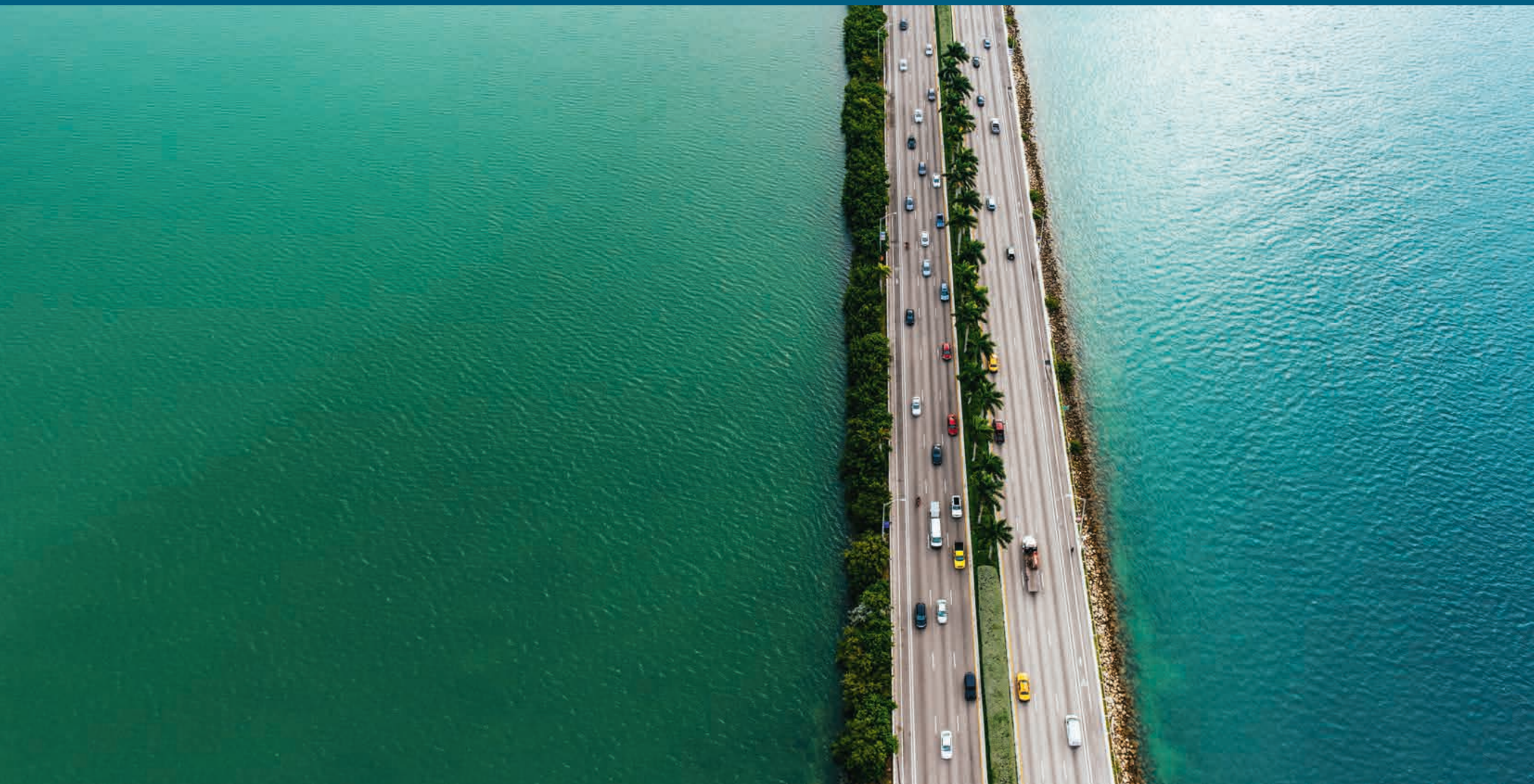
2 Living with the coasts

> For millennia, people have utilized the world's coastal areas. Coasts provide a space for trading, supply resources and underpin fisheries. It is no surprise that societies have always struggled to gain maritime supremacy. Now, however, humankind is exploiting coastal regions to such a degree that these areas are no longer able to render all of the ecosystem services that people value and need so much. Coastal areas are degraded particularly by construction and pollution.



Coastal functions

> Coastal habitats are highly diverse, as indeed are the functions they fulfil for humankind. Some of these functions, such as the production of fish, are available almost everywhere; others are highly localized – for instance, the provision of mineral resources like diamonds in the waters off Namibia. Moreover, people have been drawn to coastal locations as settlement sites and trading posts since time immemorial.

Close bonds between people and coasts

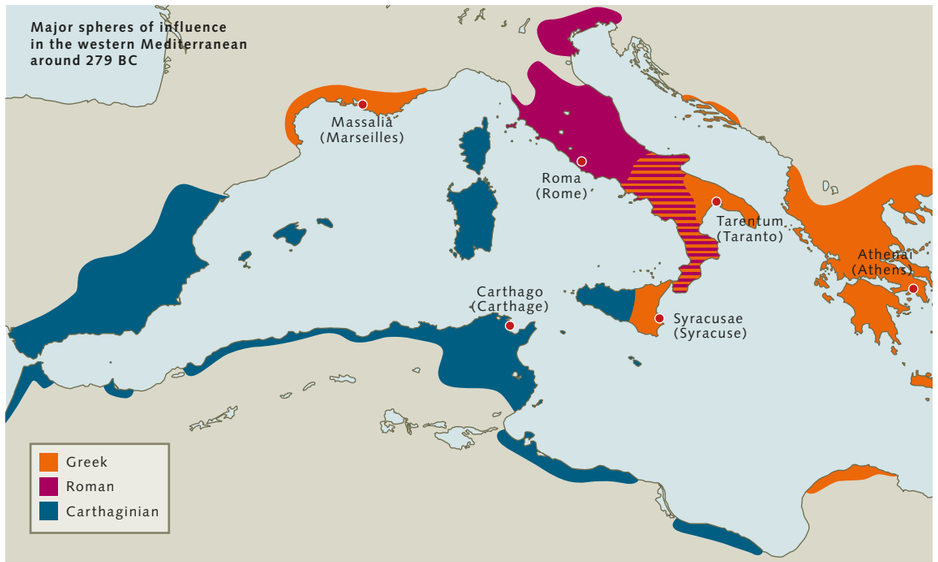
Coasts have been a significant human habitat for millennia. Initially the transition between land and sea functioned merely as a natural barrier. In time, though, people came to appreciate the advantages of the coastal region. From the earliest times, coastal waters supplied such resources as fish, algae or salt. As simple fishing boats were developed, coastal inhabitants became increasingly mobile. Fishers who were familiar with the ocean can largely be credited with venturing further out to sea and gradually discovering the islands along their native coastlines.

Early evidence of this exploration is found in China, for example. Archaeological finds in and around the southern Chinese city of Guangzhou indicate that by around 6500 BC, people in that area were using dugouts to navigate the expansive Pearl River Delta as well as open waters off the coast. From bases in the newly discovered territories, the more nautically experienced adventurers pushed ever further into previously unexplored sea regions. In time they discovered different cultures with different foods and tools at their disposal. Goods were exchanged between the different coastal peoples. This gave rise to the development of trading routes, which no longer just linked together coastal settlements but reached far inland via the traders involved.

Trading focused mainly on goods and resources that were important for everyday life. In Cyprus, for example, remnants have been found of knives made from the glass-like volcanic rock obsidian and dating from the period around 6000 BC. Since this rock does not occur on Cyprus, it must have arrived there from overseas during that period. Archaeologists suspect that it came via a Neolithic settlement on the Anatolian plateau, which had several thousand inhabitants at the time and was 150 kilometres away from the Mediterranean. Today the excavation site, named Çatalhöyük, has been listed as a World Heritage Site by UNESCO (United Nations Educational, Scientific and Cultural Organization). The obsidian itself must have come from the Göllü Dağ volcano, located another 200 kilometres east of Çatalhöyük.

Other early evidence of maritime coast-to-coast trading routes is found in the Middle East. Inscriptions from Mesopotamia, a region extending over parts of modern day Iraq and Syria, indicate that as early as 2300 BC, Indian mariners were transporting copper, timber, ivory and pearls from the highly developed Indus valley into western Asia. On that evidence, a kind of long-distance trading across the sea developed in very early times.

2.1 > Excavations on the Isthmus of Corinth in the 1960s exposed a 2600-year-old portage cartway.



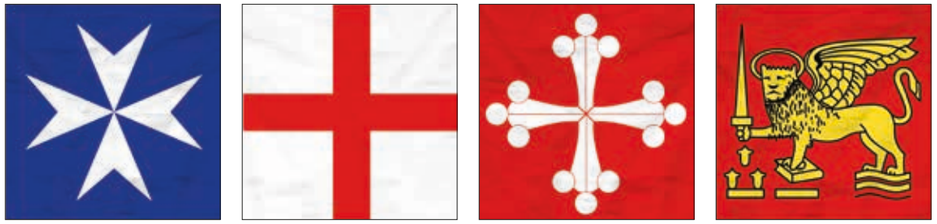
2.2 > In the third century BC the most important powers in the western Mediterranean were Carthage, Rome and Greece. Rome especially expanded its sphere of influence in the following centuries.

Coastal links

In the centuries that followed, maritime trade in Europe and Asia became increasingly important. Initially, strong regional trading zones emerged – for example, around the East China and South China Seas and around the Mediterranean. In the Eastern Mediterranean the traders along the most heavily frequented shipping routes sought ways of shortening the routes very early on. Around 600 BC a paved roadway known as the Diolkos was built across the Isthmus of Corinth so that ships could be portaged overland from the Gulf of Corinth to the Saronic Gulf. This shortcut at the narrowest part of the land bridge made it possible to avoid the 400-kilometre detour around the Peloponnese peninsula. The portage road remained in use in the first century AD until ships became large and fast enough to make it redundant.

Supremacy in the Mediterranean

Coastwise trade was not solely about the pure exchange of goods, but also about gaining economic supremacy in a region. Time and time again, coastal dwellers fell into disputes over strategically important trading posts or mineral deposits, which not infrequently led to military conflicts. This is exemplified by the conflict lasting more than 300 years between the two main powers on the Mediterranean – the Romans and the Carthaginians. In the sixth century BC both powers were already vigorously engaged in commerce. Carthage dominated the area in the north of present-day Tunisia and traded predominantly in the western Mediterranean. At that time, Rome was beginning to expand its territorial dominion beyond the Apennine Peninsula. To avert competition, the two empires concluded several agreements over the course of time. The very first was negotiated around 500 BC and clearly defined each empire's sphere of influence. The Romans were not permitted to proceed westward along the North African coast beyond a certain point north of the city of Carthage. If Roman merchants wished to conduct business in the Carthaginian territories in North Africa and on Sardinia, they could only do so in the presence of a Carthaginian official. In the western part of Sicily ruled by Carthage, on the other hand, Roman merchants were given equal stand-



Amalfi Genoa Pisa Venice

2.3 > To this day the emblems of Amalfi, Genoa, Pisa and Venice adorn the flag of the Italian Navy. The erstwhile city-states, whose growth owed much to a fortunate combination of ocean, city and hinterland, reached the heights of their prosperity in the Middle Ages.

ing with Carthaginians. For their part, the Carthaginians gave an undertaking not to attack Roman ruled cities in Latium, the region around the city of Rome.

Since both empires were still expanding, further treaties followed in 348 and 306 BC. These affirmed that both Rome and Carthage should respect each other's extended territories. Among other concessions, Carthage was granted sovereignty over Libya and Sardinia.

In the ensuing years Rome proceeded to expand, ultimately dominating the entire Apennine Peninsula. The old rivalry persisted, however. Finally it erupted into a series of conflicts known as the Punic Wars, from which the Roman Empire emerged victorious in 146 BC. The city of Carthage was completely destroyed. From that time onward, Rome enjoyed a long period as the dominant power in the Mediterranean.

From the fifth century AD, the Roman Empire fell into decline. In the aftermath, various Islamic peoples rose to prominence around the Mediterranean and in the Middle East. Cities that became important trading posts at that time were the Syrian city of Damascus, the city of Cairo's precursor settlements, Isfahan in present-day Iran, and Baghdad, later the capital of Iraq – inland cities which were nevertheless centres for the bulk of the trade between the coasts of the Mediterranean and China and India. For several centuries, Muslims controlled the trading routes along the North African coast, the Mediterranean, and the Red Sea which gave access to the Indian Ocean. In the view of historians, their great accomplishment is to have linked the trading routes of central and western Asia and the Mediterranean region into one large system.

In the early ninth century, the western Mediterranean was dominated largely by Muslim pirates who plundered the coasts and took control of Sardinia and Sicily. Christians referred to them indiscriminately as Saracens although they belonged to various Islamic peoples. The city of Amalfi on the present-day Italian Riviera was safe from the attacks due to its particular location. Situated on a steep coast on the Sorrentine Peninsula on the Gulf of Salerno, it was well protected. Its merchants succeeded in striking up business ties with the Saracens – and thus in gaining access to the important Islamic markets in North Africa. At that time the Saracens had key trading contacts with North Africa. This enabled Amalfi to grow into a major trading centre and build up a larger fleet. The city became so powerful that it eventually defeated the Saracens in the port of Ostia near Rome and significantly weakened their influence on trade in this region. Amalfi, along with Genoa, Pisa and Venice, ranks as one of the Italian maritime republics – city-states which rose to become major economic powers through astute trading and tactics, and whose trading ties reached as far as Byzantium, the empire in the eastern Mediterranean whose capital city was Constantinople, modern-day Istanbul.

Also impressive is the history of the Maritime Republic of Venice, which developed into an important economic metropolis from around the seventh century. The city had major advantages with regard to the exchange of goods. It possessed a well-established textile industry and a river port with water of considerable depth, and controlled the hinterland by means of a functioning network of rivers. Part of the reason for Venice's dynamic development was the city's aggressive actions towards its neighbours. Venice subjugated neighbouring competitors and controlled Dalmatia, the region that is now part of Croatia and Montenegro. Diplomatic skill, military brutality and trade boycotts targeting competitors: this was the mix with which Venice ultimately extended its sphere of influence to Crimea and Cyprus. Only in the course of the eighteenth century did the Maritime Republic decline in significance because trade in the Mediterranean no longer played such a major role. Thereafter, intercontinental trade to America and Asia took on more economic significance and was dominated by other powers such as England and the Netherlands.

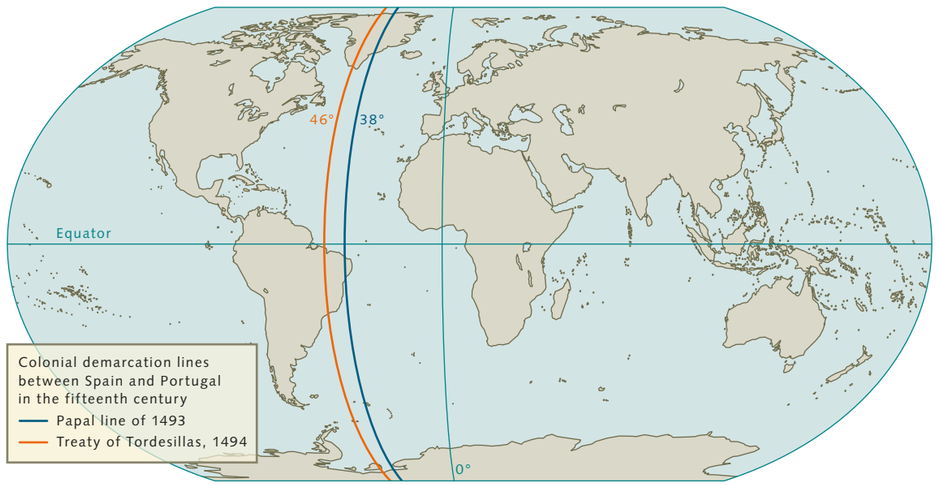
The Hanseatic League – a strong alliance for 500 years

From the middle of the twelfth century, the Hanseatic League was a large trading alliance that formed in the Baltic and North Sea region, ranging from Bruges in present-day Belgium to Reval (now Tallinn) in Estonia. Originally it consisted of an alliance of merchants whose most important aim was safe passage through the coastal waters of the North Sea and the Baltic, and who joined forces for protection against pirates. Ultimately almost 300 cities in northern Europe became members.

Not all of these were on the coast; some – like Cologne, for example – were a long way inland. The success of the Hanseatic League rests particularly on the fact that it shipped goods which were only produced in certain regions to others where they were in heavy demand. Cloths, furs, wax, salt, dried or salted fish, cereals, timber and beer accounted for the bulk of the volume of goods. For some long time, textiles were the most significant commodity. The Hanseatic League was not dissolved until the mid-seventeenth century.

Coastal prosperity and animosity

The extent to which power interests dominated merchant shipping after Christopher Columbus discovered the New World in 1492 is underlined by the way in which intercontinental trade unfolded between Europe and the ports of the newly discovered continent. The most powerful maritime nations at that time were Portugal and Spain. Spain had taken possession of the New World, while Portugal was keen to secure the newly opened trade routes to India along the African coast. Furthermore, the Portuguese had already seized Madeira and the Azores at the beginning of the fifteenth century. In 1493 Pope Alexander VI therefore issued a decree that the world beyond Europe should be



2.4 > At the end of the fifteenth century two maritime powers, Portugal and Spain, wielded such huge influence that Pope Alexander VI shared out the world between them. Territories to the west of the blue line in the Atlantic were awarded to Spain, and those to the east, to Portugal. The demarcation line was adjusted in the Treaty of Tordesillas.

Small-scale raiding tactics – privateering

Conflicts over supremacy at sea were not always fought out in open battles. In the dispute between the English and Spanish Crowns in the mid-sixteenth century, for example, Queen Elizabeth I decided to adopt special tactics. She hoped to use small-scale raiding to cause economic damage to the Spaniards. Instead of sending a fleet of warships, the battle against Spain was privatized. With royal permission, experienced sea captains were hired as privateers to prey upon the trading ships of the Spanish Crown. For this purpose the English Crown issued them with letters of marque – official licences for international piracy. Moreover, contracts regulated what share of the spoils the captains were allowed to keep or had to surrender to the royal court.

One of the most famous privateers of his time was Francis Drake, who embarked on his circumnavigation of the globe in 1577. Drake's role was not merely to plunder merchant ships. He was additionally given the risky mission of sailing round the southern tip of America via Tierra del Fuego and attacking the Spanish colonies on the Pacific side by the back door, as it were. He accomplished his mission. He sailed north up the Pacific coast of South America and ambushed the Spanish colonial rulers of the Pacific towns. He even raided Lima, the port of the Spanish Viceroy. Drake plundered gold, silver, precious stones and costly spices. The value of the booty at the time was legendary – an estimated 500,000 pounds, the equivalent of around 100 million euros in today's money. Drake was knighted for his exploits, which amounted to an insult to the Spanish Crown.

