1

Overview

People and Water

1.1 Introduction

This book provides a view of the coastal ocean from a rather unique perspective – the perspective of the urban coastal zone as the primary home of the human species. In the chapters that follow, we will discuss the physical properties of this complex domain, the dynamics that influence its movement, and its interaction with the deep ocean on one side, and landforms and tributaries on the other. We will seek a deeper understanding of the fundamental relationship between ocean and atmosphere, and thereby weather and climate, short-lived extreme events and long-term persistent phenomena in the waters that line our coasts and the skies overhead. We will discuss the range of transport and mixing processes in estuaries, shallow coastal waters, and the adjacent continental shelf, setting the stage for an examination of such dominant flow features as upwelling and downwelling, river plumes, inertial currents, and wind- and wave-driven currents. We will investigate the tide and other water level phenomena, including storm surges and tsunamis. We will address coastal sediment transport and shoreline evolution. Indeed, we will examine the full range of the physical and biogeochemical characteristics of the coastal ocean, but we will do so with the underlying aim of better understanding the relationship between the populated coastal ocean – the urban ocean – and people.

Since the dawn of civilization, the coastal ocean and the human populations that reside on and along its borders have had a complex relationship. The ocean and its tributaries serve as sources of food and energy; they provide access to waterborne transportation, trade and prosperity. They are often locations of moderate climate, enabling agriculture, recreation, and a high quality of life. But these advantages come with threats to human populations in the form of natural hazards, including tsunamis, and extreme storm events, such as tropical and extratropical storms, with their attendant storm surges and coastal flooding. For the ocean, the presence of dense populations along the coast has its negative consequences as well. Waterways, shorelines and bottom sediments are exposed to pollutants arising from human activity. These include industry, municipal wastewater, stormwater runoff, agriculture (chiefly fertilizers), spills, vessels, septic systems and other sources. Contaminants can enter the food chain and can render the water unfit for drinking and unsuitable even for contact recreation. Other human influences can have profound impacts on the very nature and configuration of the coastline. The introduction of coastal structures, the elimination of natural protective features (e.g., wetlands), and the interference with natural sand supply on both the water side (e.g., via navigation channel dredging) and the land side (e.g., river dams) can permanently alter coastal landforms, resulting in the loss of coastal islands, the landward migration of shorelines, and the loss of unique and irreplaceable habitat.

In recent decades, the advantages of living on and near the coast have combined with a global migration to urban areas to create a fundamental change to population distribution and to human vulnerability to natural disasters. Consider that in 1990, there were 10 "megacities," here defined as cities having 10 million inhabitants or more. In total, these cities were home to 153 million people or slightly less than 7% of the global urban population at that time. In 2014, there were twenty-eight megacities, home to 453 million people or about 12% of the world's urban population (United Nations, 2015). By 2017, the urban population represented more than half of the world's total population, and the number of megacities had increased to 37, representing 15% of the world's urban population (Cox, 2017). More significantly for our purposes, and not surprisingly given the benefits alluded to earlier, twenty-four of these thirty-seven megacities lie in the coastal zone (defined later in this chapter), as illustrated in Table 1.1.

The risks to coastal populations have increased dramatically by perhaps the most impactful of all feedback cycles in the ocean–human relationship: climate change. Professor E. O. Wilson, preeminent entomologist and two-time Pulitzer Prize Winner, has said "humans have become the first species who are a geophysical force" (lecture delivered at Stevens Institute of Technology, May, 2007). As the atmosphere and ocean have undergone gradual warming, the absolute level of the sea surface has risen, as a consequence primarily of the thermal expansion of seawater and the introduction of water via the melting of land-based ice cover. This sea level rise has put many populated coastal regions at risk of flooding during even minor storm events. It also threatens precious coastal groundwater sources via saltwater intrusion. The warmer waters and atmosphere appear to also be causing an increase in extreme storm frequency and

Table 1.1 *The most populous cities in the world, with coastal cities shaded in gray*

