Chapter 9

Coastal Issues

COORDINATING LEAD AUTHORS

Margaret R. Caldwell (Stanford Woods Institute for the Environment, Stanford Law School), Eric H. Hartge (Stanford Woods Institute for the Environment)

LEAD AUTHORS

Lesley C. Ewing (California Coastal Commission), Gary Griggs (University of California, Santa Cruz), Ryan P. Kelly (Stanford Woods Institute for the Environment), Susanne C. Moser (Susanne Moser Research and Consulting, Stanford University), Sarah G. Newkirk (The Nature Conservancy, California), Rebecca A. Smyth (NOAA, Coastal Services Center), C. Brock Woodson (Stanford Woods Institute for the Environment))

EXPERT REVIEW EDITOR

Rebecca Lunde (NOAA)

Executive Summary

The California coast is constantly changing due to human development and physical forces. With the increase in climate impacts—including sea-level rise, ocean warming, ocean acidification, and increased storm events—effects of these physical forces will be more significant and will present substantial risks to coastal areas in the future. Natural ecosystems, coastal development, economic interests, and even cultural attachment to the coast will be at risk. Given the high concentration of coastal development, population, infrastructure, and economic activity in coastal counties, continued and growing pressure to protect these assets and activities from rising sea levels is expected.

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We have identified the following seven key messages that highlight major climate issues facing the California coast:

- The future severity of coastal erosion, flooding, inundation, and other coastal hazards will increase due to sea-level rise and continued coastal development. (high confidence). Any increased intensity and/or increased frequency of storm events will further aggravate the expected impacts. (medium confidence)
- The implications of global sea-level rise for coastal areas cannot be understood in isolation from other, shorter-term sea-level variability related to El Niño-Southern Oscillation (ENSO) events, storms, or tides. The highest probability and most damaging events through the year 2050 will be large ENSO events when elevated sea levels occur simultaneously with high tides and large waves. Between 2050 and 2100, or when sea levels approach ~14–16 inches above the 2000 baseline, the effects of sea-level rise (flooding and inundation) and combined effects of sea-level rise and large waves will result in property damage, erosion, and flood losses far greater than experienced now or in the past. (high confidence)
- Ocean warming affects a range of ecosystem processes, from changes in species distribution to reduced oxygen content and sea-level rise. (medium-high confidence) However, there is considerable uncertainty about how changes in species distributions and lower oxygen content of ocean waters will impact marine ecosystems, fisheries, and coastal communities.
- Ocean acidification is a significant threat to calcium-carbonate-dependent species and marine ecosystems. (high confidence) There is substantial uncertainty about acidification's precise impacts on coastal fisheries and marine food webs along the West Coast.
- Coastal development and other land uses create impediments to the natural migration of coastal wetlands through "hardening" of the coastline (e.g., seawalls, revetments, bulkheads) and by the occupation and protection of space into which wetlands might otherwise migrate. (high confidence) In developing their land-use and other plans, communities need to take into account that an increase in coastal development and other hardening may result in medium- to long-term loss of coastal wetlands and the numerous benefits these habitats provide. (high confidence)
- Critical infrastructure, such as highways and railroads (see Chapter 14), power plants and transmission lines (see Chapter 12), wastewater treatment plants, and pumping stations, have been located along the coast where they are already exposed to damage from erosion or flooding. With rising sea level, risks to vital public infrastructure will increase and more infrastructure will be exposed to future damage from erosion and flooding. (high confidence) Much of the U.S. infrastructure is in need of repair or replacement and the California coast is no exception; impacts from climate change will add to the stress on communities to maintain functionality. (high confidence)
- Coastal communities have a variety of options and tools at hand to prepare for climate change impacts and to minimize the severity of now-unavoidable

consequences of climate warming and disruption. While many coastal communities are increasingly interested in and have begun planning for adaptation, the use of these tools as well as development and implementation of adaptive policies are still insufficient compared with the magnitude of the expected harm. (high confidence)

9.1 Coastal Assets

People are drawn to the coast for its moderate climate, scenic beauty, cultural and ecological richness, rural expanses, abundant recreational opportunities, vibrant economic activity, and diverse urban communities.[i] More than 70% of California residents live and work in coastal counties (U.S. Census Bureau n.d.). Over the last thirty-eight years, the California coastal county population has grown 64%, from about 16.8 million in 1970 to 27.6 million in 2008 (NOEP 2012). Almost 86% of California's total gross domestic product comes from coastal counties (NOEP 2010).

Population density, along with the presence of critical infrastructure and valuable real estate along the coast, accentuates the importance of the coast to the region's economy. California has the nation's largest ocean-based economy, valued at approximately $46 billion annually, with over 90% of this value coming from (1) tourism and recreation, and (2) ports and harbors (Kildow and Colgan 2005).

In addition, the state's natural coastal systems perform a variety of economically valuable functions, including water quality protection, commercial and recreational fish production, plant and wildlife habitat, flood mitigation, recreation, carbon storage, sediment and nutrient transport, and storm buffering. The non-market value of coastal recreation in California alone exceeds $30 billion annually (Pendleton 2009). These benefits, provided at almost no cost, would be impossible to replicate with human-engineered solutions.

9.2 Observed Threats

Overview

Human development and physical forces are constantly changing the coast. Just as growth in coastal populations and economic development have reshaped the coastline with new homes, roads, and infrastructure, so too have physical forces and processes—including waves, tides, currents, wind, storms, rain, and runoff—combined to accrete (build up), erode, and continually reshape the coastline and modify coastal ecosystems. With the increase in the rate of sea-level rise and warmer ocean temperatures related to global climate change, the effects of these physical forces will grow more significant and harmful to coastal areas over time.

Threats to the physical environment

The physical forces and processes that take place in the coastal environment occur across different spatial and temporal scales. The Pacific Basin, including the ocean off California, oscillates between warm and cool phases of the Pacific Decadal Oscillation (PDO), which is associated with differences in atmospheric pressure over the Pacific

Ocean. Ultimately, wind patterns and storm tracks are affected. El Niño-Southern Oscillation (ENSO) events tend to have stronger effects during warm phases of the PDO and are typified by warmer ocean water and higher sea levels, more rainfall and flooding, and more frequent and vigorous coastal storms, which result in greater beach and bluff erosion (Storlazzi and Griggs 2000). These conditions also affect relative abundance of important coastal forage fisheries, such as sardines and anchovies (Chavez et al. 2003).

Sea level along the coast of California has risen gradually over the past century (by about 8 inches [20 cm]), a rate that will accelerate in the future (see Figure 9.1). Sea-level rise alone, however, will have far less impact on the shoreline, infrastructure, or habitat over the next 30 or 40 years than will the combination of elevated sea level, high tides, and storm waves associated with large ENSO events. Moreover, the effects of less severe ENSO events will be magnified by progressively higher sea levels; as a result, coastal communities can expect more severe losses from these events than they have experienced in the past (see Figure 9.2).

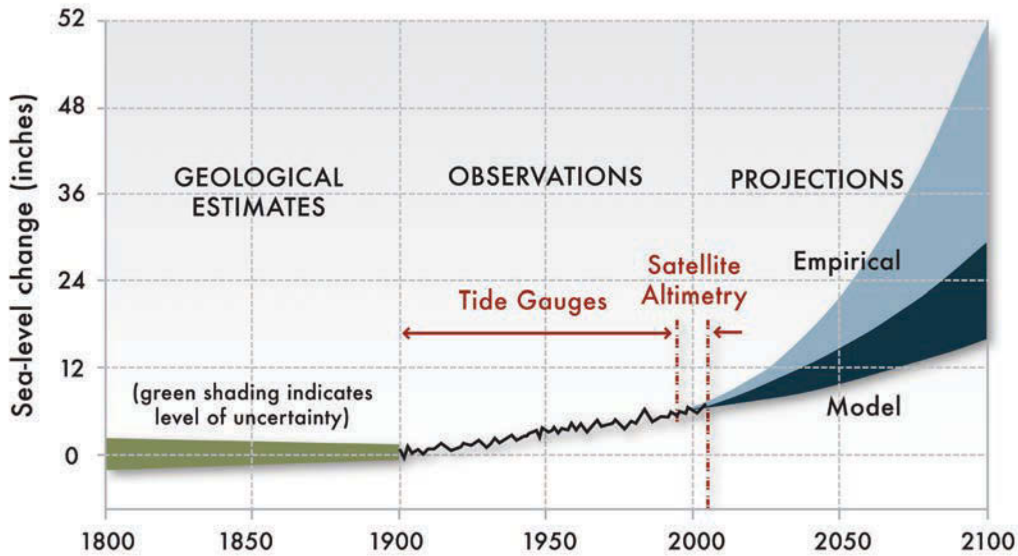

Figure 9.1 Past, present, and future sea-level rise. Geologic and recent sea-level histories (from tide gauges and satellite altimetry) are combined with projections to 2100 based on climate models and empirical data. Modified with permission from Russell and Griggs (2012, Figure 2.1).

