25. Coastal Zone Development and Ecosystems

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Key Messages

1. **Coastal lifelines, such as water supply and energy infrastructure and evacuation routes, are increasingly vulnerable to higher sea levels and storm surges, inland flooding, and other climate-related changes.**
2. **Climate change increases exposure of nationally important assets, such as ports, tourism and fishing sites, in already-vulnerable coastal locations, threatening to disrupt economic activity beyond the coast and incurring significant costs for protecting or moving them.**
3. **Socioeconomic disparities create uneven exposures and sensitivities to coastal risks and limit adaptation options for some coastal communities, resulting in the displacement of the most vulnerable from coastal areas.**
4. **Coastal ecosystems are particularly vulnerable to climate change because many have already been dramatically altered by human stresses; climate change will result in further reduction or loss of the services that these ecosystems provide, including potentially irreversible impacts.**
5. **Growing awareness of the high vulnerability of coasts to climate change increasingly leads coastal regions to plan for potential impacts on their citizens, businesses, and environmental assets. Significant institutional, political, social, and economic obstacles to implementing adaptation actions remain.**

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U.S. Coastal Population Growth

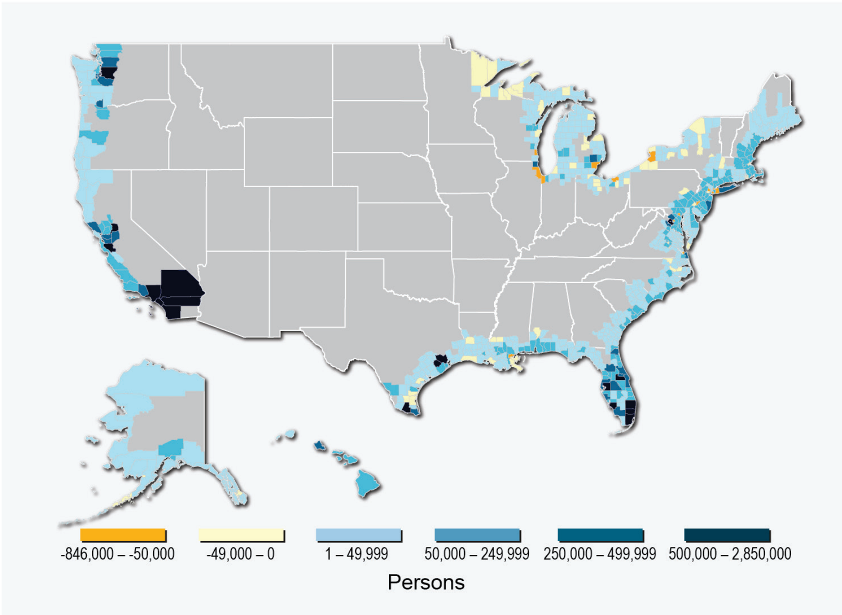

Figure 25.1: U.S. Coastal Population Growth

Caption: U.S. Coastal population growth over last 40 years (Source: U.S. Census Bureau). (Figure on projected growth to 2040 in preparation.)

Flooding During High Tides

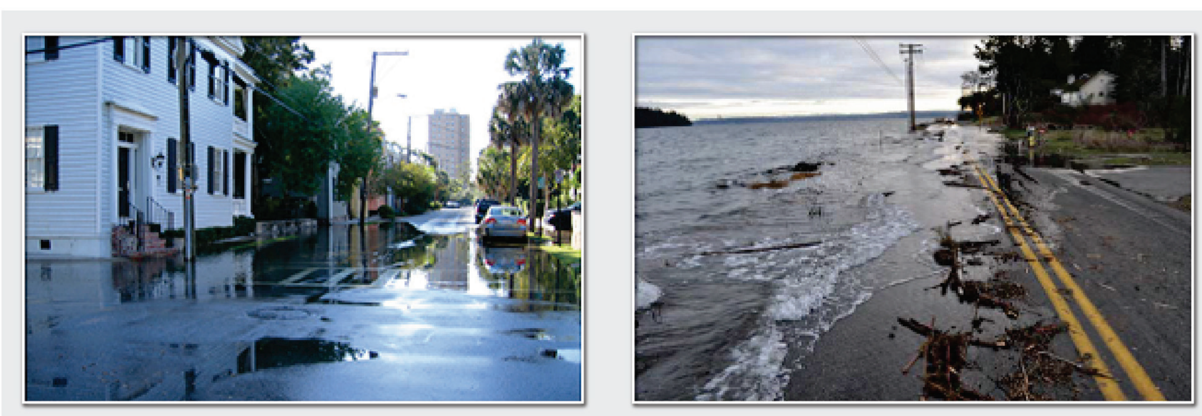

Figure 25.2: Flooding During High Tides

Caption: Sea level rise is not just a problem of the future, but is already impacting coastal communities such as Charleston, South Carolina, and Olympia Drive in South Puget Sound through flooding during high tides and impacts on coastal roads. (Sources: Left – NOAA Coastal Services Center; Right – Ray Garrido, January 6, 2010, reprinted with permission by the Washington Department of Ecology.)

Introduction

Each year, more than 1.2 million people move to the coast, adding the equivalent of nearly one San Diego or more than three Miami's to the 672 coastal counties and parishes of the U.S. As a result, 164 million – more than 50% – of Americans now live in coastal and Great Lakes watershed counties (NOAA 2011a, 2012a; U.S. Census Bureau 2010) and help generate 58% of the national GDP (NOAA 2011b). People come – and stay – for the diverse and growing employment opportunities in recreation and tourism, commerce, energy and mineral production, vibrant urban centers, and the irresistible beauty of our coasts (Bookman and Culliton 1999). Together with the millions of tourists that flock there each year, people place heavy demands on the unique natural systems and resources that make coastal areas so attractive and productive (Burkett and Davidson 2012).

Meanwhile, public agencies and officials are charged with balancing the needs of economic vitality and public safety, while sustaining the built and natural environments in the face of risks from well-known natural hazards such as storms, flooding, and erosion (NOAA 1972). Although these risks play out in different ways along the United States' more than 94,000 miles of coastline (NOAA 2012g), all coasts share one simple fact: no other area concentrates so many people and so much economic activity on so little land, so relentlessly affected by the sometimes violent interactions of land, sea, and air.

Humans have heavily altered the coastal environment through development, changes in land use, and overexploitation of resources. Now, the changing climate is imposing additional stresses (Moser et al. 2012), making life on the coast more challenging. The consequences will ripple through the entire nation, which depends on the productivity and vitality of coastal regions.

Events like "Superstorm" Sandy in 2012 have illustrated that public safety and human well-being become jeopardized by the disruption of crucial lifelines, such as water, energy, and evacuation routes. As climate continues to change, repeated disruption of lives, infrastructure functioning, and nationally and internationally important economic activities will pose intolerable burdens on those already most vulnerable, and aggravate existing impacts on valuable and irreplaceable natural systems. Planning long-term for these changes while balancing different and often competing demands are vexing challenges for decision-makers (Ch. 26: Decision Support).

Climate-related Drivers of Coastal Change

The primary climatic forces affecting the coasts are changes in temperature, sea and water levels, precipitation, storminess, and ocean acidity and circulation (Burkett and Davidson 2012).

- Sea surface temperatures are rising (IPCC 2007; Xue et al. 2012) and are expected to rise faster over the next few decades (Griffis and Howard 2012), with significant regional variation, and the possibility for more intense hurricanes as oceans warm (Emanuel et al. 2008; Grossmann and Morgan 2011; Knutson et al. 2010; Mann et al. 2007a; Mann et al. 2007b; Mendelsohn et al. 2012; Peduzzi et al. 2012; Sabbatelli and Mann 2007).

- Global mean sea levels are rising, and have been doing so for more than 100 years; higher sea levels cause more coastal erosion, more frequent flooding from higher tidal surges, and saltwater intrusion into aquifers and estuaries (Burkett and Davidson 2012; CCSP 2009b; IPCC 2007; Moser et al. 2012; Parris et al. 2012).

- Satellite observations point to an apparent increase in the rate of sea level rise since the 1990s and greater rates are expected in the future (Ch. 2: Our Changing Climate), although the exact rate remains uncertain (Anderson et al. 2010; IPCC 2007; Jevrejeva et al. 2012; Mitchum et al. 2010; Parris et al. 2012; Pfeffer et al. 2008; Rahmstorf 2007), will not be uniform along U.S. coasts (NRC 2012; Sallenger et al. 2012; Tamisiea et al. 2003; Yin et al. 2009), and can be exacerbated locally by land subsidence or reduced by uplift (Blum and Roberts 2009; Cazenave and Llovel 2010; Mazzotti et al. 2007; Nicholls and Cazenave 2010).

- Along the shorelines of the Great Lakes, lake level changes are uncertain (Ch. 18: Midwest), but erosion and sediment migration will be exacerbated by increased lakeside storm events, tributary flooding, and increased wave action due to loss of ice cover (Hayhoe et al. 2008; Uzarski et al. 2009).

- In regions where precipitation increases, coastal areas will see heavier runoff from inland areas, with the already observed trend toward more intense rainfall events continuing to increase the risk of extreme runoff and flooding. Where precipitation is expected to decline and droughts increase, freshwater inflows to the coast will be reduced (Anderson 2012; Burkett and Davidson 2012; Changnon 2009; Changnon and Westcott 2002; Hejazi and Markus 2009; IPCC 2012; Vavrus and Van Dorn 2010; Wilson and Sousounis 2000) .

- There is some observational evidence that storm tracks (for non-tropical cyclones) have shifted northward, and that the most intense tropical storms have increased in intensity in the last few decades (IPCC 2012). Future projections of storm frequency, intensity, and tracks remain uncertain (Lin et al. 2012; Mendelsohn et al. 2012; O'Gorman 2010; Rummukainen 2012; Seneviratne et al. 2012; Woollings et al. 2012).

- Carbon dioxide emitted into the atmosphere is being absorbed by the oceans, resulting in increasing ocean acidity and threatening coral reefs and shellfish (Doney et al. 2012; Hoegh-Guldberg et al. 2007). Additional threats to coastal fisheries stem from climate-related changes in oceanic circulation (Ch. 24: Ocean and Marine Resources) (Chan et al. 2008; Grantham et al. 2004).

