CHAPTER 1

Human Settlement of the Coastal Zone

Relatively early in human history it became clear that coastal regions were attractive areas for settlement. The deltas and alluvial plains adjacent to coastlines provided flat, fertile land and water that made agricultural production possible, the mild climate made life easier and more comfortable, and the coastal waters provided access to the sea. Over time, trade and commerce would develop. There were some long steps for early humans, however, from the grasslands of Africa to the Nile Delta or the fertile crescent of the Middle East, but over thousands of years these areas were gradually settled. The earliest civilizations were preceded by the domestication of plants and animals and the development of agriculture, which date to 10,000 years ago plus or minus a few thousand years. The beginnings of agriculture took place over several thousand years at nearly the same time in several different areas, including Egypt, the Fertile Crescent of the Middle East, India, China, Middle America, and parts of Europe.

THE ROLE OF CLIMATE CHANGE AND SEA-LEVEL RISE IN COASTAL SETTLEMENT

There are many ideas and hypotheses as to what triggered or led to the transition from our hunter-gatherer ancestors to farmers, among them the climate changes that took place when the last ice age ended and the modern Holocene epoch began (usually dated at about 11,700 years

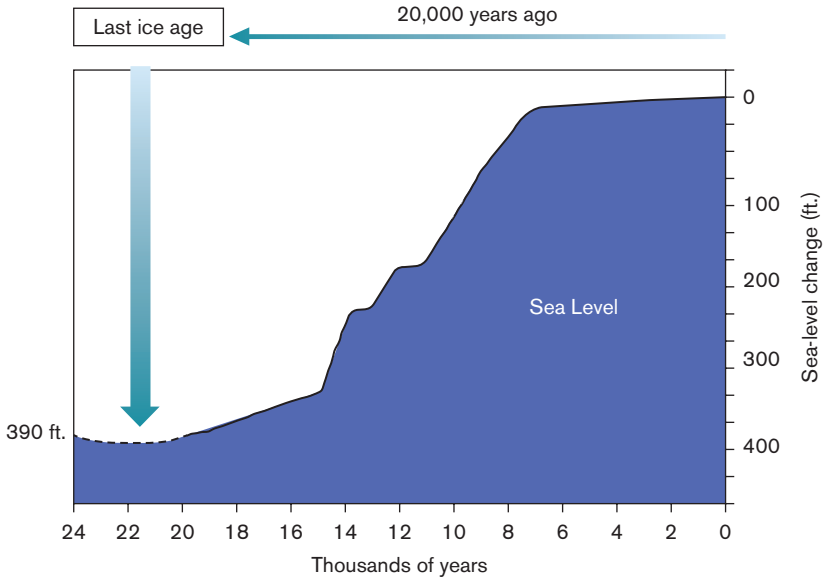

FIGURE 1.1. Global sea level has been rising for the past 20,000 years, since the last ice age ended.

ago). Much of the Earth became warmer and drier, which favored annual plants that died back but produced seeds (grains) or tubers that could be cultivated, harvested, and stored for later consumption. This was a huge step forward for humanity.

Another argument has been proposed for a connection between the early development of agriculture and the stabilization of sea-level rise. As the last ice age came to a close about 18,000 years ago, glaciers and ice sheets gradually began to melt and seawater warmed, increasing the volume of the ocean and thereby raising sea level. There was a period of fairly rapid warming and associated sea-level rise between about 18,000 and 7,000 years ago (figure 1.1). During this period, sea level rose on average nearly half an inch per year or about 45 inches per century. Within this approximately 11,000-year period of warming, there were also what are believed to have been meltwater pulses when glaciers retreated very rapidly, causing sea level to rise even faster. During these intervals, the oceans were rising at nearly an inch a year or over six feet per century. In low-relief and low-lying deltas or coastal plains, a few feet of sea-level rise could move the shoreline landward thousands of feet or more, so these areas would not have supported permanent agriculture or settlements.

About 7,000 years ago, however, climate change slowed and the rate of sea-level rise declined dramatically. Until about a century ago global sea levels were fairly stable, rising only about 0.04 inch per year, equivalent to about 4 inches per century. This created some stability and the opportunity for early humans to begin to occupy and settle the fertile coastal environments and, along with the warmer climate, begin to cultivate crops. The earliest evidence of civilization appeared within about a thousand years of the cessation of sea-level rise, although there is still considerable debate over the most important contributing factors.