Rank	City	Nation	Region	Population
1	Tokyo-Yokohama	Japan	Asia	37,900,000
2	Jakarta	Indonesia	Asia	31,760,000
3	Delhi	India	Asia	26,495,000
4	Manila	Philippines	Asia	24,245,000
5	Seoul-Incheon	South Korea	Asia	24,105,000
6	Karachi	Pakistan	Asia	23,545,000
7	Shanghai	China	Asia	23,390,000
8	Mumbai	India	Asia	22,885,000
9	New York City Area	United States	North America	21,445,000
10	Sao Paulo	Brazil	South America	20,850,000
11	Beijing	China	Asia	20,415,000
12	Mexico City	Mexico	North America	20,400,000
13	Guangzhou-Foshan	China	Asia	19,075,000
14	Osaka-Kobe-Kyoto	Japan	Asia	17,075,000
15	Dhaka	Bangladesh	Asia	16,820,000
16	Moscow	Russia	Europe	16,710,000
17	Cairo	Egypt	Africa	16,225,000
18	Bangkok	Thailand	Asia	15,645,000
19	Los Angeles-Riverside	United States	North America	15,500,000
20	Buenos Aires	Argentina	South America	15,355,000
21	Kolkata	India	Asia	14,950,000
22	Tehran	Iran	Asia	13,805,000
23	Istanbul	Turkey	Europe	13,755,000
24	Lagos	Nigeria	Africa	13,360,000
25	Tianjin	China	Asia	13,245,000
26	Shenzhen	China	Asia	12,775,000
27	Rio de Janeiro	Brazil	South America	11,900,000
28	Kinshasa	Congo	Africa	11,855,000
29	Lima	Peru	South America	11,150,000
30	Chengdu	China	Asia	11,050,000
31	Paris	France	Europe	10,950,000
32	Lahore	Pakistan	Asia	10,665,000
33	Bangalore	India	Asia	10,535,000
34	London	United Kingdom	Europe	10,470,000
35	Ho Chi Minh City	Vietnam	Asia	10,380,000
36	Chennai	India	Asia	10,265,000
37	Nagoya	Japan	Asia	10,070,000

From Cox (2017).

intensity (IPCC, 2013). The increased concentration of carbon dioxide in the atmosphere, a primary contributor to this warming, is also causing a reduction in ocean pH ("ocean acidification"). This is in turn causing profound changes in carbonate chemistry, affecting the formation of calcium carbonate (shells) by marine organisms. Clearly there is a need to acknowledge and better understand the profound ways in which human societies have been shaped by the coastal ocean and in which the coastal ocean has in turn been impacted by the presence of humans, what we will here refer to as the "Influence Cycle."

1.2 The Urban Ocean: A Definition

We have chosen to focus our attention on those areas of the world's oceans that are located along populated coastlines. This choice has the benefit of simplifying the task of examining the physical and biogeochemical properties of these domains as compared to a treatment of the 70%+ of the planet's surface that is covered by ocean. But it certainly does not mean that our region of interest is small or that its characteristics are lacking in complexity.

We will here define the coastal zone as the interface between ocean and land, extending seaward to approximately the middle of the continental shelf (a gently sloping transition from the coastline to a depth of 100–200 m, followed in most cases by an abrupt drop in water depth at the shelf break), and inland to include all areas strongly influenced by the proximity to the ocean. This region includes benthic habitats (e.g., coral reefs), intertidal habitats (e.g., beaches, wetlands, mangroves), and semienclosed bodies of water (e.g., estuaries, bays). Simply put, we are dealing with the region extending from the landward limit of tidal influence to the middle of the continental shelf. As mentioned earlier, this is not a small region of interest. On the ocean side, continental shelves often extend to more than 100 km offshore and together represent approximately 8% of the oceans' surface area (see Figure 1.1). The coastal zone is a highly dynamic region that defines the boundary between land and ocean. It is a region rich in unique and varied ecosystems, and immensely complex in its interactions of terrestrial-, water- and atmosphere-borne energy and substances.