For several centuries more, privateering was commonplace on the world's oceans – particularly on the routes from Europe to Asia in the Indian Ocean and in the Pacific. Finally, in the Paris Declaration Respecting Maritime Law of 1856, the issuing of letters of marque was internationally outlawed.

2.5 > A hero in England, a villain in Spain: the privateer Sir Francis Drake (1540–1596).

divided up between Spain and Portugal. Spain received possession of the hitherto known western world and all western territories that were yet to be discovered. Portugal was allotted the eastern world. The proposed boundary between west and east was a longitudinal line in the middle of the Atlantic Ocean at the level of the 38th meridian. However, the Portuguese protested and demanded that the boundary be shifted about another 1000 kilometres to the west, i.e. approximately to the longitude of 46 degrees west. Their protest was ultimately successful; in 1494 the demarcation line was defined accordingly in the Treaty of Tordesillas. Today it is suspected that the Portuguese already knew the course of the South American coastline, because thanks to the westward displacement of the line, a large part of present-day Brazil was apportioned to Portugal. Just a few years after the Treaty, the exploitation of South America commenced. The conquered territories were turned into colonies. Large quantities of gold and silver were shipped from the New World to Europe. Important seaports for this early intercontinental cargo traffic between Europe and America were Seville and Lisbon. The Spanish fleet was the largest and most powerful of its time.

But in the following decades, another maritime power began to stake its claim: England. The early decades of the sixteenth century saw the rising influence of an English bourgeoisie which venerated its own king, rather than the Pope, as the head of its church. Conflicts between Spain and this upstart newcomer were frequent, and in time they began to escalate. In the mid-sixteenth century, the English discovered the waters off Newfoundland to be rich fishing grounds because of the large stocks of cod to be found there. The Spaniards considered this fishing to be poaching in the waters of the western hemisphere granted to them by the Pope. Tensions rose when the Spaniards attacked English ships which were docked in the Gulf of Mexico awaiting shipyard work. Although no overt military conflicts broke out at that stage, Queen Elizabeth I sent English captains on sea raids. For a long time the conflict therefore remained more of a trade war.

Not until 1588 did a major naval battle break out between the powers. The Spanish King Philip II sent the large Spanish fleet, the Armada, to attack England and overthrow

2.6 > In 1607 Spain fought the Netherlands off the coast of Gibraltar. The Spaniards lost a substantial part of their fleet and consequently their maritime supremacy.

Elizabeth I. The invasion of England failed, however. The English were able to repel the Armada in the English Channel. But contrary to many accounts, the Spanish fleet was not destroyed completely. Spain remained a strong maritime power. Only a surprise attack by the Netherlands in the Bay of Gibraltar in 1607 was so resounding that Spain lost a substantial part of its fleet and its role as the strongest maritime power.

Historical shipping hubs

To trade between coasts separated by vast distances, it was necessary to establish ports on certain routes where crews could replenish their food and fresh water. Many of these ports developed into shipping hubs. One example is Mauritius. The island had been recorded on the maps of Arabian mariners since the tenth century. Portuguese sailors discovered it at the start of the sixteenth century as a stopover for their ships on their way to Asia and back to Portugal. The Portuguese only used Mauritius as a staging post, however, and did not turn the island into a colony. In the mid-seventeenth century the Dutch eventually settled on the island as colonial rulers, introducing sugarcane and commencing rum production. Then, in 1715, the island was occupied by the French. They not only sold food, water and, most importantly, sugar and rum to the merchant ships that headed for Mauritius during their long voyages, but also used the prime strategic location to attack English ships in transit between Europe and Asia as they traversed the waters around Mauritius. The British put a stop to this piracy in 1810 by themselves mounting an attack on the French and taking control of the island. Thereafter Mauritius was used mainly by European merchants engaged in very active maritime trading between Europe, South America, India and South East Asia. Goods transshipped on Mauritius included textiles and spices from India, porcelain from China and ivory from Africa. Only the advent of modern motorized ships that could

cover long distances non-stop, and finally the construction of the Suez Canal, caused the island's significance to decline. In contrast, other ports managed to maintain their status as important shipping hubs for centuries. For instance, from as early as the beginning of the seventeenth century, the Dutch port of Rotterdam was an important base for the Dutch East India Company, which was active in the spice trade. From that time to this, goods from all over the world have been shipped to Rotterdam and then transported onward into mainland Europe – by ship down the Rhine, in the past, but today also by freight trains and heavy goods vehicles. Measured in terms of the volume of goods transshipped, Rotterdam ranks as the world's sixth largest port today. Containers, natural gas and petroleum are mainly unloaded here.

Coasts develop as holiday destinations

The world's coasts are more than just trading zones, military border zones or sources of food supply. Very early in human history, people also discovered the significance of coasts as a place of recreation, health and a wellspring of strength for the soul. In 414 BC the Greek philosopher Euripides wrote: "The sea washes away and cleanses every human stain." He was referring particularly to the coastal zone where the elements of earth, water and wind meet. The Romans embraced the idea of the ocean's healing power. Strolls and banquets on the beach were integral to the cultivated leisure of the aristocracy. For this sweet idleness, the Romans used the word "otium". They did not bathe in the sea, however. Instead they established numerous thermal baths at warm volcanic springs, like those on the Italian island of Ischia which are still in use today.

In the Middle Ages, humans became more estranged from the ocean again. Despite the spread of trade between coasts, some of which were very long distances apart, the oceans were generally considered to be menacing and inhabited by monsters. The beaches of the Mediterranean were thought of as forbidding, pirate-infested territory.

2.7 > Back in 1907 the promenade at Brighton was already popular with visitors, and the appeal of the English coastal resort for tourists remains undiminished to this day.

It was not until the seventeenth century that the ocean reverted to being a yearned-after location. One influence in this direction was the English scholar Robert Burton, whose book *The Anatomy of Melancholy* published in 1621 was a collection of historical and philosophical reflections from the previous 2000 years on the theme of melancholy. In this treatise he praised summer retreats beside the sea and advised those suffering from melancholy to observe the restless ocean.

The English gentry, or country nobility, also began to appreciate the importance of physical exercise in the fresh air. In the town of Scarborough on the east coast of England, acidic mineral springs were discovered in 1626. The population credited the water with healing effects, and the fame of the springs quickly spread throughout the country. By the beginning of the eighteenth century the town was developing into an established spa resort, although at first it was normally only members of the gentry who could afford to stay there.

The English doctor Richard Russell prompted a surge in popularity with his studies on the healing effect of sea water. In 1747 he settled in the seaside resort of Brighton on the south coast of England. He wrote that people with glandular illnesses would recover more quickly thanks to healing baths in the cool water, and that women suffering from physical weakness also recovered quickly. Countless people now began to travel, particularly from London, to convalesce in Brighton and it developed into one of the most popular coastal resorts in the country – no longer just for the nobility but also for members of the well-off middle classes.

Germany's first seaside resort, Heiligendamm on the German Baltic coast, was founded in 1793. In the decades that followed, many other coastal locations in Europe turned into seaside resorts.

An entirely different kind of coastal tourism was launched by the Hamburg shipowner Albert Ballin in the 1890s: the passenger cruise, visiting a series of ports of call along the coasts. Ballin had been operating passenger ships on the route between North America and Europe for some long time. Many of those who set off in Ballin's ships were emigrating. Since the ships were not sufficient-

2.8 > The Hamburg shipowner Albert Ballin is acknowledged as the inventor of the cruise. In order to make better use of his passenger ships' capacity in winter, from 1891 he began to offer cruise trips to cities all around the Mediterranean.

ly used in the winter period, Ballin came up with the idea of filling the ships' capacity by offering pleasure trips to warmer regions. On 22 January 1891 the passenger ship *Augusta Victoria* put out to sea from Cuxhaven on the world's first pleasure cruise. It was at sea for 57 days, 22 hours and 3 minutes, and headed for regions which sounded very exotic to most northern Europeans in those days: Egypt, the island of Malta or the port of Lisbon.

What coastlines can do

From a human perspective, coastal habitats perform a range of other functions, the "ecosystem services", which can be categorized as follows:

- Supporting ecosystem services, which are necessary for the provision of all other ecosystem services and include, for example, primary production and nutrient cycles;

- Regulating ecosystem services, which provide benefits and utility from the regulating effects of coastal waters and their ecosystems;
- Provisioning ecosystem services, which encompass products and goods for human use on the one hand and spaces provided by the sea on the other;
- Cultural ecosystem services, which include a range of functions and utility serving the nonmaterial well-being of humans.

The concept of ecosystem services is well-suited to a systematic categorization and analysis of the multitude of services provided by coastal regions that are of material or nonmaterial benefit to humankind. However, such analyses often do not address societal issues such as, for example, the question of equitable distribution or of which societal groups benefit from services. In this respect a critical view must be taken of one-sided, purely economic assessments of ecosystem services that do not embrace sociocultural or ethical considerations.

Where habitats are considered solely with respect to the services they provide to humankind, all too often no consideration is given to the fact that every habitat can be of value whether it is utilized by people or not. Environmental ethicists speak of “non-utility value”. This includes the existence value ascribed by humans to beings such as corals or habitats such as mangrove forests regardless of whether they will ever be able to utilize or experience these organisms or habitats. The existence value is based purely on a sense of joy as to the fact that these species or habitats exist at all.

The non-utility value also includes the bequest value which is based on the human desire to pass on natural assets to future generations in as intact a condition as possible. Non-utility values, which are categorized as cultural ecosystem services, are not easily measured. Assessments of non-utility values must also obtain, for example, knowledge held by local communities and other stakeholders – such as knowledge of special religious or spiritual significance of a habitat for the population. Only if such knowledge is taken into account can the value of a habitat be measured.

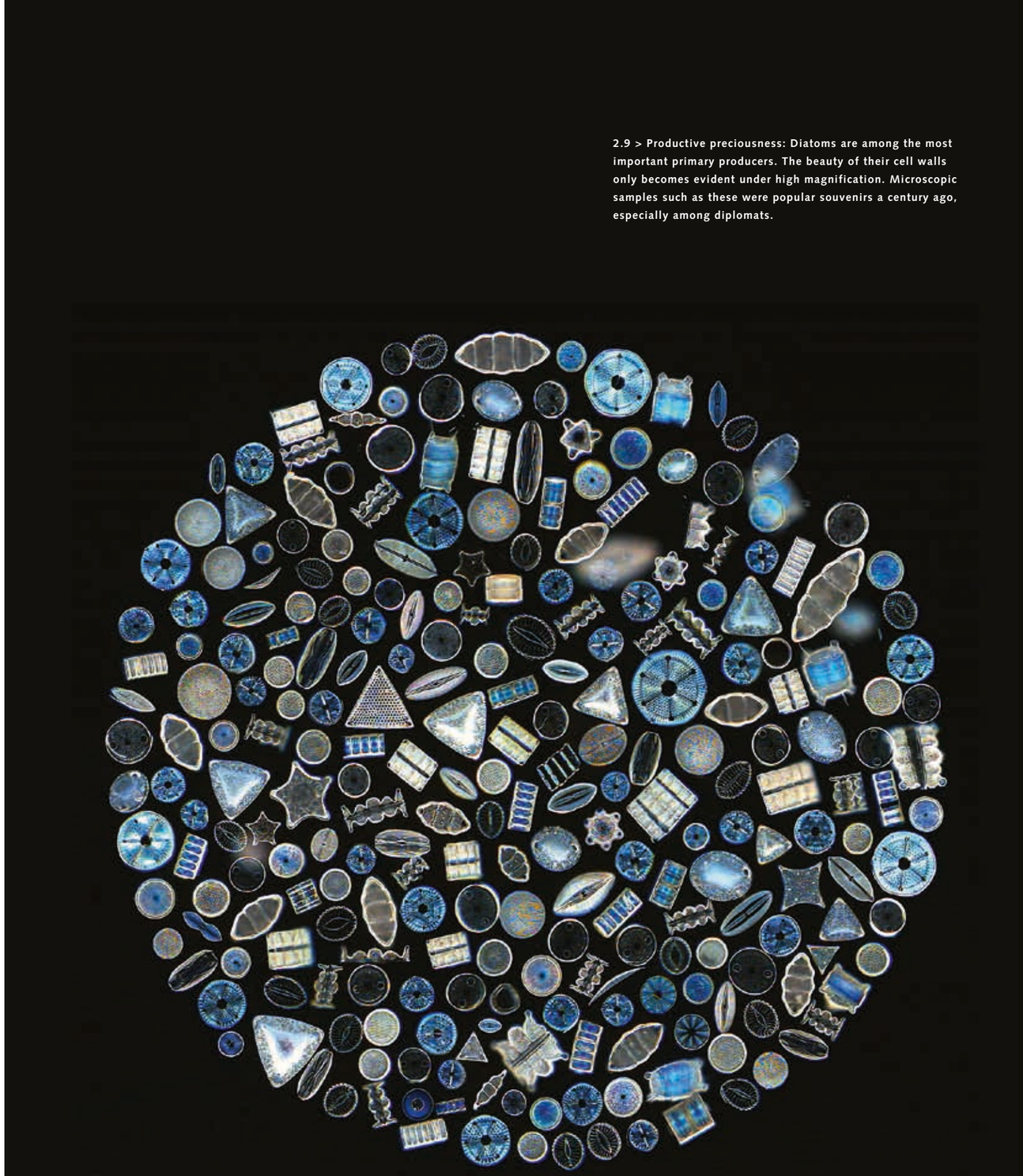
SUPPORTING ECOSYSTEM SERVICES – THE BASIS OF FOOD WEBS

Small but productive

Primary production, the production of biomass by plants and microorganisms, is the basis of all marine life as well as the most important ecosystem service. Plants and microorganisms mostly obtain their energy from **photosynthesis** or from certain chemical compounds; they produce high-energy substances such as glucose (sugar). The most important primary producers in the oceans include microscopically small components of marine phytoplankton such as diatoms, coccolithophorid algae and cyanobacteria (formerly called blue algae). Since phytoplankton is dependent on sunlight, it lives exclusively in surface ocean waters. Similar to terrestrial plants, in addition to sunlight the phytoplankton needs nutrients such as phosphorus and nitrogen compounds. These are primarily transported by rivers into the sea. As coastal waters offer both sufficient sunlight and nutrients, they are among the particularly productive oceanic regions. This productivity also gives rise to particularly abundant fish stocks since tiny crustaceans as well as larvae of fish and bivalves feed on phytoplankton, and they in turn are a food source for fish.

However, not all the nutrients are derived from rivers. In the upwelling systems, for example, nutrient-rich cold water rises from the depths of the oceans. Such systems can be found along the coasts of Chile, California, Mauritania and Namibia. Their primary production is correspondingly high. Similar to the productive coastal waters, these upwelling systems give rise to particularly abundant fish stocks.

But the level of primary production in coastal waters is not only dependent on the nutrient quantities transported by currents and rivers but also on the intensity of water mixing. This mixing of water masses results in major variations in nutrient concentrations between different coastal segments and water depths. In the Bay of Bengal, where the Ganges and Brahmaputra form a large delta and transport a great amount of nutrients from the



2.9 > Productive preciousness: Diatoms are among the most important primary producers. The beauty of their cell walls only becomes evident under high magnification. Microscopic samples such as these were popular souvenirs a century ago, especially among diplomats.

Himalaya Highlands into the ocean, the level of primary production changes with the monsoon. In the summer, when the moist monsoon winds blow, there is a lot of precipitation which strongly dilutes the coastal waters, thus reducing their nutrient concentration.

Another one of the world's particularly productive coastal regions is the South China Sea. This is because the Pearl River reaches the sea west of Hong Kong. It has several tributaries and forms South China's largest river system. Its watershed basin measures approximately 452,000 square kilometres, which is roughly equivalent to the land area of Sweden. Corresponding to the size of the river system, it transports enormous quantities of nutrients into the South China Sea.

Seagrass meadows
Seagrass meadows are special habitats found on sandy soils in shallow waters and mudflats. While seaweeds use holdfasts to attach to rocks, seagrass sets roots with which it stabilizes sandy marine sediments. Numerous organisms, such as smaller seaweeds or molluscs, can gain hold among the plants, often making seagrass meadows particularly biodiverse habitats. Moreover, seagrass is an important food source for many species of marine fauna and waterfowl.

REGULATING ECOSYSTEM SERVICES – PROTECTION FROM POLLUTION AND STORMS

The coast – a wastewater treatment plant

Coastal waters play an important role in purifying effluent and removing pollutants conveyed by rivers and sewers and deposited from the atmosphere. They thus have a regulating function and are vital for nutrient decomposition, especially for the breakdown of nitrogen compounds. Plants need nutrients, notably nitrogen and phosphorus, in order to grow. To increase the productivity of arable land and achieve higher yields, these nutrients are applied to agricultural land in the form of slurry, sewage sludge or artificial fertiliser.

In intensive agriculture regions high levels of nutrients enter the soil as the crop plants grown tend to not fully take up the fertilizers applied. Rainwater washes these surplus nutrients into the groundwater, streams and rivers, and ultimately into the sea. The phosphorus and nitrogen compounds also increase algal growth. Where there is an oversupply of nutrients, algal growth can be so rapid that it results in pronounced algal blooms. The more abundant the algae, the more intensive is their decomposition by oxygen-consuming microorganisms in deeper water layers. This phenomenon is called eutrophication. In extreme cases it results in zones devoid of oxygen in which fish, crustaceans and molluscs can no longer survive.

With the intensification of farming, the number of oxygen-deficient or oxygen-depleted zones in coastal waters has sharply increased since the 1960s, especially in the northern hemisphere. Worldwide some 400 coastal areas are regularly affected by oxygen-deficiency; these areas cover a total of 245,000 square kilometres, which is roughly equivalent to the size of Romania. Oxygen-deficiency primarily affects coastal waters in Europe, along the eastern US seaboard, the Gulf of Mexico and increasingly also in China. The decomposition of nitrogen compounds is of particular significance in this context as these enter the seas in large quantities. Fertilizers, slurry and excrements mostly contain nitrogen in the form of ammonium ions (NH_4^+). In the presence of oxygen, ammonium oxidizes to nitrate. In environmental waters, microorganisms (denitrifying bacteria) convert the nitrate to gaseous nitrogen (N_2) in a process called denitrification. Algae cannot use gaseous nitrogen as a plant nutrient. Thanks to denitrification, coastal waters to a certain degree function as the ocean's wastewater treatment plants.

However, if the quantities of nutrients entering the ocean are too large, these can no longer be fully decomposed, thus leading to eutrophication.

