation requirements. For example, relative sea level is expected to rise at least 2 feet in Chesapeake Bay (located between Maryland and Virginia) where the land is subsiding, threatening portions of cities, inhabited islands, most tidal wetlands, and other low-lying regions. Climate change also will affect the volume of the bay, its salinity distribution and circulation, as will changes in precipitation and freshwater runoff. These changes, in turn, will affect summertime oxygen depletion and efforts to reduce the agricultural nitrogen runoff that causes it. Meanwhile the warming of the bay's waters will make survival there difficult for northern species such as eelgrass and soft clams, while allowing southern species and invaders riding in ships' ballast water to move in and change the mix of species that are caught and must be managed. Additionally, more acidic waters resulting from rising carbon dioxide levels will make it difficult for oysters to build their shells and will complicate the recovery of this key species[9].

A "Ghost swamp" in south Louisiana shows the effects of saltwater intrusion.

The amount of sea-level rise likely to be experienced during this century depends on the degree of global warming, and thus the rate of greenhouse gas emissions. Considering the high uncertainty of the upper bounds of the range of projections (see *Global Climate Change* section), relative sea level is likely to rise by 2 to 4 feet in subsiding coastal areas[12]. Sea-level rise of 2 feet relative to the land surface is very likely to result in the loss of a large portion of the nation's remaining coastal wetlands, as they are not able to build new soil at a fast enough rate[13]. It also would affect seagrasses, coral reefs and other important habitats, fragment barrier islands, and place into jeopardy existing homes, businesses, and infrastructure, including roads, ports, and water and sewage systems. Portions of major cities, including Boston and New York, would be subject to inundation by ocean water during storm surges or even during regular high tides[14].

Projected Sea-Level Rise



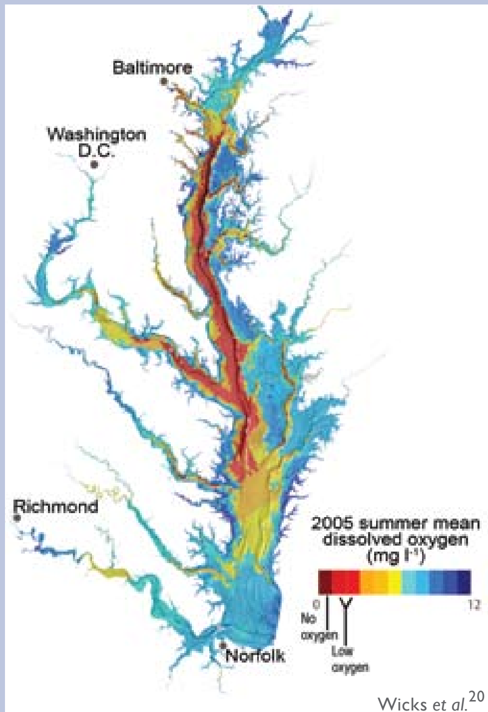
Sea-level rise by the end of the century for three emissions scenarios† based on Intergovernmental Panel on Climate Change 2007 projections[15] with the high ends of the ranges extended (light blue) based on more recent estimates that include continuation of observed ice-sheet melting[12]. Areas where coastal land is sinking would experience greater sea-level rise. For example, sea-level rise of half a foot in the Chesapeake Bay to 1.5 feet or more along portions of the Gulf Coast is projected.

Increases in spring runoff and warmer coastal waters will exacerbate the seasonal reduction in oxygen resulting from excess nitrogen from agriculture.

Coastal dead zones in places such as the northern Gulf of Mexico[16] and the Chesapeake Bay[17] are likely to increase in size and intensity as warming increases unless efforts to control runoff of agricultural fertilizers are redoubled. Greater spring runoff into East Coast estuaries and the Gulf of Mexico would flush more nitrogen into coastal waters stimulating harmful blooms of algae and the excess production of microscopic plants that settle near the seafloor and deplete oxygen supplies as they decompose. In addition, greater runoff reduces salinity, which when coupled with warmer surface water increases the difference in density between surface and bottom waters, thus preventing the replacement of oxygen in the deeper waters. As dissolved oxygen levels decline below a certain level, living things cannot survive. They leave the area if they can, and die if they cannot.

Coastal waters are very likely to continue to warm by as much 4 to 8°F in this century, both in summer and winter[14]. As with animals and plants on land, this will result in a northward shift in the geographic distribution of marine life along the coasts; this is already being observed[7,18]. Species that cannot tolerate the higher temperatures will move northward while species from farther south move in. Warming also opens the door to invasion by species that humans are intentionally or unintentionally transporting around the world, for example in the ballast water carried by ships. Species that were previously unable to establish populations because of cold winters are likely to find the warmer conditions more welcoming and gain a foothold, particularly as native species are under stress from climate change and other human activities. Non-native clams and small crustaceans already have had major effects on the San Francisco Bay ecosystem and the health of its fishery resources[19].

