Adapting to a changing climate in the management of coastal zones

POLICY PERSPECTIVES

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OECD BETTER POLICIES FOR BETTER LIVES

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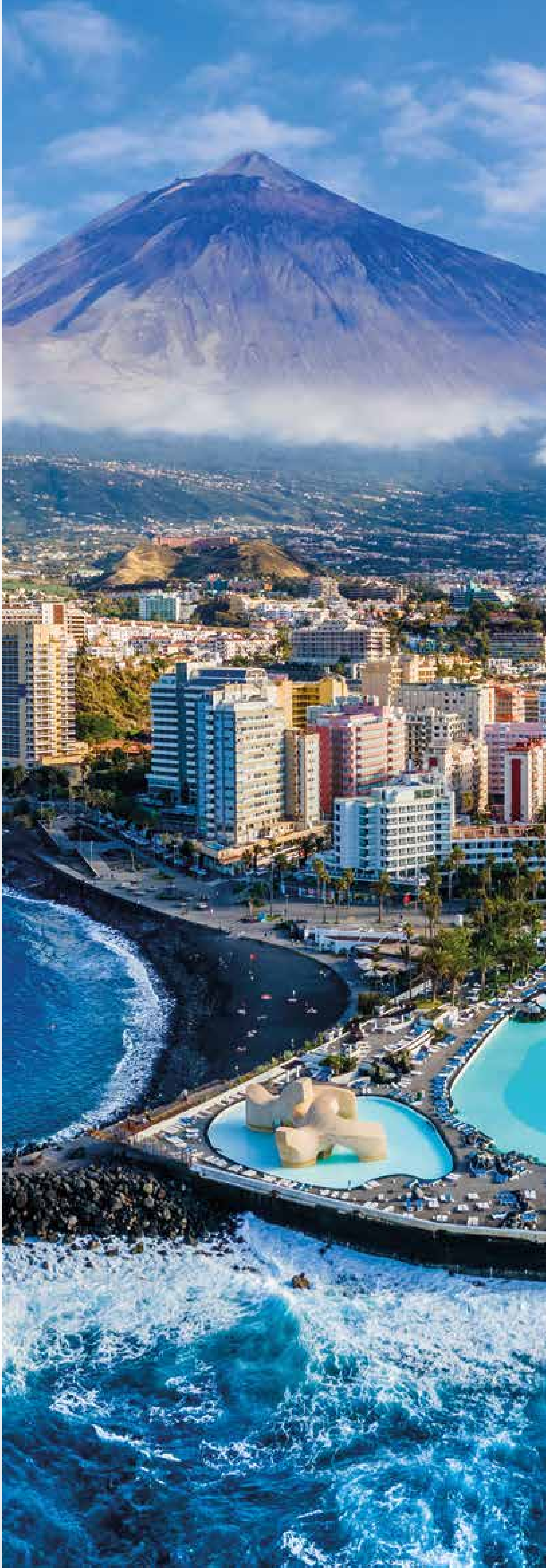
BETTER POLICIES FOR BETTER LIVES



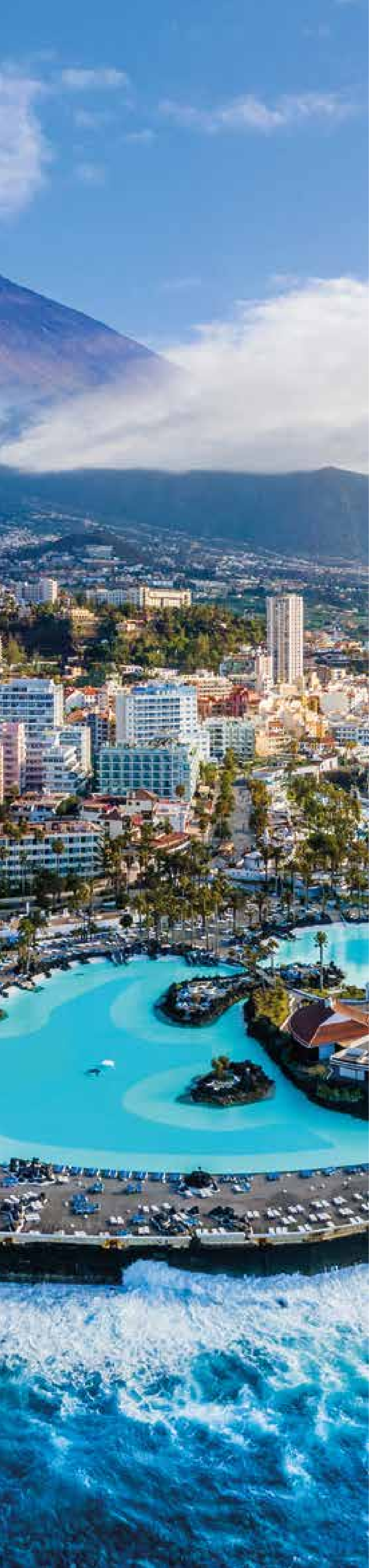


Table of contents

FIGURES

BOXES

Executive summary

Stretching over 1.6 million kilometres, sea and ocean coastlines cover an extensive territory shared by 85% of the world's countries. Coastal areas are home to a rich natural environment, hosting over 1 million marine and terrestrial species, including one-quarter of all marine species.

Their natural environment, together with the rich resources and the opportunities they offer, make coastlines attractive areas for human settlement. Today, ocean and sea coasts are home to 2.4 billion people – approximately 40% of the world's population. While coastal areas occupy only 20% of the global land surface, their population density is three times higher than the global average. In addition, 75% of the largest metropolitan areas lie in coastal areas, and the global population in low-elevation coastal zones (i.e. within 10 metres above sea level) is projected to reach 1.4 billion by 2060.

As a result, a considerable share of global economic output is generated in coastal areas. Coastal economic activities range from the exploitation of natural resources to fishing and agriculture, which benefits from the fertile soils that characterise coastal plains and deltaic areas. Coasts also represent the access point for maritime transport, which is responsible for shipping 80% of the goods traded globally. Considerable energy generation from renewable and non-renewable sources takes place on or near the coast. Furthermore, the tourism and leisure sectors generate significant income and employment: for example, in the United States, 85% of tourism depends on beach visits alone. Altogether, in the United States, coastal counties generate half of the country's gross domestic product (GDP).

Besides generating a large economic value via market mechanisms, coastal ecosystems also deliver non-market economic benefits through their services. Mangroves and salt marshes provide a natural buffer and protection from climate-related coastal risks, such as storm surges, and contribute to regulating water quality, thereby reducing the cost of wastewater treatment. In addition, coastal ecosystems serve the global community by mitigating climate change. Coastal wetlands, for example, sequester and store significant amounts of carbon. Altogether, carbon stocks in coastal sediments are estimated to be five times larger than they are in mainland tropical forests.

Rapid socio-economic expansion in coastal areas has led to significant environmental degradation that threatens coastal communities. Building and infrastructure development have contributed to land subsidence and saltwater intrusion in surface water and groundwater. Sewage, agriculture and other industrial activities have significantly increased water pollution in coastal areas, while natural resource extraction, fishing and energy generation are all associated with ecosystem disturbances and habitat loss. As a result, biodiversity loss and ecosystem depletion are accelerating. Since 1900, over 50% of coastal wetlands have been lost, and today, one-quarter of coastal zones are eroding at rates of 0.5 metres per year, with some shorelines projected to retreat by several metres in the coming years.

Climate change is expected to compound existing vulnerabilities and exacerbate impacts on coastal communities. In coastal areas, climate change will be felt principally through:

- **Sea-level rise:** by the end of the 21st century, sea levels are projected to rise on average between 40 cm and 75 cm, potentially exceeding 1 metre in certain regions. This will increase the frequency and intensity of coastal flooding, while accelerating coastal erosion and the retreat of unprotected

shorelines. Due to their low elevation, some islands face the risk of complete submergence. By 2100, sea-level rise-induced floods are projected to affect 360 million people, generating USD 50 trillion in annual losses (equivalent to 4% of global GDP).

- **Coastal storm surges:** in certain regions, increased air and sea temperatures, together with altered precipitation, wave and wind patterns, make storms more intense and more likely to hit the coast. Increased storm activity along the world's coasts will increase episodic coastal flooding and accelerate coastal erosion and saltwater intrusion into freshwater aquifers, while contributing to degrading key coastal ecosystems, such as mangroves and coral reefs, that provide a buffer and protection to the coast. Today, tropical cyclones affect millions of people annually, causing a high number of casualties and in some cases generating significant economic damages and disruption, as demonstrated by Hurricane Katrina in 2005 and Hurricane Irma in 2017.

- **Ocean warming and acidification:** oceans are expected to continue to warm, potentially reaching three additional degrees by 2100 compared to the 1980-99 average. This is projected to affect water circulation, reduce sea ice volumes, and accelerate sea-level rise and coastal erosion. The health, size and distribution of coastal fish populations will also be affected. Ocean warming and acidification are also projected to affect coral reefs, increasing the likelihood and severity of coral bleaching and death. This, in turn, undermines the ability of coastal ecosystems to provide protection against storms and floods.

- **Alterations in the hydrological cycle:** climate change alters the frequency and intensity of precipitation, affecting the volume and timing of river flows, water runoff and sediment supply. Deltaic areas characterised by higher precipitation rates are projected to face particularly high risks due to coastal flooding and storm surges compounded by riverine flooding and coastal erosion. Coastal areas subject to decreasing precipitation rates are likely to experience higher water salinity and increased water pollution.

The interactions between socio-economic development, coastal ecosystems and climate risks pose complex challenges and require adapted and co-ordinated policy responses. As growing climate variability and climate extremes pose increasing challenges to coastal areas, climate adaptation and coastal resilience should be key objectives in the planning and implementation of coastal zone policies. Successful coastal strategies need to integrate policy responses across different sectors and levels of government as well as non-governmental stakeholders.