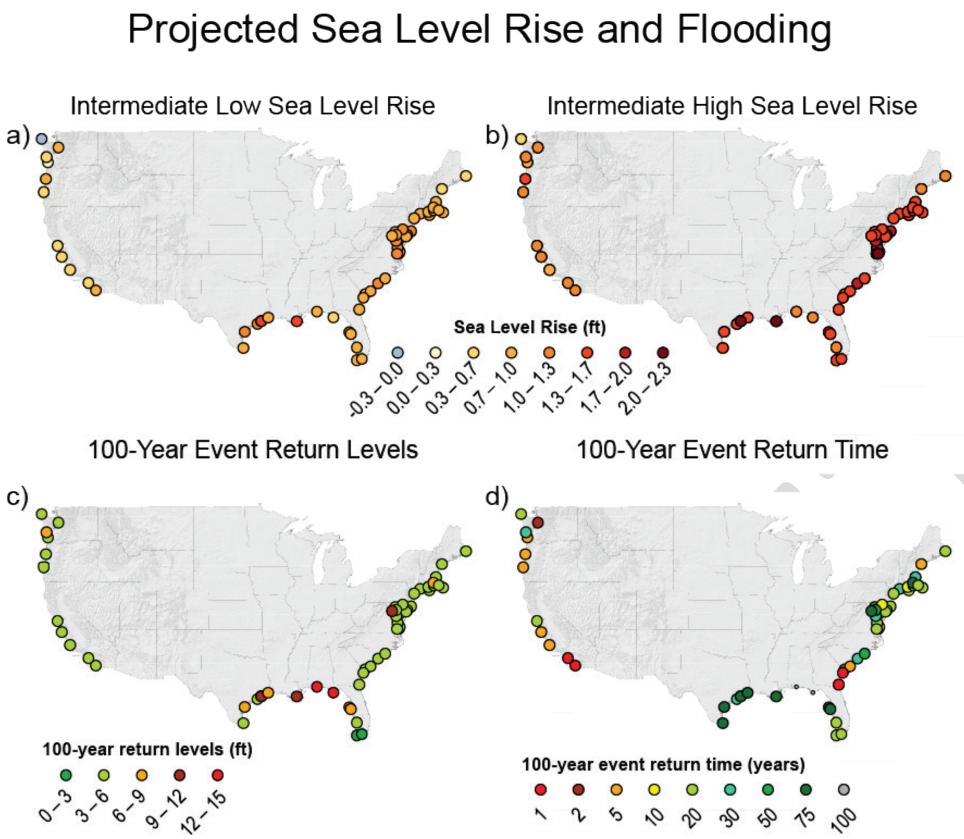

Figure 25.3: Projected Sea Level Rise and Flooding

Caption: The amount of sea level rise (SLR) will vary along different stretches of the U.S. coastline and under different SLR scenarios. The upper panels show feet of sea level above 1992 levels at different tide gauge stations based on a) a 1.6 foot SLR by 2100 and b) a 3.9 foot SLR (both within the range of 1 to 4 feet projected for 2100; Ch. 2: Our Changing Climate, Key Message 9). The amount of flooding ("return level") due to a 100-year storm (that is, a storm that has a 1% chance of occurring in any given year) is similarly projected to vary by region, as shown in panel c), which is in feet above the mean high water level during the tide gauge record (1983-2001, for most gauges).

SLR will also cause the level of flooding that occurs during today's 100-year storm to occur more frequently by mid-century, in some regions as often as once a decade or even annually, as shown in panel d). Source: Replicated Tebaldi et al. (2012) analysis with NCA sea level rise scenarios for panels a) and b); data/ensemble SLR projections used for panels c) and d) from Tebaldi et al. (2012).

None of these changes operate in isolation. The combined effects of climate changes with other human-induced stresses makes predicting the effects of climate change on coastal systems challenging. However, it is certain that these factors will create increasing hazards to the coasts' densely populated areas (Heberger et al. 2009; Strauss et al. 2012; Tebaldi et al. 2012; Weiss et al. 2011).

Figure 25.4: Social Vulnerability (a), Risk of Shoreline Change (b), Climate-Related Threats to U.S. Coastal Regions (c), and Adaptation Activities (d) (Four panels below will be integrated as overlays in a single figure in the final draft, and linked to a full set of references on adaptation examples and climate change threats.)

(a) Social Vulnerabilty Index (SoVI) at the Census tract level using procedures described in Martinich et al. (Martinich et al. 2012) and Schmidtlein et al. (Schmidtlein et al. 2008). Specific index components and weighting are unique to each region (North Atlantic, South Atlantic, Gulf, Pacific, and Great Lakes). All index components constructed from readily available Census data and include measures of poverty, age, family structure, rural vs. urban location, foreign-born status, wealth, gender, Native American status, and occupation.

(b) Risk of Shoreline Change (probability of a shoreline change >1m/yr) is based on methods described in Gutierrez et al. (Gutierrez 2011) with data as the basis for the mapped probabilistic information supplied by Thieler and Hammar-Klose (Thieler and Hammar-Klose 1999, 2000a; Thieler and Hammar-Klose 2000b).

(c) Regional Threats from Climate Change are compiled from technical input reports, the regional chapters in this report, and from the scientific literature (fully-referenced documentation will be provided in supplementary document).

(d) Examples of Adaptation Activities in Coastal Areas of the US and Affiliated Island States are compiled from technical input reports, the regional chapters in this report, the scientific literature, and other documentation available online (fully-referenced documentation will be provided in supplementary document).

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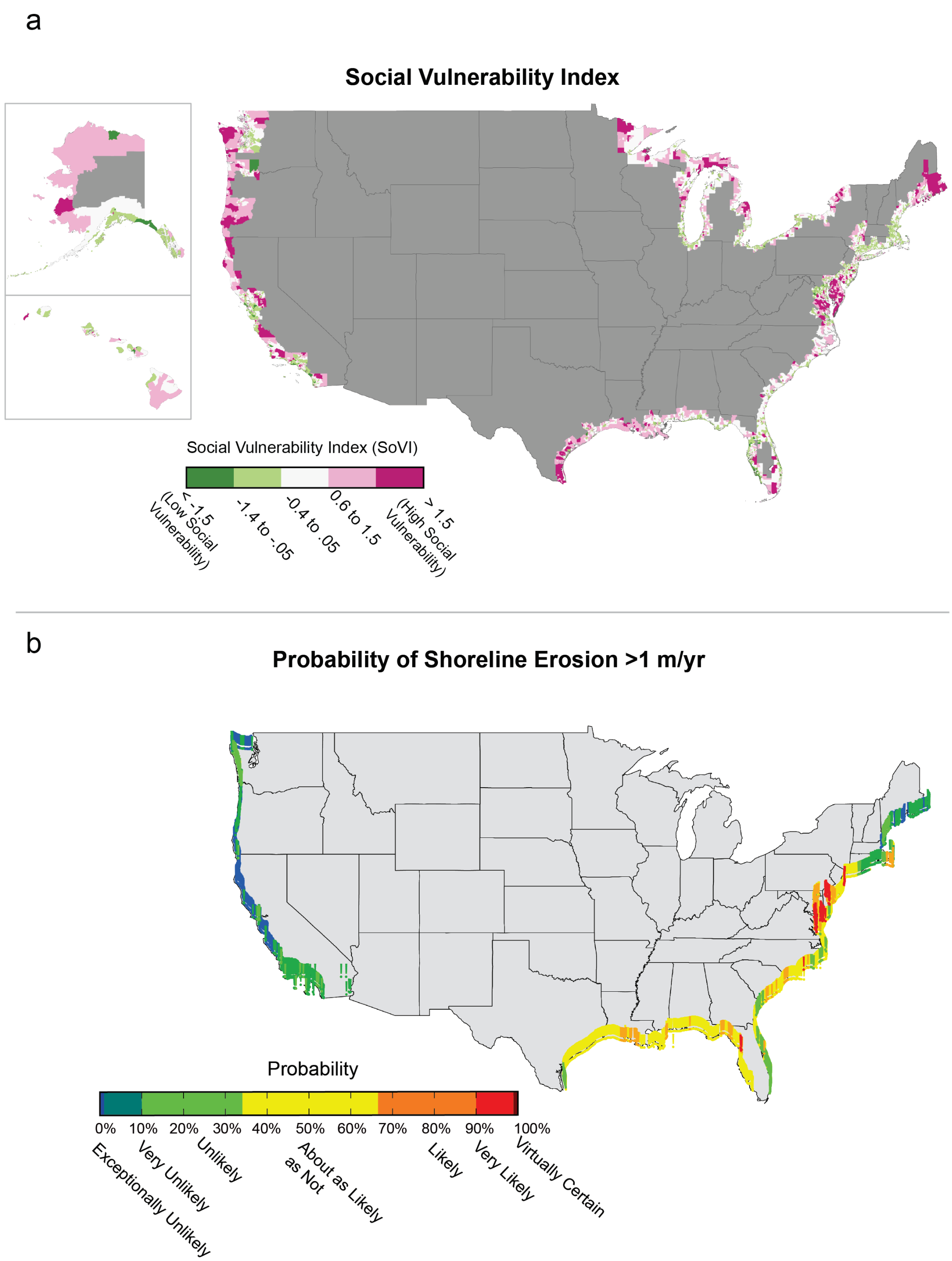
a
Social Vulnerability Index
Social Vulnerability Index (SoVI)
< -1.5 (Low Social Vulnerability)
-1.4 to -.05
-0.4 to .05
0.6 to 1.5
> 1.5 (High Social Vulnerability)
b
Probability of Shoreline Erosion >1 m/yr
Probability
0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%
Exceptionally Unlikely
Very Unlikely
Unlikely
About as Likely as Not
Likely
Very Likely
Virtually Certain


