2 How the sea serves us

> Many of the ecosystem services provided by the sea are threatened today by overexploitation, environmental pollution and greenhouse gases. Yet in many cases, how severely individual habitats are degraded and ecosystem services are impaired is just not known. Researchers are therefore attempting to assess the exact condition of marine ecosystems. Such analysis is important in order to plan concrete protection measures and to define critical limits and target values.

The bounty of the sea

> Since time immemorial we humans have been living with the seas and from their bounty. They provide us with food, mineral resources, transportation routes and other services. The climate-regulating effect of the oceans and the biochemical processes that take place in the sea are of fundamental importance. Today, some of these services are under threat, which is why it is time to develop approaches for more sustainable use of the seas.

From ocean threat to ocean under threat

For millennia the sea seemed infinitely vast. Coastal dwellers, fishers and seafarers perceived it as overpowering and even threatening although it was the basis of their livelihoods. Myths of sea monsters and sea gods grew up around its unfathomable depths.

In most countries and regions, the sea has long been demystified, and it is becoming apparent that the oceans are by no means as invulnerable as our forebears believed – on the contrary: today humans are influencing and harming the ocean. We are discharging toxic substances and excessive nutrients into the sea and plundering fish stocks. Due to emissions of the greenhouse gas carbon dioxide, large volumes of which dissolve in seawater, humans are even beginning to alter the chemistry of the water masses. Many climate researchers believe that as the atmosphere and the ocean undergo warming, ocean currents will shift in future, resulting in changing weather conditions on land. The human-induced – anthropogenic – changes taking place in the sea, the atmosphere and on land are so far-reaching that in the year 2000, scientists working with the meteorologist Paul Crutzen suggested considering the era since the beginning of the Industrial Revolution as a human-influenced geological epoch in its own right. Crutzen, one of the researchers who discovered the hole in the ozone layer, aptly names this epoch the age of humans, or the Anthropocene (from the Greek word *ánthrōpos*: human).

2.1 > A ceramic figure from the fifth century BC. Mythical figures like the Greek sea monster Scylla were popular motifs for the decoration of everyday objects.

Rising resource consumption

Although the various kinds of damage caused by humans have been known for some time, efforts to bring the global economy onto a sustainable course have had very little success, if any. Instead, the consumption of natural gas, petroleum and coal as well as metals and other resources continues to rise. Since the beginning of the 1970s, worldwide energy consumption has doubled. By the year 2035 it will increase again by more than one third, according to data from the International Energy Agency (IEA) in Paris.

In the quest for new resource supplies, humans are also encroaching ever further into the sea. Today around one third of crude oil is drilled at sea – and the trend is rising. At the same time the mineral oil industry is conquering the last bastion of the marine environment: the deep-water and ultra-deep-water zones at depths of 400 and 1500 metres respectively. Around 10 per cent of the petroleum drilled worldwide is currently recovered from such great depths. The sums invested by mineral oil corporations for offshore oil extraction are correspondingly high.

Furthermore, experts anticipate that the extraction of ores at sea could also begin in the year 2016. For instance, the Canadian mining group Nautilus Minerals definitively intends to start extracting ores off Papua New Guinea in 2016, after a dispute over financing between the corporate group and the island state was settled in the autumn of 2014. Nautilus Minerals wants to extract "massive sulphides": deposits which formed around hot volcanic vents on the sea floor and are rich in precious metals.

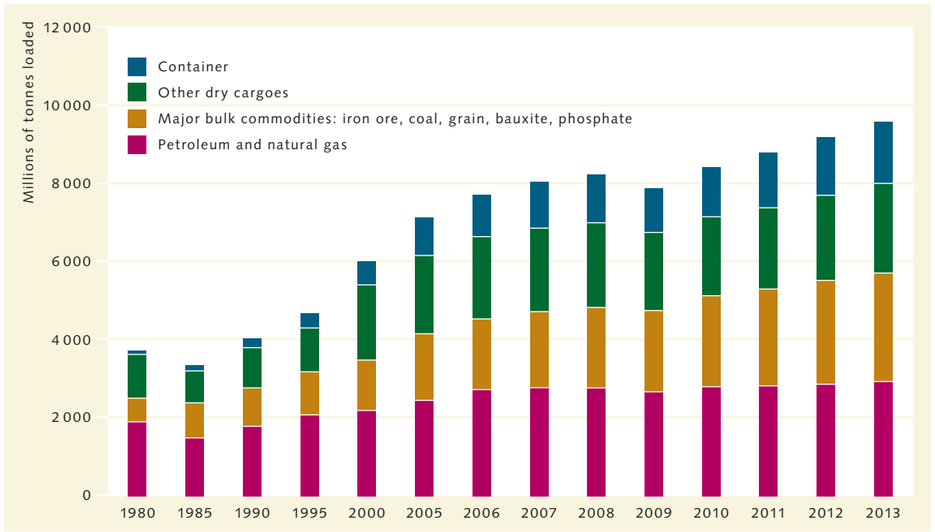
2.2 > The deep-water docks of Chinese company CIMC Raffles in Shandong Province. Up to nine drilling rigs at a time can dock at this pier, showing the vast scale on which deep-sea drilling of natural gas and petroleum now operates.