Coastal areas are defined as the interface between land and sea, an area that goes beyond the line where water and land meet physically.

Introduction

Coastal zones play a crucial role economically and environmentally. They cover less than 20% of the Earth's land surface, but are home to over 40% of the world's population and to 75% of the world's largest cities (United Nations, 2017[1]; Luisetti et al., 2010[2]). Human settlements concentrate around coastlines because of the diverse benefits they offer, which include income, leisure and well-being. At the same time, coastal areas are also important economic hubs, with a key role in fisheries, agriculture, resource extraction, tourism and shipping. In addition to their high socio-economic value, coastal zones offer some of the ecologically richest ecosystems and play a key role in the regulation of ecological functions.

However, due to their intensive use, the environmental health of coastal areas has been deteriorating over time. Rapid urban development, land-use changes and the unsustainable exploitation of coastal resources have all favoured a variety of negative consequences, ranging from land subsidence and coastal erosion to biodiversity loss and reduced water availability.

Coastal areas are also particularly vulnerable to the impacts of climate change, which can range from storm surges, ocean acidification and sea-level rise to increases in water temperature and the alteration of hydrological cycles. By 2100, coastal flooding risk alone is projected to affect 360 million people and generate trillions of dollars of losses every year (Kulp and Strauss, 2019[3]; OECD, 2019[4]), while storm surges and tropical cyclones already affect millions of coastal people every year, generating extensive losses in terms of lives, assets and overall disruption. The impacts of climate change are particularly detrimental for low-lying coastal areas such as river deltas, coastal plains and small island countries, which are home to 10% of the world's population (Wong et al., 2014[5]). In addition, climate change also adds to other environmental stressors, multiplying risks and further exacerbating the vulnerability of coastal communities.

This policy paper provides an overview of these issues with a view to understand how appropriate policies can be developed to address these complex challenges. For the purpose of this paper, coastal areas are defined as the interface between land and sea[1], an area that goes beyond the line where water and land meet physically, but that does not stretch beyond 100 km inland and 50 metres above or below sea level. The paper focuses on seacoasts only, thus excluding the coasts of inland rivers and lakes. This choice is based on the research focus of this analysis, and does not suggest excluding inland rivers and lakes from the definition of coastal zones.

1. In this paper, the terms sea and ocean are used interchangeably to characterise marine environments.

1 The environmental and socio-economic value of coastal zones

Coastal zones provide a wide array of environmental, social and economic benefits to human communities. They are home to 40% of the global population and 75% of the largest metropolitan areas, with a population density three times higher than the global average. Coastal areas support key economic activities, ranging from fisheries, aquaculture and agriculture to energy generation, tourism and resource extraction. Coastal ecosystems also deliver important services, with mangroves and coral reefs providing a natural protection from coastal risks and coastal sediments storing half of the carbon sequestered in ocean sediments.

THE ENVIRONMENTAL VALUE OF COASTAL ZONES

Coastal zones encompass some of the most ecologically valuable ecosystems. Beaches and wetlands, coral reefs and lagoons, cliffs and river deltas provide habitats for a variety of aquatic, terrestrial and aerial species, including a range of migratory species (Torres and Hanley, 2016[25]; FAO, 1998[15]), thus supporting a rich biological diversity. Coral reefs alone are estimated to support one-quarter of all marine species (Michel and Pandya, 2010[7]). Altogether, the world's coasts are likely to harbour over 1 million species (Martínez et al., 2007[6]).

Besides supporting a large variety of animals and plants, coastal ecosystems play a key role in the regulation of ecological functions. For example, coastal wetlands such as mangrove forests and salt marshes regulate water flows and quality by regulating groundwater recharge, filtering agricultural and industrial wastewater, and transforming or removing nutrients,[2] chemicals and waste from water flows (FAO, 2020[26]; Nicholls et al., 2007[27]). Furthermore, beaches, coral reefs, barrier islands and wetlands provide buffer zones that attenuate waves and winds, thus protecting inland areas from floods, hurricanes and storm surges and eventually reducing coastal erosion and shoreline retreat (IPCC, 2019[28]; Nicholls et al., 2007[27]).

In addition, coastal ecosystems stabilise sediment flows, secure nutrient transfer across different ecosystems (Michel and Pandya, 2010[7]) and play a crucial role in the carbon cycle. Indeed, coastal ecosystems sequester about half of the carbon stored in ocean sediments (Conservation International, 2019[29]), thus contributing to important biogeochemical cycles and providing significant mitigation co-benefits by containing carbon dioxide (CO_2) concentrations in the atmosphere (IUCN, 2017[30]) (Box 1.1).

2. Coastal ecosystems such as wetlands work as nitrogen sinks, storing excess nitrogen and thus contributing to enhanced water quality.

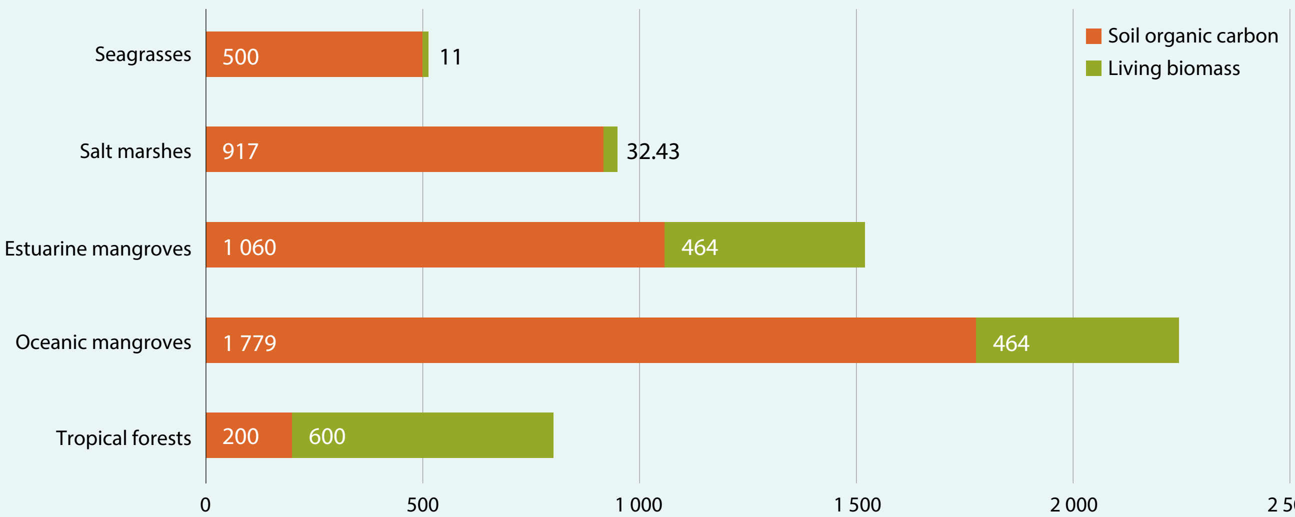
BOX 1.1. COASTAL ZONES AND BLUE CARBON SEQUESTRATION

Coastal ecosystems play a crucial role in the carbon cycle. Seagrasses and coastal wetlands such as mangroves and salt marshes capture carbon dioxide from the atmosphere and store it in living biomass and in the soil, thus acting as carbon sinks. The carbon stored in coastal and marine ecosystems is referred to as "blue carbon". Although coastal ecosystems cover less than 2% of the global ocean area, they store approximately half of the carbon sequestered in ocean sediments globally (Conservation International, 2019[29]). Compared to terrestrial carbon-rich ecosystems such as tropical rainforests, coastal and marine ecosystems sequester significantly larger amounts of carbon per hectare of area, as demonstrated by a recent assessment on coastal ecosystems in Africa (Figure 1.1). In addition, blue carbon remains in coastal soils for longer periods of time. Altogether, at the global level, carbon stocks in coastal and marine areas are estimated to be up to five times larger than they are in mainland tropical forests.

Sources: Karani and Failler (2020[31]); Conservation International (2019[29]); IPCC (2019[28]); IUCN (2017[30]); Intergovernmental Oceanographic Commission (2017[32]).

FIGURE 1.1. **Global carbon sequestration by selected coastal ecosystems**

Tonnes of CO_2eq stored per hectare



Note: The graph represents the average carbon-storage capacity of soil organic carbon and living biomass at the global level, only taking into account the top metre of soil. Tropical forests are included to provide a comparison.

Source: Duke University Nicholas Institute for Environmental Policy Solutions (2011[77]).

