Coasts

Nearly half of all Americans live in the narrow coastal zone around the United States. In addition to accommodating major cities, the coasts and the exclusive economic zone extending 200 miles offshore provide us 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 these ecosystems hold rich biodiversity and provide invaluable services[1]. 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.

Global climate change poses additional stresses on coastal environments. Rising sea levels are already eroding shorelines, drowning wetlands, and threatening the built environment. The destructive potential of Atlantic tropical storms and hurricanes has increased since 1970 in association with warming Atlantic sea surface temperatures, and it is likely that hurricane rainfall and wind speeds will increase in response to global warming[2]. Coastal water temperatures have risen by about 2°F, and marine species have shifted their geographic distributions[3]. Precipitation increases on land have increased river runoff, bring more nitrogen and phosphorous, sediments, and other pollutants into coastal waters. 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[4]. 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, with low-lying and subsiding areas most vulnerable.

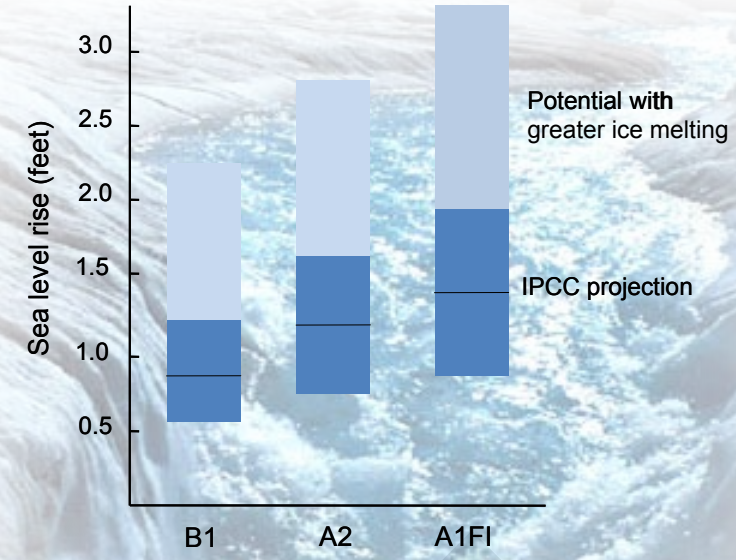
During the past century, the rise in sea level relative to the land ranged from a few inches to two feet, depending on whether and how fast the land was rising or falling. High rates of relative sea level rise, coupled with cutting off the supply of sediments from the Mississippi River and other human alterations, have resulted in the loss of 1,900 square miles of Louisiana's coastal wetlands, weakening their capacity to absorb the storm surge of hurricanes including Katrina[5]. Shoreline retreat is occurring along most of the nation's exposed shores.

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

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, sea level is likely to rise at least two feet in the Chesapeake Bay, where the land is subsiding, threatening most of the estuaries, tidal wetlands, inhabited islands, and other low-lying regions. Climate change will also 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 summer-time 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 such northern species 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 due to rising carbon dioxide levels will make it difficult for oysters to build their shells and will complicate recovery of this key species.

Global sea level rise has been projected to rise 1 to 2 feet during this century,[6] but these estimates purposefully do not include the accelerated melting of the Greenland and West Antarctic ice sheets that many scientists think is likely to occur. Several recent projections suggest that sea level rise by the end of this century could be 3 to 5 feet, especially in subsiding coastal areas[7]. Sea level rise of over 1 foot 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 great enough rate[8]. It would also fragment barrier islands and place into jeopardy many existing homes, business, 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[9].