Manganese nodules or cobalt crusts, some of which are high in metal content and even contain larger quantities of certain metals overall than equivalent mineral deposits on land, are further attractions of the deep sea. The first heavy underwater vehicles are currently being built for ocean mining.

The sea – the main trading route

The sea is of great economic significance to humans in other respects as well. For instance, it is the most important trading route. Ships move more commodities than any other means of transportation. And unlike land-based roads where tolls are often payable, the trading routes across the open ocean are available for free. Ships carry petroleum, coal, ores and grain around the world. Container-loads of electrical appliances, clothing and foods are sent from Asia to North America and Europe. Crude oil from the Persian Gulf or South America is shipped in oil tankers. Apart from a decline in the cargo statistics during the economic crisis in 2008 and 2009, the quantity of goods transported by ships since the mid-1980s has constantly grown – from around 3.3 billion tonnes in 1985 to around 9.6 billion tonnes in 2013. Some 620 000 ships' officers are employed in sea travel alone. Added to these are many millions of people who work as sailors or dockers.

Above all, the sea coasts exert a special appeal to human beings. It is not by chance that many major cities, like Hong Kong, New York or Singapore, are in coastal locations. Numerous industrial plants have been and are being constructed by the sea, because raw materials and goods can be delivered and dispatched rapidly across the water. Experts estimate that today 41 per cent of the global population lives no more than 100 kilometres from the



2.3 > The oceans are the world's most important transportation routes. The volume of seaborne cargoes continues to rise since the 1980s.

sea. The United Nations believes that this figure is likely to rise further in future. In many regions, it is also boosted by the millions of domestic tourists who seek out the coasts for bathing and recreation.

The sea's most important living resource, from the human viewpoint, is fish. According to estimates by the Food and Agriculture Organization of the United Nations (FAO), today the livelihoods of 600 to 820 million people worldwide depend directly or indirectly upon fisheries. These people include fishers' families and suppliers – the makers of fishing equipment, for instance. Moreover, fish is the principal component of food in many places and a very important source of protein. Overall, about 20 per cent of humankind's nutritional needs are met from the sea. Apart from fish, crustaceans and bivalves, people also consume algae and jellyfish.

Critical issues go unseen in the sea

As pressure on the sea continues to grow, the question arises of how any sustainable use of the oceans could be achieved under these circumstances. Normally sustainability theories refer to the situation on land, where critical issues quickly become evident. If the effluent from a mine contaminates rivers and soils for a long period, for example, then there are people directly affected whose usage or property rights are infringed. Damage is normally directly visible or at least measurable. It is also obvious right away who the beneficiary is. This means that interest groups can be clearly defined, conflicts aired and negotiations conducted about a sustainable use of natural resources.

Processes in the sea remain invisible to most people, however, and are difficult to bring to light. For example, at the mouth of the Mississippi in the Gulf of Mexico, a 20 000-square-kilometre dead zone has formed in recent years which is almost devoid of oxygen. It has been caused by large quantities of nutrients discharged by agriculture into the river and then carried into the coastal region. In the sea, nutrients lead to rampant algal growth. When the algae die, they sink into the deeper water layers and are broken down by bacteria in a process which consumes oxygen. When the algae multiply especially quickly, the microbial degradation gradually exhausts all the oxygen. For higher organisms such as fish, crustaceans, bivalves and molluscs, this is disastrous: either they flee, or they die of oxygen starvation. Humans living on land barely notice any of this – with the exception of a few fishers whose fishing grounds have shrunk or shifted due to the expansion of the dead zone.