C
Regional Differences in Climate Change Threats
PACIFIC NORTHWEST
• Sea level rise is moderated by the continuing uplift of land, with few exceptions, such as the Seattle area.
• Commercial shellfish populations are suscepti-ble to shell thinning from ocean acidification.
• The region's relatively high economic dependence on commercial fisheries makes it sensitive to climate change impacts on marine species and ecosystem and related coastal ecosystems.
GREAT LAKES
• Higher temperatures and lengthened growing seasons in the Great Lakes region favor production of blue-green and toxic algae that can harm fish, water quality, habitat, and aesthetics.
• Increased winter air temperatures led to decreased Great Lakes ice cover, making shorelines more suseptible to erosion and flooding.
• Current projections of lake level changes are uncertain.
NORTHEAST
• Highly built-up coastal corridor concentrates population and supporting infrastructure.
• Storm surges from northeasters and hurricanes can cause significant damage.
• The historical rate of relative sea level rise varies across the region.
• Wetlands and estuaries are vulnerable to inundation from sea level rise; buildings and infrastructure are most vulnerable to higher storm suges as sea level rises.
CALIFORNIA
• Sea level has risen approximately 7 inches from 1900 to 2005, and is expected to rise at growing rates in this century.
• Higher temperatures, changes in precipitation, runoff and water supplies, and saltwater intrusion into coastal aquifers will result in negative impacts on coastal water resources.
• Coastal storm surges are expected to be higher due to increases in sea level alone, and more intense "atmospheric river systems" will increase coastal flooding risks from inland runoff.
• Expensive coastal development, critical infrastructure, and valuable coastal wetlands are at growing risk from coastal erosion, temporary flooding, and permanent inundation.
MID-ATLANTIC
• Rates of local sea level rise in the Chesapeake Bay are greater than globally averaged ones.
• Sea level rise threatens coastal homes, infrastructure and commercial develop-ment, including ports.
• Chesapeake Bay ecosystems are already heavily degraded, making them more vulnerable to climate-related impacts.
• Climate change and ocean acidification pose threats to Chesapeake Bay fisheries.
GULF COAST
• Hurricanes, land subsidence and sea level rise already pose great risks to Gulf Coast areas, placing homes, critical infrastructure, and people at risk, and causing permanent land loss.
• Coastal inland and water temperatures are expected to rise; and coastal inland areas are expected to become drier.
• There is still uncertainty about future frequency and intensity of Gulf of Mexico hurricanes but SLR will increase storm surges.
• The Florida Keys and coastal Louisiana are particularly vulnerable to additional sea-level rise.
HAWAII & PACIFIC ISLANDS
• Warmer and drier conditions will reduce freshwater supplies on many Pacific Islands, especially on low lying islands and atolls.
• Sea level rise will continue at accelerating rates, exacerbating coastal erosion, damaging infrastructure and agriculture, reducing critical habitat, and threatening shallow coral reef systems.
• Extreme water levels occur when high tides combine with interannual and interdecaldal sea level variations (e.g., ENSO, PDO, mesoscale eddy events) and storm surge.
• Coral reef changes pose threats to communities, cultures, and ecosystems.
ALASKA
• Summer sea ice is receding rapidly, altering marine ecosystems, allowing for greater ship access and offshore development, and making Native communities highly susceptible to coastal erosion.
• Ice loss from melting Alaskan and Canadian glaciers contributes almost as much to sea level rise currently as does melting of the Greenland Ice Sheet.
• Current and projected increases in Alaska's ocean temperatures and changes in ocean chemistry are expected to alter the distribution and productivity of Alaska's marine fisheries.
SOUTHEAST / CARIBBEAN
• A large number of cities, critical infrastructure, and water supplies are at low elevations and exposed to sea level rise.
• Ecosystems of the Southeast are vulnerable to loss from relative sea level rise, especially tidal marshes and swamps.
• Sea level rise will affect coastal agriculture through increasing the height of storm surge inundation, saltwater intrusion, and impacts on freshwater supplies.
• The number of land-falling tropical storms may decline, reducing important rainfall.
• The incidence of harmful algal blooms is expected to increase with climate change, as are health problems previously uncommon in the region.


d
Adaptation Examples
ALASKA
• Newtok, AK is relocating away from the eroding shoreline.
NORTHEAST
• Portland, ME is assessing costs for retrofitting its wastewater infrastructure.
• New Hampshire's Coastal Adaptation Workgroup is providing education, guidance, and networking for local planners.
• City of Boston considers adaptation and mitigation equal priorities, and sea level rise is a top concern.
• Connecticut State Assembly amended the state's Coastal Management Act to promote adaptation to sea level rise.
GREAT LAKES
• Wisconsin's state adaptation plan includes emphasis on lake shorefront areas.
• Bay-Lake Regional Planning Commission updated hazard mitigation plans.
• Ohio's Lake Erie Commission is in the process of developing model shoreline development legislation.
PACIFIC NORTHWEST
• Swinomish Tribe's Climate Change Initiative highlights special challenges of coastal tribes.
• Oregon Sea Grant surveyed its coastal professionals on preparedness for local climate change impacts.
MID-ATLANTIC
• Delaware launched a multi-faceted effort to prepare coastal communities for sea level rise
• Maryland's Comprehensive Strategy for Reducing Vulnerability to Climate Change has a strong initial focus on sea level rise and coastal hazards.
• Hampton Roads area and City of Norfolk, VA are working to reduce recurrent flooding and impacts on
CALIFORNIA
• San Diego Bay engaged in a multi-sector, multi-level stakeholder process to develop a first adaptation plan.
• California Ocean Protection Council developed sea level rise guidance to state and local governments.
• Bay Conservation & Development Commission passed Bay Plan Amendment.
GULF COAST
• Mississippi – Coastal Improvements Program includes buy-outs and relocation.
• 2012 Louisiana Coastal Master Plan ambitiously aims to protect and restore low-lying land.
• Entergy, America's Wetland Foundation, Oxfam champion joint adaptation planning for America's Energy Coast.
• Texas requires rolling easements.
SOUTHEAST / CARIBBEAN
• NC Department of Transportation is raising the road bed of US Highway 64 to account for future sea level rise.
• The City of Charleston upgraded stormwater pumps and sewer systems to reduce tidal flooding.
• Charlotte Harbor National Estuary Program and City of Punta Gorda, FL involved community stakeholders in its adaptation planning process.
• Southeast Florida Regional Climate Change Compact designated Adaptation Action Areas.
HAWAII & PACIFIC ISLANDS
• Researchers map sea level rise in Honolulu to help communities assess risks.
• USGS helps monitor saltwater intrusion on Majuro Atoll, Marshall Islands.

Coastal Lifelines at Risk

Coastal lifelines, such as water supply and energy infrastructure and evacuation routes, are increasingly vulnerable to higher sea levels and storm surges, inland flooding, and other climate changes.

Key coastal vulnerabilities arise from complex interactions among climate change and other physical, human, and ecological factors. These vulnerabilities have the potential to fundamentally alter life at the coast and disrupt coast-dependent economic activities.

Coastal infrastructure is exposed to climate change impacts from both the landward and ocean sides (Aerts and Botzen 2012; Bidwell et al. 2012; Biging et al. 2012; Bjerklie et al. 2012; Bloetscher et al. 2011; Burkett and Davidson 2012; DOT 2011; Flick and Murray 2003; Heberger et al. 2009; Irish et al. 2010; Kirshen et al. 2012; Markon et al. 2012; Marra et al. 2012; ORNL 2012; Poulter et al. 2009; Rosenzweig et al. 2011a; Weiss et al. 2011; Wilby and Keenan 2012). Some unique characteristics increase the vulnerability of coastal infrastructure to climate change (Ch. 11: Urban and Infrastructure) (Burkett and Davidson 2012; Zimmerman and Faris 2010). For instance, many coastal regions were settled long ago, making much of the infrastructure older than in other locations (ASCE 2012). Also, inflexibility of some coastal, water-dependent infrastructure, such as onshore gas and oil facilities, port facilities, thermal power plants, and some bridges, makes landward relocation difficult, while build-up of urban and industrial areas inland from the shoreline inhibit landward relocation (Burkett and Davidson 2012).

Infrastructure is built to certain site-specific design standards (such as the once-in-10-year, 24-hour rainstorm or the once-in-100-year flood) that take account of historical variability in climate, coastal, and hydrologic conditions. Impacts exceeding these standards can shorten the expected lifetime, incur greater maintenance costs, and decrease services. In general, higher sea levels, especially when combined with inland changes, will result in accelerated infrastructure impairment, with associated indirect effects on regional economies and a need for infrastructure upgrades, redesign, or relocation (Aerts and Botzen 2012; Bidwell et al. 2012; Biging et al. 2012; Bjerklie et al. 2012; Bloetscher et al. 2011; Burkett and Davidson 2012; DOT 2011; Flick and Murray 2003; Heberger et al. 2009; Irish et al. 2010; Kirshen et al. 2012; Marra et al. 2012; Poulter et al. 2009; Rosenzweig et al. 2011a; Weiss et al. 2011; Wilby and Keenan 2012).

Figure 25.5: Adaptation Possibilities for Coastal Infrastructure

Caption: This “mock-up” photo shows the existing Highway LA-1 and Leeville Bridge in coastal Louisiana (on the right) with a planned new, elevated bridge that would retain functionality under future, higher sea level conditions (center left). A 7-mile portion of the planned bridge has been completed and opened to traffic in December 2011. (Source: LA1-Coalition)

The more than 60,000 miles of coastal roads (Douglass et al. 2005) are essential for human activities in coastal areas (Ch. 5: Transportation), especially in case of evacuations during coastal emergencies (NOAA 2012e; U.S.A. Evacuation Routes 2012). Population growth to date and expected additional growth place growing demands on these roads, and climate change will decrease their functionality unless adaptation measures are taken (DOT 2012; Transportation Research Board 2011). Already, many coastal roads are affected during storm events (Federal Highway Administration 2008; Florida Department of Environmental Protection 2012; Texas General Land Office 2012; Wolshon 2006) and extreme high tides (California King Tides Initiative 2012; State of Washington 2012; Turner 2011; Watson 2011). Moreover, as coastal bridges, tunnels and roads are built or redesigned, engineers must account for inland and coastal changes, including drainage flooding, ground ice thaw, higher groundwater levels, and increasing saturation of roadway bases (Maine Department of Transportation 2003). During

Hurricane Katrina, many bridges failed because they had only been designed for river flooding but were also unexpectedly exposed to storm surges (Berry et al. 2012; DOT 2012).

Drainage and wastewater management systems constitute critical infrastructure for coastal businesses and residents (Ch. 3: Water Resources). With 20 of the 25 largest cities of the U.S. located along coastlines, saltwater intrusion in coastal aquifers will have widespread impacts (Solecki and Rosenzweig 2012). Wastewater treatment plants are typically located at low elevations to take advantage of gravity-fed sewage collection. Increased inland and coastal flooding make sewage treatment plants more vulnerable to disruption, while increased inflows will reduce treatment efficiency (County 2008; Daigger 2008; Daigger 2009; Flood and Cahoon 2011; Freas et al. 2010; Kirshen et al. 2011; Mailhot and Duchesne 2010; NYCDEP 2008; Rosenberg et al. 2010; Water Research Foundation 2012; WERF 2009). The drainage systems – designed using mid-20th century rainfall records – will drain less effectively in the future because of increased rainfall intensity (Changnon 2011; Peterson et al. 2012; Seneviratne et al. 2012; Ch. 2: Our Changing Climate) over more impervious surfaces (like asphalt and concrete) (Bierwagen et al. 2010; Bjerklie et al. 2012; Johnson 2012; Klein et al. 2003; Toll 2010), and reduced outlet capacity due to higher sea levels, resulting in more local flooding and combined sewer overflows (Center for Clean Air Policy and Environmental and Energy Study Institute 2012; EPA 2008). Together, these impacts on water systems increase the risks of urban flooding (Ch. 11: Urban and Infrastructure), deteriorating water quality, and human health impacts (Chillymanjaro 2011) (Ch. 9: Human Health). Wastewater system adaptations nationwide could cost utilities between $123 and $252 billion by 2050 (AMWA 2009).