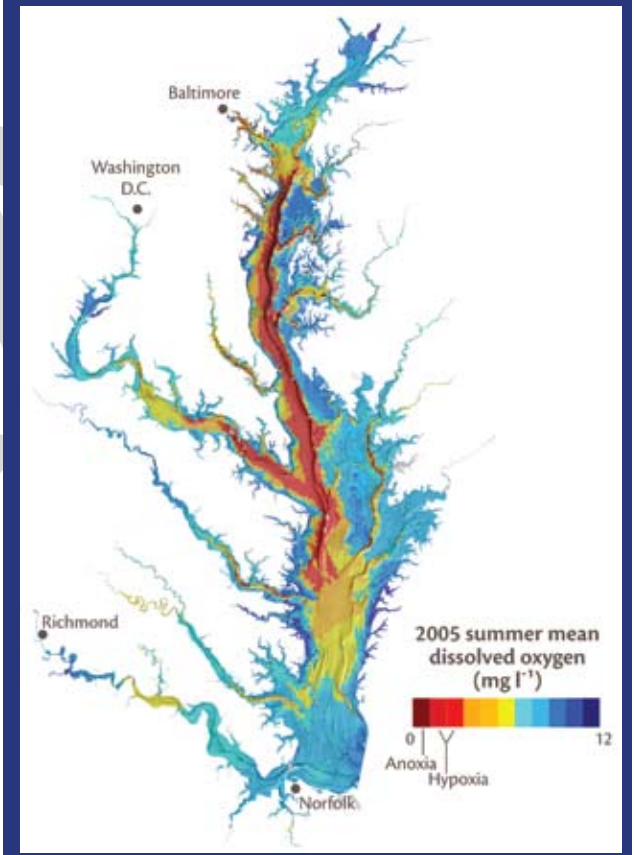


Sea-level rise projections by the end of the century for three emissions scenarios. Land subsidence would increase these rates locally, for example by 0.5 feet in the Chesapeake Bay to 1.5 feet or more along portions of the Gulf Coast. Even greater sea level rise could be realized with greater melting of glaciers and ice sheets.

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 like the northern Gulf of Mexico[10] and the Chesapeake Bay[11] 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 sea floor 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 can't.

Chesapeake Bay "Dead Zone"



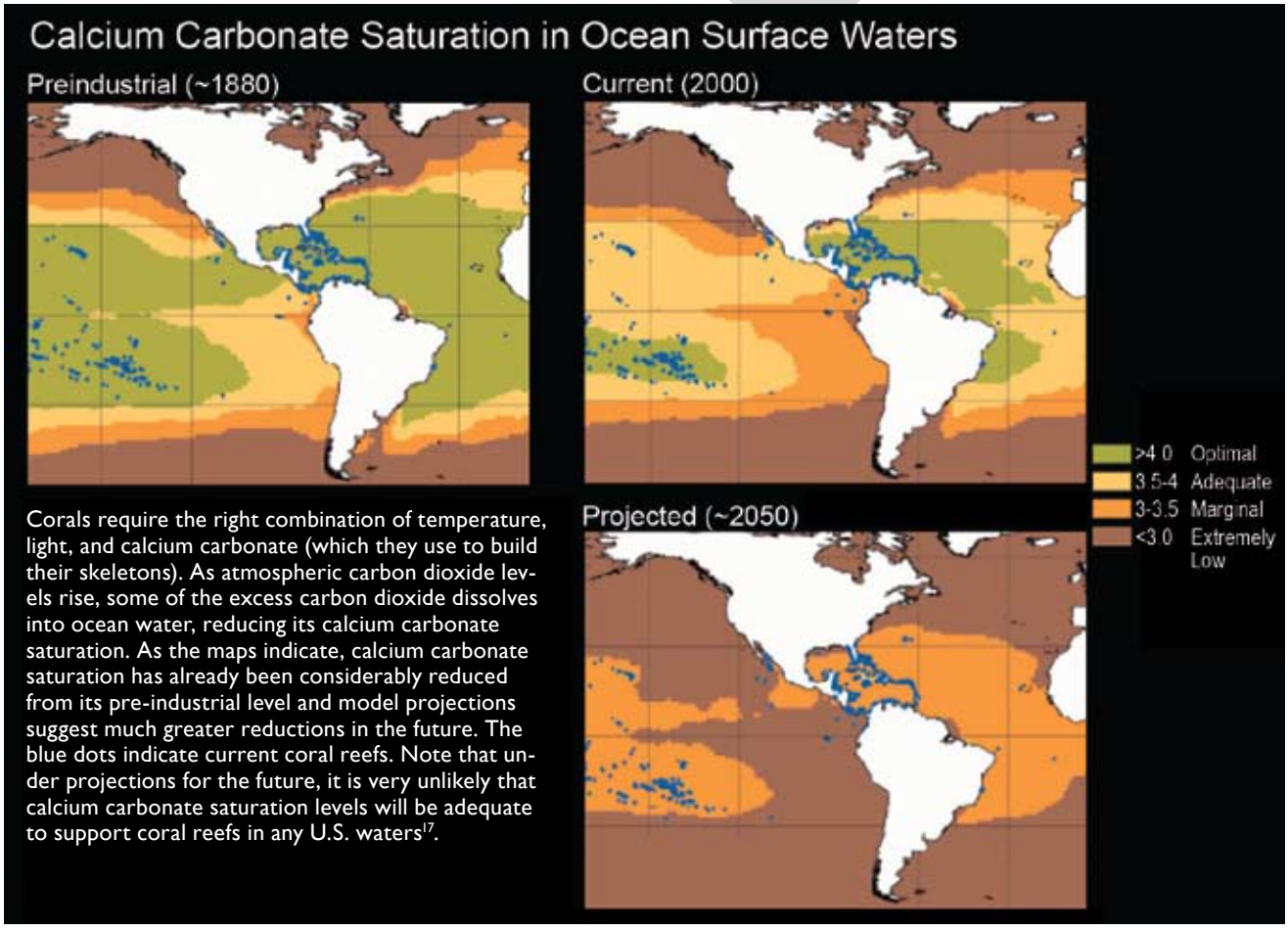
Climate change is likely to exacerbate "dead zones," areas where bottom water is depleted of dissolved oxygen because of nitrogen pollution, such as this example from Chesapeake Bay.