The second major difference from land is that continuous sea areas extend beyond national borders or are even – like the high seas – international areas. Ocean sustainability can therefore only be achieved if numerous nations pull together. So today it is necessary to find new approaches for sustainable ocean use which are internationally applicable above all else.

Critical limits in sight

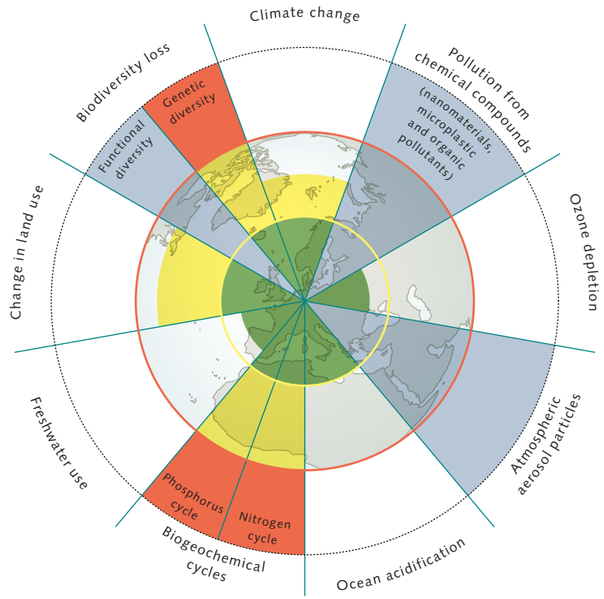
An accessible approach that is currently inspiring the international sustainability debate, and which combines the terrestrial and marine realms, is the concept of planetary boundaries. To develop this concept, which was first published in 2009 in the scientific journal *Nature* and updated in 2015 in *Science* magazine, an international Swedish-led research team asked itself how potentially catastrophic environmental changes could be avoided in future. For this purpose they defined nine essential environmental dimensions, or Earth system processes, such as climate change, freshwater consumption or ocean acidification. For seven of these dimensions – based on existing and to some extent provisional calculations – the researchers were able to quantify critical limits. If these were exceeded, they say, it could result in grave global or regional environmental changes – with unforeseeable consequences for life on Earth. In the scientists' view, this applies particularly to climate change and biodiversity loss.

In order to illustrate the potential hazards of crossing the thresholds, for every dimension three levels of risk are specified: the first is a zone of safety; the second is a zone of uncertainty or danger which indicates that the risk of grave effects is rising; and the third zone signals a high risk of grave effects or that such effects have already occurred. Large-scale extinction of different organisms, for example, is already taking place and is clearly irreversible.

Currently, according to researchers, the planetary boundaries or critical environmental limits are already being exceeded on four of the nine dimensions: biodiversity, the global phosphorus and nitrogen cycles, climate change and land use. If the situation is considered from a regional rather than a global perspective, limits are also being exceeded on other dimensions such as water consumption, e.g. in dry regions like the western USA, parts of Southern Europe, Asia and the Middle East.

According to estimates by the International Union for Conservation of Nature and Natural Resources (IUCN), the persistent destruction of species-rich and near-natural habitats is accelerating the speed at which species – along with their genetic information – are being irretrievably lost. Compared with the fossil record, the extinction rate today is substantially higher. Historically, only one mammal species died out per millennium, for example. In the period from the 1970s until today, the rate was 100 to 1000 times higher. By the year 2050 it is likely to have risen once more by a factor of 10. A key reason for biodiversity loss is the progression of land use. Forests continue to be cleared to create farmland, e.g. in South Ame-

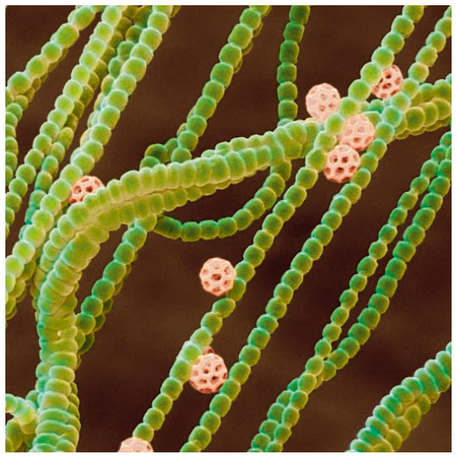
2.4 > The planetary boundaries model makes it clear how excessively humankind is overusing resources. The different colours indicate the status of the individual environmental dimensions.



rica or in China and South East Asia. More intensive land use is likely to cause the worldwide area of forest and grassland to shrink by a further 10 to 20 per cent by 2050 – affecting many near-natural habitats along with the species they host.