THE SOCIO-ECONOMIC VALUE OF COASTAL ZONES

Coastal zones offer many socio-economic benefits for countries bordering the sea as well as for the global economy as a whole. The social and economic opportunities offered by coastal zones, together with their favourable climatic and biophysical conditions, make coasts the most populated areas in the world (Ranasinghe, 2016[33]). To date, 2.4 billion people – approximately 40% of the world's population – live in coastal zones, although these represent only 20% of global land surface[3] (United Nations, 2017[1]). At the global level, one out of ten people live in low-elevation coastal zones[4] (LECZs) (IPCC, 2019[28]; Wong et al., 2014[5]; Cazenave and Le Cozannet, 2013[34]), which represent only 2% of total land surface (Wong et al., 2014[5]). Consequently, coastal zones display a population density approximately three times higher than the global average (Nicholls et al., 2007[27]; OECD, 2016[35]). These global trends are reflected by national and regional trends in many countries. For example, over 95% of the population lives within 100 kilometres of the coast in several OECD countries, including Greece (99%), Israel (99%) Japan (97%), Norway (97%), and the United Kingdom (98%) (OECD, 2020[36]) (Figure 1.2).[5]

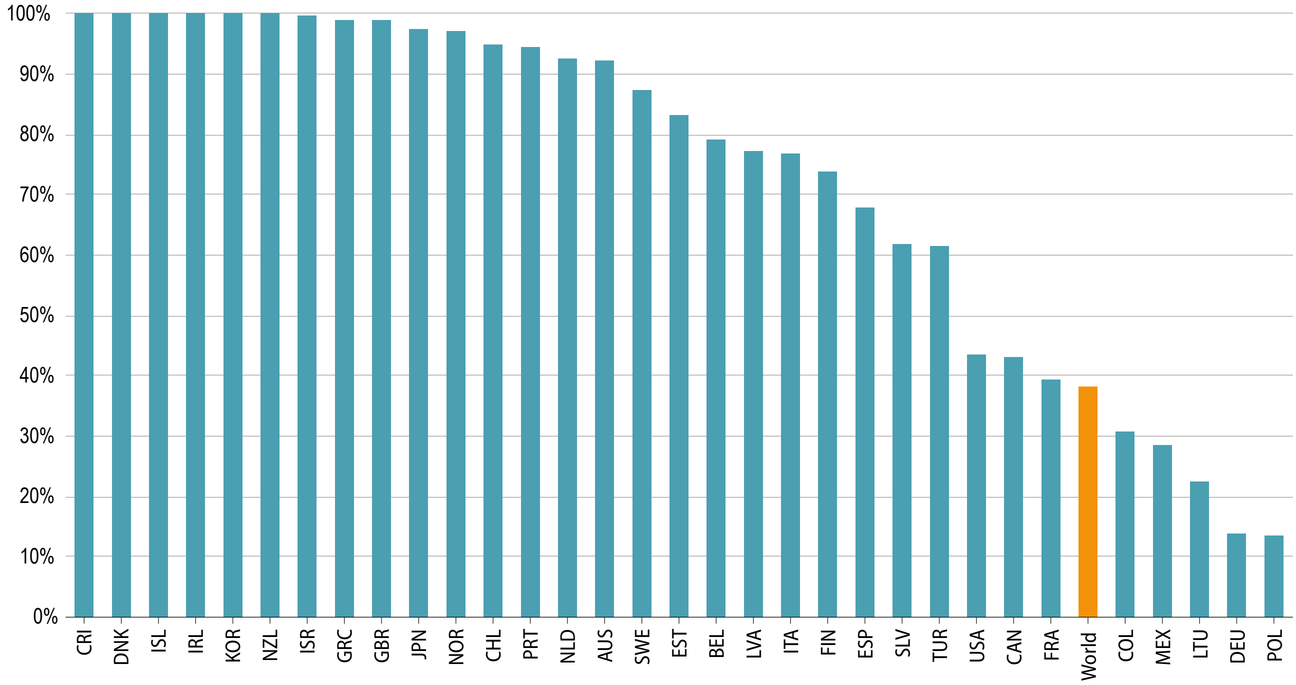
3. This estimate is based on a definition of coastal zone that includes coastal land up to 100 kilometres from the shoreline.

4. Low-elevation (or low-lying) coastal zones are defined as an area along the coast characterised by an elevation of less than ten metres above sea level. The figure refers to the world population in 2010.

5. All of these figures refer to 2015.

FIGURE 1.2. **Population living in coastal zones across OECD coastal countries**

Share of population living within 100 km of the shoreline, 2015

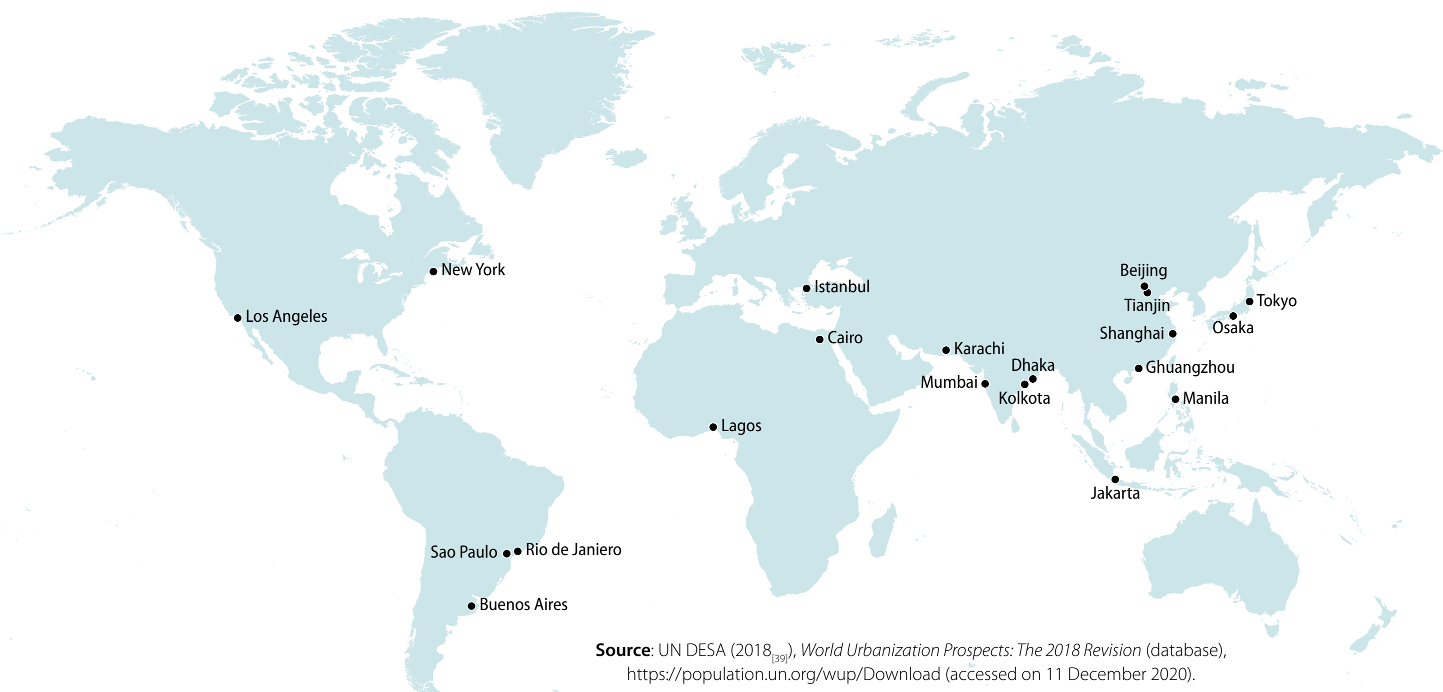


Source: OECD (2020[36]), Sustainable Ocean Economy (database), https://stats.oecd.org/index.aspx?datasetcode=OCEAN (accessed on 9 March 2021).

These population trends go hand in hand with high levels of urban development (Ranasinghe, 2016[33]) (Figure 1.3). For example, the totality of Togo's coastal population is urban (Croitoru, Miranda and Sarraf, 2019[37]) and nearly one-third of Viet Nam's coastline is covered by urban settlements (Rentschler et al., 2020[38]). Globally, 75% of the world's largest urban agglomerations are located in coastal zones (Luisetti et al., 2010[2]), and two-thirds of all cities with more than 5 million inhabitants are located in LECZs (Wong et al., 2014[5]).

FIGURE 1.3. **Major urban agglomerations along the world's coasts**

Selected agglomerations above 10 million inhabitants within 100 km from the coast, 2015



Source: UN DESA (2018[39]), *World Urbanization Prospects: The 2018 Revision* (database), https://population.un.org/wup/Download (accessed on 11 December 2020).

Coastal settlements have grown rapidly during the past decades and will continue to do so in the coming years (Ranasinghe and Stive, 2009[40]). By the middle of the century, over 1 billion people are projected to live in LECZs (IPCC, 2019[28]; Merkens et al., 2016[41]) under all Shared Socioeconomic Pathways and, under a high-end population growth scenario, global LECZ population may reach 1.4 billion by 2060 – i.e. 12% of the total world population (Neumann et al., 2015[42]). The largest changes are projected in the African continent, as well as in the already densely populated deltaic regions of Southeast Asia (Wong et al., 2014[5]; Nicholls and Cazenave, 2010[43]).

Urban coastal development has also led to the rapid concentration of critical assets along the coast, including ports and other transport infrastructure, energy, communications, waste and water treatment facilities, as well as sea defence infrastructure (Sadoff et al., 2015[44]). While in 2005 the global value of coastal assets was estimated around USD 3 000 billion (i.e. 5% of global GDP in 2005) (Sadoff et al., 2015[44]), this value is set to continue growing, potentially reaching USD 35 000 billion in 2070[6] (i.e. 9% of projected global GDP) (Nicholls et al., 2008[45]). Today, in the European Union, physical assets within 500 metres of the coast are estimated to be worth between EUR 500 billion and EUR 1 trillion (European Environment Agency, 2019[46]).

The high concentration of population, assets and resources makes coastal zones key economic hubs and tend to generate an above-average economic value. In the United States, coastal counties represent less than 10% of the country's land mass, but 40% of its population and almost half of the national GDP[7] (NOAA, 2017[47]). Similarly, in 13 of the 20 EU member states bordering the sea, coastal regions tend to generate higher GDP per capita than non-coastal regions (Eurostat, 2015[48]). In West Africa,[8] coastal zones generate over half of the region's GDP, despite being home to only one-third of the region's population (Croitoru, Miranda and Sarraf, 2019[37]) and in Viet Nam, coastal regions display poverty rates below the national average (Rentschler et al., 2020[38]). The ocean economy[9] is also gaining increasing importance globally, with large positive impacts on coastal incomes and employment. Prior to COVID-19, the OECD estimated that the ocean economy contributed approximately 2.5% of global GDP and generated 31 million jobs every year (OECD, 2016[35]).[10]

6. The latter estimate only accounts for the 136 largest port cities around the world in 2005, i.e. port cities that had over 1 million inhabitants (Nicholls et al., 2008[45]).