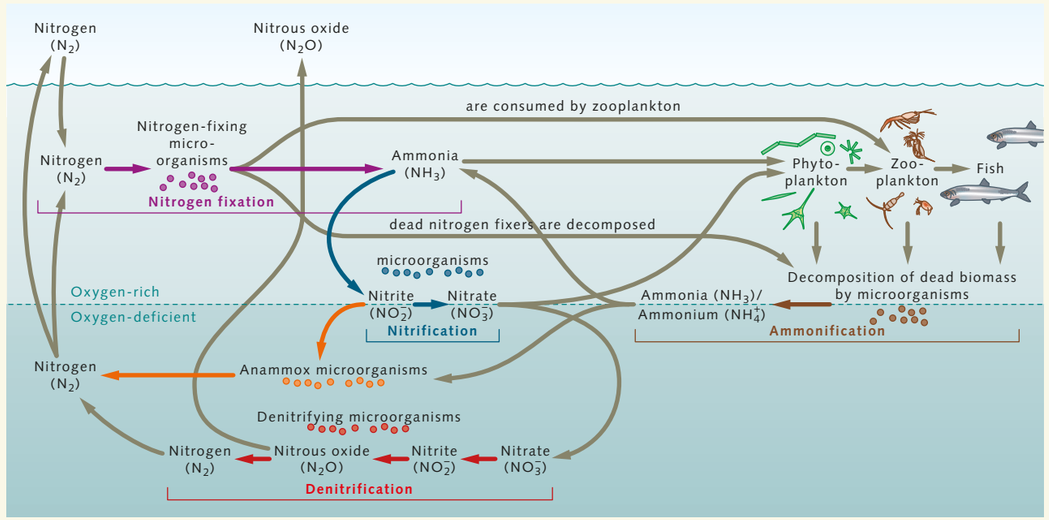
The various plant communities occurring in coastal waters contribute significantly to the elimination of nutrients. These communities include, in particular, mangroves and seagrass meadows, the roots of which take up large quantities of nutrients in the same manner as terrestrial plants. Nutrient decomposition is further enhanced by the numerous organisms living in the seabed, such as molluscs or worms. Millions upon millions of these organisms live buried in the seabed. Their several centimetres long burrows give many sediments the appearance of sponges. Compared to the normally solid and dense sediment which water can only enter through the spaces between the sediment grains, the numerous burrows enlarge the surface area on which microorganisms can engage in denitrification. This significantly enhances the effluent purification function of coastal waters.

Transformations of a key nutrient – the nitrogen cycle

Nitrogen is a nutrient vital to plant growth. In the environment, nitrogen undergoes several conversions in a natural cycle through biological processes along various pathways. Gaseous atmospheric nitrogen is largely converted into nitrogen compounds by microorganisms; this makes these compounds available to macro-algae, phytoplankton and terrestrial plants. When the biogenic nitrogen compounds are converted back into gaseous nitrogen the cycle is completed.

Elementary (pure) nitrogen (N_2) constitutes 78 per cent of the Earth's atmosphere, but this element cannot be used by plants directly. However, a number of microorganisms are capable of using gaseous nitrogen. These organisms include the marine cyanobacteria (formerly termed blue algae) as part of the phytoplankton, and the terrestrial rhizobia associated with legumes such as beans. They can take up pure nitrogen and convert it into ammonia (NH_3) or ammonium ions (NH_4^+). This process is called nitrogen fixation. In the further course of the cycle, the ammonia or ammonium is taken up by other groups of microorganisms, and especially by *Nitrosomonas* bacteria, which convert it into nitrite ions (NO_2^-) and ultimately into nitrate ions (NO_3^-). This conversion process is called nitrification. These ions can be taken up directly by macro-algae, phytoplankton and terrestrial plants which use it to assemble amino acids among other organic compounds. When they die, their dead biomass is decomposed by a multitude of other microorganisms.

Along with the rest of the biomass, the nitrogen compounds contained in the macro-algae, phytoplankton and terrestrial plants are also decomposed, primarily through a process called ammonification. As part of this process, the nitrogen compounds contained in dead biomass, such as the amino acids, are converted back into ammonia and ammonium. The ammonia and ammonium are then once again available for nitrification by microorganisms, and by *Nitrosomonas* in particular. The nitrogen cycle is completed by a process of decomposition called denitrification, which ultimately is also of particular importance to keeping waters clean. Nitrate ions (NO_3^-) contained in water are converted directly into elementary nitrogen (N_2) as well as nitrous oxides (NO and N_2O) by microorganisms (denitrifying bacteria). As a result, terrestrial plants and the majority of phytoplankton can no longer use these substances as nutrients.



2.10 > Nitrogen is the most plentiful element in the Earth's atmosphere as well as an important plant nutrient. In nature, nitrogen circulates and is continuously converted chemically from one form into another by bacteria and plants.

2.11 > The estuary of the Salak River on the island of Borneo is dominated by mangrove forests. They protect the coastline from hurricanes and storm surges.

Coastal waters also have a regulating function when it comes to the decomposition or neutralization of pollutants such as persistent chemical compounds or heavy metals transported into the coastal seas by rivers or the atmosphere. The dilution of pollutants is one of the processes, while they are also sequestered into the sediment through the activities of sediment-dwelling organisms which, for example, filter pollutants from the water with their feed and subsequently deposit them in the sediment with their faeces. While the pollutants are not removed from the environment in this manner, their sequestration into the sediment prevents other marine organisms from ingesting them. Ultimately these processes also prevent pollutants from being ingested by humans through the food chain.

Taming the ocean's force

Coastal habitats such as dunes, coral reefs and mangroves perform a key protective function for humans as they are able to break winds and swells, thus regulating the oceans' physical forces. For example, Abidjan, the Ivory Coast town, is protected by seaward dunes, as are the Dutch city of Amsterdam, the Nigerian city of Lagos or Durban in South Africa.

The importance of mangrove forests for coastal protection has become particularly evident in recent years. Tropical storms can produce tidal waves of up to 7 metres in height. As a study conducted by British researchers has shown, mangroves provide outstanding protection against such storm surges and hurricanes. Using mathematical modelling the scientists were able to demonstrate that a one kilometre wide mangrove forest can be expected to reduce surface wind energy by 75 per cent and wave height by up to half a metre. Considering that natural mangrove forests can be many square kilometres in size, they offer significant protection, for example along the southern coastline of Florida where they cover an area of roughly 2000 square kilometres. However, mangrove forests along many tropical coasts have suffered large-scale destruction over many years. In Indonesia, for instance, they were removed to make space for aquaculture. Colombia has lost almost 20 per cent of its mangrove forests – here they fell victim to timber extraction. Studies have shown that the damage caused by the 2004 tsunami in the Indian Ocean, and especially the damage caused along the Indonesian coast, would not have been anywhere near as severe if the mangrove forests had not been cut down over many years.

PROVISIONING ECOSYSTEM SERVICES – FISH, DIAMONDS, AND A WHOLE LOT MORE

Protein for a growing world population

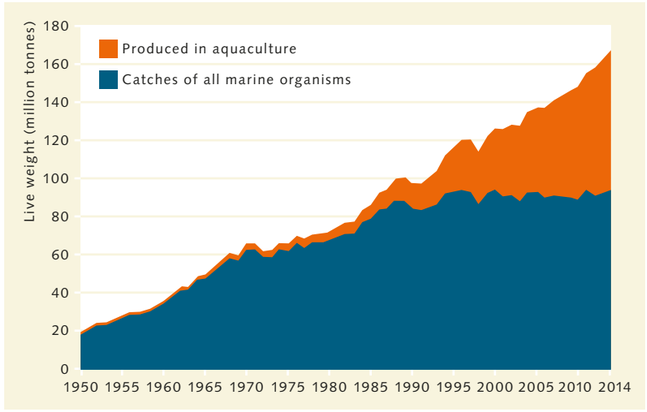
Since time immemorial humans have eaten fish and seafood from the oceans. For thousands of years marine fish were only consumed near the coasts as it was not possible to transport fish inland over long distances. Over time, however, processes were developed that made it possible to preserve fish. At first, fish was preserved in salt. Later it was canned, which made it possible to transport it over great distances. Only when freezing technology was invented and allowed for the almost indefinite preservation of food did fish become a staple food even far away from coastal regions. Today fish is consumed in significant quantities worldwide and plays a major role in human protein supply. This is particularly true for West African countries such as Senegal or the small island states in the South Pacific where fish is one of the most important staple foods.

With the growth of the world population, the consumption of fish and seafood has increased vastly since the middle of the previous century. While in the 1960s the per capita consumption level stood at 9.9 kilograms, it passed the 20 kilograms mark for the first time in 2014, as the Food and Agriculture Organization of the United Nations (FAO) reports. This means that the consumption of fish and seafood doubled in just half a century. According to the United Nations, the world population will grow from 7 billion to approximately 9.5 billion people by 2050. More than an additional 2 billion people will need to be supplied with food and with protein in particular. Fish will contribute a significant proportion of this protein but it is obvious that wild caught fish cannot supply these additional quantities of protein if fish stocks are no longer to be subjected to overexploitation.

The degree to which coastal waters contribute to the supply of wild caught fish and seafood is difficult to quantify. Since the FAO's global statistics do not differentiate between coastal waters and other waters, there are only rough estimates in the region of 90 per cent. In Europe, fisheries experts distinguish between coastal fishing, middle water fishing and distant water fishing, differentiating by size and levels of motorization of fishing vessels. Coastal fishing is dominated by smaller trawlers that are mostly 18 to 24 metres in length and have engine sizes of up to 300 HP. It overlaps with middle water fishing with trawlers that are mostly 18 to 32 metres long and have engine sizes of no more than 600 HP. Distant water fishing is carried out by even larger vessels up to and including factory ships with on-board facilities for processing and freezing caught fish.

Another definition of coastal fishing is that it is limited to the shelves – a term that describes the areas of relatively shallow water near the coastlines. The shelves slope gently to an average depth of 130 metres, ending at the break to the continental slope, which falls more steeply to greater depths. According to this definition, the fisheries in many of the shallow marginal seas, such as the East

Aquaculture
The term "aquaculture" covers several different forms of production. Traditionally the term was used for freshwater fish production such as carp farming. However, aquaculture also includes mariculture, i.e. the cultivation of marine organisms at sea. There are now also hybrid forms in which marine animals are bred on land in special salt water tanks.



2.12 > The quantities of fish and seafood produced today are many times greater than they were in 1950. While aquaculture was insignificant at first, it now provides almost half of the global production.

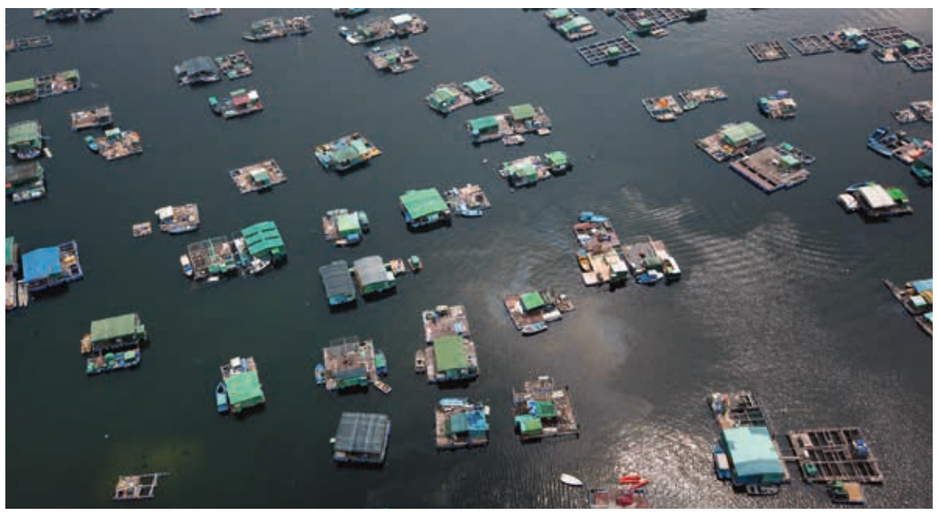
China Sea or the North Sea, would be considered coastal fisheries in their entirety, despite the fact that in purely legal terms a country's coastal sea is limited to the 12 nautical mile zone.

Fish to feed the world

Aquaculture – the production of fish and other organisms in specialized installations – can play an important role in securing fish supplies in the future. This form of production has grown significantly in recent years while the quantities of fish and seafood caught in the wild have hardly changed. In 2014 a total of 167.2 million tonnes of fish and seafood were consumed worldwide. Of these, 93.4 million tonnes were caught in the wild, 73.8 million tonnes originated from aquaculture production, and 26.7 million tonnes of the latter were produced at sea, exclusively in coastal waters. However, a much larger quantity, i.e. 47.1 million tonnes, now comes from land-based aquaculture installations. China accounted for the largest share of global aquaculture production at 60 per cent.

Aquaculture must be carried out in a sustainable way if it is to offer hope for the future, as major mistakes have been made in recent decades. For example, in the 1990s hundreds of kilometres of mangrove forests along the coast of Indonesia were cut down in order to establish shrimp farms in the form of aquaculture monocultures. In many places, shrimp as well as fish continue to be produced intensively and with a view to maximum yields. As a result they are more susceptible to diseases than their wild relatives and are preventively given antibiotics and other medication – with unforeseeable repercussions for the marine environment as well as for the end consumers. Another problem is the fact that the animals' faeces lead to regional marine eutrophication, which considerably impairs water quality.

Meanwhile there has been something of a shift in thinking towards environmentally sound aquaculture. Mixed aquaculture systems in which several organisms are kept together and in which the faeces of one species serve as a food supply for other organisms are regarded as a promising alternative. Such systems are termed Integrated Multi-Trophic Aquaculture (IMTA). They allow for the combined production of, for example, fish, algae, molluscs and sea cucumbers. The fish are fed, while the sea cucumbers feed on excess fish feed and fish faeces. The algae, for their part, take up inorganic substances exuded by the fish. The molluscs, finally, filter particles from the water and keep the installation clean. The feed is thus put to optimum use while several different products can be harvested from a single installation.



2.13 > China contributes 60 per cent of the global aquaculture production. Aquaculture installations such as the one shown here in Tolo Harbour near Hong Kong can be found in many of China's coastal regions.

Natural gas and oil extraction

Subsea deposits of natural gas and oil are a significant provisioning service from an economic perspective. Although the bulk of both resources are extracted onshore, the proportion coming from the ocean (offshore gas and oil) is now substantial. Currently, offshore oil accounts for about 40 per cent and offshore gas for about 30 per cent of global extraction. It is not always possible to draw a hard and fast line between coastal and offshore drilling rigs, but one certainty is that offshore extraction began directly on the coast and then shifted ever further out to sea. One reason for this is the increasing exploitation of coastal deposits, but another factor is the technical progress that has made it possible to extract gas and oil from ever greater depths.

Offshore oil extraction began surprisingly early on. The first oil rigs in the sea were built back in 1896 in the Summerland field off the coast of Santa Barbara in California. In 1937 for the first time, oil was drilled from a platform two kilometres off the Gulf Coast of the United States. In the 1970s the relatively shallow North Sea with an average water depth of 90 metres was exploited as a natural gas and oil field. The first drilling platform was erected in 1971 in the Ekofisk oilfield on the Norwegian continental shelf. The Ekofisk field is 270 kilometres away from the Norwegian coast – in the middle of the North Sea, and thus a very long distance from the coast. Exactly as for fisheries, it is unclear how much of this sea area can reasonably be classified as coastal.

For example, in Ghana where the shelf is relatively slender and only extends 60 kilometres before dropping steeply into the deep sea, the large Jubilee oilfield is markedly closer to the coast. It is located on the steep slope at the edge of the continental shelf where the water depth is already around 1100 metres. The Iara oilfield off the Brazilian coast, only discovered in the year 2008, is in a similar situation. It is located around 230 kilometres off Rio de Janeiro at the foot of the continental slope at around 2200 metres depth.

It is now rare for oil drilling to take place directly on the coast within sight of land. With a few exceptions, most natural gas and oil fields today are found at water depths of several hundred metres. Among the exceptions are smaller and older natural gas or oil drilling rigs on the Dutch and German North Sea coast, which are just a few kilometres offshore.

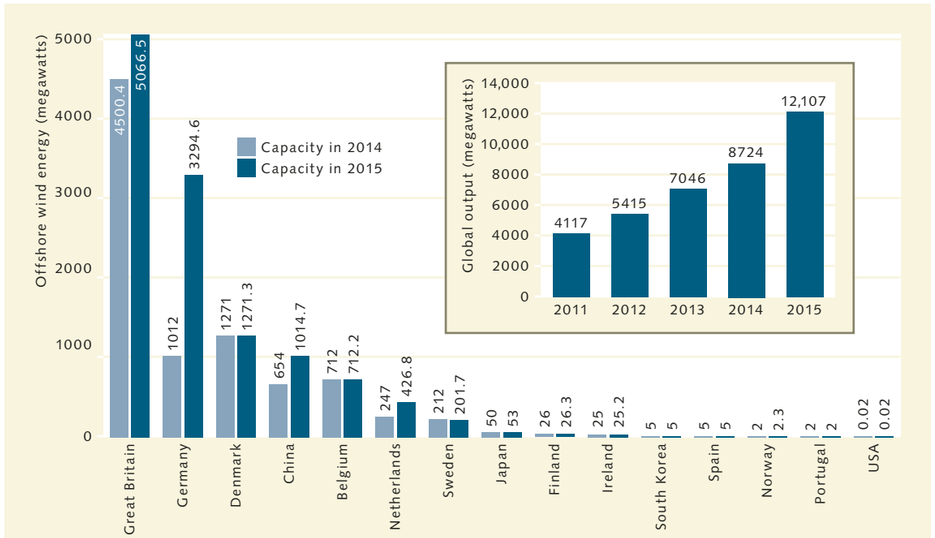
Harvesting energy at sea

Coastal waters have also recently begun to attract more interest for the generation of electricity from wind power. The number of offshore wind turbines has risen rapidly over the past few years. Global installed capacity trebled between 2011 and 2015 alone. The wind is stronger and more constant over the ocean than inland, and the electricity output from the open sea is distinctly higher than on the mainland. On land, markedly less land area is available in any case because minimum distances from buildings or conservation areas must be respected. By making use of special ships and new technologies, it has now become possible to install wind turbines at sea far more cheaply, quickly and in larger numbers than a few years ago.