At what point does a coastal zone come to be defined as an "urban ocean"? We have already mentioned the fact that a majority of the world's megacities are located along coastal ocean regions. But surely these are not the only locations where humans exert significant influence over the ocean and vice versa. As illustrated in our graphical depiction of the Influence Cycle in Figure 1.2, these influences are wide-ranging.

Indeed, relatively small cities have experienced this same complex relationship with the sea, many for hundreds if not thousands of years (e.g., Rome,

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Figure 1.1 Map of the world showing major topographic features. The continental shelves are indicated with the color cyan. Note the very wide continental shelves along the coastlines of Argentina, northeast North America, Southeast Asia, northern Australia, and the Arctic (Amante and Eakins, 2009). (A black-and-white version of this figure appears in some formats. For the color version, please refer to the plate section.)

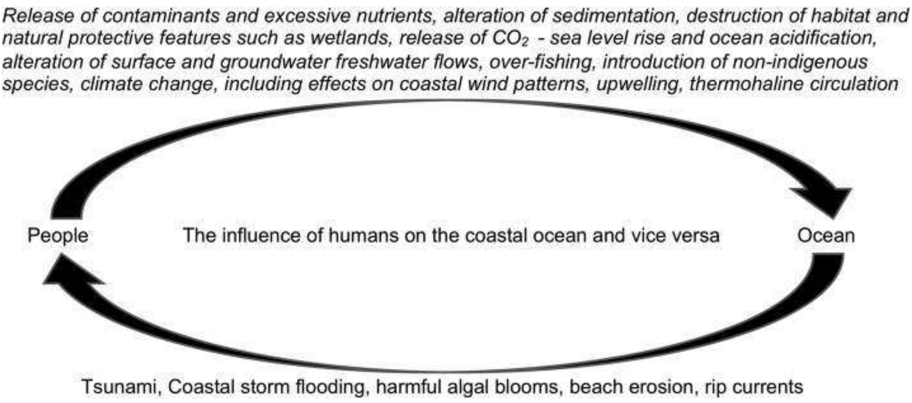

Figure 1.2 The “Influence Cycle” between humans and the coastal ocean.

Alexandria, Rotterdam, Hong Kong, Dar Es Salaam, Miami, San Juan, and Cartagena, to name a few). These regions must be included in our domain of interest. So too must regions that are not necessarily “urban” in their population density but are nonetheless home to a sufficiently large community that *the coastal ocean is markedly influenced by the human presence and is therefore decidedly different in its physical and biogeochemical properties compared to unpopulated coastal ocean regions*. This, then is the urban ocean.

Table 1.2 *Populations exposed to coastal flooding in 2005 and (predicted) in 2070*

Rank in 2070	Urban area	Nation	Exposed population in 2005	Exposed population in 2070
1	Kolkata	India	1,929,000	14,014,000
2	Mumbai	India	2,787,000	11,418,000
3	Dhaka	Bangladesh	844,000	11,135,000
4	Guangzhou	China	2,718,000	10,333,000
5	Ho Chi Minh City	Vietnam	1,931,000	9,216,000
6	Shanghai	China	2,353,000	5,451,000
7	Bangkok	Thailand	907,000	5,138,000
8	Rangoon	Myanmar	510,000	4,965,000
9	Miami	United States	2,003,000	4,795,000
10	Hai Phong	Vietnam	794,000	4,711,000

From Nicholls et al. (2008).

1.3 The Urban Ocean: The Risks

As we have already discussed, coastal communities face a number of natural hazards, including tsunamis and extreme storm events such as tropical and extratropical storms, with their attendant storm surges and coastal flooding. Flooding is in fact the most significant hazard, in terms of both loss of life and property damage (see, e.g., Doocy et al., 2013). We might reasonably expect, therefore, that urban coastal regions are high-risk areas in which to live, work, and play. But are they?