Furthermore, changes in global climate cycles, such as the PDO, may soon become an imminent and significant factor in accelerating regional sea-level rise. While over the past century there has been a gradual increase in global sea levels, since about 1993, California tide gauges have recorded very little long-term change in sea level. This "flat" sea level condition had been out of sync with the prevailing global rise in sea level and the historic trends in sea-level rise along the West Coast. The PDO causes differences in sea-surface elevation across the Pacific. Sea levels have been higher in the Western Pacific and lower along the California coast over the past two decades, coinciding with a warm phase of the PDO (see Box 9.1). This recent warm phase appears to have been related to a dramatic change in wind stress (the dragging force of air moving over a surface) (Bromirski et al. 2011). The predominant wind stress regime along the U.S. West Coast served to mitigate the trend of rising sea level, suppressing regional sea-level rise below the global rate. A change in wind stress patterns over the entire North Pacific may result in a resumption of sea-level rise along the West Coast approaching or exceeding the global mean sea-level rise rate (Bromirski et al. 2011).

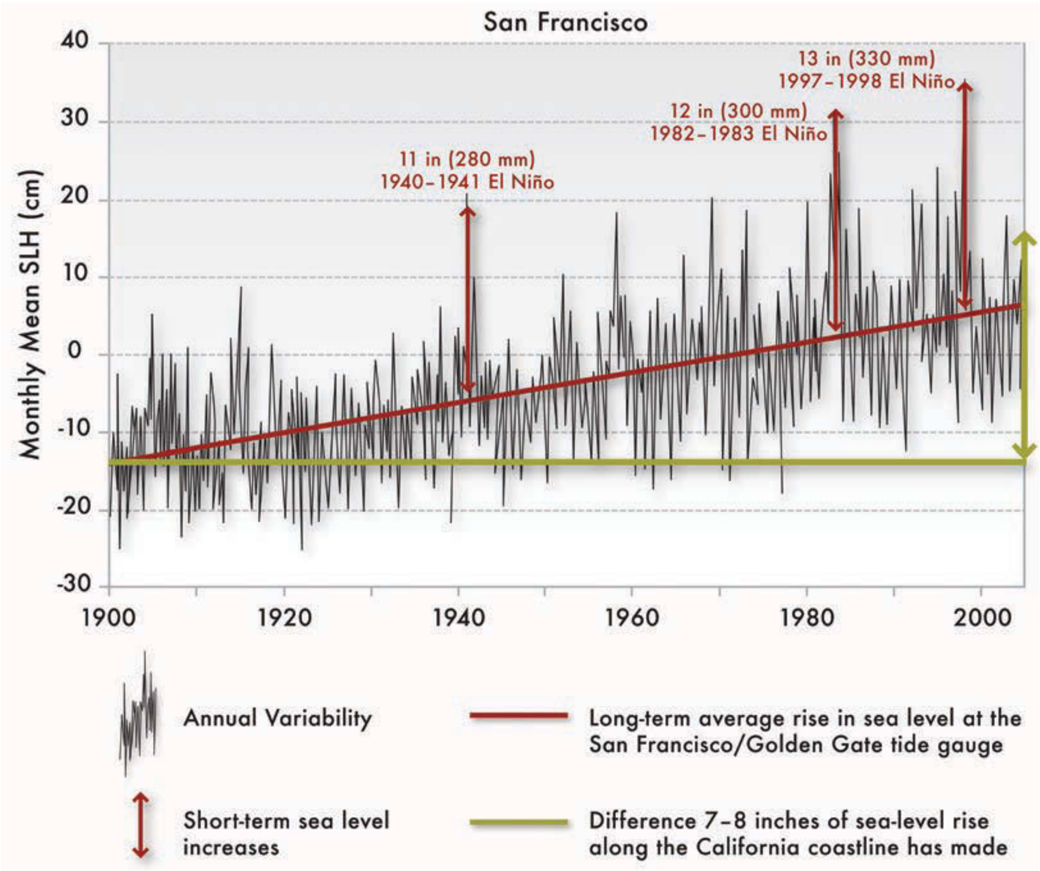

Figure 9.2 Sea-level rise and El Niño events. The implications of sea-level rise for coastal California cannot be understood in isolation from other, shorter-term sea-level variability related to El Niño events, storms, or extreme tides that affect the coast. As historical experience has shown, the greatest damage to coastal areas has occurred during large El Niño events (for example in 1940–41, 1982–83, and 1997–98) when short-term sea-level increases occurred simultaneously with high tides and large waves. If sea level were still at the same elevation in 2005 as it was in 1900, a major El Niño event like that in 1997–98 would fall within the “noise” of today’s interannual variability. As sea level is continuing to rise, the impacts of future large ENSO events will be greater than those historic events of similar magnitude, exposing coastal areas to the combined effects of sea-level rise, elevated sea levels from El Niño events, and large waves. Source: Pacific Decadal Oscillation monthly values index (http://jisao.washington.edu/pdo/), NOAA Earth System Research Laboratory Multivariate ENSO Index (http://www.esrl.noaa.gov/psd/enso/mei/#ref_wt3), Wolter and Timlin (2011).

Box 9.1

Coastal Development During Cool PDO Phase

Comparison of periods of coastal development. In the graph below (a), red corresponds to periods with positive or warm PDO conditions and blue corresponds to negative or cool PDO conditions. The vertical axis is a dimensionless PDO index based on North Pacific sea surface temperature variability.

The maps show the increase in housing density [difference in housing units per km^2] along the Southern California Bight that occurred (b) during the extended cool PDO period from about 1950 to 1980 and (c) during the extended warm PDO period from about 1980 to 2010.

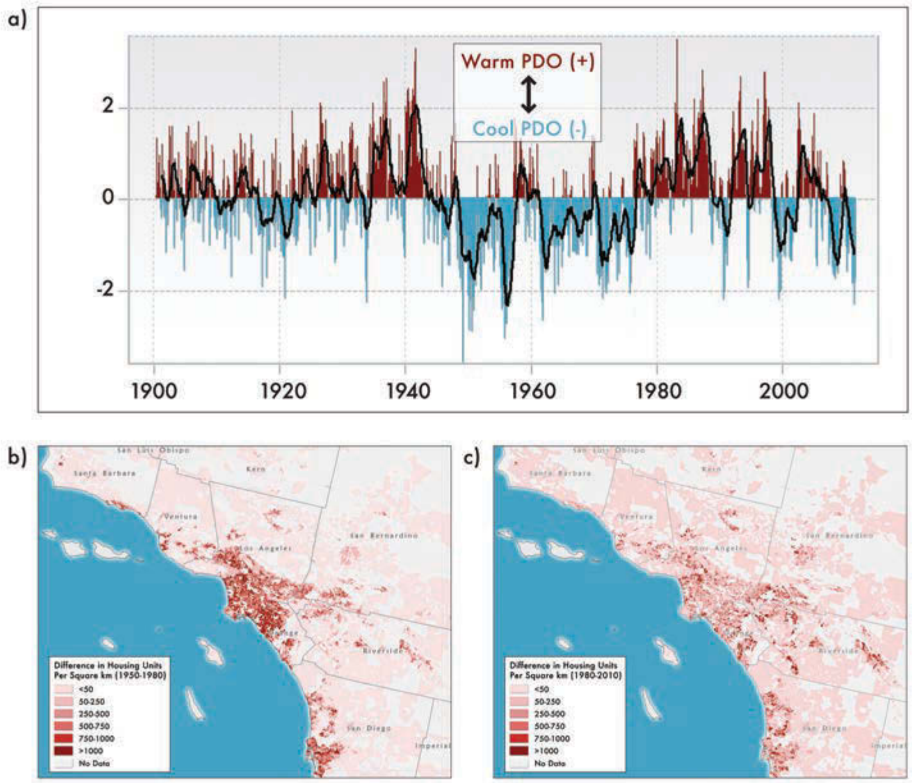

Figure 9.3 Monthly value for the Pacific Decadal Oscillation. The period from about 1945 to 1978 was a cool PDO period marked by an overall calm or benign coastal climate, but also was a period of intensive growth and development along the California coast. The vertical axis is a dimensionless PDO index based on North Pacific sea-surface temperature variability. 9.3(a) adapted from Pacific Decadal Oscillation monthly values index, http://jisao.washington.edu/pdo/; data in 9.3(b) and (c) from http://silvis.forest.wisc.edu/old/Library/HousingDataDownload.php?state=California&abrev=CA; see also Hammer et al. (2004)..