During the Neolithic (~12,000 to 7,000 years ago), a number of population groups began to abandon hunting and gathering and for the first time started to settle in villages, domesticating animals and tending crops. Settlements in that era tended to be in inland areas, in the valleys, foothills, and mountains, and burials at that time usually lacked indications of social classes or distinctions. Within about a thousand years of sea-level stabilization, however, a transition seems to have taken place, with people beginning to migrate to coastal areas, where communities began to develop with significant increases in population, as well as burials that show the existence of social classes. These communities also began to construct monumental architecture, indicative of societies with large labor forces (think about the Great Pyramids of Egypt). These concentrations of people and labor forces required a large and dependable food supply, and the stabilization of sea level allowed that in several ways. Rivers delivered soil, nutrients, and organic matter to the more stable coastal plains and deltas, allowing for essentially continuous agricultural production. In addition, the nearshore marine environment stabilized, with highly productive wetlands, estuaries, intertidal zones, and reefs, which soon were discovered to be important year-round food sources to complement what was grown on the adjacent land. Archaeological records from sites around the world from this time period show that fish and shellfish, as well as marine mammals, were part of the emerging food supplies made possible by this stable and productive coastal environment. The development of irrigation canals and the construction of fishponds further enhanced this new coastal margin productivity. Early civilizations gradually developed and expanded, although it would be a few thousand years more before the world's coastal regions began to be recognized as sites of considerable value to human settlement and cities began to develop and expand. In addition to important settlement sites, coasts or shorelines likely provided routes for migration to new areas.

FIGURE 1.2. Route of early human migration to the Americas from Asia across the Bering Land Bridge.

Recent discoveries at the Monte Verde archaeological site in southern Chile has confirmed this as the oldest known human settlement in the Americas discovered to date and provides additional evidence in support of the theory that one early migration route followed the Pacific coast of the Americas more than 15,000 years ago, from one end of the Americas (the Bering Strait) to the other (Patagonia). In fact, to the surprise and initial disbelief of many anthropologists and archaeologists, this migration appears to have taken place remarkably quickly. The Monte Verde site shows the existence of a group of people living along the beaches and banks of sand and gravel of a small stream about 14,800 years ago.

The dominant theory since the 1930s suggests that the ancestors of Native Americans crossed the Bering Strait about 15,000 years ago, when sea level was about 350 feet lower than today (figure 1.2). They were likely following herds of large game, and these early visitors then quickly spread out through North and then South America. The recent analysis of genetic data, however, based on the rate at which mutations occur, indicates that the first Native Americans were isolated from their Asian ancestors for thousands of years before dispersing through the Americas. They likely departed from their Siberian relatives about 25,000 years ago and entered Beringia, a former landmass that now

encompasses the far eastern area of Russia, the shallow parts of the Bering Sea, and western Alaska. Evidence also indicates that this area was likely drier grassland where large mammals like wooly mammoths, giant ground sloths, steppe bison, musk ox, and caribou grazed. Steller sea lions were also present along the shoreline during this time. The presence of an abundant food supply from the ocean and the land, as well as woody plants that could be used for fires and shelters, may have provided a reasonable place to settle down for a while, perhaps until ice melt opened up migration paths into North America.

Based on the number of sites in the Americas where evidence of human habitation has now been uncovered, stretching from Alaska to Chile, and despite some archaeological arm wrestling over what counts for concrete evidence of human presence and what does not, it seems that humans arrived in the Americas at least 15,500 or 16,000 years ago. Pushing the arrival date back introduced another problem to be solved, however. Based on sea levels and ice coverage 15,000 years ago, there does not appear to have been an ice-free highway for these early visitors to follow into North America.