The risk equation can be stated simply as Risk = probability × consequence. We can say with some surety that the consequence of a coastal flood in a densely populated community is higher than it would be in a sparsely populated region. As an illustration, Table 1.2 lists the top ten coastal urban areas in terms of the number of people exposed to flooding, ranked by the 2070 predicted values (Nicholls et al., 2008). Table 1.3 provides a similar ranking, but according to the value of assets (buildings, infrastructure, etc.) exposed to flooding, again ranked as predicted for the year 2070. Actual values for the year 2005 are also shown in both tables. Note that six cities appear on both lists. Note also that several cities are not on our list of coastal megacities.

Because of extreme weather events along the urban coasts of the world, the loss of lives and economic damage have dramatically increased over the last decade. Four recent events are provided here as examples.

Hurricane Sandy hit the New York metro–region on October 29, 2012. Its size and direction of travel resulted in a significant storm surge, more than 3 m

Table 1.3 *Assets exposed to coastal flooding in 2005 and (predicted) in 2070*

Rank in 2070	Urban area	Nation	Exposed assets in 2005 (US$ billions)	Exposed assets in 2070 (US$ billions)
1	Miami	United States	416.29	3,513.04
2	Guangzhou	China	84.17	3,357.72
3	New York–Newark	United States	320.20	2,147.35
4	Kolkata	India	31.99	1,961.44
5	Shanghai	China	72.86	1,771.17
6	Mumbai	India	46.20	1,598.05
7	Tianjin	China	29.62	1,231.48
8	Tokyo	Japan	174.29	1,207.07
9	Hong Kong	China	35.94	1,163.89
10	Bangkok	Thailand	38.72	1,117.54

From Nicholls et al. (2008).

in some areas, along the coast of New Jersey and inside New York Harbor. Throughout the United States, more than 650,000 homes were destroyed or seriously damaged, and more than 9 million customers lost electricity. Total direct economic losses due to the hurricane have been estimated at US$72 billion (Aon Benfield, 2013). The preparation and response to Hurricane Sandy varied widely across businesses and governments. In Jersey City, for example, about 75% of the population lost power, with many residents not having gas and electricity restored for more than a week; 2,500 residents sought shelter due to lack of power, water, and heat. With 50,000 people living in one square mile, Hoboken is the fourth most densely populated municipality in the United States. Many of its residents were without power for nearly two weeks after the storm. The hurricane crippled the Port Authority Trans-Hudson line (PATH), a 24-hour subway, which in 2016 ferried 76.6 million passengers between Manhattan and New Jersey. The entire system was out for two weeks, the line to the World Trade Center was out for four weeks, and the Hoboken line was out for nearly two months. All repairs and projected costs to the PATH system are expected to ultimately exceed US$700 million.

Cyclone Phailin made landfall in October 2013 along the eastern coastline of India, in Orissa and Andhra Pradesh states. The storm affected more than 13 million people, damaged more than 300,000 homes, and caused forty-four deaths. The impacts from this potentially devastating storm were significantly reduced because of the preparation and response by emergency management authorities, including early warning, the implementation of evacuation plans (among the largest evacuations in the nation's history), the provision of cyclone shelters, and the training of thousands of first responders. This is noteworthy because in 1999, a cyclone killed more than 10,000 people in Orissa state.

On March 11, 2011, a magnitude-9 earthquake shook northeastern Japan, near Sendai. The effects of the great earthquake were felt around the world. Less than an hour after the earthquake, the first of many tsunami waves hit Japan's coastline. The tsunami waves traveled inland as far as 6 miles and flooded an area of approximately 217 square miles in Japan. The waves overtopped and destroyed protective seawalls at several locations. The Fukushima Daiichi Nuclear Power Plant suffered a level 7 nuclear meltdown after the tsunami. The total damages from the earthquake and tsunami are estimated at more than US$220 billion dollars.

Over the last decade, England and Wales have experienced frequent water-related challenges. The floods of Gloucestershire in 2007 and Somerset in 2014 in particular demonstrated the multifaceted challenges of ensuring resilience to flooding. The impacts were both local (extensive property damage and three deaths) and more widespread, with national food and transport systems severely impacted. The 2014 event caused major disruptions to road and rail systems, including the severing of the only rail line to the South West of England resulting in rail services to the west being suspended for two months. Gatwick Airport suffered severe disruption on the 23rd and 24th of December, with partial closure of its North Terminal because basement flooding knocked out key power and IT systems.