Threats to the built environment

The nature of most human development is increasingly in conflict with the physical and climatic forces that occur along the coast. Efforts to protect development through shoreline armoring and beach nourishment are very costly and often negatively impact coastal ecosystems (Caldwell and Segal 2007). Armoring the coast with hard structures may inhibit natural sediment movement, and thus prevent accretion to and landward migration of beach and other coastal ecosystems. Armoring can also increase vulnerability by encouraging development in erosion or flood-prone areas and giving people who live behind coastal armoring installations a false sense of security (Dugan et al. 2008).

Increasing demand for freshwater resources in coastal areas for domestic, agricultural, and industrial uses adds stress to the provision of surface water and ground water supplies. Increased withdrawals from rivers and streams damage the habitats of anadromous fish (species that spend most of their lives in the ocean but hatch and spawn in freshwater). The overdraft of coastal aquifers increases seawater intrusion, which requires water wells in these areas to be either deepened or abandoned, or water supplies to be imported (Hanson, Martin, and Koczot 2003). Terrestrial runoff and wastewater discharges can be harmful to coastal areas. Their effects are exacerbated when heavy rainfall washes large amounts of fertilizers and other pollutants from the land or causes wastewater systems to overflow and send untreated or inadequately treated wastes into streams, estuaries, and the ocean (Ho Ahn et al. 2005). Finally, the loss of wetlands due to increasing urbanization and development will reduce the resiliency of these coastal ecosystems (CNRA 2010).

9.3 Ocean and Coastal Impacts to Ecosystems

Overview

The global ocean—in particular the Pacific Ocean for the U.S. West Coast—plays a significant role in shaping coastal ecosystem processes. As climate and ocean chemistry continue to change, significant alterations in the composition, structure, and function of coastal ecosystems are anticipated. These changes will manifest most clearly as a result of rising sea levels, changing ocean temperatures, and increasing acidity of coastal waters—each of which is discussed below. The relationship between humanity and the coastal environment will inevitably shift in response to dynamic ocean and coastal ecosystems, and each of the changes enumerated above is likely to intensify threats to human development in coastal regions.

Sea-level rise

As sea levels rise, tidal wetlands and beaches will accrete vertically to keep up, become inundated, or "migrate" landward. Their fate depends on whether there is adequate sediment from nearby watersheds to increase wetland elevation as the sea rises and on the availability of space into which wetlands can migrate (CNRA 2010). Coastal development affects this by altering sediment availability (through, for instance, reduction of sand discharge from streams through the construction of dams and debris basins, and by eliminating bluff erosion through coastal armoring) and by occupying or protecting space into which wetlands might otherwise migrate. The loss of coastal wetlands causes the loss of the numerous benefits they provide, including flood protection, water treatment, recreation, carbon sequestration, biodiversity, and wildlife habitat (see Box 9.2) (King, McGregor, and Whittet 2011). Specifically, with a rise in sea level projected to be as high as 4.6 feet (1.4 meters) by 2100, approximately 97,000 acres of coastal wetlands in California will potentially be inundated. Nearly 55% of these wetland areas may be able to migrate inland successfully with no loss of function; however, about 45% could lose either their habitat functions or their ability to migrate (see Figure 9.4) (Heberger et al. 2009).

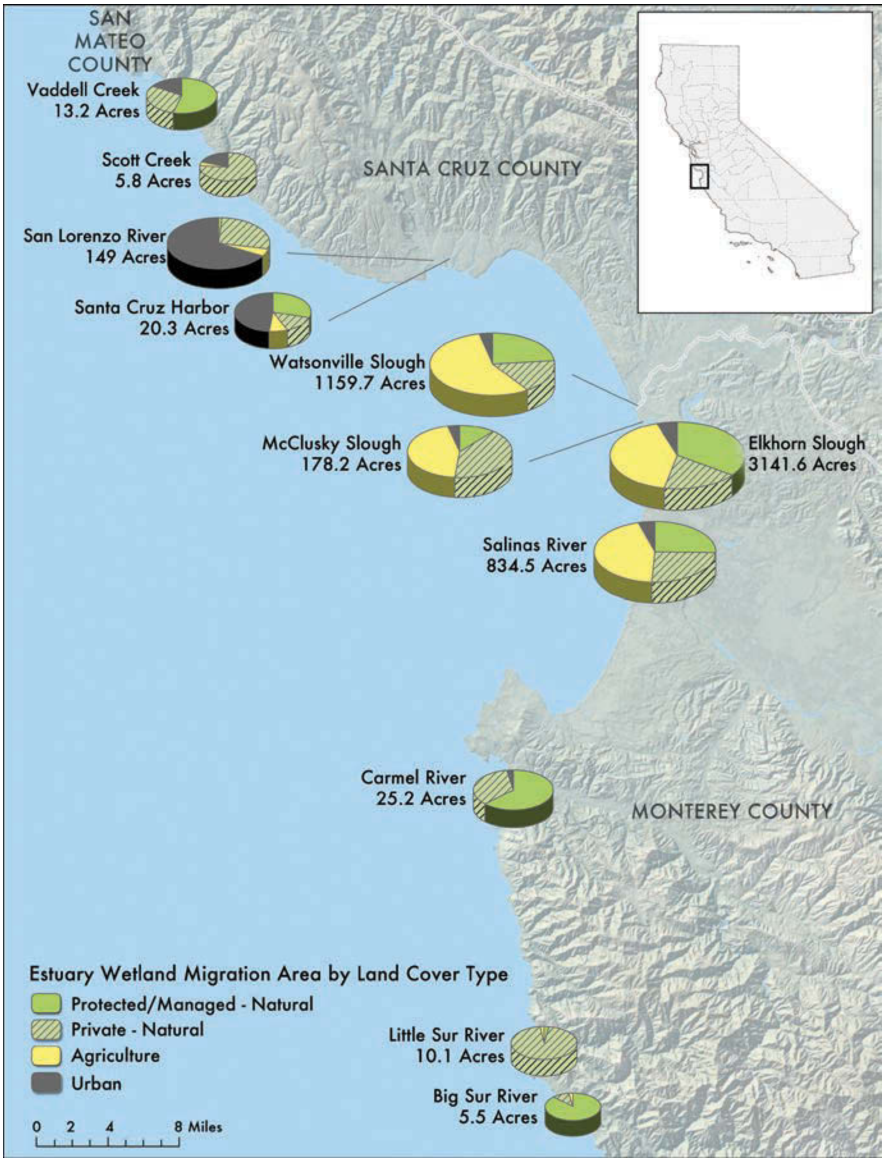

Figure 9.4 Estuary wetland migration area by land-cover type in the Monterey Bay region. Different land-use types will have different capacities to accommodate wetland migration, ranging from urban areas (which are unlikely to accommodate migration at all) to public natural areas (which will likely accommodate migration completely). Between these extremes are agricultural areas and privately owned natural areas, both of which could accommodate migration if landowners choose not to prevent it, such as by not fortifying or armoring their lands. Adapted from Gleason et al. (2011, 23); Heberger et al. (2009).