The nation's energy infrastructure, such as power plants, oil and gas refineries, storage tanks, transformers, and electricity transmission lines, are often located directly in the coastal floodplain (Hayhoe et al. 2010; Perez 2009; Sathaye et al. 2011; Wilbanks et al. 2012). Roughly two-thirds of imported oil enters the U.S. through Gulf of Mexico ports (DOT 2012), where it is refined and then transported inland. Storm-related flooding and permanent inundation from sea level rise will disrupt these refineries (and related underground infrastructure) and, in turn, will constrain the supply of refined products to the rest of the nation unless adaptive measures are taken (Ch. 4: Energy Supply and Use; Ch. 10: Water, Energy, and Land Use; Francis et al. 2011; Rosato et al. 2008; Vugrin and Camphouse 2011; Vugrin et al. 2011; Zimmerman 2006).

Figure 25.6: Ecosystem Restoration

Caption: Coastal ecosystem restoration projects, such as the one shown in this example from New York City, help protect coastal waterfronts and maintain resilience of coastal infrastructure. Source: Department of City Planning, New York City, reprinted with permission.

To avoid these impacts, coastal infrastructure needs to be designed for changes in future inland and coastal conditions, including stressors not previously experienced in certain locations, as well as the possibility that infrastructure like bridges, roads, and culverts need more frequent replacing (Hallegatte 2008; U.S. Government 2009). Coastal communities have a variety of options to protect, replace, and redesign existing infrastructure, including flood proofing and flood protection through dikes, berms, pumps, elevation, or relocation. Relocation of large coastal infrastructure can be very expensive, however, and even the addition of new infrastructure in high-hazard zones is sometimes viewed as a more cost-effective option than siting elsewhere (SFRPC 2012; South Florida Regional Climate Change Compact 2012). A combination of built and natural infrastructure is increasingly recognized as a potentially cost-effective approach (Center for Clean Air Policy and Environmental and Energy Study Institute 2012; Davoudi et al. 2009; Jones et al. 2012; Nolon and Salkin 2011; Tzoulas et al. 2007) to reducing risks to communities and economies (Burkett and Davidson 2012; Irish and Resio 2010; Roseen et al. 2011).

BOX 25.1: Assessing Flood Exposure of Critical Facilities and Roads

NOAA's Critical Facilities Flood Exposure Tool provides an initial assessment of the risk to a community's critical facilities and roads within the "100-year" flood zone established by the Federal Emergency Management Agency (FEMA) (the 100-year flood zone is the aerial extent of a flood that has a 1% chance of occurring in any given year). The tool helps coastal managers quickly learn which facilities may be at risk – providing information that can be used to increase flood risk awareness and to inform a more detailed analysis and ultimately flood risk reduction measures. The critical facilities tool was initially created to assist Mississippi/Alabama Sea Grant in conducting its "Coastal Resiliency Index: A Community Self-Assessment" workshops and is now available for communities nationwide. For additional information contact: http://www.csc.noaa.gov/digitalcoast/tools/criticalfacilities

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Economic Disruption

Climate change increases exposure of nationally important assets, such as ports, tourism, and fishing sites, in coastal locations that are already vulnerable, threatening to disrupt economic activity beyond the coast and incurring significant costs for protecting or moving them.

Economic activity in coastal counties accounts for approximately 66 million jobs and $3.4 trillion in wages (NOAA 2011c) through a diversity of industries and commerce. In many instances, economic activity is fundamentally dependent on the physical and ecological characteristics of the coast. These features provide the template for coastal economic activities, including natural protection from waves, access to beaches, flat land for port development and container storage, and wetlands that support fisheries and provide flood protection.

More than 5,790 square miles (15,000 km^2) and more than $1 trillion of property and structures are at risk of inundation from sea level rise of two feet (66 cm) above current sea level – an elevation which could be reached by 2050 under a high rate of sea level rise of approximately 6.6 feet by 2100 (Parris et al. 2012), 20 years later assuming a lower rate of rise (4 feet by 2100) (Ch. 2: Our Changing Climate, Key Message 9), and sooner in areas of rapid land subsidence (Neumann et al. 2010a; Neumann et al. 2010b). Roughly half of the vulnerable property value is located in Florida, and the most vulnerable port cities are Miami, Greater New York, New Orleans, Tampa-St. Petersburg, and Virginia Beach (Biging et al. 2012; Cooley et al. 2012; Heberger et al. 2009; Neumann et al. 2010a).

Although comprehensive national estimates are not yet available, regional studies are indicative of the potential risk: the incremental annual damage of climate change to capital assets in the Gulf region alone could be $2.7 to $4.6 billion by 2030, and $8.3 to $13.2 billion by 2050; about 20% of these at-risk assets are in the oil and gas industry (America's Wetland Foundation et al. 2010). Investing approximately $50 billion for adaptation over the next 20 years could lead to approximately $135 billion in averted losses over the lifetime of adaptive measures (America's Wetland Foundation et al. 2010; State of Louisiana 2012).

More than $1.9 trillion in imports came through U.S. ports in 2010, with commercial ports directly supporting more than 13 million jobs (NOAA 2011) and providing 90% percent of consumer goods (Cordero 2011; IMO 2012; U.S. Navy 2007). Ports damaged during major coastal storms can be temporarily or permanently replaced by other modes of freight movement, but at greater cost (Ch. 5: Transportation). Although the stakes are high and adaptation options are available, a recent survey showed that most U.S. ports have not yet taken actions to adapt their operations to rising seas, increased flooding, and the potential for more extreme coastal storms (Becker et al. 2012).

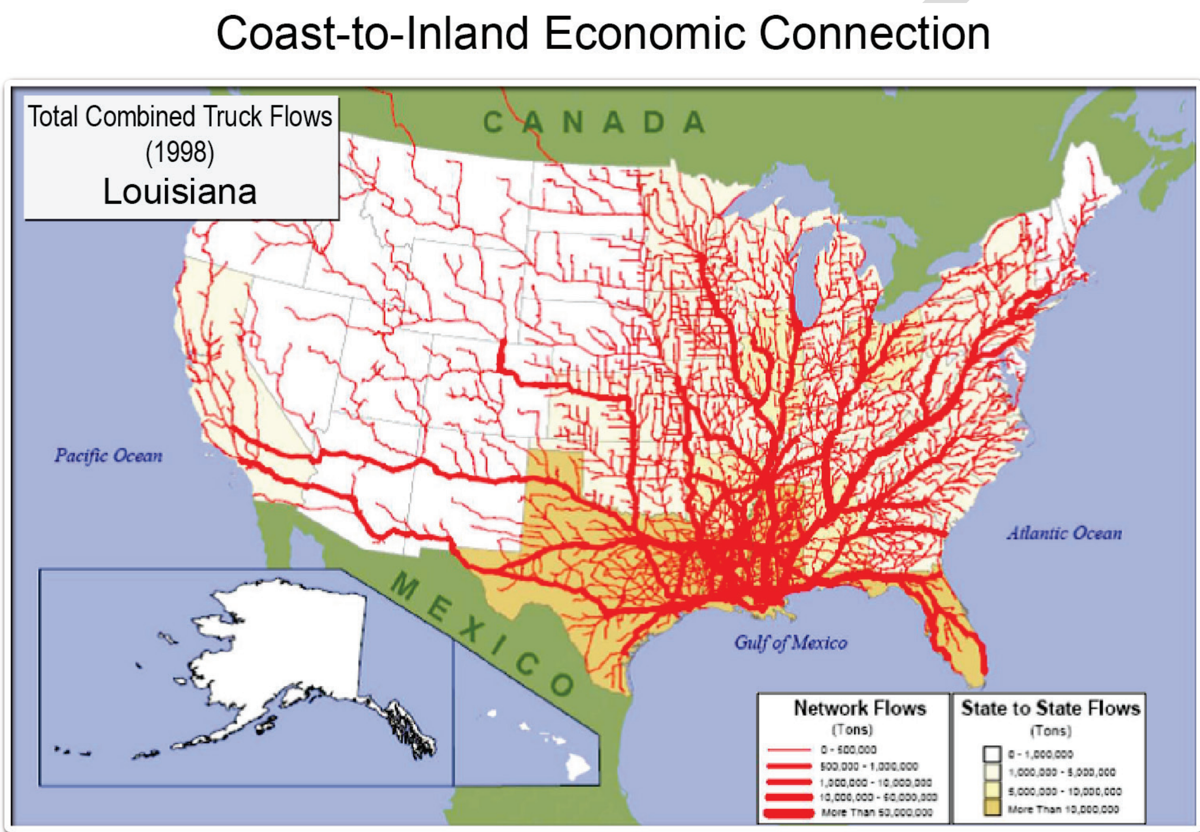

Figure 25.7: Coast-to-Inland Economic Connection

Caption: Coastal and inland economic activities are tightly linked. Such coast-hinterland connections can be temporarily disrupted from extreme events with significant economic implications for the rest of the nation. (Source: DOT) (Updated figure in preparation.)

Coastal recreation and tourism comprises the largest and fastest-growing sector of the U.S. service industry, accounting for 85% of the $700 billion annual tourism-related revenues (Houston 2008; NOAA 1998; U.S. Travel Association 2012), making this sector particularly vulnerable to increased impacts from climate change (NPCA 2012). Historically, development of immediate shoreline areas with hotels, vacation rentals, and other tourism-related establishments has frequently occurred without adequate regard for coastal hazards or shoreline dynamics (for example, inlet migration) (Nordstrom et al. 2011; Pendleton et al. 2012). Hard shoreline protection against the encroaching sea (like building sea walls or riprap) generally aggravates erosion and beach loss, and causes negative effects on coastal ecosystems, undermining the attractiveness of beach tourism. Thus "soft protection" through beach replenishment is increasingly preferred to "hard protection" measures. To continue the practice in the face of faster rising seas, sand replenishment would need to be undertaken more frequently, and thus at growing expense (Caldwell et al. 2012; Fletcher et al. 1997; Herrmann 1997; Kittinger and Ayers 2010; Leatherman and Gaunt 1989; Merrifield et al. 2012; NRC 1995, 2012; Pilkey and Dixon 1996).