The lack of a convenient or even passable route on dry, ice-free land from Beringia introduced the idea that perhaps the first Americans did not walk here at all but came in small boats and followed the coastline south, perhaps sustaining themselves with the abundant marine life of the nearly continuous kelp highway that borders North America's west coast. This idea was first proposed in the late 1950s after very old human bones were discovered on Santa Rosa Island, off the coast of Santa Barbara, California. The bones were later determined to be male, named the Arlington Springs Man, after the discovery site. Significantly, the bones were later dated at 13,000 years, making these the oldest human remains found anywhere in the Americas at the time. Although at that time sea level was about 225 feet lower than today, Santa Rosa Island was still separated from the rest of California by about 5 miles of ocean. Unless this early man was an Olympic swimmer, he and his friends and family must have crossed the deep Santa Barbara channel by boat. Pygmy mammoth bones of the same approximate age were also unearthed on Santa Rosa Island, indicating coexistence with this early human and representing a long swim for a small pachyderm. While there seems to be no question that the earliest Americans dined on marine animals, it is still not clear if this nearshore kelp highway was a route used by the earliest Americans in some sort of primitive boat.

COASTAL SETTLEMENTS AND CITIES

Between the Arlington Springs Man and the Monte Verde site in Chile, it appears that at least some of the earliest human inhabitants of the Americas found the coastal areas to their liking. About eight thousand years later, the early Mediterranean civilizations, including the Egyptians and then later the Phoenicians, Greeks, and Romans, were some of the first peoples to realize the advantages of coastal areas. The development of small coastal vessels and then larger ships allowed these groups to benefit from easy access to the sea, and most of the major cities of those civilizations were seaports or had ocean access. Some eastern Mediterranean cities had natural harbors, which facilitated marine trade and commerce and the offshore expansion of fishing, which diversified diets.

A thousand or so years later, the Vikings and their predecessors adapted successfully to very different coastal environments and mastered the craft of boat building and seafaring as they colonized the Baltic and North Seas. They also reached America and established colonies five hundred years before Columbus arrived.

Each of these early coastal civilizations inhabited distinct regions or environments, from the low-relief and constantly shifting but very fertile Nile Delta to the natural or constructed harbors of the eastern Mediterranean to the deep fjords of Scandinavia, but each group benefited from the presence of the ocean. The climate of these coastal regions was nearly always more moderate than inland areas, which experienced greater extremes in temperature. In most cases, the adjacent ocean also provided a supply of protein for the growing populations. Harbors, whether natural or manmade, became new centers of trade and commerce, simply because ships allowed for the first large-scale transport of goods to other areas. They also became important for defense and military activities, and ships allowed for the development of the first navies and more effective ways of transporting soldiers and implementing invasions or battles.

As civilization advanced and populations grew, coastal regions became progressively more important, and many of Europe's large cities developed along or near coastlines as ports and centers of commerce. Athens, Venice, Rome, Lisbon, London, Amsterdam, Copenhagen, and Stockholm come to mind. As Europeans settled the Americas in the seventeenth and eighteenth centuries, many major cities were founded on the coast, around the Great Lakes, or along navigable rivers, among them New York, Boston, Chicago, Toronto, Washington, DC, Detroit,

Cleveland, and Montreal. As the west coast of the United States and Canada was settled, San Diego, Los Angeles, San Francisco, Portland, Seattle, and Vancouver emerged as coastal cities and ports.

But whether in Europe, the Americas, or Asia, the earliest settlements and the development of communities and then cities on the coast were in many cases related initially to the ability to develop agriculture on floodplains and deltas, harvest fish and shellfish from the adjacent ocean, or become centers for maritime trade. Over time, the added advantages of access to the sea for commerce and defense became equally or more important.

It was not until the late 1800s and early 1900s, however, when railroads and steamships made travel easier and faster, shorter workdays allowed for leisure time, and an urban middle class with disposable income emerged, that there developed oceanside accommodations and resorts for leisure pursuits. This began an entirely new era, with increasing numbers of people heading to the coast for recreation and relaxation, whether the coast of the Mediterranean, Brighton or Seabright in England, the Greek Isles, Australia's Gold Coast, San Diego in Southern California, or the Hawaiian Islands. People came to the coast initially for short stays and then more recently for retirement, with progressively greater impacts.

HUMAN IMPACTS ON COASTAL ENVIRONMENTS

Each of the chapters that follow focuses on a specific issue relative to greater human occupancy and use of coastal regions. The chapters in part 1 describe the natural processes and hazards that affect coastal regions around the world and the people who live and work there. Those in part 2 discuss the major impacts that human activities are increasingly having on coasts globally.