Nitrogen is important for the production of amino acids, which in turn combine to make proteins. Both plants and animals therefore require nitrogen. In nature, nitrogen occurs as atmospheric nitrogen. Normally, however, higher animals and plants cannot absorb and convert this atmospheric nitrogen directly. Only a few specialized organisms like bacteria are capable of this. In the sea, these include cyanobacteria, single-celled organisms which float freely in the water and used to be known as blue algae. Cyanobacteria absorb atmospheric nitrogen which dissolves in water in the uppermost ocean layers. This is how nitrogen enters marine food webs. Humans make use of nitrogen mainly in the form of artificial fertilizers in agriculture. Particularly in Central Europe and in the agricultural regions of China and the USA, this fertilizer is used excessively and leads to the eutrophication of rivers, lakes and coastal waters, to algal blooms and to the dreaded oxygen depletion.

Amino acids
Amino acids are the building blocks of proteins. In the cells of plants and animals, amino acids are combined into proteins through the complex biochemical process of protein biosynthesis. Depending on their amino acid composition, proteins vary in function. Some are incorporated into muscle mass, others regulate metabolic processes. The central component of every amino acid, known as the amino group, contains nitrogen.



2.5 > Under a microscope, the elongated cyanobacteria resemble strings of pearls. These aquatic creatures, formerly known as blue algae, are capable of processing pure nitrogen.

Climate change is also exceeding the planetary boundary, which is defined as a maximum concentration of carbon dioxide of 350 ppm (parts per million) in the atmosphere. The current concentration of 399 ppm puts this in a danger zone, where a high risk of grave and irreversible environmental change prevails. Climate scientists have long been warning the world that to prevent the worst consequences of climate change, the temperature of the Earth's atmosphere must not be allowed to warm by more than 1.5 to 2 degrees Celsius.

In order to attain sustainability, not only it is necessary to quantify the correct boundaries for each of these environmental dimensions, but comprehensive solutions must also be devised which can be followed through politically, both at regional and supra-regional levels. How difficult that is in the context of the sea can be demonstrated by the long-standing dispute between politicians and fishery researchers over fishing quotas in the European Union. Since the researchers can only estimate quantities of fish, this weak point has frequently been exploited by politicians in order to set higher catch quotas.

The desire for social justice

But the planetary boundaries are just one of the many challenges for future life on Earth. Humankind also finds itself confronted with social problems. Many people are still enduring hunger and living in extreme poverty. The health and education systems in many countries remain severely underdeveloped and in many places there is no social justice. In the past few years the planetary boundaries concept has therefore been refined and supplemented with these social aspects. Only once these social dimensions have also been fulfilled and the critical limits for human society are not being breached will a safe and just space for humankind become a reality. This framework is charted in the image of a doughnut, in which the safe and just space is delimited by the planetary boundaries on the outside and by the essential needs of human beings on the inside. Both the doughnut and the concept of planetary boundaries are so broadly framed that they can be applied to all cultures worldwide. Nevertheless, they do not state in detail what has to be done. To attain the ideal of a safe and just space for humankind, individual habitats must then be examined to see how sustainable use can be achieved in future.