Box 9.2

Adaptation to Climate Change in the Marine Environment: The Gulf of Farallones and Cordell Bank National Marine Sanctuaries

In 2010, a joint advisory committee for the Gulf of Farallones and Cordell Bank National Marine Sanctuaries, located off the central California coast, published a report on climate change impacts (Largier, Cheng, and Higgason 2010). The study determined that climate change will affect the region's marine waters and ecosystems through a combination of physical changes—including sea-level rise, coastal erosion and flooding, changes in precipitation and runoff, ocean-atmosphere circulation, and ocean water properties (such as acidification due to absorption of atmospheric CO_2)—and biological changes, including changes in species' physiology, phenology, and population connectivity, as well as species range shifts. With this foundational document in hand, sanctuary managers held a series of workshops aimed at developing an adaptation framework that involved both the sanctuaries and their partners onshore and in the marine environment. From those efforts and underlying studies, they determined that the success of adaptation strategies for the marine environment will depend not only on the magnitude and nature of climatic changes, but also on the pressures that already exist in marine environments, including the watershed drainage to the sanctuaries. For example, an adaptation strategy for estuaries and near-shore waters that addresses the changing timing and amount of water from spring snowmelt or more frequent winter storms will also require knowledge about whether the watershed is urbanized, agricultural, or relatively undeveloped. Efforts to foster marine ecosystem adaptation to climate change will require both stringent measures that reduce the global concentration of CO_2 in the atmosphere and the reduction of additional pressures on the regional marine environment (e.g. air pollution, runoff from land into the ocean, waste disposal, and the loss of the filtering and land stabilization services of coastal wetlands) (Kelly et al. 2011).

In 2010, the California Ocean Protection Council issued interim guidance for state and local agencies to use for project planning and development in response to projected sea-level rise (see Table 9.1; CCAT 2010). The same year, the state governments of California, Oregon, and Washington, along with federal agencies—the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, and the Army Corps of Engineers—initiated a study with the National Research Council (NRC) to develop regional West Coast estimates of future sea-level rise to better inform state and local planning and agency decisions (Schwarzenegger 2008). The NRC report was released in June 2012.

Changes or trends for other coastal environmental conditions, such as atmospheric temperatures, precipitation patterns, river runoff and flooding, wave heights and run-up (waves reaching landward), storm frequency and intensity, and fog persistence, are less well understood, often to the point of uncertainty about the direction of change, much less its extent for a specific region. In addition, there will be other changes from rising sea level. For example, "extreme events"—such as the contemporary understanding of 100-year floods—will occur more frequently as a result of both higher coastal

Table 9.1 Static sea-level rise projections (without considering storm events) using the year 2000 as the baseline sea level (California Climate Action Team Sea-Level Rise Interim Guidance Document)

Year	Scenario	Average of Models	Range of Models
2030		7 in (18cm)	5–8 in (13–21 cm)
2050		14 in (36 cm)	10–17 in (26–43 cm)
2070	Low	23 in (59 cm)	17–27 in (43–70 cm)
	Medium	24 in (62 cm)	18–29 in (46–74 cm)
	High	27 in (69 cm)	20–32 in (51–81 cm)
2100	Low	40 in (101 cm)	31–50 in (78–128 cm)
	Medium	47 in (121 cm)	37–60 in (95–152 cm)
	High	55 in (140 cm)	43–69 in (110–176 cm)

Note: For dates after 2050, three different values for sea-level rise are included, based on the IPCC 2007 low, medium, and high GHG emission scenarios as follows: B1 for low projections, A2 for the medium projections, and A1FI for the high projections.

In contrast to the Sea-Level Rise Interim Guidance Document, in this assessment report we refer to the B1 emissions scenario as "low emissions" and the A2 emissions scenario as "high emissions."

Sources: Vermeer and Rahmstorf (2009), IPCC (2007).

storm surges due to sea-level rise and from inland runoff due to extreme rainfall events (see Chapter 7). In addition, tides will extend farther inland in coastal streams and rivers, and saltwater will penetrate farther into coastal aquifers (Loaiciga, Pingel, and Garcia 2012).

Changes in ocean temperature and dynamics

Direct climate change impacts, such as warming sea surface temperatures and ocean acidification, are expected to accelerate or exacerbate the impacts of *present* threats to coastal ecosystems, including pollution, habitat destruction, and over-fishing (Scavia et al. 2002). Warming atmospheric temperatures have already led to an increase in surface-water temperatures and a decrease in the oxygen content of deeper waters (Bograd et al. 2008; Deutsch et al. 2011). Elevated surface temperatures and higher nutrient runoff have led to increased harmful algal blooms and increases in hypoxia in the coastal ocean (Kudela, Seeyave, and Cochlan 2010; Ryan, McManus, and Sullivan 2010). As oceans warm, species adapted to these conditions may be able to expand their native ranges and migrate into ("invade") new regions (see Figure 9.5). For example, Humboldt squid have recently invaded central and Northern California waters, preying on species of commercial importance such as Pacific hake (Zeidberg and Robison 2007). In addition, warmer waters lead to habitat loss for species that are adapted to very specific temperature ranges (Stachowicz et al. 2002). Along with range expansion, the number of invasive species, the rate of invasion, and resulting impacts will increase as coastal ocean waters warm (Stachowicz et al. 2002).

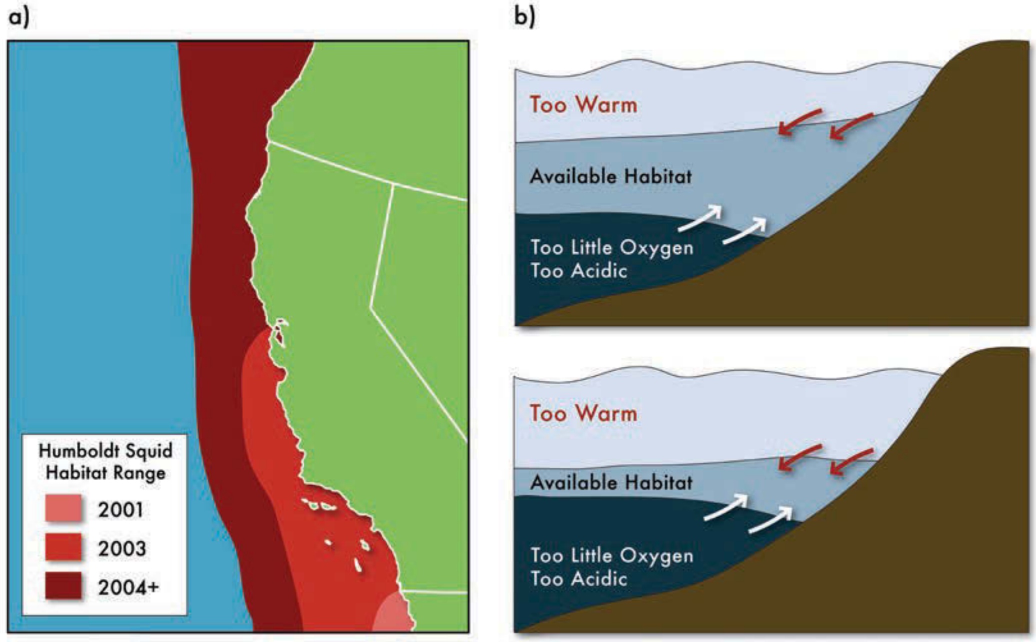

Figure 9.5 Impacts of climate change on marine species distributions and habitat. Many marine species are confined to particular habitats based on water temperature, salinity, or depth. In panel (a) Humboldt squid are confined at their northern edge by temperature. In 2003, the northern edge reached the mouth of the San Francisco Bay, but has recently expanded as far north as Alaska. In panel (b) some fish have limited habitat due to temperature levels of shallower waters above and oxygen or acidity levels of deeper waters below. As surface waters warm and oxygen minimum zones expand or acidity increases, the available habitat for these species is compressed. This leads to lower available resources and potentially increased predation. Source: Bograd et al. (2010), Stramma et al. (2011).