The footprints of the early humans who occupied and settled the coast were quite modest in comparison to today's impacts. Dune vegetation was sometimes grazed by domesticated animals, which resulted in destabilization, forests were cut down, and sediment loads to the shoreline were increased, leading to coastal accretion or outbuilding and damage to coral reefs in tropical latitudes. Waste discharge was minimal, however, and fishing pressures were initially low. These impacts were all recoverable because they were generally on a small and local scale relative to what is possible with the population numbers, machines, and technology that developed over the past 150 years or so.

The coastline began to change, however, in response to natural processes as well as human activities. The ancient Greeks and Romans were very capable engineers and built ports and harbors, along with their monumental architecture. Today many of these early ports are filled with sediment and are several miles inland from the present shoreline as a result of a thousand or more years of sedimentation.

There was also the progressive awareness that living at the edge of the ocean presented significant hazards. Tsunamis have taken large death tolls historically, in Japan, in the Indonesia archipelago, and even on the Mediterranean coastlines. Cyclones, hurricanes, and typhoons have also taken their toll over the years throughout South Asia. Despite these risks, people have continued to be drawn to coastal areas. Cities have grown along with exposure to natural hazards and the impacts of the expanding populations on coastal environments and natural systems.

THE COAST AS A DESTINATION

The attraction of the coast as a vacation or holiday destination exploded after World War II for a number of reasons but built on what had begun fifty or more years earlier. Widespread automobile ownership brought access to the coastline within the reach of most people, regardless of income. Campgrounds and caravan parks replaced farmland and grazing land. Vacation resorts multiplied, hotels expanded, and new attractions, such as marinas and golf courses for those who could afford them, were added to draw even more people. Many former sleepy fishing villages along the Mediterranean coast of Spain, France, and Italy, if they had beaches, became summer resorts for the sun-craving people of northern Europe. High-rise condominiums and apartments were constructed by the thousands to accommodate these seasonal visitors, which took their toll on the social and cultural fabric of these former towns but also provided new types of employment and increased economic activity. Oceanfront promenades and boardwalks often replaced hauled-out fishing boats and drying nets.

All of this changed the character of coastal towns, although the sun and warm ocean waters continued to draw people: the Costa Brava, Costa Blanca, Costa del Sol, Costa Verde, Costa de la Luz, to name a few in Spain (figure 1.3). Florida is a lot like Spain's Mediterranean coast, drawing people from New York and New Jersey first to vacation and then, often, to relocate permanently. The beaches in Florida have

FIGURE 1.3. Intensive shoreline development at Peniscola along the Mediterranean coast of Spain. (Photo: D. Shrestha Ross © 2015)

always been magnets, but they are getting narrower in many areas due to the effects of jetty construction at inlets. Miami is also building higher and higher, as if trying to outpace the increasing rate of sea-level rise.

COASTAL POPULATION EXPANSION

Regardless of how we define "the coast" or "the coastal zone," it has become substantially more crowded globally than inland regions in recent decades, and all indications are that this trend will continue. The number of people around the world occupying coastal regions is difficult to determine, and the figures vary according to different sources and criteria: approximately 3 billion people living within 125 miles, 3 billion people living within 100 miles, or 3 billion people living within 60 miles, you can take your pick. Give or take a few hundred million, this is a big number, and it's growing, producing an expanding crisis at the coast.

In the United States in 2010, of the three million total square miles of land area (excluding Alaska), less than 20 percent (512,971 sq. mi.) is in *coastal watershed counties* (counties containing watersheds that drain to the coast). But 52 percent, or 163.8 million of the U.S. population of

313 million, live in these counties. Less than 10 percent of the nation's land area (275,351 sq. mi.) is in *coastal shoreline counties* (those that border on a coast), but 39 percent, or 123.3 million people, live in these counties.

Not surprisingly, following a global trend, population densities in U.S. coastal regions are high and getting higher, simply because more people are crowding into the same desirable areas. In 2010 the average population density of the United States as a whole was 105 persons per square mile. For coastal watershed counties, average density was three times as high, 319 persons per square mile. For coastal shoreline counties, the density was 446 persons per square mile, or over four times as high. Nationally, population density grew to 36 persons per square mile in the forty years between 1970 and 2010. In contrast, coastal watershed counties added 99 persons per square mile, while coastal shoreline counties grew by 125 persons per square mile. Many of these new migrants to coastal counties are older or retired, with the percentage increase in people sixty-five or older being significantly higher in coastal states; South Carolina had a 443 percent increase in seniors in the period 1970–2010; Hawai'i, 340 percent; Virginia, 248 percent; and Florida, 208 percent.