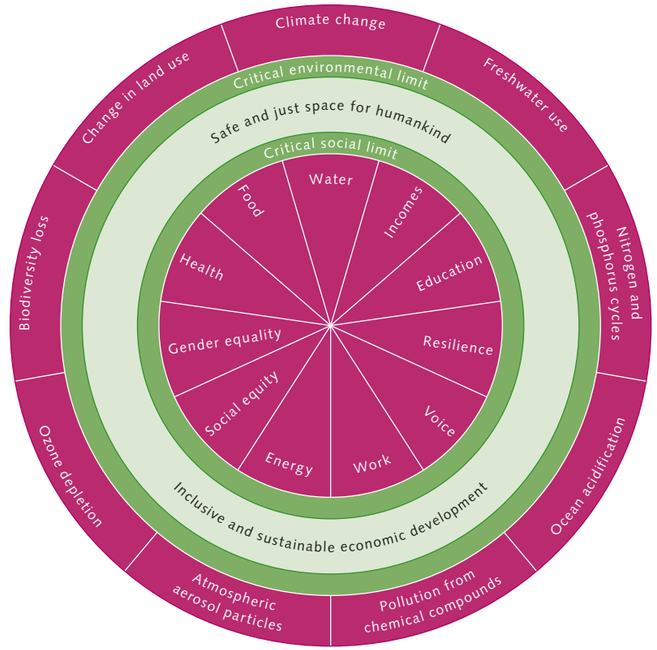
All manner of good

Before ecological limits can be defined, it is necessary to identify which aspects are actually relevant. For instance, the oceans provide special services, many of which are of global importance, and which human beings directly or indirectly use and exploit. Oceans store the energy from sunlight over many months and thus even out seasonal climate fluctuations. Furthermore, ocean currents distribute that heat over thousands of kilometres. The Gulf Stream transports subtropical heat from the Gulf of Mexico across the Atlantic into cooler Europe. Thanks to oceanic heat storage and the Gulf Stream, Europe's prevailing climate is temperate, which is an important prerequisite for its agricultural productivity.

Based on the model of the United Nations Millennium Ecosystem Assessment (MA), a large-scale international project, marine experts have researched marine ecosystem services and allocated them to the four categories of provisioning services, supporting services, regulating services and cultural services. It is not always possible to assign each of the services to a single category. For example, there are some marine assets which represent both provisioning and a cultural service – bivalves, for instance, which are not only sold to the population as vital food but also to tourists as traditional jewellery.

Provisioning services

Among the important provisioning services of the sea from the viewpoint of human beings are oceanic transportation routes as well as the fish and seafood that are existentially important for the nutrition of many millions of people. Around 80 million tonnes per year are fished from oceans worldwide. The value of the annual fish catch amounts to some 115 billion US dollars. Subsequent processing into different fish products, which are likewise



2.6 > The doughnut chart visualizes linkages between the environmental and social dimensions. A safe and just space for humankind emerges within the green-shaded area only, because that is where the critical limits are not being exceeded.

sold, increases value creation in the fishery industry even further. Fish is thus an important economic factor. Around 90 per cent of fishery activities take place in the nutrient-rich and productive coastal areas.

Particularly in the newly industrializing countries, the coastal population often lives directly from the fish catch. According to a scientific study, in 136 out of 144 coastal countries, small-scale fishery in simple motorized, rowing or sailing boats is many people's principal livelihood. In a few regions of Madagascar, up to 87 per cent of adults earn their living from small-scale fishery. Turning to Oceania, 82 per cent of people working in fisheries operate as small-scale fishers – industrial fishery with large trawlers is more or less non-existent there. In such regions fish is particularly significant because in the absence of alternatives it provides both food and incomes at once.

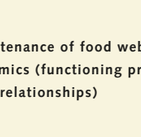
Equally, craft production based on marine animals such as bivalves and molluscs which are processed into souvenirs or jewellery is deemed to belong to the provi-

Overview of marine ecosystem services

The advantages and benefits that the oceans provide from the human perspective are referred to as ecosystem services. Ecosystem services can be both material and non-material, and are grouped into four categories.

SUPPORTING ECOSYSTEM SERVICES

can be regarded as the indispensable basis for the other categories of services



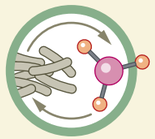
Maintenance of food web dynamics (functioning predator-prey relationships)

Maintenance of intact habitats (by supplying food, oxygen, clean water etc.)

Water cycle (evaporation and rainfall; exchange between land, atmosphere and sea)

Safeguarding biodiversity

Primary production (production of biomass)



Nutrient cycles (formation of nutrients through primary production, degradation of nutrients by bacteria and biochemical conversion on the sea floor or in water)

Maintenance of the resilience of marine habitats

CULTURAL ECOSYSTEM SERVICES

comprise diverse functions which serve the non-material well-being of humankind

Contribution to science and to natural history education

Aesthetic value
beautiful marine landscapes

Religious and spiritual value of marine landscapes and places near and in the sea

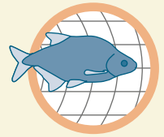
Inspiration for folklore, art, architecture etc.