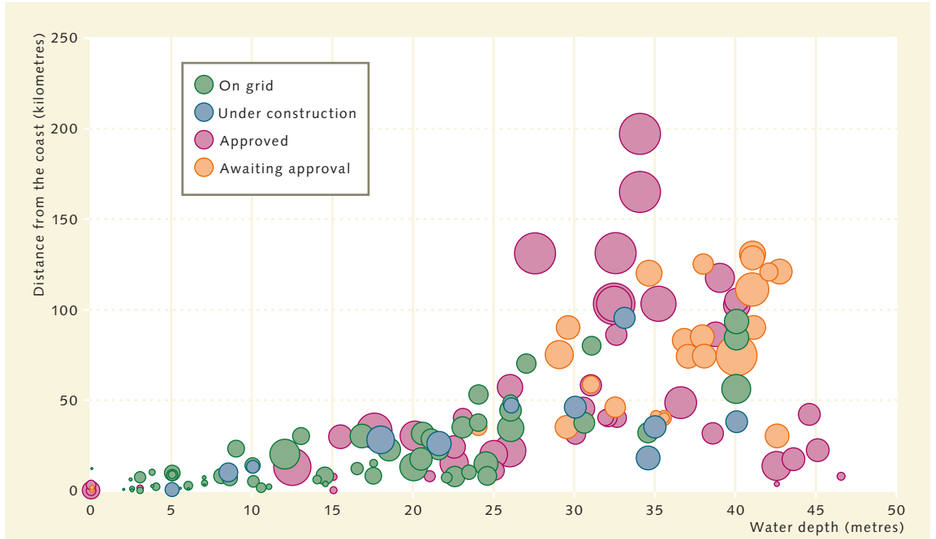
Manufacturers of wind power plants have now even begun to manufacture rotor blades directly on the coast, in the vicinity of large offshore wind farms, so as to avoid the need for costly and cumbersome transportation on special trucks. This has given rise to new jobs in structurally weak coastal areas, especially in Great Britain. Nevertheless, because of the higher cost of constructing foundations for offshore turbines and the expense of deploying special ships, it is still more expensive to construct wind farms offshore than onshore at present. The costs of one kilowatt-hour of offshore electricity, known as the levelized costs of electricity generation, currently range from 12.8 to 14.2 euro cents depending on the site. In contrast, the onshore levelized electricity generation costs are between 5.3 and 9.6 euro cents.

The wind turbines in operation worldwide at the end of 2015 had a **rated capacity** of well over 12,000 mega-

Levelized electricity generation costs
To determine how much it costs to generate electricity using a particular technology, generally the levelized cost of electricity generation is calculated. The levelized generation costs take account of all investment and operating costs and the costs of financing the technical plant. These are divided by the electricity output achieved over the plant's lifetime, meaning that levelized electricity generation costs are usually stated in euros per megawatt-hour or euro cents per kilowatt-hour.



2.14 > Great Britain leads the expansion of offshore wind power. Germany connected several large wind farms to the power grid in 2015, taking second place in the worldwide rankings ahead of Denmark.



2.15 > So far the majority of the world's wind farms have been constructed at distances of up to 40 kilometres from the coast and water depths up to 20 metres. In the meantime, offshore technology is so fully developed that installations can now be planned and built at far greater distances offshore. Proposed sites are located 120 kilometres offshore in extreme cases.

watts, which is roughly equivalent to the capacity of 24 nuclear reactors. A good 5000 megawatts of this was attributable to the coastal regions of Great Britain alone. The next-highest ranking countries in terms of installed wind farm capacity are Germany, Denmark and China.

Paralleling the trend in natural gas and oil extraction, offshore wind turbines are no longer being installed directly adjacent to the coast but further out at sea. The world's first offshore wind farm was commissioned in 1991 and consisted of eleven wind turbines just two kilometres off the Danish island of Lolland at a water depth of two to four metres. Today, offshore wind farms are constructed at average water depths of 27.1 metres and an average distance of 43.3 kilometres from the coast. A substantial distance is observed particularly in Germany and the Netherlands because the Wadden Sea along their coasts is an important resting site for migrating birds. Furthermore, wind speeds are higher at greater distances from land. German wind farms are an average of 52.6 kilometres from the mainland, as opposed to an average of 9.4 kilometres from the coast for those around Great Britain. The world's largest wind farm, with 175 wind turbines over an area of 100 square kilometres, is the London Array wind farm in the outer Thames estuary on the east coast of England.

Wind power is not the only renewable form of energy that can be utilized in coastal waters. Additional forms are:

- wave power,
- tidal power,
- marine current power,
- salinity gradient power (osmotic power),
- ocean thermal energy conversion (power generated from temperature differentials at different ocean depths).

The role of these forms of energy is still relatively minor in comparison to wind power. In recent years facilities harvesting wave power have been taken into commission, but have not yet proven economically viable to operate. Generally they consist of research and development projects.

Also still in its infancy is the technology for generating power from differentials in salinity. Commissioned in 2009, a small power plant in Norway was the first of its kind in the world to feed electricity into the public grid. In terms of its developmental status, however, it is considered a prototype. The technology for ocean thermal energy conversion is likewise at prototype status. In 2015 a pilot plant was commissioned off the coast of Hawaii with a capacity of 105 kilowatts. It now supplies 120 households with electricity.

In comparison, the use of tidal and marine current power plants to harvest energy is a fully developed technology. An example is the La Rance tidal power plant near the French city of Saint-Malo, which has been in operation since 1966. All told, only a few larger plants exist worldwide because they are extremely elaborate to construct, since dams and barrages with large turbines have to be installed in order to harness energy from tides and currents.

Valuable minerals

Another resource supplied by coasts are mineral raw materials, particularly sand and gravel which are used in concrete production, as filling sand on building sites, or for hydraulic filling to create new port or industrial sites on the coast. Well-known examples are the hydraulic fills that created land for the expansion of Hong Kong airport, the artificial Palm Islands off Dubai, or the new container terminal in Rotterdam, Europe's largest port. Sand and gravel are either dredged from the sea floor using suction dredgers or extracted onshore – especially by demolishing dunes. Exact quantities are very difficult to estimate because data are not recorded centrally. Nonetheless, sand and gravel extraction and the export of both resources are considered to be a lucrative business.

For example, the island city-state of Singapore constantly consumes large quantities of sand in order to expand the city's area by means of hydraulic filling. As a result of these activities, the area of the former British colony has expanded by a good 20 per cent since the 1950s. Singapore has much of the sand shipped in from very long distances. Many other countries also import sand. Sand from Australia is in particular demand because of its extremely hard, resilient and angular grains. On the one hand, this sand is good for concrete production because the grains adhere well to one another as the cement sets. On the other hand, the sand is used

2.16 > Particularly on the west coast of Africa, as here in the Western Sahara but also in Morocco, sand is extracted on a large scale close to the coast. This is exported worldwide for use as building sand and for other purposes.

in industry as a blasting abrasive for sanding or smoothing other materials. According to data from the Australian Bureau of Statistics (ABS), Australia exports sand, gravel and stones valued at 5.5 to 8.5 million euros per month. It is extracted both from the coast and from inland sites.

Natural gold-panning effect

A more uncommon type of mineral resource are mineral placers: shallow deposits of metal or phosphorus compounds which form along coasts near to river estuaries. They come about through a kind of natural gold-panning effect: particles ranging from light to heavy are transported from the hinterland by flowing river water. In and around the estuary these are deposited in the shallow water off the coast. If the ocean swell is strong enough, the lighter particles are washed away while the heavier ones are buried more deeply in the sea floor. Over the course of millennia this process results in the formation of deposits several metres thick, which can be recovered by mining. Mineral placers can contain metals like iron, gold, platinum, tin or **rare earth metals**. At present, extraction is confined to especially valuable mineral placers only, such as those containing gold, platinum or diamonds. The latter are found along the coast of Namibia, where there is a strip just a few kilometres wide with a relatively shallow ocean depth of up to 150 metres. Ever since it was discovered in the late 1950s that large quantities of diamonds occurred in this part of the ocean, it has been the site of intensive offshore mining. Initially the sediments were only harvested by divers with large suction tubes. Currently extraction is taking place at depths of 90 down to 150 metres on an industrial scale using special ships. The area was divided up into several concessions in which different consortiums of firms operate. Today some two-thirds of all Namibian diamonds are obtained from the sea.

The fact that the sea floor off Namibia happens to be so rich in diamonds is thanks to the Orange River. The frontier river between Namibia and South Africa washed the gemstones from their region of origin, South Africa's volcanic areas, into the sea. Over time, sea currents transported the sediment containing the diamonds northwards from the Namibian coast, where they concentrated in the sea floor as a result of the gold-panning effect.

Currently it is under discussion whether the mineral placers here containing phosphate compounds should also be extracted in future. These would be sold as fertilizers. Because the sea level has risen by around 130 metres since the last Ice Age, today these phosphate deposits lie deep below the waterline.

Resources from hydrothermal vents

Another type of valuable minerals that are likely to be recovered from the sea in future are the massive sulphides. These are found around hydrothermal vents on the sea floor, either at active undersea volcanoes or at plate boundaries where two continental plates are diverging.

Massive sulphides originate when cold seawater penetrates through fissures several kilometres deep in the sea floor. Around magma chambers at this depth, the water heats to temperatures of more than 400 degrees Celsius and dissolves sulphides, i.e. sulphur compounds, as well as minerals containing metals from the surrounding rock. Because it has been heated the mineralized water rises very quickly and shoots back into the sea. As soon as it mixes with the cold seawater, the minerals form a precipitate that settles around the plume in the form of massive ore deposits.

Normally the active volcanic sites are in the middle of the oceans and far from land. One exception is the Bismarck Sea off New Guinea, where a plate boundary is found just 30 kilometres from the coast. Known as the Solwara-1 field, its deposits are easily accessible by ship and contain copper, zinc, lead, gold and silver as well as numerous important trace metals like indium, germanium, tellurium and selenium. But despite the proximity to the coast, the water depth is around 1600 metres because the sea floor drops away steeply at this point. The Canadian mining company Nautilus Minerals has long been planning the extraction of the valuable ore deposits and has already had heavy underwater mining machinery built. In addition, a production ship is currently under construc-

The Palm – artificial islands alter a whole coast

A unique example of the exploitation of new land along coasts is the Palm Islands construction project on the coast of Dubai in the United Arab Emirates. It uses hydraulic filling to create archipelagos of artificial islands, each of which, when viewed from the air, is shaped like a palm tree with a trunk and palm leaves. The purpose of land reclamation on coasts is normally to enlarge existing ports or to create industrial facilities or new residential property close to the water. Dubai is going considerably beyond the scale of normal enlargement, however. The construction of the Palm Islands will create entirely new island worlds for an especially well-heeled clientele.

One archipelago, The Palm Jumeirah, has already been completed with hotels and villas. The total area of the islands is 560 hectares, the equivalent of around 780 football pitches. Building work on the next archipelago, The Palm Jebel Ali, has not been realized as yet because the construction company got into financial difficulties during the 2009 economic crisis. When building will actually be completed is uncertain. Since 2001 the sand required for The Palm Jumeirah and The Palm Jebel Ali has been obtained from the Persian Gulf using hopper suction dredgers; these are special ships that suck sand from the floor of a water body and store it in large holds known as hopper tanks. The sand can then be pumped off the ship again through pipes. This is the technique used to build up the islands artificially by means of hydraulic filling.

2.17 > Luxury built on sand: The Palm Jumeirah off Dubai.

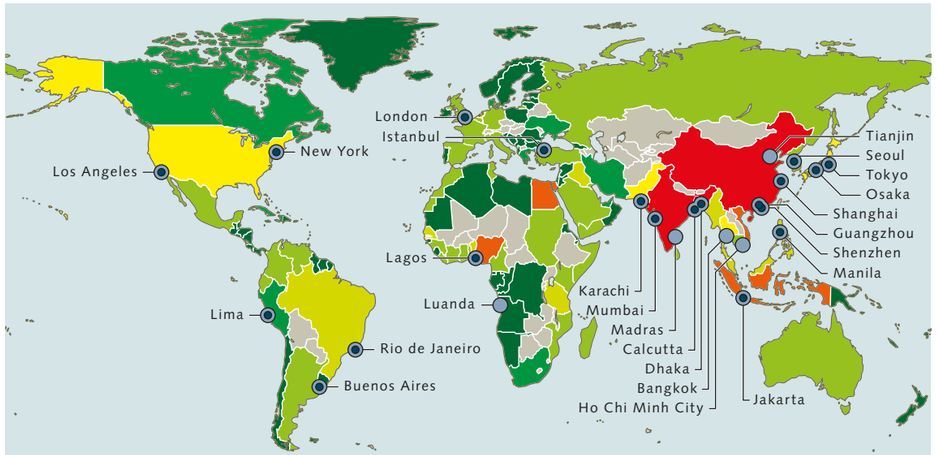
tion. So far the commencement of mining activities has been repeatedly postponed because the financing of the project was not adequately secured or no agreement could be reached between Nautilus Minerals and the Papua New Guinea authorities. When the mining of massive sulphides might begin therefore remains to be seen.

Areas for growing coastal cities

The availability of areas for particular uses can also be understood in a broader sense as an ecosystem service provided by coastal waters. This includes areas used for military training and for pipelines, residential complexes, port and industrial facilities, hotels and wind farms. Due to the growing population in coastal regions, land use along the coasts will increase, as new projections by a German-English team of researchers show. On the basis of various global population growth scenarios the scientists estimated how large the coastal population will be in the years 2030 and 2060. The study applied to the coastal strip located a maximum of 10 metres above sea level, which is known as the Low Elevation Coastal Zone (LECZ). This is especially under threat from sea-level rise, and is therefore of great interest. In the most extreme scenario assumed by the researchers, the global population will have grown to 11.3 billion people by the year 2060. In that scenario, up to 12 per cent of the global population will be living in the LECZ: around 1.4 billion people. For comparison: in the year 2000 it was inhabited by some 625 million people. The study predicts that megacities close to the coasts will grow proportionately.

According to this study, the most drastic population increases will occur along the coasts of Bangladesh, China, India, Indonesia and Nigeria. It is also expected that cities such as the Angolan capital, Luanda, Madras in India and the Chinese city of Tianjin will turn into megacities of far in excess of 8 million inhabitants.

Future population growth will not be the only reason for greater land consumption along the coasts. There is demand for new land even today for growing international trade – particularly for the enlargement of container ports such as Rotterdam. A start was made in 2008 with



2.18 > Global population growth means that low-lying coastal areas, especially in Africa and Asia, will be increasingly densely settled in future.

reclaiming an area of around 2000 hectares to form a site for what is now the Maasvlakte 2 container terminal. Surrounded by a foredike 12 kilometres long, it protrudes like a nose into the North Sea, i.e. into deep water. In contrast to many shallower parts of the port, even the largest container ships in current use with a capacity of 19,000 containers and a loaded draft of up to 20 metres can dock here.

The drastic expansion of offshore wind power in Great Britain and Germany is another factor that is changing the character of original marine landscapes. At these construction sites the sea floor of the North Sea normally consists of sandy sediments, and solid structures like rocks are seldom found. Now, to accommodate the hundreds of wind turbines, increasing numbers of solid structures – also referred to as hard substrates – are being created. These can increasingly be colonized by species that require a hard substrate – for example, sea anemones, various snail species and calcareous tubeworms. How this will change the species composition in the North Sea is a current subject of research.

Since shipping and the operation of fishery vehicles are prohibited in the vicinity of windfarms for safety reasons, it is possible that these areas might also contribute to the recovery of sea-floor biotic communities that have been adversely affected by years of fishery.

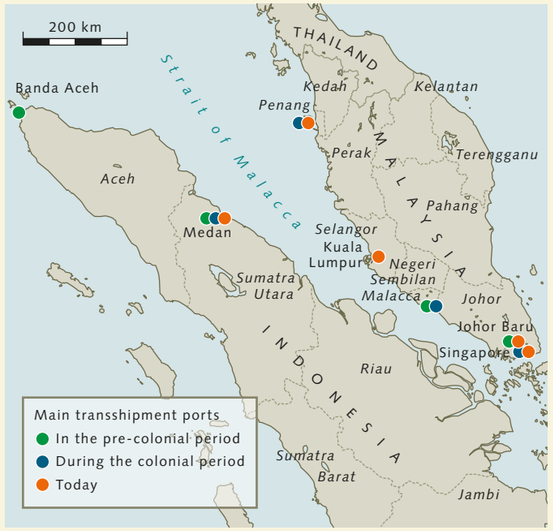
The highways of global trade

The transportation routes afforded by coastal waters are one of the provisioning ecosystem services that are taken for granted. Land-based transportation entails the great expense of constructing infrastructure in the form of canals, rails or roads. By contrast, coastal waters essentially provide waterways that are almost entirely cost-free. Today around 90 per cent of all goods worldwide are transported by ship – a total of almost 10 billion tonnes of goods per year according to the latest data from the United Nations Conference on Trade and Development (UNCTAD). The lion's share is made up of crude oil, containerized goods, and what are known as "minor bulk" cargoes such as steel, cement or sugar.

The Strait of Malacca – a historical shipping metropolis

For centuries, ports along the coasts have been more than transshipment sites for goods; they are also places of interaction between people from foreign cultures. The chequered history of the Strait of Malacca and the city-state of Singapore illustrate how maritime transportation has influenced the development of a coastal region in the course of history. The Strait of Malacca is the shortest shipping route between the Far East and the Indian Ocean. Ships have passed through it for centuries, and trading posts grew up from an early stage, which simultaneously became centres of education, science and art. People with different religious backgrounds – Hindu monks, Christian priests, Muslim scholars – from many regions of the world met here. There was lively exchange about navigation techniques and the art of shipbuilding.

An important trading and knowledge centre from the seventh into the thirteenth century was the Buddhist maritime and trading empire Srivijaya, which encompassed parts of the island of Sumatra and the Malayan peninsula as well as the western part of the island of Java. At that time Srivijaya controlled commercial shipping through the Strait of Malacca. The state disintegrated in wars from the end of the thirteenth century, and two important power centres emerged: first Malacca in the fifteenth century, and later Aceh (in northern Sumatra) and Johor (in present-day Malaysia) at the beginning of the sixteenth century. Whereas Aceh was primarily an important Muslim centre of commerce, Johor grew in importance because of the tin mines located in its hinterland and the valuable pepper that was cultivated. The seaport town of Malacca was used mainly by Muslim merchants as a major transshipment port on the route between India and China. In 1511 it was conquered by the Portuguese, not least to weaken the Muslim dominance of shipping in the region. But despite the conquest, the Muslim merchants remained influential in the region, for ultimately they brought fresh impetus to Aceh which remained Muslim-dominated. The seaport of Malacca then developed into an important centre for European mariners. Various European nations attempted to bring Malacca under their own control by means of blockades and attacks. For instance, the Dutch initially blockaded the seaport of Malacca in 1640 with the aim of cutting off the town's cargo flows and weakening the influence of the Portuguese. In 1641 they finally captured the town and expanded their territorial power from there. In the following years they took over other seaports in the region, including Aceh, and sporadically diminished the influence of Muslim merchants.



2.19 > Over the centuries there have been several different major transshipment ports along the Strait of Malacca. Although the city that gave the Strait its name has little influence nowadays, before and during the colonial period it was a significant power base.

2.20 > Today goods from Southeast Asia and China are delivered to Europe via the Suez Canal. As the ice masses in the Arctic increasingly melt, during the summer months the shorter route via the Northeast Passage could become more attractive in future.

The new major rivals were now British merchants. In 1786 they established the port of George Town in Penang on the northwest coast of the Malaysian peninsula. It was later expanded to become a main transshipment port for the British East India Company. To avert conflicts, in 1824 the two powers agreed to divide up the South East Asian region between them. The Netherlands ceded to Great Britain all property rights northward along the Strait of Malacca, and in return received the areas south of the Strait, including some British territory.