Changes in climate will alter the wind fields that drive coastal upwelling (Bakun 1990; Checkley and Barth 2009; Young, Zieger, and Babanin 2011). It is not clear, however, if changing wind patterns will increase or decrease coastal upwelling or whether each may occur in different locations. Warming surface waters are expected to increase stratification (rate of change in density over depth) and may deepen the thermocline (an abrupt temperature gradient extending from a depth of about 300 feet to 3,000 feet [100m to 1000m]), resulting in a decrease in the amount of nutrients that are delivered to the surface. The timing of seasonal upwelling—during which cold, nutrient-rich water rises to the surface—may shift. Such a mismatch between physical and ecological processes can lead to significant ecosystem consequences (Pierce et al 2006; Barth et al. 2007; Bakun et al. 2010). It is generally accepted that upwelling will be affected by climate change; however, experts differ over what specific changes will occur (Bakun 1990;

Checkley and Barth 2009; Young, Zieger, and Babanin 2011). Hypoxic events—the occurrence of dangerously low oxygen levels that can lead to widespread die-offs of fish or other organisms—will increase as stratification and coastal agricultural runoff increase (Chan et al. 2008). Moreover, as waters warm, they become less able to hold oxygen, resulting in long-term reductions in ocean oxygen content (Bograd et al. 2008; Deutsch et al. 2011). Because warmer coastal waters already are closer to hypoxic thresholds, weaker phytoplankton blooms and smaller nutrient inputs could initiate hypoxia, possibly leading to more frequent, larger, or longer-lasting events, even in regions that have not previously experienced hypoxia.

Ocean acidification

Increased atmospheric CO_2 continues to dissolve in the ocean, making the ocean significantly more acidic than during the preindustrial age (Feely, Doney, and Cooley 2009). Lower pH (more acidic) seas will alter marine ecosystems in ways we do not fully understand, but several predictions are clear: (1) there will be ecological winners and losers as species respond differently to a changing environment (Kleypas et al. 2006; Fabry et al. 2008; Ries et al. 2009; Kroeker et al. 2010); (2) areas of coastal upwelling and increased nutrient runoff will be the most affected (see Figure 9.6) (Kleypas et al. 2006; Feely et al. 2008; Cai et al. 2011; Kelly et al. 2011); and (3) an increase in the variance of pH in nearshore waters may be more biologically important than the changing global average pH, as high frequency peaks in the amount of CO_2 dissolved in water can push marine species beyond their physiological tolerance limits (Thomsen et al. 2010; Hofmann et al. 2011).

Marine food webs are shifting in the already-acidified ocean. Higher CO_2 increases algal growth while hindering the development of shells and other hard parts in mollusks, corals, and other marine animals. These changes are already having direct economic effects: upwelling-intensified acidification has severely harmed several years of hatchery-bred oyster larvae, sending reverberations throughout the industry (Welch 2010; Barton et al. 2012). While the oyster fishery is a relatively small segment of the U.S. seafood industry, about 75% ($3 billion) of the overall industry directly or indirectly depends upon calcium carbonate (the component of shell material that dissolves in lower pH waters). An acidified ocean may change which species the industry targets for cultivation (Cooley and Doney 2009; Langston 2011). Beyond these ecological and economic impacts, ocean acidification is also anticipated to pose direct threats to human health by increasing the number and intensity of harmful algal blooms, which can result in amnesic shellfish poisoning (a disease in humans caused by ingestion of toxins that concentrate in shellfish (Sun et al. 2011; Tatters, Fu, and Hutchins 2012). Existing policy tools to combat the effects of ocean acidification include improved coastal management and more stringent pollution controls under the U.S. Clean Water Act, but addressing the root cause will require reducing atmospheric CO_2 globally (Kelly et al. 2011).

9.4 Coastal Impacts to Communities

Overview

Development along coasts often places residences, coastal tourism development, community resources, and public infrastructure at risk from floods and/or ongoing coastal

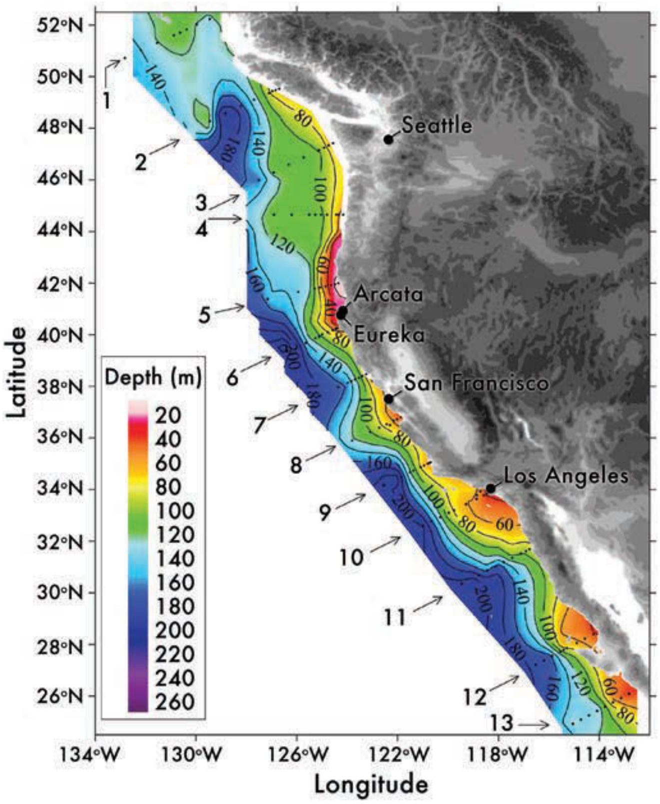

Figure 9.6 Coastal impacts of ocean acidification. This image depicts the aragonite saturation depth on the continental shelf of western North America; warmer colors indicate shallower depths. Aragonite is one of the two most common forms of calcium carbonate, which forms naturally in almost all mollusk shells. Below this depth, it becomes difficult for mollusks and other species to precipitate the calcium carbonate necessary to make shell material. Corrosive waters—those that begin to dissolve calcium carbonate—now occur at shallower depths than in the past because the ocean is absorbing increasing amounts of CO_2 from the atmosphere. Note that in transect 5, corrosive water reaches the ocean surface north of Eureka and Arcata, California. Modified from Feely et al. (2008), reprinted with permission from the American Association for the Advancement of Science.

erosion (see also sections below and Chapter 14 [for more on transportation infrastructure] and Chapter 12 [for more on power plants and energy infrastructure]). Sea-level rise will expand the areas at risk from flooding, accelerate erosion of coastal bluffs and dunes, and, as discussed earlier, permanently inundate large areas of coastal wetlands (Heberger et al. 2009; Revell et al. 2012). Table 9.2 shows some of the current and future vulnerabilities to both flooding and erosion related to increased exposure of the coastal bluff base to expected rise in sea level of 4.6 feet (1.4-meters) by 2100 with no additional development along the coast beyond what existed in 2000 (Revell et al. 2012). In addition, based on a methodology that correlates bluff erosion with increased frequency of exposure to wave attack, erosion could claim as much as nearly 9,000 acres of dunes and 17,000 acres of coastal bluffs from the open ocean coast between the California-Oregon border and Santa Barbara County (Revell et al. 2012).

Table 9.2 Estimated flood and erosion losses for California associated with future sea-level rise on the ocean and bay shoreline

Asset or Concern	Risk [a]	Number or Dollar Amount at Risk in 2000	Number or Dollar Amount at Risk in 2100 (with 55 Inches of Rise in Sea Level)	Dominant Location of Risk [b] (2000/2100)
People	100-year Flood	260,000	410,000	SF Bay/SF Bay
Replacement value of buildings	100-year Flood	$50 billion	$109 billion	Both/SF Bay
People	Erosion [c]		14,000	ND/Ocean
Number of land parcels lost	Erosion [c]		10,000	ND/Ocean
Value of property loss	Erosion [c]		$14 billion	ND/Ocean
Schools	100-year Flood	65	137	Both/SF Bay
Healthcare facilities	100-year Flood	20	55	SF Bay/SF Bay
Police, fire and training areas	100-year Flood	17	34	SF Bay/SF Bay
Hazardous waste sites	100-year Flood	134	332	ND/ND
Highway and (road) miles	100-year Flood	222 (1,660)	430 (3,100)	Ocean/Ocean
Power plants number and (megawatt capacity)	100-year Flood		30 (10,000)	ND/Ocean
Waste treatment plants number and (millions of gallons/ day capacity)	100-year Flood		29 (530)	ND/SF Bay

Note:
(a) Flood risks and erosion risks are not mutually exclusive; many of the same assets will be at risk from both flood and erosion.
(b) ND is no data – often since the analysis looked at change from the current conditions.
(c) Erosion impacts were only examined for the open ocean coast from Del Norte County through Santa Barbara. Estimates for erosion losses do not include Ventura, Los Angeles, Orange, or San Diego counties. Nor do estimates include San Francisco Bay, since, "In San Francisco, however, the erosion-related risk is small." (Heberger et al. 2009)

Source: Heberger et al. (2009).