Chesapeake Bay Program
U.S. EPA



Wicks *et al.*[20]

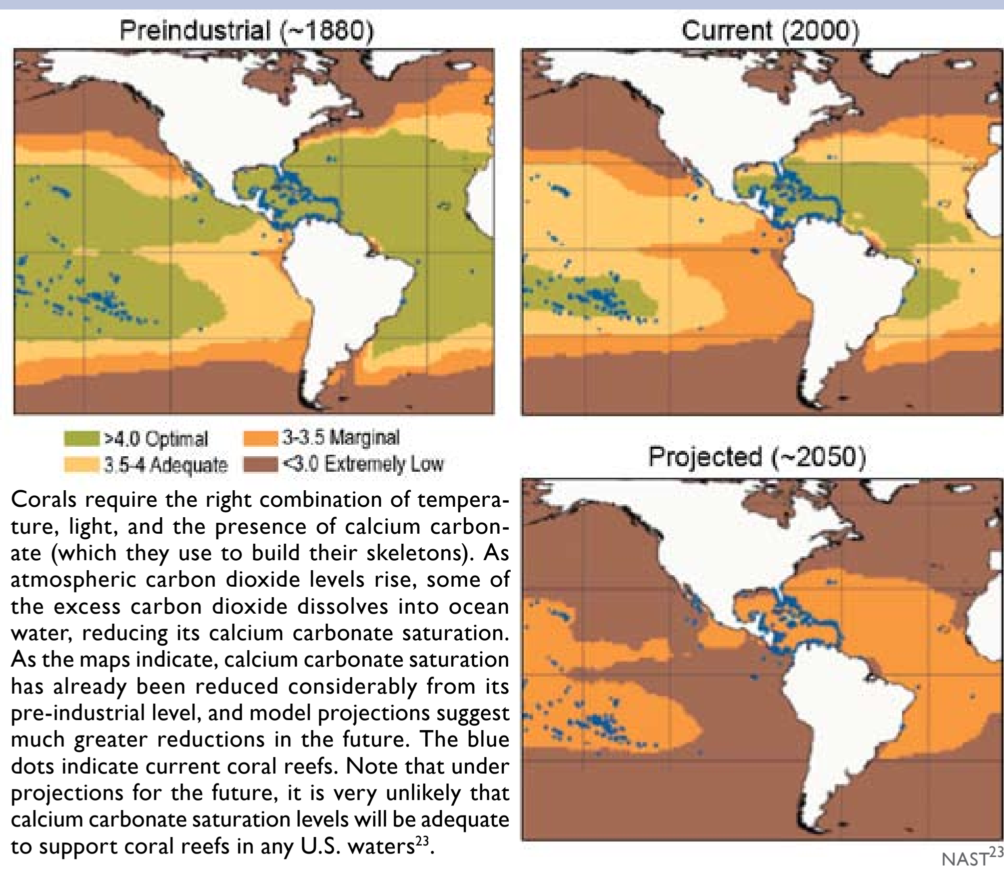
Climate change is likely to exacerbate "dead zones", areas where bottom water is depleted of dissolved oxygen because of nitrogen pollution, threatening living things.

Rising water temperatures and ocean acidification due to increasing atmospheric carbon dioxide will present major additional stresses to coral reefs, resulting in significant die-offs and limited recovery.

In addition to carbon dioxide's heat-trapping effect, the increase in its concentration in the atmosphere is gradually acidifying the ocean. About one-third of the carbon dioxide emitted by human activities has been absorbed by the ocean, resulting in a decrease in the ocean's pH. Since the beginning of the industrial era, ocean pH has declined demonstrably and is projected to decline much more by 2100 if current emissions trends continue. Such a decline in pH is very likely to affect the ability of living things to create shells or skeletons of calcium carbonate because lowering the pH decreases the concentration of the carbonate ions required. The living things affected include important plankton species in the open ocean, mollusks and other shellfish, and reef-building corals[18,21].

Acidification imposes yet another stress on these corals, which are also subject to bleaching—the expulsion of the microscopic plants that live inside the corals and are essential to their survival—as a result of heat stress[18] (see *Ecosystems* sector and *Islands* region). As a result of these and other stresses, the corals that form the reefs in the Florida Keys, Puerto Rico, Hawaii, and the Pacific Islands are projected to be lost if carbon dioxide concentrations continue to rise at their current rate[22].