Great Britain developed into the dominant power on the Strait of Malacca, with Malacca, Penang (George Town) and Singapore as its most important trading posts. Unlike Malacca, Singapore – an island at the southern tip of the Strait of Malacca – was still rather insignificant in economic terms at the beginning of the nineteenth century. It was predominantly inhabited by Malayan fishing families. In 1819, just a few years before the Anglo-Dutch Treaty of 1824, the British East India Company had founded its first trading outpost there. Its massive expansion into a major trading port finally began in 1867, when Singapore was declared a British Crown colony.

Today Singapore is the most important location on the Strait of Malacca. Measured in terms of container transshipments, Singapore is the second-largest port in the world. In addition, Singapore has invested heavily in research since the 1980s to establish itself as a modern centre of excellence for high-tech and science. Back in 1987 it had just one research institute; today it boasts more than twenty. And under its Biopolis programme, the city-state even established an entire campus for biotechnology research between 2003 and 2006.

Other important locations along the Strait of Malacca today are the Medan agglomeration on Sumatra and the Special Economic Zone in the Malaysian state of Penang at the Strait's northern extremity. Today Malacca itself is a relatively insignificant port, not least because the coastal waters are too shallow for modern ocean-going vessels.

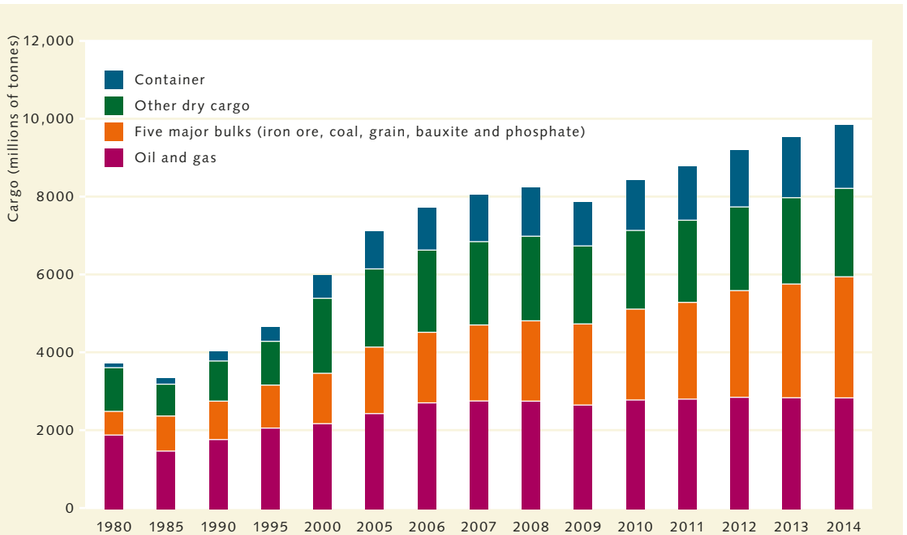
Recently, however, there have been signs that the maritime trading situation in the region might be subject to renewed changes in future. Climate change and the large-scale melting of sea ice in the Arctic may mean that in the next few decades, the sea route north of Siberia – the Northeast Passage – will become navigable during the summer months. This would be a shorter and quicker route for cargo transport between Europe and East Asia than the route via the Suez Canal and the Strait of Malacca.

Plans for a future northern route are now taking shape in China, where the 250,000-strong city of Hunchun in the northeast, on the border with Russia and North Korea, is already being promoted as a future hub. According to Chinese thinking, this city on the Tumen River could become as significant as Singapore and supply China with goods via the northeastern route. In July 2016 the large Chinese shipping company Cosco sent five merchant ships from the eastern Chinese port of Tianjin via the northern route, carrying components for wind energy plants to Europe. In August and early September 2016 the ships reached their destination ports in Belgium, Germany and England. For now the point of these voyages is to continue testing the feasibility of a regular shipping link. Nevertheless, Cosco is already planning to send far more ships via the north in future.

Another sign that the Northeast Passage could become established as a sea route in the near future came in September 2016, when a major Chinese mineral corporation acquired a 12.5 per cent shareholding in the mining corporation Greenland Minerals and Energy, which extracts such resources as rare-earth metals, uranium and zinc in Greenland. Experts believe that far more of these resources will be transported to China in future via the Northeast Passage.

Currently it is still impossible to foresee what impact the development of this northern sea route will have on trade in Singapore in the next few decades. Whatever the case, Singapore is endeavouring to diversify by introducing measures such as research promotion to avoid being too heavily dependent upon trade in future.

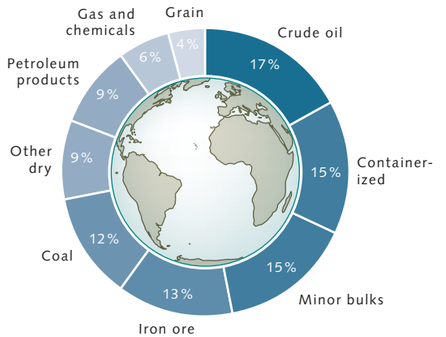
2.21 > Heavy traffic in the Strait of Malacca, the main artery of global intercontinental shipping. Almost a quarter of international maritime trade flows are moved through this seaway, which is around 800 kilometres in length and 50 kilometres in breadth at the narrowest point.



2.22 > Ships are the most important means of cargo transportation. Every year they move almost 10 billion tonnes of goods around the world.

The most significant shipping routes today are those between South East Asia and Europe and between South East Asia and America. Particularly container freighters operate a regular schedule of crossings between the continents nowadays. Freighters often cover extremely long routes non-stop and in most cases offload their cargoes at large central ports which act as hubs for onward distribution. A share of the containers are transferred to the mainland transport networks and transported by truck or rail into the country's interior. Another share of the containers are taken to smaller ports by smaller ships known as feeder ships.

From the container terminal in the port of Hamburg, some 40 per cent of containers are transported onward by heavy goods vehicle. 30 per cent are transshipped onto feeder ships and 30 per cent are transported inland on rail freight wagons. A noteworthy aspect is that in many cases, transportation inland remains in the hands of the terminal operators on the coast, meaning that the influence of the coastal hubs reaches far into the hinterland. From the seaport of Hamburg, for example, onward connections extend as far as Eastern and South Eastern Europe. One large terminal operator in Hamburg even maintains its own railway company which transports containers to its own terminals elsewhere, in Slovakia for example, in order to supply goods to the markets there and in neighbouring countries.



2.23 > The most important goods transported by ship are crude oil, containerized goods and minor bulk goods like steel, cement or sugar.

CULTURAL ECOSYSTEM SERVICES – COASTS OFFER RECREATION AND FORGE IDENTITY

The value of coastal aesthetics

In aesthetic and cutural terms, too, the world's coasts play a special role. Moreover, they have religious and spiritual value for many people.

By way of an example, the significance of this ecosystem service is reflected in the traditions of the islanders of the Torres Strait, the relatively shallow seaway some 185 kilometres wide between Australia and the island of New Guinea. Within the strait are around 270 islands surrounded by extensive coral reefs, parts of which fall dry during the tidal cycle. Hence the transition from land to open sea is not abrupt but relatively gentle, over an area of many square kilometres. Therefore the language of the indigenous inhabitants does not have distinct concepts for "land" and "sea"; they refer to their environment as "sea country" or "saltwater country". Traditionally they conceive of the islands, coral reefs and open sea as a kind of continuum without strict boundaries. Their sense of identity is bound up with the coastal habitat in its totality.

In past centuries the ocean has increasingly become a landscape that people yearn for and a destination for coastal tourists. Tour operators entice customers with images of palm beaches and blue water. Although comprehensive global data on coastal tourism does not exist, its huge economic importance is undeniable in the view of the United Nations Environment Programme (UNEP). It sees coastal tourism as based on a unique combination of factors resulting from the conjunction of land and sea. Among these are the intense sunlight that frequently prevails, the recreational value of the water and its numerous opportunities for sporting activities, panoramic views and a vast biological diversity of birds, fish and coral species.

According to data from the World Tourism Organization (UNWTO), the global added value of tourism is immense, accounting for a 7-per-cent share of all worldwide exports of goods and services. In 2015 alone, it gene-

2.24 > Wyer Island which is fringed with a coral reef is situated in the seaway between Australia and the island of New Guinea, the Torres Strait. The indigenous inhabitants refer to this marine landscape as "saltwater country", a concept encompassing both the dry land of the islands and the ocean with its coral reefs.

2.25 > The town of Positano on Italy's Amalfi Coast illustrates the attraction that the coasts exert on people. They are aesthetic areas which offer cultural and spiritual enrichment and recreation.

International tourist arrivals

Rank		2014 (millions)	2015 (millions)	Change '14/'13 (per cent)	Change '15/'14 (per cent)
1	France	83.7	84.5	0.1	0.9
2	United States of America	75.0	77.5	7.2	3.3
3	Spain	64.9	68.2	7.0	5.0
4	China	55.6	56.9	–0.1	2.3
5	Italy	48.6	50.7	1.8	4.4
6	Turkey	39.8	39.5	5.3	–0.8
7	Germany	33.0	35.0	4.6	6.0
8	United Kingdom	32.6	34.4	5.0	5.6
9	Mexico	29.3	32.1	21.5	9.4
10	Russia	29.8	31.3	5.3	5.0

2.26 > The importance of coastal regions for tourism can be seen from the list of the ten most popular travel destinations. Four of these countries with well-developed tourism sectors are on the Mediterranean alone.

rated income amounting to 1.26 trillion US dollars. Whereas the number of tourists travelling internationally was put at just 25 million in 1950, by 2015 the figure had reached almost 1.2 billion worldwide.

Measured in terms of numbers of tourists entering the country, the global rankings of the most popular countries for holidays are headed by nations with highly developed coastal tourism. Four of the top ten travel destinations are countries bordering the Mediterranean, led by France with 84.5 million foreign visitors, although it should be borne in mind that the French holiday destinations also include inland locations like Paris or the châteaux of the Loire Valley. In second place is the USA with 77.5 million visitors. Spain is placed third with 68.2 million and China fourth with 56.9 million holidaymakers from abroad. Narrowing the perspective solely to international travel within Europe, Spain actually achieves first place, being the destination for a good 20 per cent of all foreign travel by Europeans within Europe.

Highly developed coastal tourism also has its downsides, however. In many locations, the construction of hotel complexes has resulted in the loss of natural areas. Moreover, the wastewater and waste from tourism centres have polluted coastal waters, while coral reefs have been severely degraded by heavy use for tourism. Original, unspoiled coastal landscapes are ever more seldom found; a state of affairs that is criticized by many. Ultimately it can be said that the uniqueness, beauty and special aesthetic quality of the coasts is an ecosystem service in its own right.

Even more of a good thing

Coastal areas in their entirety provide numerous other ecosystem services, although it is not always possible to differentiate strictly between coastal waters and the open sea. The ocean absorbs large quantities of carbon dioxide, thus regulating the climate and having a very significant effect on the global climate system. What share of this is attributable to coastal waters alone is impossible to quantify with certainty. Nevertheless, it is evident that they are under particular threat since they are far more severely exposed than more remote ocean regions to human-induced negative impacts.

Coastal pressures

> Human overexploitation constitutes the greatest threat to the coasts today. Coastal sites attract increasingly high-density building development. Coastal waters are being contaminated by pollutants or excessive nutrient run-off. And because population growth and migration continue unabated, pressure on the coasts is unlikely to diminish in future.

Overuse harms habitats

The appeal of the coasts is explained to a great extent by the large number of ecosystem services that they provide. In past decades the power of this attraction led to many coastal regions becoming increasingly heavily populated and pressured beyond their carrying capacity – be it through excessive fishery or the challenges of wastewater treatment. By using the coasts unsustainably, people harm themselves in the end because there will come a time when certain ecosystem services can no longer be provided.

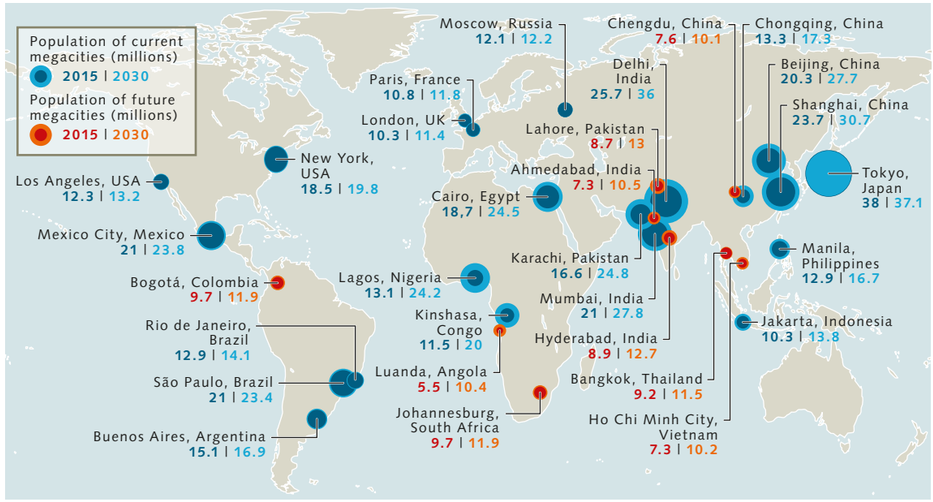
One example is the development of mass tourism in many locations. Coastal regions want to attract holidaymakers to their beaches with attractive landscapes and clean water, yet obtrusive hotel-building destroys the pristine appearance of the landscape, while immense quantities of wastewater from the hotel complexes cause water pollution. This is how overuse blights the recreational value of a landscape, undermining its provision of cultural ecosystem services.

2.27 > As seen in this view of Cancún, Mexico, the effects of mass tourism have obliterated the pristine appearance of many coastal regions. This kind of overuse can blight the recreational value of these areas.

Hard-to-pinpoint threats

Some forms of overuse are not always easy to identify and measure. Humans and the environment are closely interwoven in socio-ecological systems. Coastal regions extend over vast areas between land and sea and are very difficult to define in precise spatial terms. There can also be a lengthy time lag between cause and effect.

One example is the industrial use of polychlorinated biphenyls (PCBs): chlorine compounds that were used until the end of the last century in transformers, in hydraulic fluids and as softeners in sealants and plastics. Because they were applied in such diverse uses, significant quantities found their way into the environment. Only in the early 1970s was it recognized that the substances are toxic and have carcinogenic effects. Moreover, it was observed that in sea mammals such as seals they cause pathological changes to the uterus. This has resulted in a drastic decline in the number of successful seal births in the North Sea and the Baltic, particularly since the 1970s. Finally, in 2001 the use of PCBs was prohibited by the Stockholm Convention, an international treaty to protect the environment from particularly dangerous chemicals. Thus, several decades elapsed between the actual cause, the emergence of the environmental problem, the identification of the substances and the systematic ban on their use.



2.28 > Many of the megacities of the future, cities of over 10 million inhabitants, are in Asia and Africa.

Ever expanding megacities

Within socio-ecological systems where people live in large numbers or sources of pressure are multifarious, the interactions can be especially complex and in many cases difficult to discern. Today this applies particularly to coastal megacities of over 10 million inhabitants. Such regions are characterized by high population density and high-density building development. Many people need to be supplied with fresh water, food and electricity, which imposes high demands upon infrastructure, logistics and waste disposal. Because people from poorer rural regions inland are constantly moving to the coastal megacities in search of work or training, these metropolitan centres will continue to grow in future – above all in Africa, South America and South East Asia.

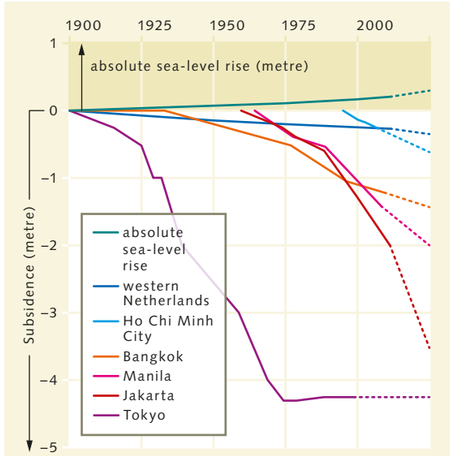
One of the biggest problems in the wake of this continuous urbanization has been the increasing frequency of floods affecting entire urban districts. Flooding can be caused both by heavy rainfall events and by storm surges in the sea level. Apart from the immense economic damage caused by floods, they pose a very real risk to life and limb. Interestingly, so far these have been attributable not so much to global climate change and sea-level rise than to bad urban planning. The following causes have been identified:

- Subsidence due to building density: the construction of high-rise buildings and other large structures has significantly increased the load on the ground. Under the heavy weight, the densely built-up sites slowly subside.
- Subsidence due to groundwater abstraction: because ponds, lakes and rivers at ground level in many coastal cities are heavily polluted by untreated wastewater and detritus, they cannot be used as sources of drinking water. Drinking water for many millions of inhabitants therefore has to be abstracted from the groundwater in the deeper geological rock layer, the aquifer. Since groundwater normally acts as a natural abutment against the downward force of buildings, pumping it away in large quantities exacerbates the subsidence of densely built-up areas. Construction measures themselves also lead to a fall in the groundwater level. Deep excavations are made for large buildings and any water that penetrates is pumped out, with the result that the ground in the excavations settles and the pore volume that was previously filled by the groundwater shrinks. The land surface then sinks.

Aquifer
The term "aquifer" denotes a subsurface body of rock containing pore spaces through which groundwater flows.

- Construction on low-lying river catchments and marshlands: many of the migrants to cities from poorer rural regions settle at the growing periphery of the cities in what are known as informal settlements. These are often located in low-lying areas that are unsuitable for building development, which are frequently along the banks of rivers or on marshes and meadows at especially high risk of flooding.
- Poor sewer construction: in many cities, developments have been built across natural watercourses or flood-prone areas such as alluvial plains. As a result, natural rainwater drainage areas have disappeared in many places. Added to that, surfaces have been sealed by the construction development so that rainwater no longer has much seepage area, but drains away torrentially instead.
- Natural subsidence: in some coastal regions the land is slowly sinking naturally. There can be a number of causes for this. For example, in some areas the land mass may slowly subside due to the movement of a continental plate. In other coastal areas, particularly in river deltas, the ground sinks because sediment layers become more densely packed over time and sag under their own weight.

Apart from increasing the general risk of flooding, subsidence also gives rise to very obvious urban planning problems and structural damage, including cracks in roads and buildings, broken gas and water pipes, and leakages in the sewage system.



2.30 > Tokyo managed to halt its land subsidence from the mid-1970s, unlike most other cities.

Subsidence in sinking cities

	Mean cumulative subsidence from 1900 to 2013 (millimetres)	Mean annual subsidence (millimetres)	Maximum annual subsidence (millimetres)	Estimated additional subsidence by 2025 (millimetres)
Bangkok	1250	20–30	120	190
Ho Chi Minh City	300	up to 80	80	200
Jakarta	2000	75–100	179	1800
Manila	1500	up to 45	45	400
New Orleans	1130	6	26	> 200
Tokyo	4250	around zero	239	0
Western Netherlands	275	2–10	> 17	70

2.29 > Many of the world's largest cities are sinking today, primarily due to groundwater abstraction and massive building development. In many cities this subsidence will continue into the future.