Airport infrastructure

Several of California's key transportation facilities are situated in coastal areas and will be affected by rising sea level. For example, the runways at both the San Francisco (SFO) and Oakland (OAK) International Airports will begin to flood with a 16-inch (40-cm) sea-level rise (within the 2050 sea-level rise scenarios in Table 9.1) (see Figure 9.7). This change would severely impact not only airlines and passengers internationally, but also air cargo, as SFO is the largest air cargo handler in the region and expects to double cargo throughput in the next thirty years. Given the importance of these airports to the local and regional economy, an increase in runway elevation, floodwalls, or the development of some alternative response strategies will be required to avoid these debilitating impacts (Metropolitan Transportation Commission 2004).

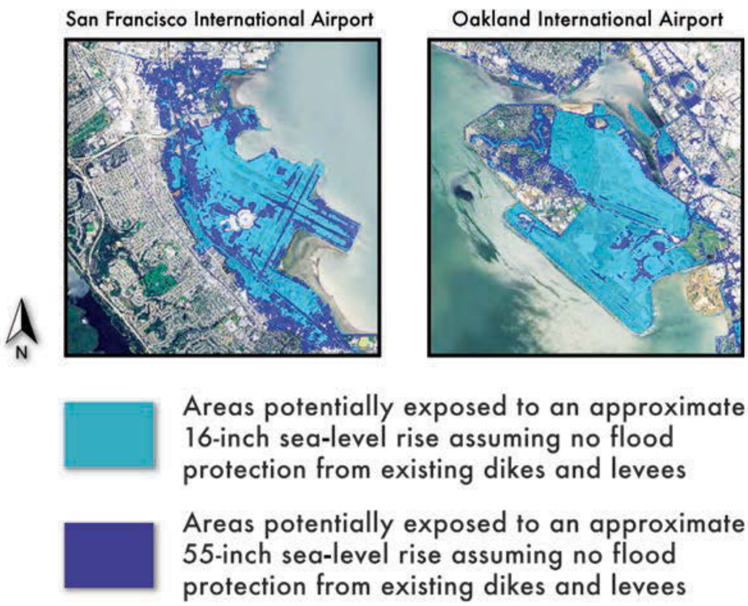

Figure 9.7 Impacts to San Francisco and Oakland International Airports. The impacts to San Francisco and Oakland airports will require planning and resources to ensure that these major economic drivers for the San Francisco Bay Area can continue to operate in the future. Modified from Siegel and Bachand (2002), Knowles (2008); see also http://www.bcdc.ca.gov/planning/climate_change/index_map.shtml, Central Bay West Shore map 16 & 55, Central Bay East Shore map 16 & 55.

Vehicular transportation infrastructure

The rise in sea level and increased frequency and intensity of storm events will lead to a combination of increased shoreline inundation and landslides induced by rainfall or wave erosion. With even small sections of roadways disrupted due to these processes, the greater transportation network will be at risk. As a result, the California Department of Transportation prepared guidance on incorporating sea-level rise into project programming and design (Caltrans 2011) (see Box 9.3). (For further discussion of climate impacts on transportation systems, see Chapter 14.)

Box 9.3

The Role of Adaptation in California Ports

California's three major ports—Los Angeles, Long Beach, and Oakland—had a combined throughput of over $350 billion[7] in cargo in 2009, equivalent to 13% of the GDP of the six Southwest states. With such noted economic importance, port authorities are starting to address issues related to sea-level rise. While the greater water depth that will accompany rising sea level will help deeper draft ships, many landside changes will be needed (see Chapter 14). The Port of Long Beach plans to rebuild the Gerald Desmond Bridge because the air gap (the space between the bottom of the bridge and the top of a ship) is restricting some ship transit to times of low tide. The Port of Los Angeles and the Rand Corporation prepared a climate adaptation study to consider the impacts from rising sea levels on the port. The creation and funding of additional protection or response plans for these ports—and their associated costs—is inevitable (Metropolitan Transportation Commission 2004).

Economy, culture, and identity

A large part of California culture and identity is invested in ocean and coastal resources and shoreline access, including beach-going, surfing, kayaking, hiking, and diving, as well as recreational and commercial fishing. Thus, the socio-economic impacts to coastal communities from sea-level rise go well beyond losses to buildings, properties, and infrastructure. For example, estimated losses to the Venice Beach community from a 100-year flood event after a 4.6-foot (1.4-meter) sea-level rise (the high 2100 scenario from Table 9.1) are $51.6 million (an increase of $44.6 million over the present risk), which includes loss of tax revenue, beach-going spending, ecological value, and other societal costs (King, MacGregor, and Whittet 2011). However, such estimates depend on a set of assumptions which—while reasonable—involve significant uncertainties. For example, the 1983 ENSO event caused over $215 million in damage statewide (in 2010 dollars; Griggs and Brown 1998); a similar event in 2100 would be significantly more damaging under conditions of higher sea level, more intensive development, and greater property values (Griggs and Brown 1998). Thus, future losses may be higher than the best available current economic science suggests. In addition, Native American communities, such as the Yurok and Wiyot of Northern California, are also examining traditional uses of coastal areas and the impacts to tribal lands of sea-level rise (including loss of land due to inundation), undertaking coastal restoration projects, assessing the impacts to salmon of overall ecosystem changes. (For further discussion of the impacts of climate change on the lands and resources of Native nations, see Chapter 17.)

9.5 Managing Coastal Climate Risks

Overview

Due to the high concentration of coastal development, population, infrastructure, and economic activity in coastal counties, continued and growing pressure to protect these assets and activities from rising sea levels is expected. Further concentration of wealth, infrastructure, and people along the coast—which historically has resulted in the tendency to protect and harden developed shorelines—is expected to increase the risk of loss of the remaining natural coastal ecosystems in these areas (see Box 9.4) (CNRA 2009; Hanak and Moreno 2011). About 40% of the backshore area (above the high-water line) along the California coast is in public ownership (federal and non-federal)[ii] (USACE 1971), about 107 miles or 10% of the state's coastline had already been hardened as of 2001 (Griggs, Patsch, and Savoy 2005), and more than 90% of the coast's historical wetland areas have been lost or converted due to diking, drainage, and development (Dahl 1990; Van Dyke and Wasson 2005; Gleason et al. 2011).

Box 9.4

The Role of Insurance and Incentives in Coastal Development

Many federally and state-funded actions and programs continue to protect and subsidize high-risk coastal development by shifting the cost of flood protection and storm recovery from property owners and local governments to state and federal taxpayers. For example, the Federal Emergency Management Agency's (FEMA) National Flood Insurance Program (NFIP) offers flood insurance rates that do not reflect the full risk that policyholders face. In addition, the Army Corps of Engineers frequently funds and executes structural shoreline protection projects, while federal and state post-disaster recovery funding and assistance encourages replacing or rebuilding structures with a high level-of-risk exposure (Bagstad, Stapleton, and D'Agostino 2007). These programs work together to distort market forces and favor the movement of people to the coasts. Meanwhile, reinsurance companies and experts studying the insurance market increasingly urge that premiums better reflect actual risks to ensure a reliable insurance system as climate risks increase (Lloyd's of London 2006, 2008; Kunreuther and Michel-Kerjan 2009; Pacific Council on International Policy 2010).

The NFIP is over-exposed and is running a deficit as of 2010 of nearly $19 billion (Williams Brown 2010). To reduce the financial burdens on the flood insurance program and decrease overall vulnerability, FEMA also administers several grant programs designed to mitigate flood hazards prior to disasters occurring (FEMA 2010). These programs are often used for pre-disaster structural flood mitigation measures, but have also been used for structure acquisition, property buy-outs, and demolition or relocation (Multihazard Mitigation Council 2005). The resulting open space is required to be protected in perpetuity, simultaneously providing natural resource benefits and vulnerability-reduction benefits (FEMA 2010).

As mentioned previously, in 2011 the California Ocean Protection Council issued interim sea-level rise guidance for state and local agencies, thus implementing one of the key strategies proposed in California's first statewide climate change adaptation plan (CNRA 2009; California Ocean Protection Council 2011). While not mandatory, this guidance gives state and local government agencies and officials a scientific basis to vet planning and permitting decisions. The guidance will need to be updated regularly as new scientific information becomes available (e.g., through the 2012 NRC study on sea-level rise along the West Coast). Pragmatically, the management and planning mechanisms through which local governments in California are making adaptive changes include general plan updates, climate action or adaptation plans, local coastal program updates, local hazard mitigation plans, implementing regulations (such as tax or building codes), and special or regular infrastructure upgrades (Moser and Ekstrom 2012). A selected list of climate adaptation planning resources can be found in Table A9.1.