7. These figures refer to 2017. Territorial estimates exclude Alaska and territories. The employment estimate excludes self-employed activities.

8. Africa's west coast includes Benin, Cabo Verde, Cameroon, Côte d'Ivoire, Equatorial Guinea, Gabon, Ghana, Guinea, Guinea Bissau, Liberia, Mauritania, Nigeria, São Tomé and Príncipe, Senegal, Sierra Leone, The Gambia, and Togo.

9. The ocean economy is defined as "the sum of the economic activities of ocean-based industries, and the assets, goods and services provided by marine ecosystems" (OECD, 2016[35]). While most of the ocean economy is located in coastal regions, some activities that fall under the ocean economy (such as food retailing and boat building) are not necessarily located in coastal regions.

10. This estimate refers to 2010 and accounts for direct full-time employment only.

Coastal zones represent the access point for maritime traffic and shipping, playing a key role in international freight and passenger transportation. Today, over 80% of global trade in goods by volume relies on maritime freight transport.

Coastal zones play a central role for fisheries, aquaculture and seafood processing, significantly contributing to coastal revenues and employment (OECD, 2020[49]). At the global level, fisheries and aquaculture generate over USD 360 billion in first sale value every year[11] (World Bank, 2020[51]) and, in the EU alone, marine fisheries and aquaculture produce approximately EUR 7 billion in gross value added every year[12] (European Parliamentary Research Service 2020[52]). In developing economies with direct access to the sea, marine fisheries represent a significant share of national economies, accounting for 6-8% of national GDP in low-income and lower middle-income countries (OECD, 2020[53]).

Coastal zones are also very important for agriculture, as coastal plains offer some of the most productive lands on Earth (FAO, 1998[15]). Altogether, 12% of the world's coasts are used for agriculture (Martínez et al., 2007[6]). For instance, approximately half of the south-western coast of Bangladesh – and most notably the Ganges-Brahmaputra-Meghna deltaic plain – is used for agriculture, with 85% of the coastal population relying on agriculture for their livelihoods (Lazar et al., 2015[54]; Abedin and Shaw, 2013[55]).

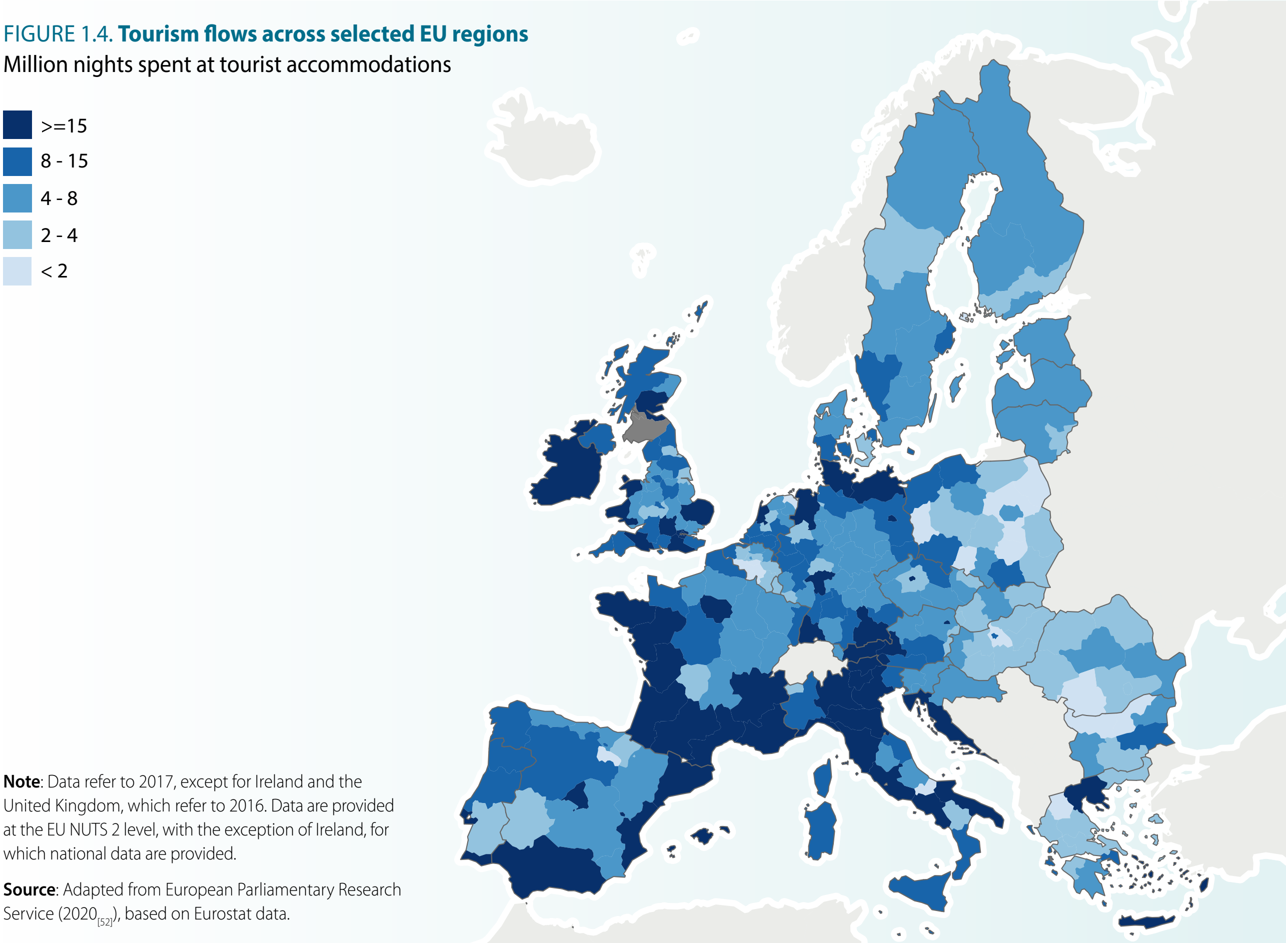
Coastal zones are also particularly profitable for the extraction of natural resources such as heavy minerals, corals and rare earth elements. Sand and gravel are the most widely mined materials in the world (Torres et al., 2017[56]) and their reserves are at least 100 times more abundant on the coast than inland (Osterkamp and Morton, 2005[57]). Together with rocks and limestone, they are used to produce construction materials, soil amendments and electronic goods (Torres et al., 2017[56]; Barwell, 2016[58]; Kildow et al., 2016[59]; Barbier et al., 2011[60]; Osterkamp and Morton, 2005[57]). Similarly, corals are also used to produce road fill, bricks and cement, as well as for manufacturing and other commercial purposes (Barbier et al., 2011[60]). Rare earth elements, such as europium and tantalum – which are used in the electronics, transport and telecommunications industries – are largely extracted in coastal sands in countries such as Australia,

11. This estimate refers to 2016.

12. This estimate refers to 2017 and excludes fish processing and distribution, which generates an additional EUR 14 billion in gross value added.

FIGURE 1.4. **Tourism flows across selected EU regions**

Million nights spent at tourist accommodations



Note: Data refer to 2017, except for Ireland and the United Kingdom, which refer to 2016. Data are provided at the EU NUTS 2 level, with the exception of Ireland, for which national data are provided.

Source: Adapted from European Parliamentary Research Service (2020[52]), based on Eurostat data.

Bangladesh, the People's Republic of China (hereafter China), India and Senegal (Carvalho, 2017[61]). Coastal zones also offer opportunities for the extraction of other heavy minerals, including gold, diamonds and magnetite.

In addition to resource-based activities, the tourism, leisure and recreation industries represent a growing source of income for coastal communities (Nicholls et al., 2007[27]). In the EU, over 2 million people are employed in coastal tourism[13] (European Parliamentary Research Service, 2020[52]) and the sector – which in 2012 represented 43% of total EU overnight tourist flows (Figure 1.4) (Eurostat, 2015[48]) – generates over EUR 180 billion in gross value added every year (European Environment Agency, 2019[46]). In the United States, 85% of tourism income depends on beach visits alone (Karani and Failler, 2020[31]; Barbier et al., 2011[60]) while in Viet Nam, coastal tourism accounts for 70% of the total tourism GDP (Rentschler et al., 2020[38]).[14] In Africa, the coastal and marine tourism sector currently generates 24 million jobs[15] and, by 2060, it is projected to generate about USD 140 billion in yearly value added (Karani and Failler, 2020[31]). Coastal tourism is also particularly important for some small island nations, in some cases accounting for over one-quarter of their GDP (United Nations, 2017[1]).

13. This estimate refers to 2017.

14. Data refer to 2017.

15. Data refer to 2018.

Coastal zones also represent the access point for maritime traffic and shipping, thus playing a key role in international freight and passenger transportation. Today, over 80% of global trade in goods by volume relies on maritime freight transport (UNCTAD, 2020[62]).

Finally, coastal areas also play an important role for the energy sector. They provide valuable renewable energy sources, ranging from ocean currents to wave, wind and tidal energy. Power generation from marine renewable sources increased by 13% in 2019 (compared to the previous year) (Chowdhury et al., 2020[67]), and by 2050 it could represent 7% of global electricity production (Esteban and Leary, 2012[68]). Coastal areas also play a key role in the production of energy from fossil sources, as they host important deposits of gas and oil. Whereas today offshore oil and gas rigs are built at increasing distance of the shore (Maribus, 2017[69]), coastal areas still host a large amount of oil and gas platforms.

Besides generating economic value via market mechanisms, coastal ecosystems can also deliver economic savings through coastal protection, water treatment and other ecosystem services (OECD, 2020[71]). While not all such services contribute directly to economic growth, they generate large benefits and have a significant impact on local and national economies (Box 1.2).