To meet the housing needs of these migrants, building is continuing in coastal areas. New building permits were being issued at the rate of 1,355 per day in coastal shoreline counties across the country between 2000 and 2010.

URBAN EXPANSION AND THE RISE OF COASTAL MEGACITIES

Major coastal cities continued to grow during the twentieth century and into the twenty-first to become some of the largest urban areas on the planet. Eight of the world's largest cities are on the coast, and their cumulative population is just over 200 million. Eighteen of the largest twenty-five cities are also coastal and combined total 357 million people, almost 5 percent of the world's total population (figure 1.4). The list of coastal megacities (usually defined as having over 10 million people) includes Tokyo-Yokohama, New York City–Newark, Shanghai, Mumbai, Karachi, Buenos Aires, Los Angeles, Rio de Janeiro, Manila, Osaka-Kobe, Lagos, Istanbul, Guangzhou, Shenzhen, and Jakarta. The number of megacities and their populations are both projected to increase substantially in the decades ahead.

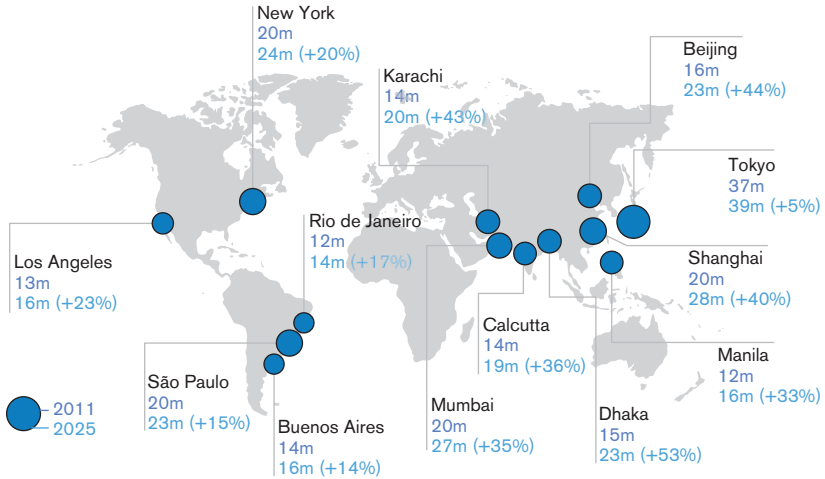

FIGURE 1.4. Populations of global coastal megacities in millions of people in 2011 and projections for 2025 (with % increase).

These coastal megacities clearly continue to offer what are perceived to be better economic and social opportunities than whatever rural areas where many people formerly lived, but they are not paradise by any stretch. These very high concentrations of people require large land areas for housing, as well as food, water, and energy to sustain themselves, which all come with costs or impacts. And the expectations of a better life and improved living conditions are typically not met due to high poverty and unemployment rates as well as social rejection in many of these areas. The added problems of a lack of sanitation and waste management infrastructure and inadequate housing conditions have also led to serious problems of human and environmental health.

In many large coastal cities where available land or topography permits limited growth, the shoreline has often been extended seaward with fill or reclamation of one sort or another to provide more buildable land area. Singapore is one of the best examples of this; its land area has been increased an astonishing 22 percent by importing rock, earth, and sand, and more expansion is under way. Hong Kong, which was historically landlocked, severely limiting growth or expansion, is another example. Land reclamation in Hong Kong actually began in the late 1860s. Hong Kong International Airport and Hong Kong Disneyland were both built on land reclaimed from the sea. Considerable fill has taken place in prime locations on both sides of Victoria Harbor, and a