U.S. oceanic and Great Lakes coasts are important centers for commercial and recreational fishing due to the high productivity of coastal ecosystems. In 2009, the U.S. seafood industry supported approximately 1 million full- and part-time jobs and generated $116 billion in sales and $32 billion in income (NMFS 2010). Recreational fishing also contributes to the economic engine of the coasts, with some 74 million saltwater fishing trips along U.S. coasts in 2009 generating $50 billion in sales and supporting over 327,000 jobs (NMFS 2010). Climate change threatens to disrupt fishing operations, through direct and indirect impacts to fish stocks (for example, temperature-related shifts in species ranges, changes in prey availability), as well as storm-related disruptions (Ch. 24: Ocean and Marine Resources).

Uneven Social Vulnerability

Socioeconomic disparities create uneven exposures and sensitivities to coastal risks and limit adaptation options for some coastal communities, resulting in the displacement of the most vulnerable from coastal areas.

In 2010, almost 24.6 million Americans lived within the 100-year floodplain or in neighborhoods that border the open ocean coast (Crossett et al. 2004; Crowell et al. 2010). Two trends will place even more people at risk in the future: the expansion of the floodplain as sea level rises, and the continuing immigration of people to coastal areas.

By 2100, the fraction of the U.S. population living in coastal counties is expected to increase by between 50% (46.2 million) under a scenario of substantial emissions reduction (B1) and 144% (131.2 million) under current emissions trends (EPA 2010; Nakicenovic et al. 2000). While specific population projections for future 100-year flood zones are only available for some locations (Carson and Montz 2009; Kleinosky et al. 2007), many of these new arrivals can be expected to locate in high-hazard areas. Thus, coastal population densities, along with increasing economic development, will continue to be an important factor in the overall exposure to climate change (Burkett and Davidson 2012; NOAA 2011b; Pielke Jr 2007; Strauss et al. 2012; Zhang and Leatherman 2011).

Despite persistent beliefs that living on the coast is reserved for the wealthy (Davis and Palumbo 2008; Neumann et al. 2010a; Zabel 2004), there are large social disparities in coastal areas that vary regionally (Burton and Cutter 2008; Cutter and Finch 2008; Emrich and Cutter 2011; Martinich et al. 2012; Moser and Ekstrom 2010a; Oxfam America 2009; Rygel et al. 2006). Full understanding of risk for coastal communities requires consideration of social vulnerability factors limiting people's ability to adapt. These factors include lower income, minority status, low educational achievement, advanced age, income dependencies, employment in low-paying service, retail, and other sectors, as well as being often place-bound, less economically and socially mobile, and much less likely to be insured than wealthy property owners (Bovbjerg 2007; Clark et al. 1998; Cutter et al. 2003; Moser et al. 2008; Texas Health Institute 2012) (see panel (a) in Figure 25.4).

For example, in California, an estimated 217,000 individuals are currently exposed to a 100-year flood; this number could double by 2100 as a result of a 4.6 foot sea level rise alone (roughly equivalent to the high end of the 1 to 4 foot range of sea level rise projections, Ch.2: Our Changing Climate) (Heberger et al. 2009). Approximately 18% of those exposed to high flood risk by the end of this century also fall into the "high social vulnerability" category (Cooley et al. 2012). This means that while many coastal property owners at the shorefront tend to be less socially vulnerable, adjacent populations just inland are often highly vulnerable.

Perhaps most important, adaptation options for highly socially vulnerable populations are limited (Cooley et al. 2012). Native communities in Alaska and Louisiana already face this challenge today (Textbox 25.2; Ch. 12, Tribal Lands and Resources)(Callaway et al. 1999; Louisiana Workshop 2012; Papiez 2009; Standen 2012; Tribal Climate Change Project 2008a, 2008b, 2010). Up to 50% of the areas with high social vulnerability face the prospect of unplanned retreat under the 1 to 4 foot range of projected sea level rise (Ch.2: Our Changing Climate), for several key reasons: they cannot afford expensive protection measures themselves, cost-benefit ratios don't favor public expense, or there is little support for a more orderly retreat process. By contrast, only 5% to 10% of the low social vulnerability areas are expected to face unplanned retreat (Martinich et al. 2012). This suggests that climate change could displace many socially vulnerable individuals and lead to significant social disruptions in some coastal areas (Titus et al. 2009).

BOX 25.2: Unique Challenges for Coastal Tribes

Coastal Native American and Native Alaskan populations, with their traditional dependencies upon natural resources, exhibit vulnerabilities that involve some unique challenges and capacities. Tribal adaptation options can be limited because tribal land boundaries are typically bordered by non-reservation lands, and climate change could force them to abandon traditionally important locations, certain cultural practices, and natural resources on which they depend. Tribes pride themselves for their experience and persistence in adapting to challenging situations. However, climate change presents a new challenge that is outside of the realm in which tribes have historically adapted (Ch. 12: Tribal Lands and Resources).

-- end box --

Vulnerable Ecosystems

Coastal ecosystems are particularly vulnerable to climate change because many have already been dramatically altered by human stresses; climate change will result in further reduction or loss of the services that these ecosystems provide, including potentially irreversible impacts.

Coastal Ecosystems Services

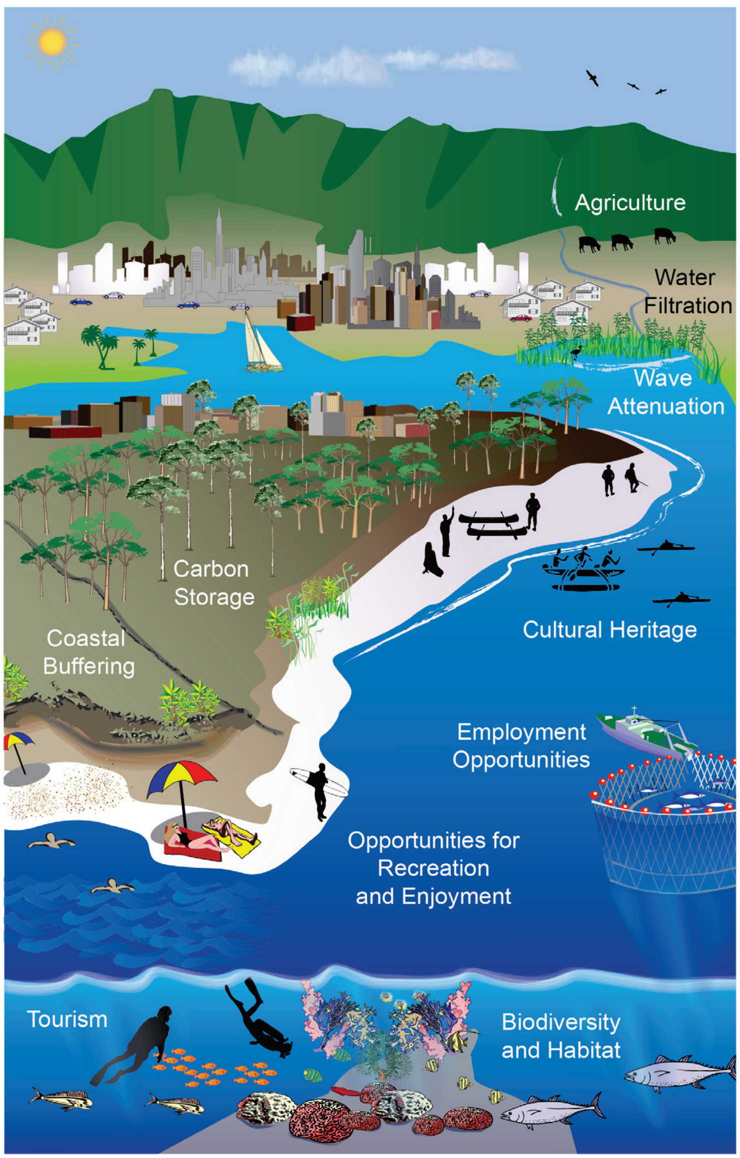

Figure 25.8: Coastal Ecosystems Services

Caption: Coastal ecosystems provide a suite of valuable benefits (ecosystem services) on which humans depend for food, economic activities, inspiration, and enjoyment. This schematic illustrates many of these services situated in a Pacific or Caribbean island setting, but many of them can also be found along mainland coastlines.

Coastal ecosystems provide a suite of valuable benefits (ecosystem services) on which humans depend, including reducing the impacts from floods, buffering from storm surge and waves, and providing nursery habitat for important fish and other species, water filtration, carbon storage, and opportunities for recreation and enjoyment (Holzman 2012; Millennium Ecosystem Assessment 2005; Principe et al. 2012).

However, many of these ecosystems are rapidly being degraded by human impacts, including pollution, habitat destruction, and the spread of invasive species. For example, 75% of U.S. coral reefs in the Atlantic, Caribbean, and Gulf of Mexico are already in “poor” or “fair” condition (EPA 2012; Waddell and Clarke 2008); all Florida reefs are currently rated as “threatened” (Burke et al. 2011). Moreover, the incidence of low-oxygen “dead zones” in coastal waters has increased 30-fold in the U.S. since 1960, with over 300 coastal water bodies now experiencing stressful or lethal oxygen levels (Ch. 8, Ecosystems and Biodiversity) (CENR 2010). Coastal wetlands are being lost at high rates in Southeastern Louisiana (Couvillion et al. 2011; Diaz and Rosenberg 2008; Yuill et al. 2009).