BOX 1.2. **Valuing coastal ecosystems**

Many of the valuable services offered by coastal ecosystems are not reflected by the market prices of goods and services, and are therefore referred to as non-market benefits. These benefits are large and existing valuation studies provide useful estimates of their value. For example, recent estimates suggest that the protection of 10% of marine and coastal ecosystems through marine protected areas would generate ecosystem service benefits of USD 622 billion to USD 923 billion between 2015 and 2050 (OECD, 2017[72]).

Existing valuation studies provide useful estimates of non-market benefits associated with ecosystem services. The coastal protection services offered by nearshore ecosystems are also instrumental to reduce the economic losses that follow natural and climate-induced disasters. For example, each hectare of mangrove forest in Thailand provides storm protection services valued at USD 9 000 to USD 11 000, while each hectare of salt marsh in the United States generates over USD 8 000 in savings every year from avoided hurricane damage alone. In line with these findings, a recent study on storm impacts in Louisiana estimates that each acre of healthy coastal wetlands reduces hurricane damage to coastal property by USD 100 to USD 140.

Coastal ecosystems also contribute substantially to tourism and leisure. At the global level, the yearly recreational value generated by coastal ecosystems is estimated to be between USD 150 and USD 71 000 per acre of land.

Besides largely contributing to coastal protection and leisure, coastal ecosystems are highly valued for their contribution to water quality as well as to food and raw material provision. For instance, mangrove forests in Thailand provide raw materials for USD 484 to USD 585 per hectare every year, while salt marshes in the United States allow saving USD 785 to USD 15 000 per acre in wastewater treatment. Similarly, Hawaiian coral reefs provide fisheries for a value of USD 1.3 million every year.

Sources: Karani and Failler (2020[31]); Kildow et al. (2016[59]); Barbier et al. (2011[60]); Kirkpatrick (2011[73]); OECD (2017[72]).

2 The growing climate risks in coastal zones

The social and economic values generated by coastal zones depend on the healthy functioning of their ecosystems. The extent and health of coastal ecosystems have been deteriorating due to the intensive use of coastal zones, as well as to the harmful impacts of human activities inland. While coastal degradation in itself poses increasing threats to coastal communities and economies, the impacts of climate change have compounded and accelerated ecosystem degradation. Indeed, coastal communities and economic activities are expected to be among the most vulnerable and exposed to the impacts of climate variability and climate extremes.

THE IMPACTS OF COASTAL SOCIO-ECONOMIC DEVELOPMENT ON COASTAL ENVIRONMENTAL HEALTH

Socio-economic development in coastal zones exerts significant pressures on coastal habitats and ecosystems, leading to land-use changes and significant coastal degradation (Wong et al., 2014[5]; Nicholls et al., 2007[27]). The conversion of previously undeveloped land has led to the sharp decline of key coastal ecosystems such as wetlands and mangroves (Wong et al., 2014[5]). For example, since 1900, over half of the world's coastal wetlands have been lost (IPCC, 2019[28]). Coastal ecosystem loss has undermined nature's ability to withstand the environmental pressures generated by socio-economic activity on the coast. These trends are projected to continue in the coming decades, leading to further pressures on coastal resources, ecosystems and biodiversity (Wong et al., 2014[5]; Nicholls et al., 2007[27]). Land-use changes and coastal degradation are largely location- and context-specific. In many countries, the tourism industry is a major driver of urban development and ecosystem loss, as it is the case of the Mediterranean and Black Sea coasts (European Environment Agency, 2019[46]). At the same time, in several developing economies – such as India, Mexico, the Philippines and Viet Nam – coastal wetlands are largely cleared to accommodate aquaculture (Nicholls et al., 2007[27]). For example, half of mangrove forest loss globally is attributed to aquaculture, and 38% of total mangrove forest cover is lost to shrimp aquaculture alone (Barbier et al., 2011[60]).

The construction of buildings, roads, ports, pipelines and other infrastructure has altered sediment dynamics, stressing the phenomenon of land subsidence (Box 2.1) and facilitating saltwater intrusion in surface water and groundwater. Increased urbanisation has generated higher rates of water abstraction along the coast, and water pollution loads have increased because of sewage and industrial effluents resulting from growing urban settlements along the coast (OECD, 2018[74]; Nicholls et al., 2007[27]).

Energy generation from marine sources can also generate disturbances to coastal ecosystems. The presence of physical machinery has an impact on marine habitats and biodiversity below and above the water. For example, offshore infrastructures can create barriers and harmful obstacles for migratory birds. In addition, the change in local water currents due to rotating motors, as well as their acoustic effect, can disrupt the movement of certain fish, affecting their activities (e.g. reproduction) as well as that of their predators.

The exploitation of living resources has also contributed to biodiversity loss and to altered ecosystem functions. Overfishing and unsustainable fish practices (e.g. dynamite fishing and bottom trawling) are a key driver of declining stocks of nearshore and offshore living resources (OECD, 2017[72]). At the global level, over one-third of marine fish stocks are overexploited[16] (FAO, 2020[79]), while in the Mediterranean and the Black Sea, over 40% of assessed fish stocks are exploited above the maximum sustainable yield (European Environment Agency, 2019[46]).

Natural resource extraction has had a significant negative impact on coastal ecosystem health. Seagrass harvesting and coral mining have led to ecosystem loss and damage, while excessive mangrove harvesting

16. This proportion, recorded in 2017 (FAO, 2020[79]), only amounted to 10% in the 1970s (World Bank, 2020[51]).

(Figure 2.1), has reduced the availability of fish habitats and fish catch and contributed to increased coastal vulnerability to climate-related risks such as storms surges. In addition, the extraction of sand, gravel and rare earth elements from the coast has been a major driver of coastal erosion and biodiversity loss. At the global level, one-quarter of coastal zones are eroding by 0.5 metres per year and, in the most vulnerable West African regions, shorelines might retreat up to 10 metres in the coming years (Croitoru, Miranda and Sarraf, 2019[37]). Sand and gravel mining also facilitates sediment siltation[17] and the destruction of shallow-water biodiversity (Torres et al., 2017[56]; FAO, 1994[21]; OECD, 2017[72]), while the extraction of rare elements contributes to eutrophication and releases substances toxic for humans and aquatic species (Schreiber et al., 2016[80]). All these impacts have long-term effects on fish stocks, food production, water quality and human health (Torres et al., 2017[56]), as well as on overall ecosystem resilience.

Coastal and marine ecosystem conservation and protection measures can be effective means to reduce the detrimental impacts of socio-economic activities in coastal zones. Nonetheless, whereas coastal and marine conservation has been established as a priority by the Convention on Biological Diversity as well as by the Sustainable Development Goals, to date, marine protected areas only cover 4% of the total marine environment (OECD, 2017[72]).

17. Sediment siltation consists in the suspension and accumulation of sediment in water ecosystems, with negative impacts on coastal habitats.

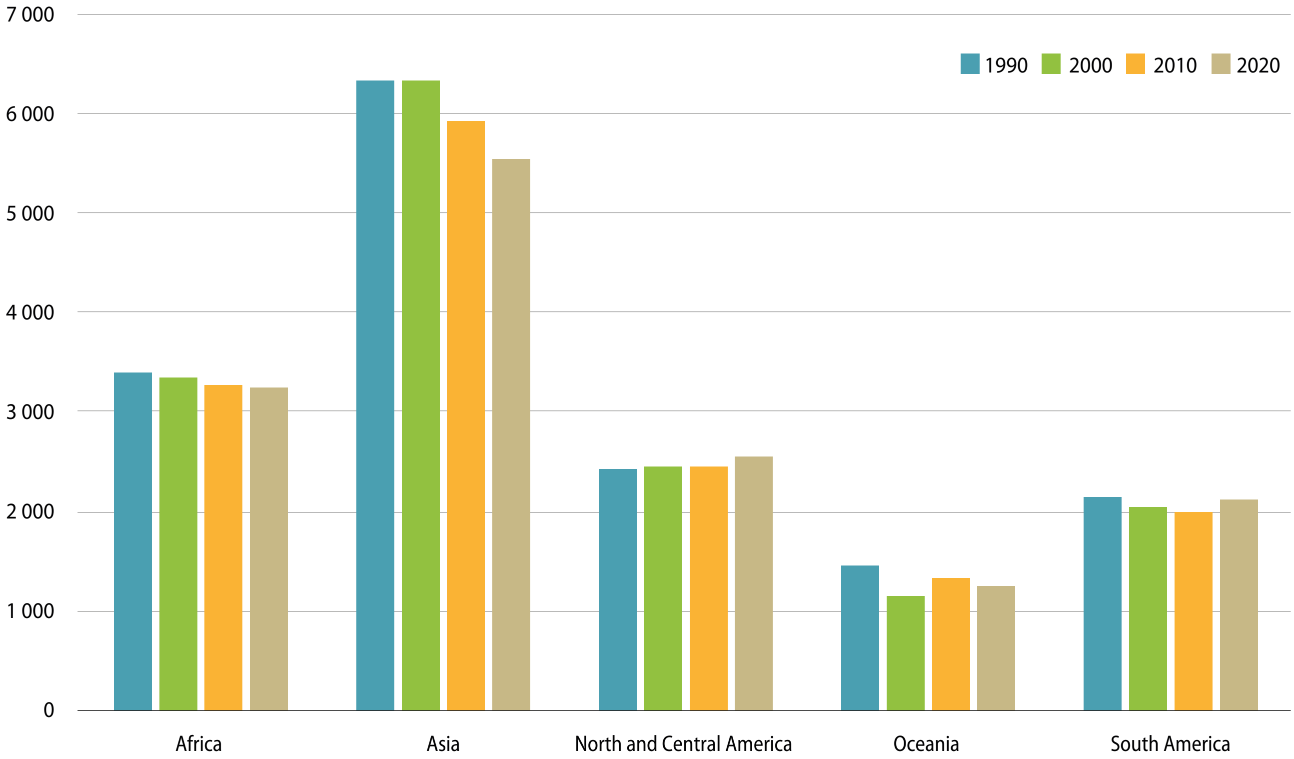
BOX 2.1. **The growing challenge of land subsidence**

One of the key challenges resulting from coastal use and development is land subsidence. Human activities on the coast, such as the extraction of groundwater and underground resources, represent a key driver of subsidence, which adds to the vertical land movements that occur naturally. Coastal land subsidence is also enhanced by sediment starvation due to dam building and waterways diversion, as well as by sediment compaction resulting from building loads. By lowering the ground level relative to the sea, land subsidence poses particular challenges in river deltas and low-lying coastal zones, making them increasingly prone to the risk of flooding. To date, many of the largest coastal cities in the world are subsiding at high rates. For example, throughout the last decades, Bangkok has subsided by 2 metres, Shanghai by 3 metres and Tokyo by 5 metres. Similarly, the city of Jakarta is subsiding at an average rate of 3-10 centimetres (cm) every year and the city of Dar es Salaam, in the United Republic of Tanzania, is projected to subside between 15 cm and 95 cm by the end of the century.