Adaptation options

Coastal managers have several adaptation options (USAID 2009; NRC 2010[iii]; Grannis 2011; NOAA 2011; Russell and Griggs 2012) that typically fall into three categories.

First, structural protection measures such as seawalls and revetments (hardened surface built to protect an embankment) as well as beach replenishment have frequently been the preferred option for local governments trying to protect public shorelines and adjacent coastal properties (which are part of the property and commercial tax base) and maintain or enhance opportunities for coastal tourism. Historically, many beach nourishment projects in California have been opportunistic in the sense that they were a means of disposing sand dredged from harbors or produced from coastal construction rather than stand-alone projects for nourishing beaches.

Hardening the shoreline along the coast has resulted in harmful environmental and ecological impacts, both directly in front of and downdrift from the hardened shoreline. Such impacts include passive erosion or beach loss in front of the hardened shoreline, visual impacts (see Figure 9.8), and reduced public access along the shoreline (Griggs 2005). The impacts of shoreline protection within interior waterways—such as bays or estuaries—include loss of tidal prisms (the volume of water leaving an estuary at ebb tide) and loss of coastal wetlands, which contain important bird habitat, fishery nursing grounds, and the capacity of such natural buffers to retain flood waters (Griggs et al. 1997; Runyan and Griggs 2003).

Second, adaptation measures that continue to allow coastal occupancy and yet aim to reduce risks of coastal erosion and flooding are common elements of hazard-mitigation plans and land-use planning (local coastal programs) under the California Coastal Act in coastal communities. These measures include adjustments to building codes (such as requirements for the use of flood-prone basements within flood zone areas) or modifications to standards for development and coastal construction (such as setbacks for building from the shoreline, limits to how much land surface can be made impervious, the amount of freeboard required between the ground and the first inhabited floor, and other flood protection measures, including stormwater retention and treatment on the property).

Generally speaking, measures depend on the environment in which development is situated. For cliff and bluff top construction, zoning or construction policies may contain standards for cliff edge setbacks and requirements to improve onsite water drainage to minimize cliff erosion may be considered (Griggs, Pepper, and Jordan 1992). For low lying areas, coastal plains, beaches, and bayside waterfront areas, development standards requiring construction above base flood elevations and setbacks from high-risk flood and/or erosion areas may be most relevant.

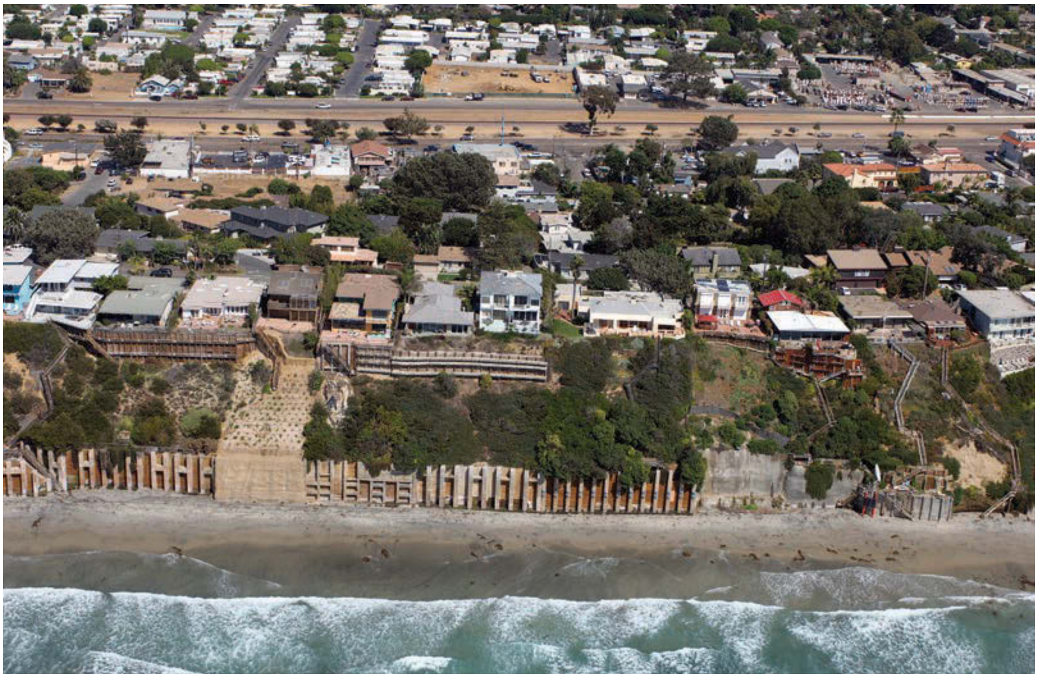

Figure 9.8 Coastal armoring in Southern California. One-third of the shoreline of Southern California (including Ventura, Los Angeles, Orange and San Diego Counties) has now been armored. The photo shows the shoreline in 2010 in Encinitas, in northern San Diego County. Photo courtesy of Kenneth and Gabrielle Adelman of the California Coastal Records Project (http://www.californiacoastline.org/).

Finally, a variety of adaptation measures focus on reducing long-term exposure to the risks associated with climate change and coastal hazards. Such measures might take the form of planned retreat from the shoreline, but might also include the restoration of natural coastal buffers, such as dunes and wetlands. Of particular value are strategies and policies that incorporate natural resource values and management (California Coastal Act 1976; UNCBD 2009). Such ecosystem-based adaptation is an approach that simultaneously builds ecological resilience and reduces the vulnerability of both human and natural communities to climate change.[iv] It is based on the premise that sustainably managed ecosystems can provide social, economic, and environmental benefits, both directly through the preservation of innately valuable biological resources and indirectly through the protection of ecosystem services that these resources provide humans (Coll, Ash, and Ikkala 2009; World Bank 2010).

Level of preparedness and engagement in adaptation planning

A 2005 survey of California coastal counties and communities assessed coastal managers' awareness of the risks associated with climate change and the degree to which they had begun preparing for, planning for, and actively managing these risks in their coastal management activities (Moser 2007; Moser and Tribbia 2007). The vast majority of surveyed coastal managers were of the opinion that climate change is real and is already happening and were significantly concerned about the associated risks. As of 2005, however, very few local governments had taken up the challenge of developing strategies to deal with those risks.

In a follow-up survey conducted in summer 2011, some important shifts could be noted (see Figure 9.9) (Hart et al. 2012). Most remarkable was the increase in the level of activity on adaptation from 2005 to 2011. In 2005, only two of the responding coastal counties and one of the participating cities had climate change plans in place, and four counties and six cities were developing such a plan. By 2011, many more coastal communities in California had begun examining and planning for the impacts of climate change.[v]