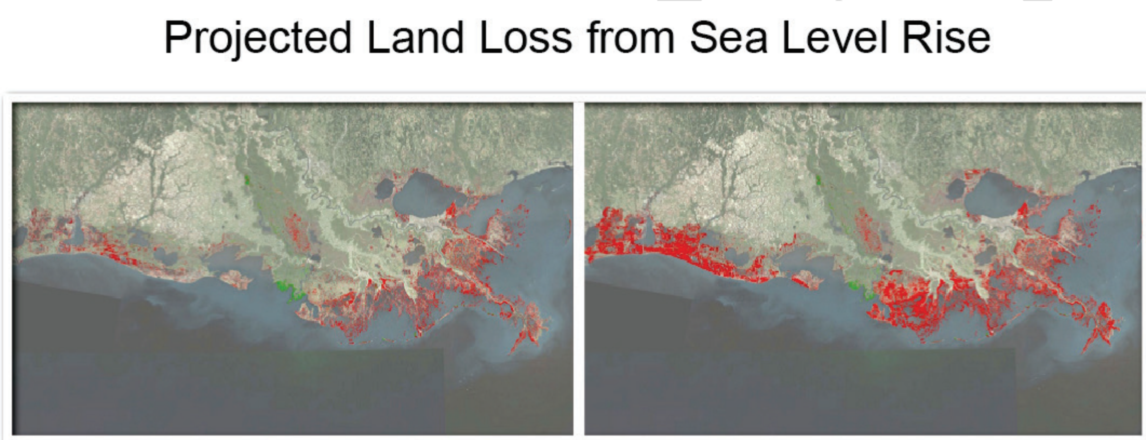

Figure 25.9: Projected Land Loss from Sea Level Rise

Caption: These maps show expected future land change in coastal Louisiana under two different scenarios of sea level rise. Land loss is influenced by factors other than sea level rise, including subsidence, river discharge and sediment load, and precipitation patterns. However, all these factors except sea level rise were held constant for this analysis. The panel on the right shows land change with a SLR of 10.6 inches between 2010 and 2060, while the one on the right assumes 31.5 inches of SLR rise for the same period. These amounts of SLR are within the projected SLR ranges for this time period (Ch. 2: Our Changing Climate). More information on the models that produced these maps can be found at www.coastalmasterplan.la.gov. (Source: State of Louisiana)

These existing stresses on coastal ecosystems will be exacerbated by effects of climate change, such as increased ocean temperatures that lead to coral bleaching (Hoegh-Guldberg et al. 2007), altered river flows affecting the health of estuaries (Petes et al. 2012), and acidified waters threatening shellfish (Barton et al. 2012). Climate change also affects the survival, reproduction, and health of coastal plants and animals in different ways. For example, changes in the timing of seasonal events (for example, breeding, migration), shifts in species distributions and ranges, changes in species interactions, and declines in biodiversity all combine to produce fundamental changes in ecosystem character, distribution, and functioning (Doney et al. 2012). Species with narrow physiological tolerance to change, low genetic diversity, specialized resource requirements, and poor competitive abilities are particularly vulnerable (Dawson et al. 2011; Feder 2010; Foden et al. 2008; Hoegh-Guldberg 1999; Hofmann and Todgham 2010; Montoya and Raffaelli 2010). Where the rate of climate change exceeds the pace at which plants and animals can acclimatize or adapt, impacts on coastal ecosystem will be profound (Alongi 2008; Craft et al. 2009; Kirwan et al. 2010). For example, high death rates of East Coast intertidal mussels at their southern range boundary have occurred because of rising temperatures between 1956 and 2007 (Jones et al. 2009). The presence of physical barriers, such as hardened shorelines, coastal development, and reduced sediment availability, and concurrent stressors such as pollution, habitat destruction, and invasive species will further exacerbate the ecological impacts of climate change and limit the ability of these ecosystems to adapt (Gedan et al. 2009; Glick et al. 2011; Williams and Grosholz 2008), as in the case of marshes attempting to migrate landward with sea level rise (Callaway et al. 2011; Craft et al. 2009; Feagin et al. 2010; Gedan et al. 2009; Kirwan et al. 2010; Phillips and Slattery 2006; Stralberg et al. 2011).

Of particular concern is the potential for coastal ecosystems to cross thresholds of rapid change (“tipping points”), beyond which they exist in an altered state or are lost entirely from the area; in some cases, these changes will be irreversible (Hoegh-Guldberg and Bruno 2010). These unique “no-analog” environments present serious challenges to resource managers, who are confronted with conditions never seen before (Barnosky et al. 2012; Burkett et al. 2005; CCSP 2009a; Nicholls et al. 2007). The ecosystems most susceptible to crossing such tipping points are those that have already lost some of their resilience due to degradation or depletion by non-climatic stressors (Folke et al. 2004). Certain coastal ecosystems are already rapidly changing as a result of interactions between climatic and non-climatic factors, and others have already crossed tipping points. Eelgrass in the Chesapeake Bay died out almost completely during the record-hot summer of 2005, when temperatures exceeded the species’ tolerance threshold of 86°F (30°C) (Moore and Jarvis 2008), and subsequent recovery has been poor (Jarvis and Moore 2010). Severe low-oxygen events have emerged as a novel phenomenon in the Pacific Northwest due to changes in the timing and duration of coastal upwelling (Barth et al. 2007; Chan et al. 2008). These have led to high mortality of Dungeness crabs (Grantham et al. 2004) and the temporary disappearance of rockfish (Chan et al. 2008), with consequences for local fisheries. Reducing non-climatic stressors at the local scale can potentially prevent crossing some of these tipping points (Biggs et al. 2009; Hsieh et al. 2008; Kelly et al. 2011; Lubchenco and Petes 2010; Sumaila et al. 2011).

Adaptation Planning

Growing awareness of the high vulnerability of coasts to climate change increasingly leads coastal regions to plan for potential impacts on their citizens, businesses, and environmental assets. Significant institutional, political, social, and economic obstacles to implementing adaptation actions remain.

Considerable progress has been made since 2009 in both coastal adaptation science and practice (Figure 25.4, panel (d)), though significant gaps in understanding, planning, and implementation remain (Blakely and Carbonell 2012; Brugmann 2011, 2012; Gregg et al. 2011; Hart et al. 2012; Moser and Ekstrom 2012; NRC 2010). U.S. coastal managers pay increasing attention to adaptation, but are mostly still at an early stage of building their capacities for adaptation rather than implementing structural or policy changes (Ch. 28: Adaptation; Hart et al. 2012; Moser 2009; NRC 2010). Although well familiar with historical approaches to structural shoreline protection, managers are less familiar with some of the more innovative approaches to coastal adaptation, such as rolling easements (Titus et al. 2009), ecosystem-based adaptation, or managed retreat (Grannis 2011; Hart et al. 2012). There is only limited evidence of more substantial ("transformational") adaptation occurring (Ch. 22: Alaska and Arctic; Kates et al. 2012; Marino 2012; State of Louisiana 2012).

Coastal populations show growing concern about climate related impacts and support the development of adaptation plans (Borberg et al. 2009; Goidel et al. 2012; Hart et al. 2012; Leiserowitz et al. 2011a, 2011b; Responsive Management 2010; The Mellman Group 2011), but support for development restrictions or managed retreat is limited (Agyeman et al. 2009; Fresque-Baxter and Armitage 2012; Goidel et al. 2012; Hart et al. 2012; Kick et al. 2011; Leiserowitz et al. 2011b; Responsive Management 2010; Wetlands Watch Inc 2012; Yale Climate Media Forum 2012). Economic interests and population trends tend to favor continued (re)development and in-fill in near-shore locations. Current disaster recovery practices frequently promote rapid rebuilding on site with limited consideration for future conditions (Kyler 2012; Schrope 2010) despite clear evidence that more appropriate siting and construction can substantially reduce future losses (Multihazard Mitigation Council 2005; U.S. Army Corps of Engineers 2012).

Enacting measures that increase resilience in the face of current hazards while reducing long-term risks due to climate change continues to be challenging (Hudson 2012; IPCC 2012), especially in light of the fact that most of the National Flood Insurance Program's repetitive flood losses occur in coastal counties (GAO 2004; King 2005). A robust finding is that the cost of preventive hazard mitigation is 4 to 10 times lower than the cost of inaction (Multihazard Mitigation Council 2005; Neumann et al. 2010a). Even so, prioritizing expenditures now whose benefits accrue far in the future is difficult (Cropper and Portney 1990). Moreover, cumulative costs to the economy of responding to sea level rise and flooding events alone could be as high as $325 billion by 2100 for 4 feet of sea level rise, with $130 billion expected to be incurred in Florida and $88 billion in the North Atlantic region (Neumann et al. 2010b). The projected costs associated with one foot of sea level rise by 2100 are roughly $200 billion, not including indirect losses from business disruption, lost economic activity, impacts on economic growth, or the non-market losses (Franck 2009; Hallegatte 2012; Heinz Center 2000a; Neumann et al. 2010b). Such indirect losses, even in regions generally well-prepared for disaster events, can be substantial (in the tens of billions of dollars) as Superstorm Sandy, followed by nor'easter Athena, in fall 2012 illustrated. Sequences of extreme events that occur over a short period not only reduce the time available for natural and social systems to recover and for adaptation measures to be implemented, but also increase the cumulative effect of back-to-back extremes compared to the same events occurring over a longer period (Greening et al. 2006; IPCC SREX 2012; Miao et al. 2009; Paerl et al. 2001; Peterson et al. 2008). The cost of managed retreat requires further assessment.

Property insurance can serve as an important mode of financial adaptation to climate risks (Barthel and Neumayer 2010), but the full potential of insurance has not yet been realized (Burkett and Davidson 2012; GAO 2010; Ntelekos et al. 2010). At present, the second greatest physical liability of the U.S. government behind Social Security is the National Flood Insurance Program. While insured assets in coastal areas represent only a portion of this total liability, taxpayers are currently (as of 2010) responsible for $510 billion of insured assets in the coastal Special Flood Hazard Area (SFHA) (Mills et al. 2005; NOAA 2012e; Thomas and Leichenko 2011). However, a number of reforms in the National Flood Insurance Program have been identified and enacted in 2012 to ensure that the program is fiscally sound and hazard mitigation is improved (Czajkowski et al. 2011; Heinz Center 2000b; Kunreuther and Michel-Kerjan 2009; Michel-Kerjan and Kunreuther 2011; Michel-Kerjan 2010).

Climate adaptation efforts that integrate hazard mitigation, natural resource conservation, and restoration of coastal ecosystems can enhance ecological resilience and reduce the exposure of property, infrastructure, and economic activities to climate change impacts (Figure 25.6) (Colls et al. 2009; Danielsen et al. 2005; Principe et al. 2012; Swann 2008; The World Bank 2009; Tobey et al. 2010; UNEP et al. 2006; Villanoy et al. 2012). Yet, the integration and translation of scientific understanding of the benefits provided by ecosystems into engineering design and hazard management remains challenging (Daily et al. 2009; Koch et al. 2009). Moreover, interdependencies among functioning infrastructure types and coastal uses require an integrated approach across levels of government, but fragmented governance at the managerial, financial, and regulatory levels, and narrow professional training, job descriptions, and agency missions pose significant barriers (Ch. 11: Urban and Infrastructure; Amundsen et al. 2010; Burch 2010; McNeeley 2012; Measham et al. 2011; Moser and Ekstrom 2010, 2012; Hanemann et al. 2012). Adaptation efforts to date that have begun to connect across jurisdictional and departmental boundaries and create innovative solutions are thus extremely encouraging (Burkett and Davidson 2012; Georgetown Climate Center 2012; Moser and Ekstrom 2012; NPCC 2009; NYAS 2012).