These events are painful reminders that coastal flooding is among the world's most costly and deadly disasters, capable of causing tens to hundreds of billions of dollars in damage and destroying entire neighborhoods and critical infrastructure. Coastal urban cities must become far better able to withstand, quickly recover from, and adapt to extreme weather events and flooding. And the potential for even worse flooding is on the horizon, as sea level rise causes even previously unnoticed high tide events to produce noteworthy damaging floods.

We note that simply because an urban coastal region possesses a large population and/or a high number of assets exposed to flooding, and hence would experience a high consequence as a result of a flooding event, that region's risk is not clearly understood unless we understand the probability of that flooding event. We must turn therefore to an assessment of the probability of occurrence of extreme events such as tropical and extratropical storms, and tsunamis. In March, 2015, The UN Office for Disaster Risk Reduction (UNISDR) began to implement an ISO standard for resilient and sustainable cities, ISO 37120. The UN is promoting resilience through the Sendai Framework, which was in part a global response to the 2011 Sendai earthquake, tsunami and nuclear disaster.

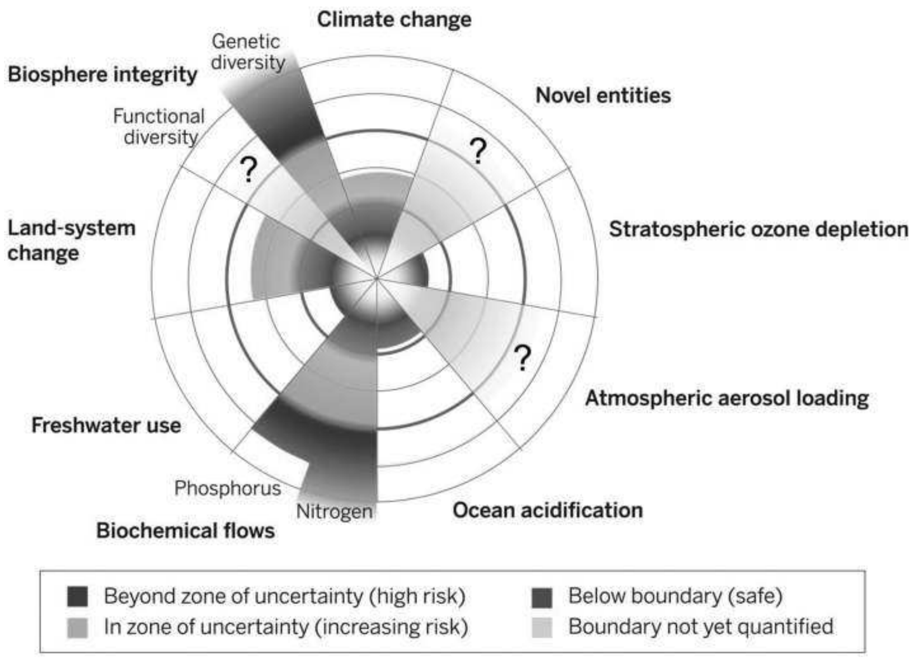

Figure 1.3 Planetary Boundaries. Reproduced from Steffen et al. (2015), with permission. (A black-and-white version of this figure appears in some formats. For the color version, please refer to the plate section.)

1.4 A Global Perspective

Rockström et al. (2009) introduced an analysis commonly referred to as the "planetary boundaries" approach. This approach aims to define the conditions under which society can thrive in a sustainable way. It can be viewed as a framework that must be updated as conditions change and as our understanding of the Earth system, with its complexities, evolves. The approach was further refined several years later (Steffen et al., 2015) and is illustrated in Figure 1.3.