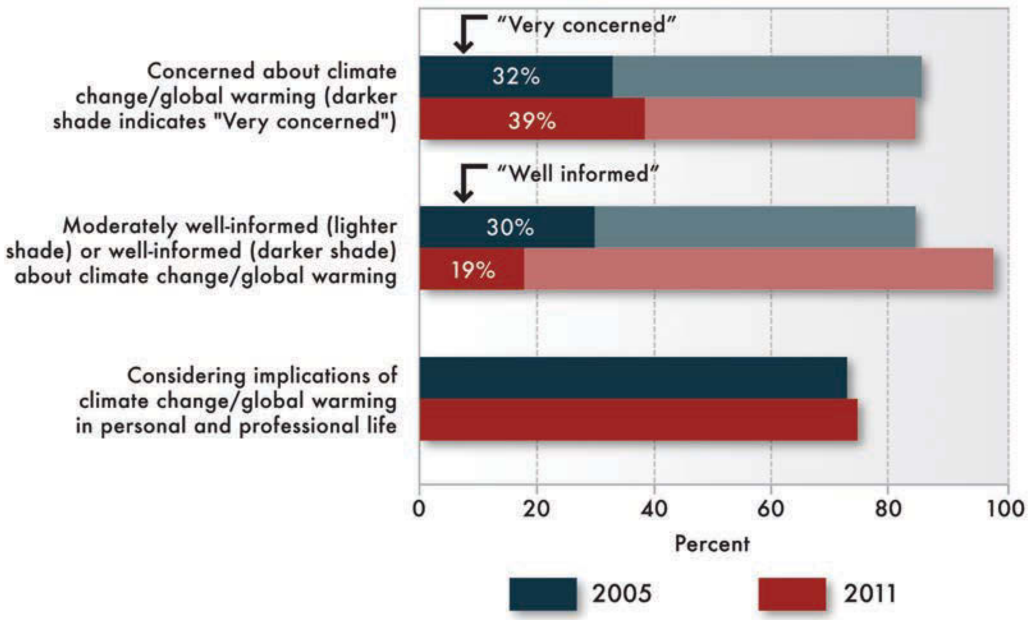

Figure 9.9 California coastal managers' attitudes toward climate change. Well over 80% of California coastal managers are concerned with climate change. The proportion saying they are "very concerned" increased significantly over the past six years. Meanwhile, local managers feel only moderately well informed, indicating a significant need for education. One indication of their readiness to advance adaptation planning is the high proportion of respondents (75%) who report that they already consider the implications of climate change in their personal and professional lives. Source: Moser (2007), Moser and Tribbia (2007), Hart et al. (2012).

A separate analysis highlighted six municipalities in California that have developed local climate adaptation plans or components thereof (Georgetown Climate Center 2012). An Ocean Protection Council resolution passed in June 2007 encouraged Local Coastal Plan (LCP) amendments to address sea-level rise, yet few local governments have even begun the process of considering such LCP amendments. Of particular regional significance is also the overall slow response of the region's major ports and marine facilities, albeit not a unique response among North American or international ports where adaptation planning is just beginning (California Ocean Protection Council 2007; California State Lands Commission 2009; Becker et al. 2012).

Thus, while the state of California has been fairly progressive in adaptation planning (for example, with a Climate Adaptation Strategy, CalAdapt website, and the 2012 sea-level rise study completed by the National Research Council), most adaptation actions will be implemented locally or regionally (often with state and federal support and permits). However, few local governments have begun taking steps to implement either their own plans or the State's existing recommendations.

Barriers to adaptation

Several studies have examined impediments or barriers to adaptation for individuals, communities, organizations, and entire nations.[vi] Increasing empirical evidence from California strongly confirms the presence of barriers to adaptation in coastal communities (Hanak and Moreno 2011). In the above-mentioned 2005 survey of local jurisdictions, coastal managers considered their top barriers to adaptation management to be local monetary constraints, insufficient staff resources, lack of supportive funding from state and federal sources, the all-consuming nature of currently pressing issues, and the lack of a legal mandate to undertake adaptation planning (Moser and Tribbia 2007). When asked again in 2011, the lack of funding to prepare and implement a plan, lack of staff resources to analyze relevant information, and the all-consuming currently pressing issues were again mentioned as overwhelming hurdles for local coastal professionals, followed (with far less frequency) by issues such as lack of public demand to take adaptation action, lack of technical assistance from state or federal agencies, and lack of coordination among organizations (Moser and Ekstrom 2012). Case study research in two cities and two counties in the San Francisco Bay Area found that institutional barriers dominate, closely followed by attitudinal barriers among decision makers. Funding-related barriers were important, but ranked only third (Storlazzi and Griggs 2000; Griggs, Patsch, and Savoy 2005; Kildow and Colgan 2005; Moser and Ekstrom 2012).

There is additional independent evidence that local jurisdictions vary considerably in their technical expertise and capacity to engage in effective coastal land-use management and that they do not use available management tools to the fullest extent possible to improve coastal land management overall (Tang 2008, 2009). For example, experts assert that the California Coastal Act and the Public Trust Doctrine are considerably underutilized in protecting public trust areas and the public interest (Caldwell and Segall 2007; Peloso and Caldwell 2011). Thus, the persistence of this range of institutional, attitudinal, economic, and other adaptation barriers goes a long way toward accounting for the low level of actual preparedness and lack of active implementation of adaptation strategies in coastal California.

The in-depth case studies conducted in the San Francisco Bay Area, however, also reveal that local communities have many opportunities, assets, and advantages that can help them avoid adaptation barriers in the first place, or which they can leverage in efforts to overcome those barriers they encounter (see Chapter 19, Box 19.4). Among the most important of these advantages and assets are people and existing plans and policies that facilitate and allow integration of adaptation and climate change (Moser and Ekstrom 2012) (see also Chapter 18, Section 18.7).

In conclusion, adaptation in coastal California is an emerging mainstream policy concern wherein institutions and the individuals involved—along with supporting financial and technical resources—pose the greatest barriers and constitute the greatest assets in avoiding and overcoming them. While some barriers originate from outside sources (such as the national economic crisis or federal laws and regulation) and communities require state and federal support to overcome entrenched challenges (such as legal and technical guidance or fiscal support), local communities have the power and control to overcome many of the challenges they face (Moser and Ekstrom 2012; for further discussion of the effects of climate change on urban areas, see Chapter 13, and for a discussion of local adaptation and mitigation choices, see Chapter 18).

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Appendix

See following page.

Table A9.1 Selected Resources in Support of Coastal Adaptation

Name	Website	Description
CalAdapt	http://cal-adapt.org/	Localized, searchable climate change projections for California
California Climate Change Portal	http://www.climatechange.ca.gov/	Research results on climate change, its impacts on California (including coasts), and the state adaptation strategy
California Ocean Protection Council	http://www.opc.ca.gov/	Sea-level rise guidance for state and local agencies, funding opportunities
USGS Coastal Vulnerability Assessment	http://woodshole.er.usgs.gov/project-pages/cvi/	Historical sea-level rise and erosion hazards (not including future risks)
NOAA Coastal Services Center	http://collaborate.csc.noaa.gov/climateadaptation/default.aspx	Wide range of information and tools for impacts and vulnerability assessments, adaptation planning, visualization, communication, stakeholder engagement, etc.
Rising Sea Net	http://papers.risingsea.net/	Sea-level rise, impacts (erosion, flooding, wetlands), adaptation options, costs, legal issues (property rights, rolling easements etc.)
Georgetown Law Center - Adaptation	http://www.georgetownclimate.org/adaptation	Searchable database of case studies, adaptation plans, sea-level rise tool kit, and other documents

Endnotes

i The term "coast" refers to the open coast and estuaries.

ii There is no direct link between land ownership and reliance upon shoreline armoring. Public ownership does not guarantee a natural shoreline, and since much of the public backshore may be used for public infrastructure such as roads or parking lots, armoring might also be present. Conversely, private ownership does not necessarily mean there will be development or that coastal armoring will be present. In general however, areas of open space or with low-intensity development are most likely to experience natural shoreline dynamics without human interference.

iii In NRC (2010), see in particular Section 3 and pp. 117–119, which list different coastal adaptation options.

iv Examples of ecosystem-based approaches along the California shoreline include managed retreat (or realignment) projects at Pacifica State Beach and the Surfers Point project at Ventura Beach, both of which improved recreation and habitat values while reducing long-term costs and exposure to risks. Additional case studies illustrating both climate change risks and the efforts made to date toward adapting to them can be found in the state's 2009 *Climate Adaptation Strategy,* in the Pacific Council on International Policy's 2010 advisory report for the state, in Chapter 18 of this report, and in case studies cited throughout this chapter.

v Of the 162 survey responses, which represented 14 coastal counties and 45 coastal municipalities, only 10% had not begun looking at climate change impacts at all, 40% were in the early stage of understanding the potential impacts of climate change and their local vulnerabilities, 41% had entered the more advanced stage of planning for those impacts, and another 9% were implementing one or more identified adaptation options. More detailed survey results have shown that communities are still early in their respective processes, but a clear increase in engagement has been confirmed by several other studies (Hanak and Moreno 2011; Moser 2009; Tang 2009; Cruce 2009).

vi See the extensive literature review in Ekstrom, Moser, and Torn (2011) and Moser and Ekstrom (2010).

vii Based on reportings from the ports; see http://www.portoflosangeles.org/maritime/growth.asp; http://logisticscareers.lbcc.edu/portoflb.htm; http://www.portofoakland.com/maritime/facts_comm_02.asp.Chapter 10