Traceable Accounts

Chapter 25: Coastal Zone, Development and Ecosystems

Key Message Process: A central component of the assessment process was a Chapter Lead Authors meeting held in St. Louis, Missouri in April 2012. The key messages were initially developed at this meeting. Key vulnerabilities were operationally defined as those challenges that can fundamentally undermine the functioning of human and natural coastal systems. They arise when these systems are highly exposed and sensitive to climate change and (given present or potential future adaptive capacities) insufficiently prepared or able to respond. The vulnerabilities that the team decided to focus on were informed by ongoing interactions of the author team with coastal managers, planners, and stakeholders as well as a review of the existing literature. In addition, the author team conducted a thorough review of the technical inputs and associated literature, including the coastal zone foundational document prepared for the NCA (Burkett and Davidson 2012). Chapter development was supported by numerous chapter author technical discussions via teleconference from April to June 2012.

Key message #1/5	**Coastal lifelines, such as water supply and energy infrastructure and evacuation routes, are increasingly vulnerable to higher sea levels and storm surges, inland flooding, and other climate-related changes.**
Description of evidence base	Coastal infrastructure is defined here to include: buildings, roads, railroads, airports, port facilities, subways, tunnels, bridges, water supply systems, wells, sewer lines, pump stations, wastewater treatment plants, water storage and drainage systems, port facilities, energy production and transmission facilities on land and offshore, flood protection systems such as levees and seawalls, and telecommunication equipment. Lifelines are understood in the common usage of that term in hazards management. The key message and supporting text summarizes extensive evidence documented in the coastal zone Technical Input (Burkett and Davidson 2012) and well as in Wilbanks et al. (2012). Technical Input reports (68) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input, along with the extant scientific literature. Additional evidence is provided in (Burkett and Davidson 2012), Chapter 2: Climate Science, Chapter key message #8 about hurricanes, and #9 regarding global sea level. For key coastal transportation vulnerabilities see Chapter 5, Transportation. For more discussion of energy-related infrastructure see Chapter 4, Energy Supply and Use. This section focuses mainly on water supply and energy infrastructure and evacuation routes, as they constitute critical lifelines. The evidence base for exposure, sensitivity and adaptive capacity to higher sea levels and storm surges is very strong, both from empirical observation/ historical experience and studies projecting future impacts on critical coastal infrastructure. There are numerous publications concerning the effects of sea level rise and storm surges on roadways, coastal bridges, and supply of refined products. The information on roadways came from various reports (for example, Transportation Research Board (Transportation Research Board 2011); U.S. Department of Transportation (DOT 2012) and publications (for example, (State of Louisiana 2012). The impact on coastal bridges is documented in DOT reports (DOT 2012; Maine Department of Transportation 2003). A number of publications explored the impacts on supply of refined products (Francis et al. 2011; Rosato et al. 2008; Vugrin and Camphouse 2011; Vugrin et al. 2011; Zimmerman 2006). The evidence base is moderate for the interaction of inland and coastal flooding. There are many publications concerning impacts to wastewater treatment plants and drainage systems. With some of the most recent ones concerning wastewater

	treatment plants being (Flood and Cahoon 2011; Kirshen et al. 2011), and a (Water Research Foundation 2012). The most recent publications concerning drainage systems include Peterson et al. (2012), Seneviratne et al. (2012), Bjerklie et al. (2012), and Johnson (2012). These lead to increased risk of urban flooding.
New information and remaining uncertainties	The projected rate of Sea Level Rise (SLR): Fully accounted for through the use of common scenarios (we note, however, that there is currently limited impacts literature yet that uses the lowest or highest 2100 scenario and none that specifically use the broader range of IPCC SLR and NCA land use scenarios.) The severity and frequency of storm damage in any given location cannot yet be fully accounted for due to uncertainties in projecting future extratropical and tropical storm frequency, intensity, and changes in storm tracks for different regions (Burkett and Davidson 2012; Ch. 2: Our Changing Climate). The timely implementation and efficacy of adaptation measures, including planned retreat, in mitigating damages is accounted for in the underlying literature (for example, by varying assumptions about the timing of implementation of adaptation measures and the type of adaptation measures). However, such studies can only test the sensitivity of conclusions to these assumptions; they do not allow statements about what is occurring on the ground. Additional uncertainties arise from the confluence of climate change impacts from the inland and ocean side, which have yet to be studied in an integrated fashion across different coastal regions of the U.S.
Assessment of confidence based on evidence	**Coastal lifelines, such as water infrastructure and evacuation routes, are increasingly vulnerable to higher sea levels and storm surges, inland flooding, and other climate-related changes.** Given the evidence base, the large quantity of infrastructure in the coastal zone, and the directional trend at least of sea level rise and runoff associated with heavy precipitation events, we have **very high** confidence that infrastructure in the coastal zone resources is increasingly vulnerable.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Chapter 25: Coastal Zone, Development and Ecosystems

Key Message Process: See key message #1.

Key message #2/5	**Climate change increases exposure of nationally important assets, such as ports, tourism and fishing sites, in already-vulnerable coastal locations, threatening to disrupt economic activity beyond the coast and incurring significant costs for protecting or moving them.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the coastal zone Technical Input (Burkett and Davidson 2012). Technical Input reports (68) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input, as well as the extant scientific literature. The evidence base for increased exposure to assets is strong. Many publications have assessed at risk areas (e.g., Biging et al. 2012; Cooley et al. 2012; Heberger et al. 2009; Neumann et al. 2010a). Highly reliable economic activity information is available from recurring surveys conducted by NOAA and others, and asset exposure is conclusively demonstrated by historical information (from storm and erosion damage), GIS-based location and LIDAR and other forms of elevation data, and numerous vulnerability and adaptation studies of the built environment (see also technical input reports on urban/infrastructure (Wilbanks et al. 2012) and transportation (DOT 2012), as well as Ch. 11: Urban and Infrastructure, Ch. 4: Energy Supply and Use, and Ch. 5: Transportation. A number of studies, using various economic assumptions, exist that aim to assess the cost of protecting or relocating coastal assets and services. Many publications and reports explore the cost of replacing services offered by ports (Caldwell et al. 2012; DOT 2012) though (Becker et al. 2012) notes that few ports are implementing adaptation practices to date. The economic consequences of climate change on tourism is supported by a number of studies (most recent being: (Caldwell et al. 2012; Merrifield et al. 2012; Nordstrom et al. 2011; NPCA 2012; Pendleton et al. 2012). The threats of climate change on fishing have been explored in (Burkett and Davidson 2012). Additional evidence comes from empirical observation: public statements by private sector representatives and public officials indicate high awareness of economic asset exposure and a determination to see those assets protected against an encroaching sea, even at high cost (New York City, Miami Dade Co., San Francisco airport etc.). The economic value of exposed assets and activities is frequently invoked when they get damaged or interrupted during storm events (e.g., Hallegatte 2012). Threats to economic activity are also consistently cited as important to local decision-making in the coastal context (e.g., Titus et al. 2009).
New information and remaining uncertainties	The projected rate of sea level rise: Fully accounted for through the use of common scenarios (we note, however, that there is currently limited impacts literature yet that uses the lowest or highest 2100 scenario and none that specifically use the broader range of IPCC SLR and NCA land use scenarios.) The projected severity and frequency of storm damage in any given location cannot yet be fully accounted for due to uncertainties in projecting future extratropical and tropical storm frequency, intensity, and changes in storm tracks for different regions (Burkett and Davidson 2012). The timely implementation and efficacy of adaptation measures, including planned retreat, in mitigating damages:

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	Accounted for in the underlying literature (for example, by varying assumptions about the timing of implementation of adaptation measures, the type of adaptation measures, and other economic assumptions such as discount rates). However, such studies can only test the sensitivity of conclusions to these assumptions; they do not allow statements about what is occurring on the ground. Well established post-hoc assessments by the Multihazard Mitigation Council (Multihazard Mitigation Council 2005) suggest that hazard mitigation action is highly cost-effective (for every dollar spent, $4 dollars in damages are avoided), yet current work finds that mitigation actions are rarely adopted by coastal property owners, thus current assessments of the cost of rational adaptation may underestimate the real cost.
Assessment of confidence based on evidence	Given the evidence base, the well-established accumulation of economic assets and activities in coastal areas, and the directional trend of sea level rise, we have **very high** confidence in the main conclusion that resources and assets that are nationally important to economic productivity are threatened by SLR and climate change. While there is currently no indication that the highest-value assets and economic activities are being abandoned in the face of sea level rise and storm impacts, we have **very high** confidence that the cost of protecting these assets in place will be high, and higher the faster (relative) sea level rises. We have **very high** confidence that adequate planning and arrangement for future financing mechanisms, timely implementation of hazard mitigation measures and effective disaster response will keep the economic impacts and adaptation costs lower than if these actions are not taken. Due to uncertainties in asset-specific elevation above SL, the presence and efficacy of protective measures – at present and in the future, the feasibility of relocation in any one case, and uncertainties in future storm surge heights and storm frequencies, we are not able to assess timing or total cost of protecting or relocating economic assets with any confidence at this time.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Chapter 25: Coastal Zone, Development and Ecosystems

Key Message Process: See key message #1.

Key message #3/5	**Socioeconomic disparities create uneven exposures and sensitivities to coastal risks and limit adaptation options for some coastal communities, resulting in the displacement of the most vulnerable from coastal areas.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the coastal zone Technical Input (Burkett and Davidson 2012). Technical Input reports (68) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input, along with the extant literature. Moderate: Assessment of the social vulnerability to coastal impacts of climate change is a comparatively new research focus in the US; clearly an advance since the 2009 NCA. There are currently multiple published, peer-reviewed studies, by different author teams, using different vulnerability metrics, which all reach the same conclusion: economically and socially vulnerable individuals and communities face significant coastal risks and have a lower adaptive capacity than less socially vulnerable populations. Studies have shown that the US coastal population is growing (EPA 2010; Nakicenovic et al. 2000) and have assessed their importance for climate change exposure (Pielke Jr 2007; Strauss et al. 2012; Zhang and Leatherman 2011). There are numerous publications on the social factors that play key roles in coastal vulnerability (Bovbjerg 2007; Clark et al. 1998; Cooley et al. 2012; Cutter et al. 2003; Moser et al. 2008; Texas Health Institute 2012) There is an additional body of evidence emerging in the literature that also supports this conclusion, namely the growing literature on “barriers to adaptation”, particular from studies conducted here in the U.S. (Burkett and Davidson 2012; Callaway et al. 2011; Cooley et al. 2012; Moser and Ekstrom 2012; Papiez 2009; Standen 2012; Tribal Climate Change Project 2010). This literature reports on the limitations poorer communities face at present in beginning adaptation planning, and on the challenges virtually all communities face, in prioritizing adaptation and moving from planning to implementation of adaptation options. There is empirical evidence for how difficult it is for small, less wealthy communities (for example, the Native communities in Alaska or on some of Louisiana’s barriers islands) to obtain federal funds to relocate from eroding shorelines (various technical input reports). Eligibility criteria (positive benefit-cost ratios) make it particularly difficult for low-income communities to obtain such funds; current federal budget constraints limit the available resources to support managed retreat and relocation (GAO 2004, 2010). The recent economic hardship has placed constraints even on the richer coastal communities in the US in developing and implementing adaptation strategies (for example, in California; (Moser and Ekstrom 2012). While the economic situation, funding priorities, or institutional mechanisms to provide support to socially vulnerable communities will not remain static over time, there is no reliable scientific evidence for how these factors may change in the future.
New information and remaining uncertainties	The body of research on this topic is largely new since 2009. Each of the peer-reviewed studies discusses data gaps and methodological limitations, as well as the particular challenge of projecting demographic variables – a notoriously difficult undertaking – forward in time. The conclusion is limited by uneven coverage of in-depth vulnerability studies; although those that do exist are consistent with and confirm the conclusions of the national study completed by (Martinich et al. 2012).