2.31 > Inundation of an entire industrial zone in the province of Ayutthaya, north of the Thai capital of Bangkok, in November 2011. Among those affected by the disaster is a Japanese car manufacturer based there.

2.32 > Jakarta is currently the world's fastest sinking metropolis. Because the city pumps groundwater on a large scale for its drinking water supply, the modern city centre is subsiding dramatically.

A sinking metropolis

An extreme example of a sinking city is Jakarta, the capital of Indonesia, which is currently the fastest sinking metropolis in the world. Particularly since the 1980s the city has grown drastically in terms of both population and road and building construction – especially high-rise buildings. In 2015 Jakarta already had at least 10 million inhabitants, and its population is forecast to reach 13.8 million by the year 2030.

Jakarta is in a very low-lying region, partly on peaty soils. The densely developed northern area, with its many high-rise buildings, and the commercial centre in particular are sinking in the soft subsurface – currently by up to 10 centimetres a year. The abstraction of groundwater for drinking water supply is also contributing to this effect, and it is feared that the sinking will accelerate. Without countermeasures and a reduction of groundwater abstraction, by the year 2025 parts of Jakarta are likely to have sunk by a further 180 centimetres.

Floods occur with growing frequency, leaving the city's highways and commercial centre half a metre under water, both after heavy rainfall events and higher than usual sea water levels. Natural watershed and floodplain areas have been built upon repeatedly over time so that rainwater has almost nowhere to seep away. The alarming fact today is that more and more people are affected by the floods. New arrivals in the city predominantly settle close to the economically attractive north of the city. This increases their prospects of finding work or reduces the length of the commute to their workplaces.

Flooding also has grave financial consequences, as seen for example in the year 2007, when a good one-third of Jakarta's area was inundated after severe rainfalls. Around 300,000 people lost their homes. The damage to infrastructure and buildings amounted to the equivalent of some 860 million US dollars.

Floods affect not just the city itself but also, indirectly, its surroundings – the city of Jakarta is part of an urban conurbation, also comprising the adjacent cities of Bogor, Depok, Tangerang and Bekasi. This is one of the largest agglomerations in the world, reflected in the name it is commonly known by today: the acronym "Jabodetabek". Every year around 250,000 people move into this agglomeration, which means that about 35 million people will be living there in the year 2020.

Every time that Jakarta is flooded, it causes transport chaos in the neighbouring areas. And another issue affects the region as a whole: if diseases or epidemics break out in the flooded areas because of the standing dirty water, these can rapidly spread throughout the whole of Jabodetabek.

A giant bird to defend Jakarta

In order to defend the city of Jakarta from greater floods in future, the Indonesian authorities are currently planning to create hydraulically filled islands that will shut off the approximately 35-kilometre wide Bay of Jakarta and be developed with residential, office and hotel complexes.

2.33 > As a defence against flooding, there are plans to create artificial islands off the coast of Jakarta by hydraulic filling. The largest island will be 10 kilometres long and shaped like Indonesia's emblematic bird. But the project is controversial. It is feared that wastewater could accumulate in the artificial lagoon, ruining the livelihoods of fishers.

The largest island alone is 10 kilometres long and will be given the form of a garuda bird with wings spread wide, the emblem of Indonesia. But resistance is stirring within the population. Wastewater could collect in the artificial lagoon landscape because there will barely be anywhere for it to flow into the open sea. Diseases could spread. The small-scale fishers fear losing their livelihoods because in future they will have to travel many kilometres further offshore in order to reach fishing grounds. But that is not possible, argue the fishers, since they only possess simple boats which are often in poor condition and not suitable for longer trips out to sea.

Construction projects on land which are planned in the course of the hydraulic filling are another major source of potential conflict. The intention is to construct new office, business and residential quarters along the shoreline. In the interim, residents who previously lived in simple shacks and houses in this area are being resettled. Although they are obtaining cheap living space in high-rise buildings in other districts of Jakarta, how can they possibly be compensated for the impending loss of their culture and identity? If the fishers are resettled inland, closer to industrial plants and factories, they can hardly continue in their traditional occupation: fishers will turn into factory workers.

Doubly threatened – by rains and storm surges

Another example of a sinking coastal metropolis that is also plagued by flooding is Manila, the capital of the Philippines. It is likewise threatened by heavy rainfall events and storm-induced high seawater levels. Between 1900 and 2013, parts of Manila sank by 1.5 metres, and further subsidence of around 40 centimetres is expected by the year 2025. This is worrying because Manila is in a region that is often affected by typhoons, huge cyclonic storms. They bring large quantities of rain and churn up the sea so violently that huge breaking waves arise. Typhoon Ketsana in 2009 was a cyclone of catastrophic proportions. The rain and the storm surge inundated some districts of Manila with 2 metres of floodwater.

The fact that flooding is increasingly affecting coastal cities that are not notably subsiding is demonstrated by the example of Mumbai. A large-scale flood hit the Indian megacity on 26 July 2005, when almost 950 millimetres of rain fell within a 24-hour period. That is roughly equivalent to the total volume that normally falls in Mumbai during the entire month of July. In the hour from 15.30 to 16.30 alone, there was 190 millimetres of rain. Since this coincided with a relatively high sea tide, the rainwater could barely seep away and instead backed up in the drains and particularly in the River Mithi which flows through the middle of the city.

Whereas most previous flooding had only affected the unauthorized (informal) settlements on the city periphery, this time the city centre was also hit, and the water rose by more than 1 metre in next to no time. Streets, shops and office buildings were inundated and traffic came to a complete standstill for many hours. In the end 22 per cent of Mumbai's area was flooded. The flood that day took a tragic toll: over 400 dead and around 100,000 badly damaged homes and businesses. 30,000 vehicles were reduced to scrap metal.

The analysis of the events made it clear that such large-scale flooding in Mumbai could only have happened because major swathes of the natural inundation areas along the rivers had gradually been sealed over, partly by the construction of informal settlements and partly in the course of official projects like the extension of the airport. Moreover, many watercourses were blocked with waste and building debris, impeding the rainwater's run-off. Elsewhere, rainwater sewers were poorly maintained, river banks had slipped and concrete walls collapsed.

USA also has self-inflicted problems

From a worldwide comparison of coastal metropolises, it is clear that the cities worst affected by flooding are mainly megacities in emerging economies. Experts attribute this to the fact that the required standards are not always adhered to in the planning of structures – particularly with regard to forward-looking land-use planning, disaster preparedness, and functional infrastructure, which includes such features as flood channels, a functioning sewerage system, flood banks and flood control barriers. On the other hand, cities in industrialized countries certainly also have to contend with subsidence. That is evident from the New Orleans conurbation, for example, in which around 1 million people live. New Orleans is in the US state of Louisiana, directly in the Mississippi Delta. Between 1900 and 2013 the city sank by a full 1 metre and is subsiding every year by a further 6 to 26 millimetres.

This is happening for several reasons. As in other affected coastal cities, the abstraction of groundwater plays a part in the subsidence – but how much of a part is very difficult to assess, because the particular characteristics of the soil in New Orleans give rise to another phenomenon: if the groundwater table falls, oxygen from the air penetrates deeper ground layers and activates the soil bacteria that live there. These decompose soil organic matter. Since the soil contains large quantities of organic material that has been carried into the delta by the Mississippi over centuries, the bacteria find large amounts to decompose. This loss of organic substance contributes substantially to the subsidence.

Additionally, in the region around New Orleans, the drilling of petroleum and natural gas and the emptying of those deposits are also causing the ground to sink. The loss of sediment that used to be transported into the delta by the Mississippi should not be underestimated, either. Today, because it is slowed down by numerous weirs, the Mississippi carries distinctly less sediment into the sea. The old sediment packages deposited in the delta are so heavy that the delta is slowly subsiding naturally. Whereas this subsidence used to be evened out by fresh sediment from the Mississippi, today the markedly reduced sediment load is far from sufficient to compensate.

These problems had been known about for decades, just like the fact that New Orleans was vulnerable to flooding in the event of even moderately severe storms. Experts had last published a warning in a scientific journal in 2003 about the consequences of severe hurricanes, which often threaten the coast on the Gulf of Mexico in the summer months. The existing flood control works were too low, and others were badly designed, maintained or constructed, their report read. The authorities had in fact planned a hurricane protection system, but due to a shortage of funding it was not built. In the view of experts, even this protection system would have failed because it would have been constructed according to outdated and unduly low design criteria.

Thus, New Orleans was relatively poorly protected when the extremely forceful Hurricane Katrina hit the city at the end of August 2005. It caused a 7-metre rise in the coastal water level. Consequently the flood banks (levees) were breached in around 50 places and the city, which lies in a hollow, filled up with water. Only after that did the authorities react and decide to construct a modern and effective flood protection system, the Hurricane and Storm Damage Risk Reduction System (HSDRRS). This was completed in 2011. It includes higher and more resilient levees and flood control barriers as well as floodgates and emergency pumps at the outlets of the pipes that drain runoff from New Orleans. These measures have considerably reduced the risk of major flooding.

Furthermore in 2012 the US authorities passed a new master plan for the protection of the delta, which will help to protect not only the city of New Orleans but the entire delta region from hurricanes and especially floods in future. A complete package of measures, including dredging works or the pumping of sediment, will allow the delta to grow again over the next 50 years. A good 700 square kilometres of new delta will be created in this way. Added to that will be 500 square kilometres of salt marshes to temper the force of the waves in the event of storms and hurricanes.

Halting the subsidence

The examples of Tokyo and Shanghai demonstrate that the subsidence of a city can be stopped if appropriate action is taken. After parts of the Japanese capital had subsided by around 4 metres since 1900, the decision was taken in the late 1960s to drastically restrict groundwater abstraction. Thereupon the soil strata carrying the groundwater slowly filled up again, so that towards the mid-1970s the subsidence had already been halted.

The Chinese metropolis of Shanghai was faced with similar problems. Its response was not only to heavily regulate groundwater abstraction but also to deploy pumping technology, which permitted more rapid replenishment of the groundwater reservoirs with water.

2.34 > Hurricane Katrina struck the southeast of the USA in late August 2005. Months later, traces of the destruction were still plain to see.

2.35 > In the past 40 years the Pearl River Delta in China has developed from an agricultural to a highly industrialized and heavily populated region. The left side of the photomontage is a satellite image from the year 1979, and the right side of the image dates from 2003. Vegetation is shown in red and built-up areas in grey. Watercourses can be seen in blue.

The largest agglomeration on Earth

The development and settlement of coastal areas is probably the most conspicuous change to these habitats. In many cases species-rich wetland biotopes like mudflats and salt meadows, marshes and peatlands have been dried out and irreparably destroyed by construction measures. An extreme example of this urbanization in coastal wetlands is the Pearl River Delta in the middle of the coastal province of Guangdong in the south of China. This is the location of a huge agglomeration consisting of eleven cities, including Hong Kong and Macao. The entire region, covering an area of almost 40,000 square kilometres, is almost the size of the Netherlands.

The region comprises several Special Economic Zones and has undergone a rapid economic upturn since the 1970s. Back then the delta was still characterized by small villages and expansive wetlands, but by the year 2000 the increasingly urban area that formed within it through the merging of the cities took up 3500 square kilometres, which is roughly four times the area of Berlin. Today the drained area covers as much as 4500 square kilometres and the population density is immense. Currently around 60 million people live in the Pearl River Delta – around 3.5 times more than in the Netherlands, which is a densely settled country by European standards. Thus, within a few decades it has developed into the most highly populated agglomeration on Earth. Experts expect growth in this region to persist until the Pearl River Delta is home to around 100 million people by 2030.

With the drainage and redevelopment of the wetland areas, the habitats of many amphibians and birds have disappeared. Furthermore, as a consequence of water pollution, today around 90 fish species in this area are threatened. Aside from that, many river branches in the region carry less water, particularly during the dry months, since numerous dams and power plants were built for drinking water abstraction and electricity generation. Overall this means that considerably less freshwater flows into the delta, and at times when sea levels are high, such as spring tides or storm surges, seawater can penetrate deeper into the delta. Plants and animals that are not adapted to brackish water or higher salt content retreat from the affected zones. The habitat is changing enormously.

2.36 > The Chinese sturgeon *Acipenser sinensis* is considered to be at acute risk of extinction.

Another consequence of dam construction is to interrupt the upstream migration routes of some fish species between the sea and their spawning grounds. In the opinion of experts, this substantially contributed to the collapse of stocks of the threatened Chinese sturgeon *Acipenser sinensis*, for example.

The removal of sand and stones for building projects represents another extreme case of interference with nature. The building material is taken from the river beds with dredgers and special ships. This alters the rivers' flow regimes, which in turn leads to changes in the composition of species assemblages. Many water organisms lose their breeding and spawning sites as a result of dredging works.

Big business built on sand

It is not just in China that sand and minerals are extracted but in many of the world's regions. According to estimates by the United Nations Environment Programme (UNEP), every year between 47 and 59 billion tonnes of minerals are mined worldwide, of which sand, gravel and crushed rock make up between 68 and 85 per cent. Since there is no standardized recording of the statistics, the quantities can only be estimated approximately. Between 25 and 30 billion tonnes of sand are needed for the cement industry alone. But in numerous places this colossal demand entails major encroachments on the landscape. Such resource extraction is therefore viewed very critically in many regions. In South Africa, for instance, dune sand is extracted for the construction industry. Critics fear that the coasts will be less well protected as a result because dunes are a natural bulwark against the breaking waves. In India fishers are protesting against sand extraction from

Blockage of a lifeline

It is not just in the Pearl River Delta that construction measures are causing broad-scale destruction of rivers and wetlands. Also under threat is the Mekong in South East Asia, a significant river system and a lifeline for millions of people. At 4350 kilometres in length, the Mekong is one of the world's longest rivers. It flows through China, Myanmar, Laos, Thailand, Cambodia and Vietnam, and splits into a large delta before discharging into the South China Sea. The Mekong is extremely rich in biodiversity; it is home to around 1500 different species. What a high number this is can be seen from a comparison with the Mississippi, where only 250 species occur. Around 120 species in the Mekong are fished. Since the river carries large quantities of minerals and nutrients as it flows down from the Tibetan highlands, it is very productive and supplies large quantities of fish. Particularly in the lower-lying Mekong Basin in Laos, Thailand and Cambodia and in the Mekong Delta in Vietnam, there is a well-developed fishery supplying around 2.6 million tonnes of fish per year. Its market value is estimated at 2 to 3 billion US dollars.

Fish is not just a trading product, however, but first and foremost an important source of protein for the approximately 60 million people living in the Mekong Basin and Delta. Depending on the region, fish contributes between 49 and 82 per cent of the population's intake of animal protein. But several dam projects are about to place the Mekong's abundant fish stocks under threat. Laos, Thailand, Cambodia and Vietnam are all planning new dams for hydroelectric power generation. Laos has set itself particularly ambitious goals and intends to commission several dams in the next few years and establish itself as the "battery of South East Asia" – a major electricity exporter. Dam construction will disrupt many fish species' migration routes between the sea and their spawning grounds up river. Some commercially important species will be affected. Thus, decisions made far inland have consequences that extend to the coastal areas.

The dam projects are colossal. The first to be commissioned, in Laos in 2019, will be the Xayaburi Dam: a structure 50 metres in height and 800 metres wide, it will impound the river into a lake of around 50 square kilometres – roughly the area of the Italian island of Ischia. Although there are plans to build fish ladders into the dam to facilitate fish migration, environmentalists warn that very few fish species can make use of these artificial passages upstream. Overall it is feared that the abundance of fish in the Mekong could decline substantially. If that happens, many people stand to lose a vitally important source of income or protein.

2.37 > Protest outside the administrative court in Bangkok against the construction of the Xayaburi Dam in Laos.

beaches. They are critical that the dredging up of suspended sediments is driving fish away. For the local small fishers, this means the loss of their livelihood.

Similarly in Indonesia and Cambodia, the removal of large quantities of sand – mainly for export to Singapore – has led to major destruction of the coasts, which prompted the government of Indonesia to prohibit the export of sand completely in 2008 while the government of Cambodia markedly restricted official exports in 2009. Nevertheless, sand extraction in Cambodia is continuing on a grand scale. Cambodian nature conservation organizations draw attention to the fact that sand is being traded in some cases by Mafioso groups. They complain that Cambodian authorities are not carrying out any controls. To what extent the government has secretly awarded permits for this extraction, or how far the corruption of officials is involved, remain unanswered questions. Sand is being extracted using suction dredgers in a coastal protection area in the Koh Kong region west of the capital Phnom Penh, among other sites. This is destroying mangroves and seagrass meadows – important habitats for the dugong, a species of sea cow.

Turning now to Singapore, the South East Asian city-state is an extreme example of sand imports. Being an island, Singapore constantly requires sand for the enlargement of its urban area. Between 1995 and 2014, around 500 million tonnes of sand were imported – for the most part from Indonesia and Cambodia. Since those countries adopted their export restrictions, sand has been imported to Singapore illegally, say the Cambodian nature conservation organizations.

Overexploited fishing grounds

The overexploitation of coastal areas is particularly evident when it comes to fishing. Not only is too much fish taken from the oceans, but fishing can also destroy marine habitats such as coral reefs. Humans take more fish out of the sea than the sea can continue to produce. As a result, **fish stocks** decline over time. It is not possible to state exactly the degree to which coastal regions are overfished, since the Food and Agriculture Organization of the United Nations (FAO) does not differentiate in detail between coastal fisheries and deep sea fishing. However, given that coastal waters worldwide constitute the most productive marine regions they no doubt provide the bulk of fish, and fisheries experts believe that they are the most intensively fished waters. According to current FAO data roughly 30 per cent of all commercially fished stocks worldwide are overfished. Given that there are more than 38 million fishers in the world who could lose their livelihoods or their food source, this situation is alarming. At particular risk are the small-scale fisheries on which approximately 20 million fishers depend in the developing countries alone, where fishing makes a significant contribution to the food supply and livelihoods of coastal people. In the tropics, small-scale fishing is primarily carried out on coral reefs. The number of coral reef fishers is estimated to be in the order of 6 million, 1.7 million of whom live in Indonesia, roughly 950,000 in India and 910,000 in the Philippines. Roughly half of the 6 million reef fishers primarily dive for sea cucumbers. These sausage-shaped echinoderms are related to starfish and are exported to Hong Kong in particular where the dried animals are valued and traded as medicine.

In many areas, coral reef fisheries are not currently managed in a sustainable manner. Not only are their stocks being overfished but the reefs are also damaged in a variety of ways. This is tragic as in the long-term people are destroying their own livelihoods.