Recreation and tourism

Cultural heritage (culturally significant landscapes and places near and in the sea, culturally significant sea creatures for traditional jewellery etc.)

PROVISIONING ECOSYSTEM SERVICES

encompass products and goods for direct human sustenance, on the one hand, and spaces and areas that the sea makes available, on the other

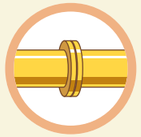


Fish and seafood from wild catch and aquaculture

Transportation routes

Renewable energies (tides, waves and wind)

Drinking water from seawater desalination plants



Areas for pipelines and sea cables

Pharmaceutical ingredients and other biochemical substances, e.g. for the food and cosmetics industry

Goods for jewellery or souvenirs

Areas suitable for military use

Non-renewable resources (natural gas, oil, gravel and sand)

Genetic resources from bacteria, sponges, and other organisms, e.g. for the development of new medicines

REGULATING ECOSYSTEM SERVICES

comprise the advantages and benefits that humankind gains from the regulating effect of the sea and its ecosystems

Coastal protection by dunes, coral reefs and mangrove forests

Maintenance of air quality through algal production of oxygen or ocean uptake of carbon dioxide

Climate regulation through the transportation of heat by ocean currents and heat exchange between water and atmosphere

Maintenance of water purity by breaking down nutrients from wastewater and agriculture which enter the sea

Maintenance of water purity by breaking down pollutants by means of dilution, chemical modification into harmless substances, or sinking and burial in the sediment

sioning services of the oceans. In many cases, even today substances from the sea are already being used for cosmetic products or in the chemical industry. Chitosan extracted from crab shells, for instance, is mixed into dental-care products because it protects the tooth enamel.

Another aspect of growing interest is the medical potential of marine organisms as well as their genetic information. Substances which combat herpes or malignant tumours have been isolated from poriferans (sponges). Moreover, in future scientists hope to isolate genes which contain the assembly instructions for proteins of medicinal interest. If genes like these can successfully be transferred into cultures of industrially-used bacteria like *Escherichia coli*, the active substances can be manufactured on a grand scale. There are also prospects of isolating new antibacterial substances from marine organisms which prove effective against the dreaded multi-resistant germs that can no longer be treated with conventional antibiotics.

The seas also offer a range of other provisioning services. Among them are the non-renewable energy sources of natural gas and petroleum, the ores on the sea floor, and diamond deposits. Sand which is dredged from offshore to replenish sandy beaches after severe storms or for use on building sites is another such service, as are the transportation routes that the sea provides for shipping.

The sea not only provides energy in the form of fossil fuels but also in the form of renewable resources. Today there are increasingly vigorous efforts to mobilize the energy that is latent in waves, in tidal currents and in the wind over the sea. Some time ago on the Irish coast, an underwater propeller was installed which is set in motion by the rise and fall of the tides. Another notable technology is the Pelamis wave energy converter which floats on the sea like a sea snake. It consists of several segments which move against each other, generating hydraulic pressure. This in turn powers a turbine. There are now several Pelamis installations in operation off Portugal and in the Orkney and Shetland Islands. Experts estimate that 1700 terawatts of electricity per year could be generated from wave energy alone, which equates to about 10 per cent of global electricity demand. The number of wind turbines in the sea is also increasing. The country leading the way in offshore wind energy is Great Britain, where a good dozen large-scale wind farms have been constructed off the coast.

2.7 > Fishers on the beach at Kayar, Senegal. In their pirogues, boats made from a single tree, they put out to sea in order to supply local markets with fish. Tens of thousands along Senegal's coast engage in "la pêche artisanale" – artisanal fishing.

Cultural services

Cultural services are those which have particular social, religious or spiritual significance or which are part of a nation's traditions. Beyond this, cultural services encompass the aesthetics of a landscape and its recreational function, leisure value or the inspiration that it provides. Likewise, a marine area's appeal for science or natural history is deemed by sustainability experts to belong to cultural services. It is perfectly possible for these to overlap with other ecosystem services – for example, with the provisioning services.