Sources: IPCC (2019[28]); Wong et al. (2014[5]); Abedin and Shaw (2013[55]); Cazenave and Le Cozannet (2013[34]); UNISDR (2012[78]); Nicolls and Cazenave (2010[43]); Nicholls et al. (2007[27]).

FIGURE 2.1. **Changes in mangrove forest cover by continent, 1990-2020**

Mangrove area, 1 000 ha



Source: Based on FAO (2020[26]).

THE IMPACTS OF INLAND SOCIO-ECONOMIC DEVELOPMENT ON COASTAL ZONES

Human activities inland also have significant impacts on coastal zones (Wong et al., 2014[5]). The growing demand for water determines increasing freshwater abstraction from both surface and groundwater reservoirs, with significant impacts on water flows. In fact, excessive freshwater abstraction affects river discharge and water runoff patterns (Wong et al., 2014[5]), while reducing groundwater recharge capacity (Jiménez Cisneros et al., 2014[81]). Agricultural activities are particularly important in this context, as today irrigation accounts for 90% of global freshwater demand (Jiménez Cisneros et al., 2014[81]). At the same time, water infrastructures, which have been constructed without taking into consideration environmental concerns, can have effects on coastal ecosystems.

Human activity in inland river basins also affects sediment supply. The construction of dams, channels and water reservoirs reduces the amount of sediment reaching the coast in many areas,[18] exacerbating coastal erosion and saltwater intrusion. In other contexts, land clearing, gravel mining and other land uses increase sediment erosion, leading to excess sediment supply to the coast and to the deterioration of coastal habitats (OECD, 2017[72]), as well as exacerbating water pollution (Failler et al., 2015[82]; Ranasinghe, 2016[33]). Whereas sediment dynamics vary depending on many local and context-specific factors, at the global level, sediment supply to the coast is projected to decrease until the end of the century (Nicholls et al., 2007[27]), with long-lasting impacts on coastline morphology and relative sea-level rise. This trend is likely to be particularly problematic for those low-lying areas that are most susceptible to land subsidence (Box 2.1) (Nicholls and Cazenave, 2010[43]). Any policy response would need to reflect local specificities for sediment management and control.

Water pollution is another challenge affecting coastal communities. High concentrations of toxic elements (such as pesticides and heavy metals) and inorganic nutrients reaching coastal waters affect water quality in several regions (European Environment Agency, 2019[46]; Wong et al., 2014[5]). In addition, inorganic nutrients increase

18. For example, nearly half of the world's major rivers have experienced a significant reduction in sediment influx (Wong et al., 2014[5]).

water acidity, eutrophication and the number of "dead zones"[19] (OECD, 2018[74]; Wong et al., 2014[5]), thus affecting ecosystems and biological processes. Water desalinisation and other industrial processes further contribute to this challenge. Marine litter represents an additional challenge to coastal zones. For example, the Danube River brings over 4 tonnes of plastic fragments to the Black Sea coast every day (Lechner et al., 2014[83]). Water pollution is particularly detrimental in coastal areas, as pollutant concentrations tend to be significantly higher near the shore. Indeed, according to the FAO (1998[15]), over 90% of all solid and chemical waste entering the sea remains near the shore. Similarly, nutrient concentrations are usually higher in coastal waters (Wong et al., 2014[5]).

THE IMPACTS OF CLIMATE CHANGE ON COASTAL ZONES

Coastal zones are particularly vulnerable to the impacts of climate change, and all the world's coastlines are shaped by climate variability. Climate change adds to the stress factors directly generated by human activity on the coast and inland, compounding existing risks and exacerbating their impacts on coastal communities.

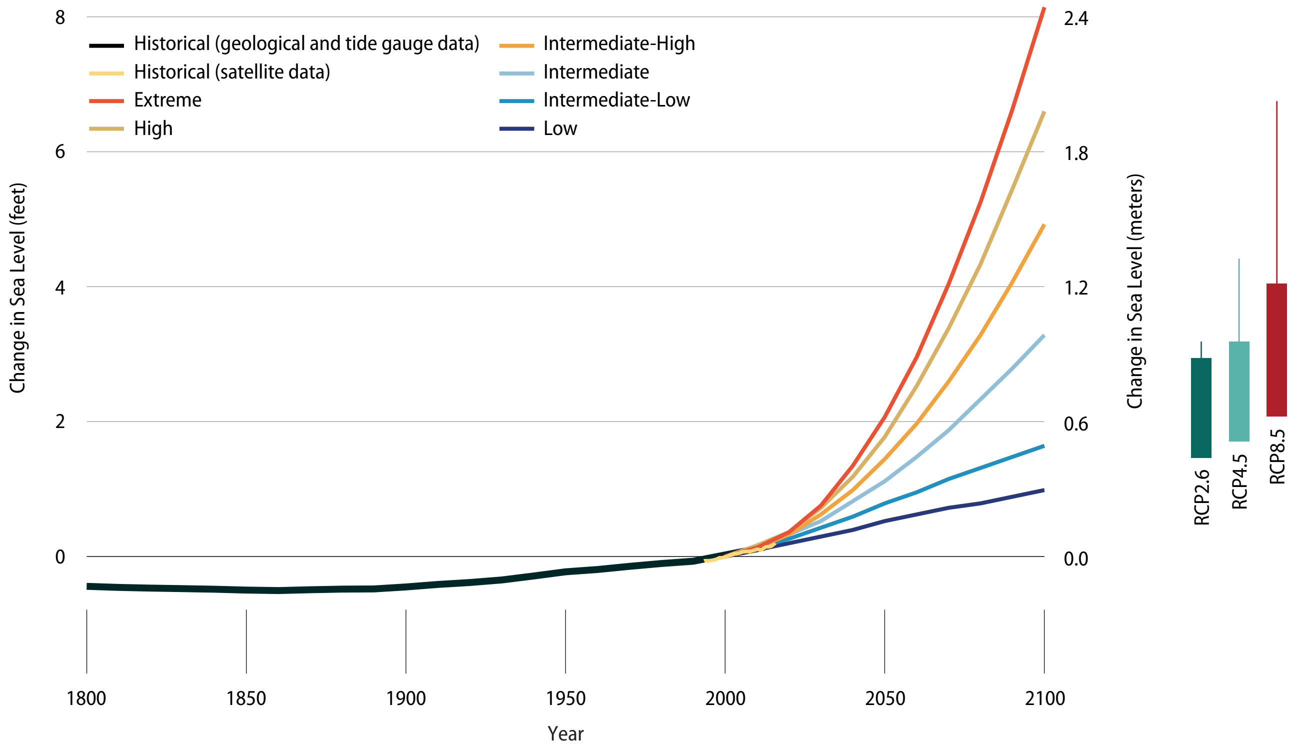
Taking into account the combination of hazards, exposures and vulnerabilities that characterise coastal zones, the following sections provide an overview of the past and projected risks posed by climate variability and extreme climate events to coastal communities , as well as of the knock-on effects these are likely to produce globally. The discussion is structured around the major climate-related risks to coastlines: sea-level rise, storm surges, increased seawater temperature and alterations in the hydrological cycle.

Sea-level rise

The rise in global mean sea level is widely considered the most important consequence of climate change for low-lying coastal zones (Box 2.2) (Nicholls et al., 2007[27]). At the global level, average sea level has risen by 1.7 mm per year over the last century (Wong et al., 2014[5]). By the end of this century, sea level is projected to rise on average between 40 cm and 75 cm compared to current levels, potentially exceeding a 1-metre rise, depending on the scenario considered (Figure 2.2) (IPCC, 2019[28]; Cazenave and Le Cozannet, 2013[34]). While almost all regions are projected to be subject to sea-level rise (SLR), projections are characterised by high regional variability (IPCC,

19. Dead zones are underwater areas where oxygen concentrations are too low to accommodate balanced aquatic ecosystems. At the global level, the number of dead zones has experienced unprecedented growth since the 1960s and is likely to keep growing in the future (Wong et al., 2014[5]).

FIGURE 2.2. **Sea-level rise trends, 1800-2100**



Note: RCP2.6 represents a scenario where greenhouse gas emissions are strongly mitigated, maintaining the increase in global temperatures within 2°C by 2100. RCP4.5 is considered an intermediate scenario, in which greenhouse gas emissions decline after reaching their peak in 2040. RCP8.5 represents a worst-case scenario, in which greenhouse gas emissions continue to rise throughout the 21st century.

Source: USGCRP (2018[62]).