Estimated number of reef fishers in coral reef regions worldwide

Region	Number of reef fishers (millions)	Reef fishers as per cent of rural coastal population
South East Asia	3.35	5
Indian Ocean	1.50	13
Eastern Pacific/Atlantic	0.50	18
Western Pacific	0.45	68
Middle East	0.34	24
Total	6.14	

2.38 > South East Asia, and especially Indonesia, has particularly high numbers of reef fishers. However, as a ratio of reef fishers to rural coastal population, Western Pacific island nations have the highest percentage, as these islands offer scarcely any other livelihood options.

Seagrass meadows
Characteristic plant communities which typically grow in sandy sediment in coastal waters and on tidal flats. They have long, herb-like fronds and thus resemble – but are unrelated to – the grasses that grow onshore. They are important habitats, providing young fish with food and protection from predators. Various species of fish lay their eggs directly on seagrass, so these meadows are often key nurseries for fish. They are also a vital foraging ground for birds, such as Brent geese during their autumn migration across Western Europe's Wadden Sea.

Reef fishing at the limit – Spermonde Archipelago

The Spermonde Archipelago is an example of the contribution made by fishing to the gradual destruction of coastal ecosystems. The Archipelago is located just off the large Indonesian island of Sulawesi. It consists of approximately 70 coral islands and was known even to European seafarers in colonial times as a particularly species-rich and productive marine area. It is home to crustaceans, large groupers, numerous smaller species of reef fish, squid and many species of corals. Chinese traders purchased sea cucumbers in this region as early as the seventeenth century. These sausage-shaped animals are related to starfish. In China and Hong Kong they are still in demand to this day for medicinal preparations.

For a long time the Archipelago's coral reefs appeared to be inexhaustible. The local population saw the abundance of fish as a God-given gift and a never-ending supply. However, some of the fish stocks in the area have been considered to be overfished since the 1960s. Several scientific studies have been conducted in the area in order to understand the underlying causes. The studies also included interviews with the islands' inhabitants. As the islands largely lack fertile soil and thus do not lend themselves to farming activities at any major scale, it was found that 80 per cent of households directly or indirectly depend on fish and other marine life for their livelihood. Depending on demand, available gear and the productivity of stocks in question, different marine organisms have been under particular pressure at different times. If it became uneconomic to catch a particular species because there was no demand or the local stocks had declined, the fishers simply switched to another species.

In the past, the fishers mostly used traditional gear such as longlines and fish traps. In the 1980s however fishers added specialized equipment to their arsenal, such as diving gear that allows them to hunt for sea cucumbers for which there is such a strong demand in China. The divers use rubber tubes to take air that is pumped down to them by on-board compressor pumps. This allows them to stay under water for longer and collect a much greater number than before. This has resulted in sea cucumbers of the species *Holothuria nobilis,* among others, to disappear completely from many of the Archipelago's reefs.

Some of the fishing methods used today are not only unsustainable but illegal. Dynamite fishing has been practised in the Spermonde Archipelago since World War II in order to catch culinary fish for local consumption. The explosions also kill numerous other animals that are not consumed. It has been estimated that between 10 and 40 per cent of the locally consumed fish comes from dynamite fishing, that proportion varying between islands. Moreover, cyanide fishing has been practised since the 1960s. This method involves the addition of poisonous sodium cyanide to the water in order to stun fish. They can then simply be gathered up and exported as live fish with smaller fish mostly used in aquariums and larger ones in restaurants. Fishers receive much higher prices for live fish than for culinary fish sold in local markets.

Groupers are among the species caught with cyanide. After being caught, the fish are kept in basins for several days in order for them to excrete the poison prior to being sold. But many of them perish before reaching the recipient countries, partly due to conditions during transport and partly because of after-effects of the poison.

One of the major problems with cyanide fishing is that the cyanide drifting in the water also kills many other organisms. It kills minute algae living in symbiosis with the corals as well as juvenile fish growing up in the reefs. It is questionable whether a reef can recover from cyanide poisoning or how long this might take.

A better understanding of the unsustainable fishery practices can only be gained by an examination of the underlying social context. From a sociological perspective, there is a system of patron-client relationships in the Spermonde Archipelago (with fishers being the clients) – a kind of two-class society. The patrons are the link between local clients and external traders and buyers. They know which products are currently in demand in the marketplace. In addition, the patrons provide gear for the different fisheries and extend credit to fishers and their families. They are well connected in civilian and military circles that are supposed to protect the coral reefs and pay significant amounts of bribes to inspectors in order to avoid sanctions for illegal or prohibited catches.

In most cases, the fishers sell their catches directly to the patrons in order to pay back the loans they have taken out. While the price they are paid is well below the patrons' sales price, it provides them with a relatively safe income and a relatively stable social safety net for their families in economically difficult times.

As advantageous as the patron-client system might appear to those involved, it brings with it long-term risks to the coral reef ecosystem and thus to the only source of income for the growing population. As the markets sell fisheries products from all the fishers participating in this system, there is always enough fish to meet the demand. If yields decline in one fisher's fishing area, this loss is hardly felt in the marketplace. If some reef areas are overfished, catches in other areas make up the shortfall. Information on overfishing in a particular area therefore rarely reaches the patrons, which means that ecological warning signals are easily overlooked and it is impossible for an awareness of the necessity of sustainable fisheries to develop. The reefs will have even less time to recover from local overexploitation if the impacts of climate warming are brought into the mix.

2.39 > The Spermonde Archipelago is centrally located in the island state of Indonesia, just off the south-western tip of Sulawesi. Some 70 coral islands make up this archipelago.

2.40 > Stocks of the sea cucumber species *Holothuria scabra* are particularly heavily exploited in the Spermonde Archipelago as they are considered a delicacy in many parts of Asia and command high prices.

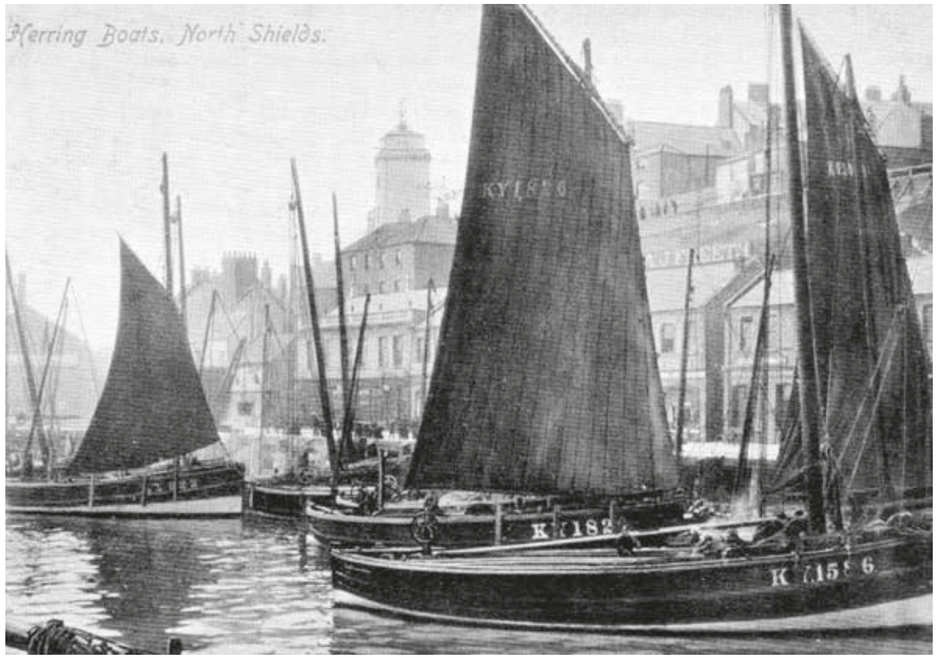
2.41 > Cyanide fishing involves the addition of poison into the water in order to stun the fish. Once they have been collected, they can later be sold as live fish.

Stronger engines, greater destruction

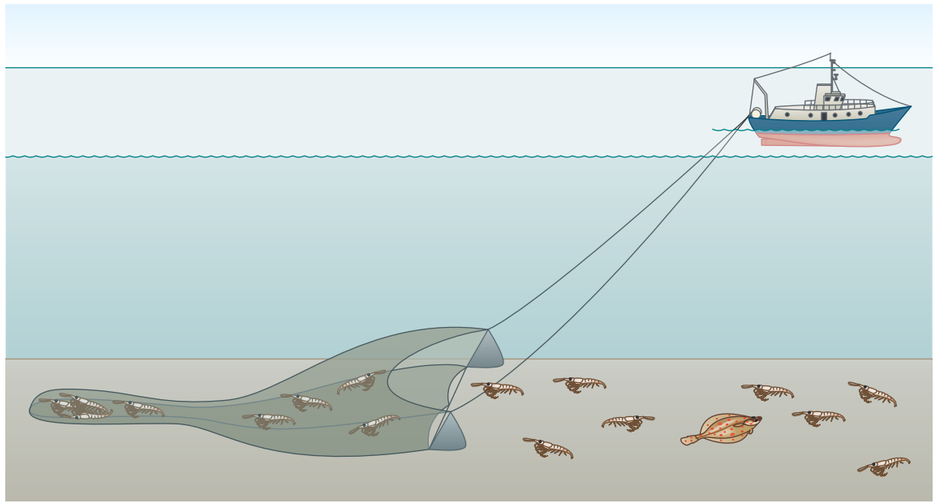
Just how strongly intensive fishing impacts on inshore marine areas can be illustrated by the example of the Belgian, German and Dutch North Sea coast where fishing has very strongly altered seafloor habitats over the last hundred years. In these habitats, flatfish species such as dab, plaice and sole that camouflage themselves by partially burying themselves in the soft seabed are caught with bag-like bottom trawls that are dragged across the sea floor on heavy metal frames. These beam trawls and the chains attached to them are designed to penetrate and basically plough up the top few centimetres of the soft seabed as they are towed along.

In the nineteenth and early twentieth century, flatfish were in many areas still caught using small rowing or sailing boats and correspondingly small beam trawls. However, with the introduction of larger, motorized vessels ever larger beam trawls came to be used in the North Sea. Due to their high weight and the attached chains they plough up the seafloor and crush many of the larger benthic organisms. Studies conducted in Belgium, Germany and the Netherlands have shown that this is the reason for the significant decline in larger, long-lived or sensitive benthic species observed since the middle of the last century. The sensitive organisms include the tiny moss animals, organisms that form delicate colonies on the seafloor, some of which resemble corals in shape.

Ocean quahog populations are also affected. This species of clam lives buried only a few centimetres deep in the ocean floor and their shells therefore are easily crushed by beam trawls. Normally, ocean quahog can grow to a size of more than 10 centimetres and live for up to 120 years. But as a result of intensive beam trawling they have been decimated in the inshore areas of the North Sea; with multiple beam trawl passes per year and area the populations are hardly given a chance to recover. Today the heavily fished areas are dominated by fast-growing bristle worms and small bivalves such as the tellinids which measure only 1 to 2 centimetres in size. Starfish and hermit crabs have also increased in abundance, both of which feed on the remains of the organisms killed by beam trawls. Hermit crabs are protected from beam trawls as they reside in thick-walled empty seashells. Starfish survive as they are relatively robust; if any of their arms are severed by a beam trawl they can regenerate these arms and survive.



2.42 > The English port town of North Shields in 1904. At the beginning of the twentieth century North Sea fishing was still mostly carried out by means of sailing boats.



2.43 > Beam trawls are bottom trawling nets that are dragged along the seafloor on heavy metal frames. They kill many of the animals living on and in the seafloor.

The end of a clam paradise

Just how fishing can destroy an almost paradisic habitat, marine biologists were able to document using unique historic datasets for the Dogger Bank, a relatively shallow area in the North Sea. The Dogger Bank has only been used for fishing since the middle of the last century, primarily to catch sandeels to be processed into fishmeal. Thanks to a detailed study conducted by British researchers in the 1920s we have knowledge of the then pristine condition of this region. At the time, the scientists found extensive mussel banks on the Dogger Bank's seafloor that hosted a multitude of large bivalve species – the thick shelled trough shell *Spisula subtruncata* for example or its up to 6 centimetres long relative *Mactra stultorum*. Another frequent species was the common necklace shell, a predatory species feeding on the two trough shell species. Large numbers of moss animals and colourful sea anemones settled on the mussel banks, while many different crustaceans and fish species used this habitat as their hunting ground. As a result of the intensive sandeel fisheries the mussel banks have disappeared and have been replaced by monotonous sandy areas. Comparative studies conducted in recent years have shown that the two trough shell species now only occur as juveniles, if at all. They develop from larvae carried to the Dogger Bank by currents passing from other regions of the North Sea. Adult specimens have become very rare. Today the biocoenoses are dominated by small hardy species instead, such as small amphipods, small tellinids or brittle stars, a particular type of starfish with long thin arms.

The biocoenosis as a functional unit

In how far such changes should be considered acceptable or intolerable is a matter of perspective. While the loss of original biocoenoses is indeed regrettable, ecologists say that first and foremost it is primarily important for a

habitat to continue to function as a whole. The term used by experts in this respect is biodiversity and ecosystem functioning (BEF), i.e. the functioning of a habitat including its potentially changing suit of species. One example of such a function is the cleaning function performed by bivalves as they draw seawater into their shells and filter it. Both small and large bivalves can perform this cleaning function. For the Dogger Bank this means that at present many small tellinids perform the cleaning function previously performed by the significantly larger trough shells of old. The cleaning function is not lost despite the fact that the habitat has changed significantly.

However, as recent studies conducted at the Dogger Bank have shown, the biocoenoses in the area are no longer impacted just by fishing alone but also by climate change. Species at home at more southerly latitudes are slowly migrating into cooler, more northern marine areas such as the North Sea. It remains uncertain how such migrations will impact on the area's diversity and ecosystem functioning.

2.44 > Mussel graveyard in the Finnish Baltic Sea: Once the water's oxygen concentration had fallen below a critical threshold, the sand gapers emerged from the seafloor sediment in an attempt to reach fresh water. Due to the low oxygen concentrations they perished nonetheless.

Nutrients destabilize the ecosystem

Habitats lose their function when changes exceed stress limits. In many areas, one of today's major stressors is eutrophication, i.e. the enrichment of a water body with nutrients. These nutrients originate in wastewater contaminated with faecal matter or in the form of crop fertilizers applied to fields from where they reach rivers and are transported into the sea. Where there is an oversupply of nutrients, algal growth can be so rapid that it results in algal blooms. The more abundant the algae, the greater is the quantity of algae that die at some point, and the more intensive is their subsequent decomposition by oxygen-consuming microorganisms and therefore overall oxygen consumption. As a result, oxygen-deficient or oxygen-depleted zones can develop in coastal waters in which fish, crustaceans and molluscs can no longer survive.

For a number of decades now such zones have been observed in many places worldwide, for example on the west coast of India, in Chesapeake Bay on the eastern US seaboard and in the Gulf of Bohai on the east coast of China. The oxygen-depleted zones often develop at greater water depths where wind and waves cannot mix the water and enrich it with atmospheric oxygen. In recent years, these zones have been found on the German Baltic coast during the summer and also in inshore areas at depths of just a few metres. The lack of oxygen in shallow coastal areas is particularly problematic as it also kills benthic organisms the activities of which would normally contribute to the decomposition of nutrients in marine waters and would thus combat eutrophication. These organisms include bivalves and worms that live burrowed into the seafloor substrate into which they fan fresh water. The many passages increase the overall area available for benthic microorganisms to break down nitrogen compounds. But if these bivalves and worms die, this filter function is lost, resulting in a negative feedback loop in oxygen-deficient coastal areas: Oxygen-deficiency results in the soil organisms' death, which adversely impacts the substrates' cleaning function and in turn leads to a further deterioration in water quality.

Nutrient loads from aquaculture

While coastal waters in most countries are primarily impacted by nutrients from agricultural sources, intensive aquaculture exacerbates the problem of eutrophication in many regions. This is particularly true for China's coastal areas where aquaculture installations are lined up like pearls on a string, such as is the case on Hainan Island, a Special Economic Zone in China's tropical south and a destination for many domestic tourists.

With an area of 34,000 square kilometres, Hainan is larger than Sicily. It is the largest island of the People's Republic. A wide mangrove belt constitutes the natural coastal vegetation, followed on the seaward side by shallow sandy areas covered by seagrass meadows and, further seaward still, by extensive coral reefs. In recent years, this natural zonation of mangroves, seagrass and corals has, in part, been hugely altered as a result of the expansion of aquaculture. An entire biodiverse ecosystem was lost when the mangroves were cut down. Moreover, nutrients from aquaculture installations, primarily in the form of faeces and excess feed, can now flow directly into the sea. Where normally the mangroves would have taken up much of this nutrient load through their root system, the nutrients now directly enter the seagrass meadows. It is a known fact that under the influence of high nutrient loads small algae thrive that overgrow and ultimately kill the seagrass. Moreover, the oxygen-deficiency caused by eutrophication results in a drop in oxygen concentrations not only in the water column but also in the seafloor, creating conditions that lead to the production of toxic compounds in the sediment which can be lethal to seagrass. Studies are currently being undertaken to determine the extent to which the seagrass meadows in the Hainan area have already died off or may die off in the future.

Just how much of the nutrient load the seagrass meadows can absorb is another unanswered question. This capacity to take up nutrients is important for the survival of the coral reefs since the seagrass meadows function as a buffer between them and the land. Corals would be impacted by excess nutrients and particularly by the resultant excess algal growth and could die off. This is an additional threat to the coral reefs of Hainan which are already impacted by overfishing as well as cyanide and dynamite fishing, similar to the Spermonde Archipelago.

Coastal waters as sewage basins

Coastal waters are not only impacted by excess nutrients but also by untreated sewage and industrial effluent. While wastewater treatment technologies in industrial nations tend to be highly developed and remove a high proportion of pollutants from wastewater before it enters rivers or the sea, there are many regions in developing countries in which wastewater treatment is insufficient. According to the World Bank, in Africa only about 10 per cent of wastewater reaches treatment facilities. Studies have shown that in the Ghanaian capital Accra untreated wastewater is responsible for the bacterial and viral load of rivers and other watercourses serving as drinking water sources for the population. Frequent cases of diarrhoea are the result. Approximately one quarter of all deaths of

children aged under five years in the greater Accra area are attributed to this problem. Moreover, there have been repeated cases of cholera.

In many regions there is not only the threat from pathogens but also the problem of pollutants that directly enter the sea via rivers or sewers. These pollutants include heavy metals, for example from mining or metal production, as well as numerous compounds originating in the chemical industry. Several environmental disasters have shown just how dangerous these substances can be. One such case is that of Minamata, a port town in western Japan. In the 1950s, a local factory discharged mercury-containing wastewater into the sea. The poison was first taken up by algae. Then the algae were consumed by fish the local people valued particularly highly as culinary fish. The mercury concentration in the fish was so high that more than 10,000 people suffered from mercury poisoning. Thousands of them died. Today this type of severe mercury poisoning is known as Minamata disease.

A lot more than a "dirty dozen"

According to the Organisation for Economic Co-operation and Development (OECD), around 100,000 different chemical substances are being produced worldwide; in Europe alone about 10,000 of these are produced in quantities of more than 10 tonnes per year. Up to 3 per cent of the global production is of concern; these environmentally relevant pollutants include, for example, compounds of lead, mercury and other heavy metals arising in the course of mining, in industrial manufacturing processes and when burning heating oil.