	The latter study was extended by applying the same approach, data sources, and methodology to regions previously not yet covered, thus closing important informational gaps (Hawaii, Alaska, the Great Lakes region). Data gaps remain for most coastal locations in the Pacific islands, Puerto Rico, and other U.S. territories. The most important limit on understanding is the current inability to project social vulnerability forward in time. While some social variables are more easily predicted (for example, age and gender distribution) than others (for example, income distribution, ethnic composition and linguistic abilities), the predictive capability declines the further out projections aim (beyond 2030 or 2050), and it is particularly difficult to project these variables in specific places subject to coastal risks, as populations are mobile over time, and no existing model reliably predicts place-based demographics at the scale important to these analyses.
Assessment of confidence based on evidence	We have **high** confidence in this conclusion, as it is based on well-accepted techniques, replicated in several place-based case studies, and a nationwide analysis, using reliable Census data. Consistency in insights and conclusions in these studies, and in others across regions, sectors, and nations, add to the confidence. The conclusion does involve significant projection uncertainties, however, concerning where socially vulnerable populations will be located in several decades from now. Sensitivity analysis of this factor, and overall a wider research base is needed before a higher confidence assessment can be assigned.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Chapter 25: Coastal Zone, Development and Ecosystems

Key Message Process: See key message #1.

Key message #4/5	**Coastal ecosystems are particularly vulnerable to climate change because many have already been dramatically altered by human stresses; climate change will result in further reduction or loss of the services that these ecosystems provide, including potentially irreversible impacts.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the coastal zone Technical Input (Burkett and Davidson 2012). Technical Input reports (68) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input, along with the extant literature. Strong: "Coastal ecosystems are particularly vulnerable to climate change because they have already been dramatically altered by human stresses" The degradation and depletion of coastal systems due to human stresses (for example, pollution, habitat destruction, overharvesting) has been widely documented throughout the U.S. and the world (Burke et al. 2011; CENR 2010; Couvillion et al. 2011; Diaz and Rosenberg 2008; EPA 2012; Waddell and Clarke 2008; Yuill et al. 2009). The degree of degradation varies based on location and level of human impact. However, evidence of degradation is available for all types of U.S. coastal ecosystems, from coral reefs, to seagrasses and rocky shores. Human stresses can be direct (for example, habitat destruction due to dredging of bays) or indirect (for example, food web disruption due to overfishing). There is also consistent evidence that ecosystems degraded by human activities are less resilient to changes in climatic factors, such as water temperature, precipitation, and sea level rise. Strong: "climate change will result in further reduction or loss of the services that these ecosystems provide," The impacts of changing coastal conditions (for example, changes associated with altered river inflows, higher temperatures, and the effects of high rates of relative sea level rise) on coastal ecosystems and their associated services have been extensively documented through observational and empirical studies (Some recent publications: (Barton et al. 2012; Dawson et al. 2011; Doney et al. 2012; Glick et al. 2011; Petes et al. 2012; Stralberg et al. 2011). Many models of coastal ecosystem responses to climatic factors have been well-validated with field data. Given the existing knowledge of ecosystem responses, future climate projections, and the interactions with non-climatic stressors that further exacerbate climatic impacts, evidence of the potential for further reduction and/or loss is strong. Suggestive: "including potentially irreversible impacts." Severe impacts (for example, mass coral bleaching events, rapid species invasions) have been extensively documented for U.S. coastal ecosystems. Many experts have suggested that some of these impacts may be irreversible (Hoegh-Guldberg and Bruno 2010) and never before seen conditions are documented (Burkett et al. 2005; CCSP 2009a; Nicholls et al. 2007). Recovery may or may not be possible in different instances; this depends on factors that are not well-understood, such as the adaptive capacity of ecosystems, future projections of change that consider interactions among multiple climatic and non-climatic human alterations of systems, the dynamics and persistence of alternative states that are created after a regime shift has occurred, and whether or not the climatic and/or non-climatic

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	stressors that lead to impacts will be ameliorated (Barth et al. 2007; Chan et al. 2008; Folke et al. 2004; Grantham et al. 2004; Jarvis and Moore 2010; Moore and Jarvis 2008).
New information and remaining uncertainties	Since 2009, new studies have added weight to previously already established conclusions. The major advance lies in the examination of tipping points for species and entire ecosystems. Existing uncertainties and future research needs were identified through reviewing the NCA technical inputs and other peer-reviewed, published literature on these topics, as well as through our own identification and assessment of knowledge gaps. Key uncertainties in our understanding of ecosystem impacts of climate change in coastal areas are associated with: • the interactive effects and relative contributions of multiple climatic and non-climatic stressors on coastal organisms and ecosystems; • how the consequences of multiple stressors for individual species combine to affect community- and ecosystem-level interactions and functions; • projected magnitude of coastal ecosystem change under different scenarios of temperature change, sea level rise, and land-use change, particularly given the potential for feedbacks and non-linearities in ecosystem response; • the potential adaptive capacity of coastal organisms and ecosystems to climate change; • trajectories, timeframes, and magnitudes of coastal ecosystem recovery; • the dynamics and persistence of alternative states that are created after ecosystem regime shifts have occurred; and • the potential and likelihood for irreversible climate-related coastal ecosystem change. In general, relatively little work to date has been conducted to project future coastal ecosystem change under integrative scenarios of temperature change, sea level rise, and changes in human uses of, and impacts to, coastal ecosystems (for example, through land-use change). Advancing understanding and knowledge associated with this key uncertainty, as well as the others included in the above list, would be fostered by addressing the research needs described below.
Assessment of confidence based on evidence	We have **very high** confidence that coastal ecosystems are particularly vulnerable to climate change because they have already been dramatically altered by human stresses as documented in extensive and conclusive evidence. We have **very high** confidence that climate change will result in further reduction or loss of the services that these ecosystems provide, as there is extensive and conclusive evidence related to this vulnerability. We have **high** confidence that climatic change will include “potentially irreversible impacts." Site-specific evidence of potentially irreversible impacts exists in the literature. This vulnerability is frequently identified by studies of coastal ecosystems. However, methods, research, and models for understanding, documenting, and predicting potentially irreversible impacts across all types of coastal ecosystems are still being developed.

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CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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Chapter 25: Coastal Zone, Development and Ecosystems

Key Message Process: See key message #1.

Key message #5/5	**Growing awareness of the high vulnerability of coasts to climate change increasingly leads coastal regions to plan for potential impacts on their citizens, businesses, and environmental assets. Significant institutional, political, social, and economic obstacles to implementing adaptation actions remain.**
Description of evidence base	The key message and supporting text summarizes extensive evidence documented in the coastal zone Technical Input (Burkett and Davidson 2012). Technical Input reports (68) on a wide range of topics were also received and reviewed as part of the Federal Register Notice solicitation for public input, along with the extant literature. Moderate to strong: The results on which this conclusion relies are based on case studies, direct observation and "lessons learned" assessments from a wide range of efforts, surveys, and interview studies in ongoing adaptation efforts around the country. There has been some planning for remediating climate change impacts (Some recent publications include: (Goidel et al. 2012; Hart et al. 2012; Hudson 2012; IPCC 2012)) and there are publications on the many barriers that affect adaptation (Amundsen et al. 2010; Burch 2010; McNeeley 2012; Measham et al. 2011; Moser and Ekstrom 2010a; Moser and Ekstrom 2012) (Hanemann, 2012;). In addition there is confirming evidence of very similar findings from other locations outside the US (some, from Canada, were also submitted as Technical Input Reports to the NCA), such as the UK, continental Europe, Australia, and others (Agyeman et al. 2009; Amundsen et al. 2010; Burch 2010; Fresque-Baxter and Armitage 2012; Measham et al. 2011) .
New information and remaining uncertainties	Adaptation is a rapidly spreading policy and planning focus across coastal America. This was not previously captured in the 2009 NCA and is thus a major advance in understanding, including what adaptation activities are underway, what impedes them, and how coastal stakeholders view and respond to these activities. Given the local nature of adaptation (even though it frequently involves actors from all levels of government), it is difficult to systematically track, catalog, or assess progress being made on adaptation in coastal America. The difficulty, if not impossibility, of comprehensively tracking such progress has been previously acknowledged in (NRC 2010). This conclusion is reiterated in the Adaptation Chapter of this report. While the findings and integrative conclusion stand on strong evidence, some uncertainties about US coastal regions' adaptive capacity, the level of adoption of hazard mitigation and other adaptation strategies, the extent and importance of barriers to adaptation remain. Possibly the least well understood aspect about coastal adaptation is how and when to undertake large-scale, transformational adaptation.
Assessment of confidence based on evidence	We have **very high** confidence in this conclusion, as it is primarily based on studies using well-accepted social science research techniques (for example, surveys, interviews, participant observation), replicated in several place-based case studies, and a nationwide compilation of adaptation case studies. Consistency in insights and conclusions in these studies, and in others across regions, sectors, and nations, add to the confidence.

	As described above, a comprehensive catalogue of all adaptation efforts, and of related challenges and lessons learned, is difficult if not impossible to ever obtain. Nevertheless, the emerging insights and evidence from different regions of the country provides considerable confidence that the situation is reasonably well captured in the documents relied on here. The coastal stakeholders represented on the Burkett and Davidson, 2012, Chapter team confirmed the conclusions from their long-term experience in coastal management and direct involvement in adaptation efforts locally. Moreover, evidence from other regions outside the U.S. add weight to the conclusions drawn here.

CONFIDENCE LEVEL			
Very High	**High**	**Medium**	**Low**
Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus	Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus	Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought	Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts

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