Warming coastal waters will allow new invasions by non-native species that occur through ship transport and other human activities.

Coastal waters are very likely to continue to warm by as much 4-8°F in this century, both in summer and winter. 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.[12] Species that cannot tolerate the higher temperatures will move northward while species from further south move in. This 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. Nonnative clams and small crustaceans have already had major effects on the San Francisco Bay ecosystem and the health of its fishery resources.[13]

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

In addition to its heat-trapping effect, the increase in the concentration of carbon dioxide in the atmosphere is gradually acidifying, or lowering the pH, of the ocean. Much of the carbon dioxide emitted by human activities is absorbed by the ocean. When this carbon dioxide dissolves in sea water it decreases the pH. Since the beginning of the industrial era, ocean pH has declined



Corals require the right combination of temperature, light, and 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 considerably reduced 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[17].

considerably 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 organisms 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 not only important plankton species in the open ocean, mollusks and other shellfish, but reef-building corals. 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 (see *Natural Environment and Biodiversity* 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 rising on their current path[14].

Location of the Pacific Northwest low oxygen "dead zone" in September of 2006.

Changing coastal currents will result in shifts in fisheries and cause surprising changes such as oxygen-depleted waters that either kill marine species or cause them to leave the area.

Because it affects the distribution of heat in the atmosphere and the oceans, climate change will affect the currents that move along the coast, such as the California Current that bathes the west coast from British Columbia to Baja California. 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 impact such coastal currents, and possibly the larger scale natural oscillations as well, though these effects are not yet well understood. 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 like those in the Gulf of Mexico or Chesapeake Bay – may be one such surprise[15].

Adaptation Strategies

Adaptation to sea level rise is already taking place in three main categories: 1) building hard structures like levees and seawalls, 2) soft protection like 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.

A number of states have laws or regulations that require setbacks for construction that vary based on the life of the development and observed erosion rates. Michigan, North Carolina, Rhode Island, and South Carolina use 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).