Persistent organic pollutants (POPs) are particularly critical. They are defined by the following problematic characteristics: They are persistent and toxic, they accumulate in living organisms and they can also volatize into the atmosphere and travel long distances. Since POPs are strongly resistant to breaking down in the environment they can continue to enter the food chain for many years.

A group of twelve particularly dangerous compounds of this nature, known as the "dirty dozen", were the first such substances to be banned worldwide under the Stockholm Convention. Polychlorinated biphenyls (PCBs) are among the twelve. Today a total of 24 substances are banned under the Convention.

Fighting fire with fire?

In 2007 the EU REACH Regulation (Registration, Evaluation, Authorisation and Restriction of Chemicals) entered into force in the European Union; it was adopted in order to improve the protection of human health and the environment from risks potentially posed by chemicals. The Regulation requires industrial companies manufacturing or using chemical substances to register these substances and provide evidence of their harmlessness. However, companies may put substances that have already been in the marketplace for some time to new uses without having to furnish any additional evidence.

Therefore, substances that are banned today on account of their toxicity may be replaced by established substances with similar characteristics. But these replacements may equally be of concern. Polybrominated diphenyl ethers (PBDEs) are an example of this problem. For a long time these bromium containing compounds were used as a flame retardant. Experts had found that PBDEs are persistent and carcinogenic, which is why they were banned some time ago. As an alternative, the industry then began to use Dechlorane Plus, an established substance originally used as an insecticide in the 1970s, the use of which in the outdoors had since been banned in the EU. Dechlorane Plus is persistent too and in water it attaches to suspended solids together with which it is primarily deposited in coastal sediments. Scientists have shown that eels in European coastal waters are contaminated with Dechlorane Plus.

This example highlights the weakness in common practice whereby banned substances may be replaced with established substances that are similarly problematic. As a consequence, discussions are underway as to whether Dechlorane Plus should also be banned internationally under the Stockholm Convention. Denmark has launched an initiative to this effect.

2.45 > For decades, mercury-containing wastewater had been pumped into the bay off the Japanese fishing town of Minamata. Making its way through the food chain, the poison was ultimately ingested by humans.

A ban on chemicals posing environmental hazards is normally preceded by years of discussions. Countries in which the relevant substances are produced or processed often oppose a ban. However, the Stockholm Convention contains a provision under which particularly hazardous POPs can be banned within a shorter timeframe if they are extremely bioaccumulative and extremely persistent. These substances are termed very P/very B (very persistent/very bioaccumulative).

The chemical compound PFOS (perfluorooctane sulfonate) is an example of substances of this kind. It was primarily used in the textile industry, for example in the manufacturing of breathable membranes for outdoor jackets. But it was also used in the paper industry for the production of stain, grease and water repellent papers used for example in fast-food packaging. In addition it was used for surface treatments for furniture, carpets and clothing. Because of the persistent nature of PFOS it has strongly accumulated in nature. It has been detected in water, soils, air and living organisms worldwide. Comparatively high concentrations can be found in the top links of the food chain, such as fish, seals, marine birds and polar bears and of course also in humans.

When it became obvious at the end of the last century that PFOS are among the vP/vB compounds, the substance was banned. The chemically closely related compound PFOA (perfluorooctanoic acid) was similarly taken off the market. A period of only five years passed between various groups of researchers providing evidence of the substance's potential hazardous nature and its ban. For other POPs that are not considered to be vP/vB this process can take up to 20 years.

Shifting problems

PFOS and PFOA primarily accumulate in the blood and liver. Following their ban, they were replaced by chemically closely related compounds in the perfluorocarbon group (PFCs) which includes PFOS and PFOA. The industry now uses PFCs that less strongly accumulate in the blood and liver and thus are less bioaccumulative. However, this poses a new problem: These PFCs are relatively well soluble in water. Studies have shown that concentrations of these water-soluble PFCs have increased strongly, especially in China's rivers and coastal waters. The introduction of new PFCs has therefore only shifted the environmental problem from bioaccumulation in organisms to elevated concentrations in the water.

Regardless of the type of pollutant, it has been shown that the concentrations of many problematic substances in rivers and coastal waters in the EU and the USA have declined in recent years. This is due in part to improved wastewater treatment technologies and the improved treatment of industrial effluents but it is also due to the fact that the production and processing of many chemicals has been shifted from western industrialized nations to countries such as China and India. Therefore it is hardly surprising that the situation has worsened in these countries even though, at least in part, modern wastewater treatment technology is being used.

But even modern technology is not capable of completely removing all contaminants from wastewater. Given that China produces particularly large quantities of chemicals, the quantity of pollutants entering the environment remains relevant, including the total amount of PFCs. Many estuarine coastal areas are contaminated by PFCs, for example the Yangtze River Delta in eastern China. This is where the PFCs are produced and used by several textile companies. Other rivers along China's east coast are also heavily polluted. The PFC concentration in the Xiaoqing River Delta, for example, is 2000 times as high as that found in the estuary of the Elbe River in Germany, a situation that is attributed first and foremost to the relocation of production to China. There has not yet been any in-depth research on the potential environmental impact of these high concentrations in the water or on the overall severity of this accumulation.

Surface mining poisons entire regions

Large-scale mining operations are another significant contributor to pollution in rivers and coastal waters. Mostly these involve the mining of economically interesting chemical elements such as iron, copper or gold. Since these elements do not occur naturally in their elemental form but are bound to other elements they must be separated and concentrated. The resultant mining waste is deposited either as dry waste in spoil heaps or together with partially toxic wastewater and sludges in basins or tailings ponds. Time and again such basins and pits fail, releasing into the environment the substances they contain.

There are also cases where wastewater is directly discharged into rivers, one example being the Ok Tedi mine in Papua New Guinea which has discharged directly into the Ok Tedi and Fly rivers since the 1980s. These rivers, together with their tributaries, form one of the largest tropical river systems worldwide. At times the inland mine discharged such vast quantities of sludge into the rivers that it deposited on the riverbanks, polluting not only the river water but also the surrounding environment with copper residues in particular. It is assumed that the decline of the river's fish populations is due to this contamination.

Similar environmental pollution is evident in the southwest Indian coastal region in the Panmana village area in the state of Kerala. Heavy-metal-rich placer deposits, mineral-rich sediments deposited over millions of years, have been mined here since 1922. The placer deposits were initially mined for metal. Since the 1980s, the interest has shifted to ilmenite, a titanium-iron oxide mineral. Ilmenite is the main source of the widely used whitener titanium dioxide, a pigment used in wall paints, automotive paint and toothpaste. Since 1984, ilmenite has been processed directly at a local factory. The resultant heavy metals are no longer used. Together with other chemical elements, the heavy metal-containing wastewater is discharged into storage basins which, however, have been leaking for more than a decade. During this time this leakage has slowly contaminated water wells and soils over an area of 16 square kilometres around the factory. The heavy metal concentrations in the area exceed international threshold values multiple times over. The contamination of soils and water not only result in plants dying in many places, but more and more people are suffering from excema and are getting cancer. Many of the local people have left their home region as a result.

Inland sludge spill contaminates the coast – the Rio Doce case

Even mines situated well inland can pollute coastal regions, as demonstrated by an iron ore mine located near the Brazilian town of Mariana 250 kilometres north of Rio de Janeiro. On 5 November 2015 a dam holding waste sludge from opencast iron mining burst, spawning a mud tsunami into the Rio Doce, a river that flows into the Atlantic Ocean. According to the United Nations Human Rights Council (UNHRC), approximately 50 million tonnes of iron ore sludge, roughly equating to the volume of 20,000 Olympic-size swimming pools, spilled downhill and buried the village of Bento Rodrigues located 5 kilometres away from the mine as well as large swathes of land. The red sludge wave traversed 600 kilometres of the Doce River before spilling into the Atlantic. Sixteen people lost their lives in the disaster.

Since the sludge was laced with high concentrations of heavy metals and other toxic substances, the affected areas around Bento Rodrigues are still inhabitable to this day and agricultural land use is impossible. The impacts of the pollutants on the affected Atlantic estuary are not yet known. There are fears that large quantities of pollutants have been deposited on the ocean floor. If marine animals ingest these with their feed, fishing will also be affected as fish and seafood would no longer be fit for sale.

2.46 > Environmental disaster in the Brazilian state of Espírito Santo: Toxic iron ore sludge spills from the Doce River into the ocean.

Mysterious marine litter

In recent years, scientists and the media have paid particularly strong attention to marine pollution caused by plastic waste, not least owing to the fact that this threat is often directly visible and the relationship between cause and effect is easily understood. Current discussions revolve around potential risks caused by the plastic debris and the question of how just much litter is floating around the oceans. Marine litter is categorized as follows:

- macroplastics are greater than 25 millimetres in size,
- mesoplastics are 5 to 25 millimetres in size,
- large microplastics are 1 to 5 millimetres in size,
- small microplastics measure from only a few micrometres up to 1 millimetre.

The impact this waste has on marine organisms depends on its size and nature. Macroplastics can become deadly traps for marine organisms. Discarded fishing nets for example can entrap marine turtles, leading to their death by asphyxiation. There is an on-going debate as to whether marine macroplastics and mesoplastics might be capable of not only killing some individuals but putting whole populations of marine animals at risk. A recent study has shown that presently as many as 90 per cent of all seabirds are already ingesting pieces of plastic. The degree to which different seabird species are at risk depends on their feeding behaviour.

For some time now investigations have been underway on the impacts of microplastics on marine life. In a laboratory experiment, mussels were exposed to high concentrations of microparticles. The particles were absorbed from the digestive tract into tissues where they triggered inflammatory responses. These experiments have been criticized for working with extremely high particle concentrations, i.e. significantly higher than the concentrations found in the oceans. For comparative purposes, similar experiments were conducted in which the mussels were kept in water with significantly lower particle concentrations, i.e. concentrations similar to those found in the North Sea. The mussels suffered no evident damage in these experiments.

2.47 > Heavy metal contamination is widespread in the soils in the village of Panmana in the Indian state of Kerala. Plants can hardly grow here anymore.

Waste beyond measure

In general, it is impossible to precisely measure and quantify the amount of litter present in the oceans. Nonetheless, in 2015 US American scientists attempted to come up with an estimate as part of a study. To this end, they looked at the production side and calculated that the 300 million tonnes of plastic materials produced worldwide every year result in the generation of 275 million tonnes of plastic litter, i.e. approximately 90 per cent of the production. For their study, the researchers had analysed the existing waste disposal infrastructure and recycling quotas in a range of countries. From this information they deduced that approximately 4.8 to 12.7 million tonnes of plastic litter end up in the oceans each year. While these figures have often been cited since their publication, criticism has been levelled at the study to the effect that production data in conjunction with information on waste recycling do not allow for conclusions as to the quantities of waste that ultimately end up in the oceans, given that litter finds its way into the marine environment through very different pathways: by way of rivers, through direct disposal into the oceans, or by being blown out to sea from landfill sites. It is impossible to quantify all these pathways. Owing to the fact that a major proportion of the plastic waste has sunk to greater depth where it can no longer be discovered, it is similarly impossible to quantify the amount of waste that has entered the oceans in the past.

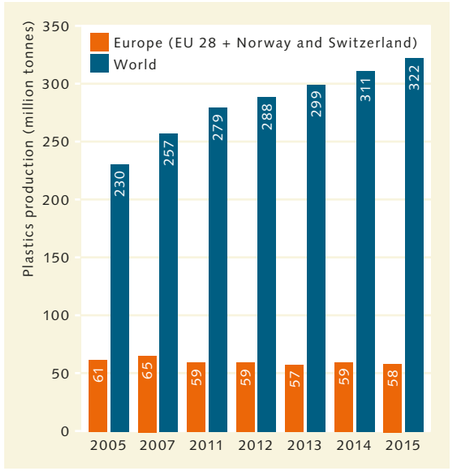
Exaggerated estimates?

Many different sources contribute microplastics to the marine environment: the slow degradation or disintegration of larger plastic marine litter items under the influence of saltwater and UV sunlight, ship coatings, abrasion from plastic items and car tyres, and also plastic microbeads in scrubs. The difficulty in determining the overall quantities of microplastics is primarily due to the fact that different groups of researchers have thus far used different methods and devices to record and study microplastics. Some scientists extrapolated particle concentrations in water to cubic metres, others to square kilometres. Some stated the absolute number of particles found while others stated their weight in milligrams per kilogram. As a result, the comparability of figures is very limited at present. To remedy this situation an EU project is underway which aims to develop the first harmonized measurement standards. These will concern not only the way waterborne particles are counted but also their correct identification. For a long time researchers have tried to use microscopes to record the number of particles. However, this optical method overestimated the quantity of particles by up to 70 per cent as quartz sand was often misidentified as plastic. New devices that use infrared light and are capable of precisely identifying plastics are to avoid such errors in the future.

Tourism: recreation at the expense of coastal habitats

While the risk to coastal habitats posed by plastic litter is as yet largely unknown, the adverse impacts of tourism have been evident for years. The construction of hotels and roads, especially in highly popular holiday regions, has considerably altered many coastal landscapes. Wetlands have been drained and built over and beaches are visited by high numbers of people. The organisms dependent on the coastal strip, i.e. the immediate transition area between water and land, are strongly impacted by these developments. Many bird species, for example, depend on coastal wetlands such as lagoons or estuaries as breeding or resting areas. Seals similarly use the coastal strip for hunting or resting, and marine turtles need pristine sandy beaches on which they can bury their eggs. In some regions such sites have become very rare. At the beginning of the nineteenth century, many Mediterranean regions still hosted large populations of green sea turtles, loggerhead sea turtles and leatherback sea turtles. As a result of the transformation of natural sandy coastal areas into tourist resorts these species have almost completely disappeared. In the Mediterranean, green sea turtles can now only be found off Cyprus, loggerhead sea turtles have become limited to small areas off Greece and Turkey, and in exceptional cases leatherback sea turtles may still be found off Syria or Israel.

The transformation of natural coastal margins into tourist sites, some of which have taken on an urban character, also gives rise to other impacts on the coastal



2.48 > The amount of plastics produced worldwide has been increasing for years. It is reasonable to assume that the amount of plastic waste reaching the oceans has similarly increased. However, there are no reliable data.

2.49 > Intensive tourism can severely damage coral reefs – for example when holidaymakers carve graffiti into marine organisms.

environment. In many places, concrete walls and harbour infrastructure have been built for the purposes of coastal protection, as seafront esplanades or as marinas. Such developments have completely altered the habitats of many different aquatic organisms. Caves, refuges and feeding grounds were lost. Even where the seashore is primarily rocky, concrete buildings alter biocoenoses. The chemical composition of the surfaces of concrete structures differs from that of natural stone. Many marine organisms that attach to solid surfaces therefore avoid concrete structures, which tend to be significantly less species-rich overall as a result.

Great pressure on coral reefs

The gradual destruction of coastal habitats is caused not only by building development but also by intensive tourism use. Coral reefs are among the heavily frequented habitats. The impacts of intensive diving tourism were studied in greater detail at the Great Barrier Reef on Australia's East Coast. The reef was found to be subject to different types of destruction:

- In areas where boats set off, corals are destroyed by holidaymakers wading from shore to boats and back. Corals are completely destroyed in heavily frequented sections. Anchored pontoons, floating restaurants and bars etc. permanently shade out sections of reefs. Corals die off in such sections.
- Anchors that are carelessly dropped by pleasure boats or diving boats may directly destroy corals.
- Where fish are fed for observation purposes, inappropriate or spoilt feed may result in the spread of diseases on the reef. Moreover, feeding may attract large predatory fish that do not normally frequent the reef sites concerned, which in turn leads to a significant decline in certain fish species.
- Divers, and inexperienced divers in particular, come into contact with reef material and break off especially the finely branched corals.

While the Australian researchers emphasised that optimized local management could avoid all this damage, other experts argue that diving tourism on coral reefs is damaging as a matter of course, independent of the degree to which the tourists are informed and guided. They also emphasise that minor damage caused by diving tourism in conjunction with other stressors, such as an increase in water temperatures caused by climate change, can result in greater cumulative damage.

Conclusion

Immense performance, immense pressure

Humans have been closely associated with coastal ecosystems for millennia. They have used the coasts both as a source of food and a space for trading. Archaeological finds indicate that humans navigated coastal waters in simple boats as early as 6000 years BC, for example in the South China Sea and the eastern Mediterranean. Coasts have also always been the arena of countless conflicts among parties seeking to gain political or economic dominance in a given region.

Coasts deliver many different types of services that are generically termed ecosystem services. These include the "provisioning ecosystem services", i.e. the goods provided by the oceans such as fish or fossil resources. The "supporting ecosystem services" are of key importance. They include primary production, i.e. the production of biomass by algae through the process of photosynthesis. Primary production is in fact a precondition to marine life. In addition, there are "cultural ecosystem services" such as the coasts' spiritual significance and their vital role in tourism. "Regulating ecosystem services" are clearly of special importance with regard to environmental pollution caused by humans. These services primarily include the cleaning function performed by coastal waters, as they significantly contribute to the degradation of nutrients reaching the oceans from intensively used arable farmland or untreated sewage.

In many cases, humans are overexploiting coastal waters at present, thus preventing them from performing their ecosystem functions. If nutrient inputs into the oceans from agriculture or aquaculture are too high, these nutrients can no longer be eliminated. Watercourses suffer from eutrophication, resulting in the spread of oxygen-depleted zones. Moreover, industrial pollutants are a threat to coastal waters. The latter include heavy-metal-containing compounds as well as persistent chemical substances that accumulate in the food chain and cause illnesses such as cancer. Such substances include, for example, polyfluorinated compounds which have been used for years in common products such as outdoor clothing or cookware coatings.

Plastic litter is another type of pollution reaching the oceans through diverse pathways. Marine animals and seabirds ingest plastic particles and die as a result. Moreover, plastic litter breaks down into microscopically small fragments. These microplastics are now present throughout the world's oceans. Scientific studies are underway to determine the degree to which animals are ingesting and are at risk from microplastics.

Overfishing is doubtlessly one of the most significant problems currently faced in coastal waters. These waters are particularly productive, and are thus fished too intensively. Moreover, in many places fishing activities destroy seafloor habitats such as coral reefs.

Uncontrolled proliferation of settlements and the growth of coastal megacities are profoundly changing the coasts today and have led to the loss of important ecosystems such as floodplains, wetlands and mangroves. Moreover, sand extraction for building projects causes widespread damage to coastal areas. A particular threat to human society is arising from the gradual sinking of coastal metropolises. This subsidence is caused, in particular, by the pumping of groundwater for human consumption. Normally the groundwater functions as an abutment to the heavy mass of buildings above. Incidences of flooding are becoming ever more frequent as a result of urban subsidence. Rising sea levels in the wake of climate change may exacerbate this situation in future.