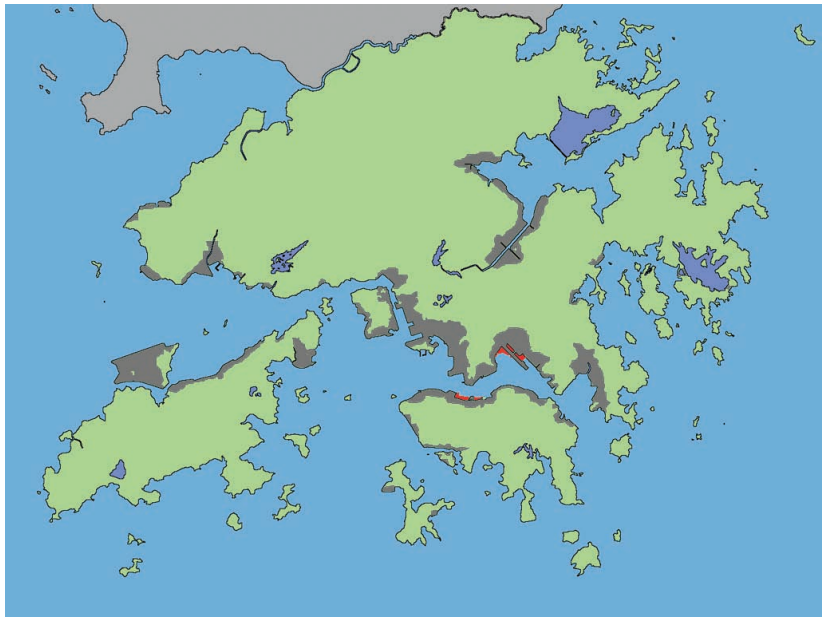

FIGURE 1.5. The shoreline of Hong Kong has been extended seaward over 150 years of land reclamation (areas in gray have been added; those in red are planned).

number of entirely new towns have been built in recent decades on reclaimed land, among them Tuen Mun, Tai Po, West Kowloon, Kwun Tong, and Tseung Kwan O (figure 1.5).

Mumbai, India, was originally an archipelago of seven separate islands that have all been joined by reclamation over several hundred years. Macau has increased its land area 170 percent, or 6.6 square miles. Ninety-six square miles of Tokyo Bay, Japan, have been reclaimed, including the construction of Odaiba Island. Kobe, Japan, has added 8.9 square miles, creating several intensively developed "port islands." The Netherlands may be the best-known example of land acquisition, with about one-sixth of the nation (2,700 sq. mi.) reclaimed from marshes, swamps, lakes, and the sea. As a result of sea-level rise, the Dutch are starting to give some land back.

The wetlands and marshes around the margins of San Francisco Bay began to be filled over 150 years ago, at the time of the California gold rush. The filling continued with little control or oversight until 1970, when the Bay Conservation Development Commission (BCDC) was established to bring the haphazard and unplanned filling under control.

FIGURE 1.6. Approximately one-third of the original extent of San Francisco Bay has been filled (areas shaded in brown) for development. (Image: Exobyte via Wikimedia, in the public domain)

In the meantime, however, about one-third of the entire bay had been filled to make space for housing developments, commercial and industrial buildings, as well as two international airports and baseball parks (figure 1.6). In the case of San Francisco Bay, which is underlain by many feet of soft and compressible mud, subsidence and differential settlement and cracking of buildings and streets created major problems in areas of artificial fill. Shoreline land reclaimed around the world has the

potential to subside or settle depending on what the underlying material consists of, the nature of the fill, and the engineering and method of emplacement.

Around San Francisco Bay, the fill and the underlying sediments also are highly susceptible to liquefaction during strong seismic shaking if not engineered carefully, and the Bay Area is surrounded by active faults. Damage during the great 1906 San Francisco earthquake and again in the 1989 Loma Prieta earthquake, which was centered 75 miles from downtown San Francisco in the Santa Cruz Mountains, was greatest in areas underlain by fill. The largest number of fatalities in the 1989 earthquake (forty-two of sixty-three) occurred during the collapse of a section of freeway in the Oakland waterfront area that had been built on deep water-saturated sediment and fill.

Careful engineering, including replacing the poorest soils or materials with engineered fill, can reduce the hazards of settlement, subsidence, and liquefaction during seismic shaking. Surcharge or excess loading for extended periods prior to construction can accelerate compaction and settlement and reduce subsequent subsidence. Supporting structures on deep piles or caissons that extend to firm material or bedrock is another common approach for large buildings. There will always be pressure to expand the boundaries of megacities, and shoreline land reclamation has been the most common approach historically. There are many areas in tropical waters where important habitats (coral reefs in the case of Singapore and Hong Kong, for example) have been covered over with fill or destroyed in the past. These losses are not recoverable; once they are lost, they are gone. Coastal planning and controls on future reclamation need to be an essential part of any government's future policies and coastal protection measures. The San Francisco BCDC provides an excellent model for what can be accomplished with political will and governmental interagency cooperation.