2019[28]; Wong et al., 2014[5]; Cazenave and Le Cozannet, 2013[34]). Such variability can be determined by various factors, including land ice loss, thermal expansion, and other sea and ocean dynamics, as well as land subsidence – which today is the most important component of relative sea-level rise in several deltaic regions (IPCC, 2019[28]). For example, while sea level is rising three times faster than the global average in the western Pacific,[20] in other regions, such as the eastern tropical Pacific, SLR is proceeding more slowly (Cazenave and Le Cozannet, 2013[34]; Nicholls and Cazenave, 2010[43]).

In the short term, SLR is expected to increase the frequency and intensity of coastal flooding, while in the longer term it is likely to accelerate coastal erosion, eventually leading to the retreat of unprotected shorelines (Ranasinghe, 2016[33]; Wong et al., 2014[5]; Nicholls and Cazenave, 2010[43]). SLR also exacerbates

20. Based on observations started in 1993.

BOX 2.2. **The impact of climate change on sea-level rise**

Climate change contributes to sea-level rise in two distinct ways. On the one hand, as air temperatures rise, glaciers and land ice melt, increasing the inflow of water into the sea. On the other hand, as seawater warms because of a rise in air temperature, it expands in volume. Altogether, thermal expansion is responsible for approximately 30% of the sea-level rise (SLR) observed between 1993 and 2012, while ice melt is responsible for approximately 50-60%. In addition, changes in land water storage also contribute to SLR (less than 10%).

While these phenomena have been observed for several decades, recent estimates suggest that they are accelerating. Since 1993, sea level has increased considerably faster than it did in previous decades and, under a worst-case scenario (RCP8.5), sea level is projected to rise up to 4.2 times faster by 2100 than it did in the 2006-15 period.

Sources: IPCC (2019[28]); Wong et al. (2014[5]); Abedin and Shaw (2013[55]); Cazenave and Le Cozannet (2013[34]); UNISDR (2012[78]); Nicolls and Cazenave (2010[43]); Nicholls et al. (2007[27]).

the problem of saltwater intrusion in surface water and groundwater. The impacts of sea-level rise are particularly dire in coastal plains, river deltas and small island nations, as well as in all those coastal areas where ecosystem health has already deteriorated due to human impacts. Other vulnerable areas are those such as the city of Venice, where there are substantial barriers to adaptation (Nicholls et al., 2007[27]).For example, by 2050, SLR will affect over 1 million people every year in three major deltas in Bangladesh, Egypt and Viet Nam. In Viet Nam alone, almost 15% of the population is exposed to intense coastal flood risk and over one-third of settlements are threatened by coastal erosion (Rentschler et al., 2020[38]). Similarly, many deltaic cities – including Bangkok, New Orleans and Shanghai[21] – are projected to experience increasing flood and erosion damage (Nicholls and Cazenave, 2010[43]; Nicholls et al., 2007[27]). Atolls and small island nations are projected to suffer the highest relative impacts (Nicholls and Cazenave, 2010[43]) due to the combination of their high exposure, the small size of their national economies and their high dependence on international markets. Low-elevation islands such as the Maldives, Kiribati and the Marshall Islands might also face the risk of "submergence and complete abandonment" by 2100 (Nicholls and Cazenave, 2010[43]). Altogether, by the end of the century, SLR-induced flooding could be ten times larger than it is today[22] (Nicholls et al., 2007[27]) and is projected to affect 360 million people every year under a medium warming scenario (RCP4.5) (Kulp and Strauss, 2019[3]).

Over the past century, SLR-induced coastal floods have generated significant losses in many countries. For example, they have caused an estimated USD 11 billion in losses and damages in Japan, USD 3 billion in the Netherlands, and over USD 1 billion in Mexico and Viet Nam (EM-DAT, 2020[88]). The socio-economic losses and damages induced by SLR are expected to grow dramatically around the world, reaching up to USD 50 trillion losses every year by 2100 (under the RCP8.5 scenario), i.e. approximately 4% of the world's gross domestic product (OECD, 2019[4]). Agriculture is one of the economic sectors projected to suffer the greatest damages, with SLR threatening 16% of rice production in Bangladesh[23] and up to 15-20% of agricultural land in Egypt (FAO, 1994[19]; IPCC, 1990[83]). To date, in Viet Nam, yearly productivity losses in agriculture and aquaculture due to coastal floods amount to USD 50 million and USD 80 million respectively, while future flooding threatens USD 1.5 billion in food exports and almost 2.5 million jobs in the two sectors combined (Rentschler et al., 2020[38]). Similarly, tourism is likely to be severely hit by coastal flood damage and beach erosion. For example, various coastal municipalities in the United States already depend on beach nourishment programmes to maintain their attractiveness as summer holiday destinations (Nicholls et al., 2007[27]). In Viet Nam, intense coastal flooding causes tourism losses for USD 180 million every year and, coupled with erosion risk, it threatens 1 million jobs in the tourism sector alone (Rentschler et al., 2020[38]). In addition, coastal floods and erosion pose a risk to physical assets, such as housing, industrial sites and infrastructure, with consequences for service provision. In Viet Nam, 20% of coastal power plants, 20% of schools and almost half of healthcare infrastructure are exposed to intense coastal flooding risk (Rentschler et al., 2020[38]).

Coastal storm surges

Climate change can have important impacts on coastal storm activity in certain regions of the world. The effects of climate change on storm activity are still subject to significant uncertainty. Nonetheless, evidence shows that, in some regions, increased temperatures and altered precipitation, wave and wind patterns can make storms[24] more intense and storm surges[25] more likely to hit the coast (IPCC, 2019[28]; Ranasinghe, 2016[33]; Wong et al., 2014[5]; US EPA, 2009[89]; Nicholls et al., 2007[27]). Storms currently account for over one-quarter of disaster events globally[26] (UNDRR and CRED, 2020[90]) and the occurrence of extreme hurricanes[27] might grow by 45 to 87% by 2100[28] (Stuart, Yozell and Rouleau, 2020[91]). In

21. These cities lie in the deltaic plain of three major world rivers, namely the Chao Phraya in Thailand, the Mississippi in the United States and the Yangtze in China.

22. This figure refers to projections to 2080, as compared to 2007.

23. SLR-induced floods, in particular, can have severe effects on agricultural productivity. The flood that hit Bangladesh in 1988 reduced agricultural yields in the country by almost half, with devastating effects on the 40 million people who relied on coastal agriculture for their subsistence (Abedin and Shaw, 2013[55]).

24. Based on their location, storms can also be referred to as hurricanes, cyclones, typhoons or tornadoes.

25. As defined in McInnes et al. (2016[17]), storm surges consist in the combination of strong winds and gravity waves, where winds enhance currents over shallow waters while waves increase sea level.

26. The EM-DAT Database considers as disasters those events that affect at least 100 people and kill more than 10, inducing a government to declare the state of emergency and call for international assistance (EM-DAT, 2020[88]).

27. The intensity of hurricanes is defined based on their wind speed, which is associated to different levels of potential property damage. The most intense hurricanes are those falling in categories 4 and 5 of the Saffir-Simpson Hurricane Wind Scale, which are associated to wind speeds above 209 km/h and result in "catastrophic" damage (NOAA, 2020[110]).

28. The figure is obtained using the CMIP 3 and CMIP 5 scenarios.

FIGURE 2.3. **Storm-induced coastal flood risk**

Notes: In this map, coastal flood risk measures the share of the population likely to be affected by storm-induced coastal flooding every year. The indicator takes into account human exposure in flood zones, their vulnerability and the existing flood protection measures. The map represents an average year, thus it does not provide figures on the maximum possible impact.

Source: Adapted from World Resources Institute's Aqueduct tool (2020[92]).

certain contexts, storms are also likely to move poleward, thus concerning previously unaffected regions and likely intensifying risks in others, such as the northern Atlantic (Wong et al., 2014[5]; Nicholls et al., 2007[27]).

Increased storm intensity makes extreme sea-level events[29] more frequent (IPCC, 2019[28]; McInnes et al., 2016[17]; Wong et al., 2014[5]), exposing low-lying areas to episodic coastal flooding (Figure 2.3) and accelerating coastal erosion and saltwater intrusion into freshwater aquifers. Storm surges can also alter coastal freshwater systems, compounding water circulation and salinity problems and eventually reducing water quality (Ranasinghe, 2016[33]; Wong et al., 2014[5]). Coastal storms also contribute to the degradation of buffering ecosystems such as mangrove forests and coral reefs (OECD, 2017[72]), in turn exacerbating the impacts of SLR and coastal degradation (IPCC, 2019[28]).

Storm surges and extreme sea levels are particularly problematic for low-lying coastal communities. Every year, millions of people are exposed to tropical cyclones, especially in coastal areas in the United States, the Gulf of Mexico and the Caribbean; Australia and the tropical Pacific; the Rio de la Plata delta in Argentina; and many Asian countries such as Bangladesh, India, Japan and the Philippines (Martínez et al., 2007[6]; Nicholls et al., 2007[27]). For example, in the past two decades, Caribbean coastal storms have affected almost 26 million people – i.e. over 60% of the region's population (UNDRR and CRED, 2020[90]). African coasts, most notably those in Mozambique and Egypt, are also projected to become increasingly vulnerable to storms, due to their growing coastal populations (Nicholls et al., 2007[27]).At the global level, population in cyclone-prone areas is increasing more than twice as fast as the global average (SAMHSA, 2017[93]).

29. Extreme sea levels are episodic events in which local sea water levels are unusually high over a relatively short period. Extreme sea levels differ from relative sea levels, which are indicative of longer-term trends.