The planetary boundaries can be regarded as constraints, similar to the constraints (regulations) that communities place on the amount of a particular pollutant that an industrial activity may release into the ocean. In the case of planetary boundaries, however, we are treating human influences that extend far beyond the local or regional, and instead impact the Earth system. The Boundaries define a so-called safe operating space in which humans can thrive without adversely and perhaps permanently altering certain critical Earth system processes. The assessment of the state of each process depicted in Figure 1.3 is based on an assumption that the preservation of a Holocene-like state of the Earth system is desirable. It is important to realize that impacts at local or regional scales could conceivably propagate across scales to planetary scales. The figure therefore represents a tool to guide the discussion of human influences on the Earth system, incorporating both gaps in our knowledge and uncertainty in our understanding of the functioning of the system. Nine planetary boundaries are defined. The current status of the control variables for seven of the nine planetary boundaries are shown in Figure 1.3. The green zone represents the safe operating space; the yellow zone represents the zone of uncertainty, which in order to allow for proactive response by society is termed the zone of increasing risk; and the red zone is the high-risk zone, which resides beyond the heavy circle that defines the planetary boundary. Processes for which global-level boundaries cannot yet be quantified are represented by gray wedges and question marks; these are atmospheric aerosol loading, novel entities and one aspect of biosphere integrity. With respect to biosphere integrity, two components are employed. One, E/MSY (extinctions per million species-years), employs the global extinction rate as the control variable that defines the long-term capacity of the biosphere to survive and adapt to both extreme and gradual changes in the environment. The other component, Biodiversity Intactness Index (BII), measures the loss of biodiversity by assessing changes in population abundance (across a wide range of taxa and functional groups) as a result of human impacts, using preindustrial era abundance as a reference point. Note that the treatment of biochemical flows addresses phosphorus (P) and nitrogen (N) only, although other elements as well as the ratios between elements are known to be important to biodiversity. Novel entities is a measure of the new substances and modified life-forms that can produce adverse biological and/or geophysical impacts. Research is continuing into the quantification of the boundaries for this and the other two processes. We expect many, if not all, of the control variables and their perceived limits to change as our understanding improves, and so the reader is encouraged to acquaint herself/himself with the latest developments in planetary boundaries.

It is not difficult to imagine that global phenomena are contributing to the risks and challenges facing coastal communities worldwide, even in communities that have not contributed to the disruption of the particular process, e.g., climate change or ocean acidification. The planetary boundaries assessment described here concludes that several processes, including biochemical flows, biosphere integrity, land-system change, and climate change, are beyond or near the boundary. This is particularly noteworthy for urban coastal communities. Alteration to normal or "stable" biochemical flows are often attributable in coastal and estuarine environments to excessive nutrients associated with agriculture. Impacts include so-called dead zones, or ocean regions with anoxic or near-anoxic conditions (e.g., in the Gulf of Mexico offshore of Texas), as well as harmful algal blooms. Coastal ocean habitat loss and degradation, particularly in coral reef and wetland ecosystems, and coupled in many cases with overfishing, threatens the survival of many aquatic species and hence biosphere integrity. These impacts are compounded by other processes, notably climate change and ocean acidification. The vast scale of land use change along coastal regions, including in particular deforestation, has been a major contributor to land-system change and climate change. And clearly climate change presents among the most profound threats to coastal communities, via sea level rise and the increased frequency and intensity of extreme weather events.

In future chapters, we will discuss the implications of human activity for the coastal ocean, including climate change, and the risks associated with living near and along a rapidly changing ocean. Throughout, we will take care to understand the uncertainties, both in the predictions of the severity of future coastal hazards and in the ability of human populations to respond and adapt to these hazards. We will discuss the prospects for reducing the vulnerability of urban coastal communities via science-informed public policy and urban design, enabled by improved ocean observations, understanding, and forecasting. We will introduce the concept of resilience, wherein we recognize the limits of our ability to reduce the likelihood of certain hazards and so focus our attention on learning and adapting in a way that ensures the functioning of socio-technical systems under the full range of conditions, including the expected and the unexpected.