VULNERABILITY OF LARGE CITIES TO COASTAL HAZARDS

Global sea-level rise and short-term elevated coastal ocean levels from hurricanes, typhoons, cyclones, El Niño events, and tsunamis are discussed in chapters 2, 3, 4, and 5. Hurricane Katrina, the 2011 Tohoku, Japan, earthquake and tsunami, Superstorm Sandy (2012), and Typhoon Haiyan (2013) in the Philippines are all tragic examples of short-term events, which are usually followed by government aid for reconstruc-

FIGURE 1.7. Intensive high-rise development along the shoreline of Miami Beach, Florida. (Photo: D. Shrestha Ross © 2015)

tion in the same low-lying hazardous locations. These short-term events will continue to present the greatest risks to coastal cities around the world over at least the next several decades. However, over the longer term, sea-level rise combined with future storms or extreme events may well present the greatest challenge that human civilization has ever faced. More people are moving to and living in coastal areas, and many of the planet's biggest cities were built along shorelines very close to sea level, originally at a time when sea-level rise was not a concern. And there are those today who still do not believe that sea level is rising or that it is of concern. We don't get to vote on sea-level rise. It's happening; the rate is increasing, and 95 percent of climate scientists believe that human activity is the greatest driver.

By 2050, according to the United Nations, more than 6 billion people are expected to live in cities. More than half of the world's largest cities are ports, and they will face unique challenges due to their low-lying elevations and increasing populations. Over 130 port cities around the planet are at increasing risk from rising sea level, combined with severe storm-surge flooding, damage from high storm winds, and, in some places, local land subsidence. It is safe to say that none of these cities were planned with sea-level rise in mind. In many cases, construction is proceeding as if sea level were standing still (figure 1.7). Miami,

Florida, is one of the best examples. In 2016 from Miami to West Palm Beach 417 condominium towers (with over 50,000 individual units) were being built, and not one of them was taking sea-level rise into account. Poorly planned development often puts more people in vulnerable areas, increasing future risk.

The Organization of Economic Cooperation and Development (OECD) has determined that in 2015 the twenty global port cities with the highest vulnerability had 25.2 million people and $2.2 trillion in assets exposed to a 100-year storm. By 2070, however, with additional sea-level rise and projected population growth, these same twenty port cities will have approximately 88 million people at risk, along with a projected $27 trillion in assets. And this is just twenty of 130 global port cities. The number one city on the list in terms of exposed assets is Miami, with $416 billion at risk in 2015, which is projected to rise to $3.51 trillion by 2070.

HUMAN IMPACTS ON THE COASTAL OCEAN

Not only are natural hazards taking their toll on the large coastal concentrations of people, whether in megacities or in smaller cities and towns, but the three billion people living in coastal areas are having their effects as well. Chapters 6 through 17 discuss the wide range of human impacts on the coastal ocean. The by-products of civilization are diverse, widespread, and complex. Waste discharge, whether domestic, industrial, or agricultural, is damaging to the coastal ocean and its life in multiple ways, and the more people, the greater the volumes of discharge. Marine life and the habitats they occupy, from temperate to tropical latitudes, have all been affected. While renewable energy from the ocean is an admirable and necessary long-term goal, we have made only modest progress. We are still heavily dependent globally on fossil fuels, and their extraction, transport, combustion, and by-products are taking their toll, from oil spills to greenhouse gas emission, with their effects on global climate and ocean acidification. Dams in our coastal watersheds and sand mining along the shoreline have damaged our beaches, which are critical to tourism and our own recreation.

As was stated in a popular comic strip decades ago, "We have met the enemy and he is us." The Earth cannot support 7.5 billion people in the lifestyle the wealthier nations have grown accustomed to. The coastal zones of the world, more than any other environment or geography, are where the impacts of civilization have been concentrated and

are becoming most obvious. The chapters that follow offer an explanation and a status report on these multiple stressors and their effects. In each case and for every issue, the chapters conclude with thoughts, perspectives, and recommendations for the future—how we can begin to reduce our impacts on the coastal zone and improve the health of the coastal environment for all of us to enjoy.