Consequently, the global death toll of coastal storms is particularly high. Since 2000, storms have killed over 200 000 people globally (UNDRR and CRED, 2020[90]), with some single events being particularly devastating. Hurricane Jeanne killed almost 3 000 people in Haiti in 2004 (Pichler and Striessnig, 2013[94]; Felima, 2009[95]) and Hurricane Katrina – one of the most intense storms ever hitting the United States – caused 2 000 casualties (Nicholls et al., 2007[27]). Storms figure among the deadliest disasters of the past decades, with Cyclone Nargis in Myanmar (2008) and the 1991 Bangladesh cyclone killing about 140 000 people each (UNDRR and CRED, 2020[90]; Rentschler, 2013[96]).

Coastal storms also cause significant economic losses and disruption, destroying or damaging buildings and infrastructure such as roads, bridges, harbours and power plants (Wong et al., 2014[5]). In 2005, Hurricane Katrina destroyed over 300 000 houses and 1 000 cultural sites (Nicholls et al., 2007[27]), while in 2017 Hurricane Irma destroyed 95% of Barbuda's buildings and left two-thirds of Saint Martin's homes uninhabitable (Stuart, Yozell and Rouleau, 2020[91]). In coastal Viet Nam, where over one-third of power lines and a large share of the transport network are highly exposed to storms, these generate over USD 25 million in energy and transport losses every year (Rentschler et al., 2020[38]). By damaging infrastructure, coastal storms are also likely to affect water quality and to disrupt the delivery of public services such as transport, education and the health system, as well as emergency response (Rentschler et al., 2020[38]). For example, in the Caribbean island of Saint Lucia, Hurricane Tomas generated damages to hospital infrastructure for over USD 3 million in 2010 (Stuart, Yozell and Rouleau, 2020[91]). Furthermore, storms usually affect a variety of coastal economic activities, such as tourism and agriculture (Karani and Failler, 2020[31]; Nicholls et al., 2007[27]). Altogether, the economic consequences of all such losses are immense, and they prove particularly detrimental for small island nations and developing economies. Over the past century, storms generated damages for USD 160 billion in Japan, USD 150 billion in China and over USD 50 billion in India (EM-DAT, 2020[88]) and, in the past two decades alone, the cost of storms reached USD 1.4 trillion globally (UNDRR and CRED, 2020[90]).

Ocean warming

Ocean warming represents an additional challenge to coastal areas. The average sea surface temperature has increased by around 0.18°C per decade over the last 30 years (Wong et al., 2014[5]), and the rate of ocean warming has more than doubled since the early 1990s (IPCC, 2019[28]). These trends are projected to accelerate under the highest end emission scenarios (RCP8.5), leading to an expected temperature increase of up to 3°C by 2100, compared to the 1980-99 average (IPCC, 2019[28]; Wong et al., 2014[5]; Nicholls et al., 2007[27]). In addition, climate change is likely to increase the likelihood and intensity of marine heatwaves (IPCC, 2019[28]). Altogether, water warming is projected to increase faster than average in shallow waters (Wong et al., 2014[5]), thus proving particularly detrimental for coastal areas.

Warmer water temperatures are likely to affect water circulation and further reduce sea ice volumes at high latitudes, thus accelerating sea-level rise and coastal erosion (IPCC, 2019[28]; Wong et al., 2014[5]; US EPA, 2009[89]; Nicholls et al., 2007[27]). Besides affecting coastal ecosystems, warmer temperatures reduce oxygen levels in seawater, accelerating coastal eutrophication (IPCC, 2019[28]; Wong et al., 2014[5]; US EPA, 2009[89]) and increasing the diffusion of coastal dead zones. Altogether, warmer waters alter the health, size and distribution of coastal fish populations and are particularly detrimental for coral reefs, as they increase eutrophication as well as the likelihood and severity of coral bleaching and mortality[30] (IPCC, 2019[28]; Wong et al., 2014[5]; Nicholls et al., 2007[27]).

Warmer coastal waters are likely to reduce fish catch and increase the vulnerability and exposure of coastal communities and economic activities to the impacts of storm surges and coastal flooding (IPCC, 2019[28]). For example, corals protect over 100 million people from coastal flooding globally (Beck et al., 2018[97]; Nicholls et al., 2007[27]) and their degradation – through heat-induced coral bleaching – is likely to substantially increase economic damages and human loss. The degradation of corals can also decrease the attractiveness of certain coastal areas. For instance, after the Indian Ocean bleaching event in 1998, coastal property values decreased by USD 174 per hectare of land yearly (Barbier et al., 2011[60]). In addition, the diffusion of aquatic invasive species, such as algal blooms, further decreases the attractiveness of coastlines and can have dire effects on biodiversity (IPCC, 2019[28]). For example, in Hawaii, algal blooms have already generated million dollars losses to the tourism sector (Barbier et al., 2011[60]). All such impacts are further accelerated by ocean acidification, which can

30. Global coral reefs are declining at unprecedented rates. For example, one out of five of Martinique's coral reefs has disappeared in the past decade and 80% of global reef cover is classified as degraded (Failler et al., 2015[82]).

have particularly detrimental impacts on coral reefs, coastal fisheries and shallow water ecosystems (Box 2.3).

Broader alterations in the hydrological cycle

Climate change alters the frequency and intensity of precipitation, which is the major driver of freshwater input to the coast (Wong et al., 2014[5]; US EPA, 2009[89]). Such changes affect the volumes and timing of river flows, water runoff and sediment supply reaching the coast, (Nicholls et al., 2007[27]), accelerating coastal erosion (Ranasinghe, 2016[33]; US EPA, 2009[89]) and exacerbating the effects of flooding, coastal storms and environmental degradation. Deltaic areas are particularly vulnerable to compounded risks, as they are subject to increased coastal flooding and storm surge risk, while at the same time facing an increase in the risk of riverine flooding, coastal erosion and other water-related risks (Nicholls et al., 2007[27]).

Coastal regions subject to reduced river flows and water scarcity are projected to experience increased water salinity – partly due to increased saline intrusion and partly due to more frequent dry spells – as well as increased water pollution (US EPA, 2009[89]; Nicholls et al., 2007[27]). Water pollution and salinity contribute to the degradation of coastal ecosystems and can have severe impacts on the productivity of firms and agricultural lands. For example, the drought that hit the Mekong delta in 2016 exposed fields to extreme salinity levels, rendering 1.5 million hectares of agricultural land unproductive and thus affecting the livelihood of 3 million farmers (Rentschler et al., 2020[98]).

Human and economic losses are likely to be high also for coastal regions experiencing increased river flows. Indeed, as human settlements in coastal floodplains around the world grow rapidly, exposure to the compounded effects of riverine flooding and other coastal risks is growing too. For example, in the United Kingdom, the costs associated with flood-induced coastal erosion are projected to increase by three to nine times by 2080 (Office of Science and Technology, 2004[99]). Altogether, at the global level, the economic losses resulting from riverine flooding in coastal regions are expected to exceed USD 1 trillion by the end of the century (Stuart, Yozell and Rouleau, 2020[91]).

BOX 2.3. **Ocean acidification**

The challenges posed by warming seawater temperatures are further exacerbated by ocean acidification. When CO_2 is absorbed into the ocean, it alters the carbonate chemistry of seawater, decreasing its pH and thus making water more acidic. The global oceans have already absorbed 20 30% of total anthropogenic CO_2 emitted in the past 40 years and, since 1750, ocean surface pH is estimated to have decreased by 0.1. In many cases, more significant pH variations have been observed in coastal waters, where higher CO_2 concentrations add to other anthropogenic pressures, eventually posing severe stress to local ecosystems.

As atmospheric concentrations of CO_2 are projected to keep growing over time, seawater acidity is expected to increase at unprecedented rates over the next decades, with high geographical variability. By 2100, on average, surface water pH might range between 8.0 and 7.7, compared to an average pH level of 8.1 today.

Higher water acidity adds to the effects of warmer waters, leading to changes in plant development and distribution and, in particular, to increased algal blooms. Ocean acidification is also particularly problematic for calcifying organisms such as corals and shellfish, because a lower water pH reduces the amount of carbonate at their disposal, thus affecting their ability to build skeletons and shells. In combination with the impacts of rising water temperatures, ocean acidification is likely to have severe repercussions on coastal communities that rely on biodiversity, tourism, fisheries and commercial aquaculture, while at the same time increasing coastal vulnerability to extreme climate events.

Sources: IPCC (2019[28]); Wong et al. (2014[5]); US EPA (2009[89]); Nicholls et al. (2007[27]).

Conclusions

This paper demonstrates that the interactions between intensive socio-economic development, their impact on coastal ecosystems and growing climate risks pose complex challenges. To address such complexity, it is important to provide comprehensive policy responses that aim at strengthening the resilience of coastal zones to any detrimental impact. The challenge for coastal zone management strategies lies in integrating different policy responses, ranging from spatial and urban planning to disaster risk reduction, from ecosystem conservation to infrastructure planning, from climate adaptation to agriculture and resource management. In this process, it is important to integrate and balance different policy objectives, accounting for their trade-offs and the synergies across them. Hence, the co-ordination among different policy makers from different sectors and levels of government as well as those of non-governmental stakeholders (such as private infrastructure operators) is key to strengthening coastal resilience.

Over the past few decades, governments have acknowledged the multidimensionality of managing coastal zones by promoting integrated policy approaches such as integrated coastal zone management (ICZM). Yet, in recent years, climate resilience has become an indispensable consideration to sustaining coastal areas in the future. This means that any coastal zone management strategy developed or updated today needs to take into account the projected impacts of climate change and the measures that need to be taken to safeguard communities and economic development. More work is then needed to understand whether climate resilience polices can be promoted as separate policies or whether they would benefit from further integration with ICZM strategies.

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This paper provides a comprehensive assessment of the recent and projected socio-economic development of coastal areas. It reviews the environmental pressures exerted by human activities on coastal areas, as well as the impacts of climate change that exacerbate existing challenges. The paper calls for a co-ordinated and well-adapted policy response to address these challenges.

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