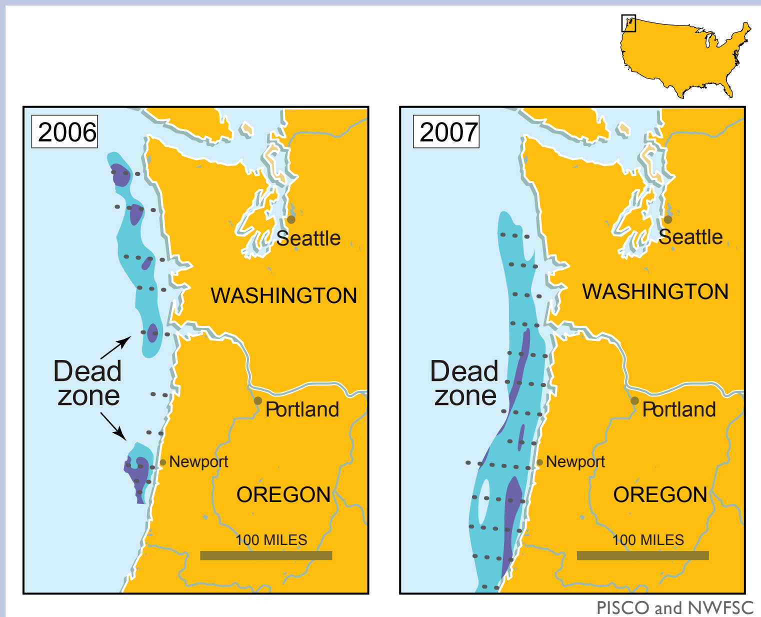
Calcium Carbonate Saturation in Ocean Surface Waters



Corals require the right combination of temperature, light, and the presence of calcium carbonate (which they use to build their skeletons). As atmospheric carbon dioxide levels rise, some of the excess carbon dioxide dissolves into ocean water, reducing its calcium carbonate saturation. As the maps indicate, calcium carbonate saturation has already been reduced considerably from its pre-industrial level, and model projections suggest much greater reductions in the future. The blue dots indicate current coral reefs. Note that under projections for the future, it is very unlikely that calcium carbonate saturation levels will be adequate to support coral reefs in any U.S. waters[23].

NAST[23]

Pacific Coast "Dead Zone"
2006 to 2007



Climate change affects coastal currents that moderate ocean temperatures and the productivity of ecosystems. As such, it is believed to be a factor in the low-oxygen "dead zone" that has appeared along the coast of Washington and Oregon in recent years[24]. In the maps above, light blue indicates low-oxygen areas and purple shows areas that are the most severely oxygen depleted.

Because it affects the distribution of heat in the atmosphere and the oceans, climate change will affect the currents that move along the nation's coasts, such as the California Current that bathes the West Coast from British Columbia to Baja California[18]. This southward flowing current produces upwelling of deeper ocean water along the coast that is vital to moderation of temperatures and the high productivity of Pacific Coast ecosystems. Such coastal currents are subject to periodic variations caused by the El Niño-Southern Oscillation and the Pacific Decadal Oscillation, which have substantial effects on the success of salmon and other fishery resources. Climate change is expected to affect such coastal currents, and possibly the larger scale natural oscillations as well, though these effects are not well understood yet. The recent emergence of oxygen-depletion events on the continental shelf off Oregon and Washington (a dead zone not directly caused by agricultural runoff and waste discharges such as those in the Gulf of Mexico or Chesapeake Bay) is one example[24].

Adaptation: Coping with Sea-Level Rise

Adaptation to sea-level rise is already taking place in three main categories: (1) building hard structures such as levees and seawalls, (2) soft protection such as enhancing wetlands and adding sand from elsewhere to beaches (not a permanent solution, and can encourage development in vulnerable locations), and (3) accommodating the inland movement of the coastline through planned retreat. Building hard structures can, in some cases, actually increase risks and worsen beach erosion and wetland retreat.

Several states have laws or regulations that require setbacks for construction based on the planned life of the development and observed erosion rates. Michigan, North Carolina, Rhode Island, and South Carolina are using such a moving baseline to guide planning. Maine's Coastal Sand Dune Rules prohibit buildings of a certain size that are unlikely to remain stable with a sea-level rise of 2 feet. The Massachusetts Coastal Hazards Commission is preparing a 20-year infrastructure and protection plan to improve hazards management and the Maryland Commission on Climate Change has recently made comprehensive recommendations to reduce the state's vulnerability to sea-level rise and coastal storms by addressing building codes, public infrastructure, zoning, and emergency preparedness. Governments and private interests are beginning to take sea-level rise into account in planning levees and bridges, and in the siting and design of facilities such as sewage treatment plants (see *Northeast* region).