A historical example is the pigment purpura, which was a briskly traded commodity in ancient times. In those days the pigment was extracted mainly in Greece from the purple dye murex, a species of sea snail. Since each mollusc contains a tiny amount of pigment, lots of the creatures are needed, which makes production time-consuming and expensive. The extracted purpura was an exclusive product and was, for a long time, reserved for dignitaries and high officials. Therefore it was also high in symbolic value. In Rome, for example, the members of the Senate decorated their togas with purple borders. The purpura trade was a profitable business for centuries.

Another natural product which for a long time embodied great meaning and considerable wealth was pearls, which were obtained in the Persian Gulf by pearl divers. For many years the pearl trade was the most important economic branch in this region. At the beginning of the twentieth century the pearl industry was in its final flush of success. The annual turnover of pearls was valued at 160 million US dollars. Not long after that, however, the Japanese succeeded in breeding pearl oysters in large quantities. This broke the monopoly of the pearl divers around the Persian Gulf.

2.8 > The purple dye murex *Bolinus brandaris*. The purple dye was extracted from a whitish secretion in the mantle cavity. 8000 of the molluscs were necessary in order to produce 1 gram of the dye. 200 grams of dye were needed to dye 1 kilogram of wool.

Unlike purpura and pearls from the Persian Gulf, sharkfin soup is still of significance even today. The dish is a traditional delicacy in Chinese-speaking regions in particular. Today the soup is offered at very high prices. It not only serves as food but also symbolizes prestige and status, which makes it both a provisioning and a cultural service at once.

Shark fishing is highly contentious, however. Because it is very profitable, sharks – including threatened species – are hunted intensively and some populations have diminished drastically as a result. Furthermore, in many cases the captured animals are not fully utilized. Often only the valuable fins are removed and the cadavers are thrown back into the sea, unused.

A different situation is faced by the Nuu-chah-nulth people, First Nation people living on and around Vancouver Island on the Canadian Pacific coast. They used to hunt whales, but today that is prohibited for species conserva-

2.9 > Oostduinkerke in Belgium still has a few fishers who catch shrimps using a very peculiar method. They sit on a horse, which drags the heavy shrimping nets along behind it.

tion reasons. The Nuu-chah-nulth people perceive the ban as the painful loss of a tradition, for the whaling, the collective hunting, the butchering of the animals and the traditional festivals which accompanied whaling fostered the community of First Nation people fundamentally. Once whaling was banned, this important social bonding element went missing. This case makes clear how complex it can be to evaluate cultural ecosystem services.

An example of the sea's religious and spiritual aspects is sea burial, which is commonly practised in Europe and Japan. Many people express the wish not to be buried in the ground but in the open sea, the origin of all life. After the cremation of the body, the ashes are consigned to the sea in a water-soluble urn. This type of burial is only allowed in certain sea areas. Furthermore, it is only possible because the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (shortened to: London Convention, LC) permits the committal of urns as an exception.

Also of cultural importance today is the old tradition of Lenj boat-building that is still practised in Iran. The roughly 15-metre-long wooden boats have long been used along the north-east coast of the Persian Gulf for trade, travel, pearl diving and fishery. Numerous folk tales have grown up around the Lenj boats. Today, artists also maintain the tradition, and certain places organize their own Lenj festivals.

UNESCO (the United Nations Educational, Scientific and Cultural Organization) has placed Lenj boat-building on its intangible cultural heritage list. Other assets on this list include the traditional Belgian form of prawn or shrimp fishery which makes use of heavy work-horses. The cart-horses drag fishing gear through the water parallel to the beach. For decades the vast majority of shrimps in Western Europe have been fished from cutters, but on the Channel coast near Oostduinkerke there are still families who hold on to the laborious tradition with the horse. The catch yielded by the horse-drawn technique is just enough to live from, say the fishers. Its economic significance for the region is more or less negligible.

Currently the UNESCO list contains a total of 42 marine and coastal areas or associated traditions.

Cultural services – Basis for tourism

Aspects like the recreational value or the beauty of a coastal landscape, which are categorized as cultural ecosystem services, are closely associated with tourism. Religious sites and other cultural monuments, landscapes of natural beauty and recreational areas attract millions of holidaymakers every year. The number of people who take seaside vacations and the resultant importance of coasts for global tourism can barely be quantified at the moment, according to the United Nations World Tourism Organization (UNWTO), because the data is gathered in different ways in different regions or is incomplete. Added to that, it is almost impossible to analyse the extent to which the hinterland also benefits from coastal tourism – when beach holidaymakers visit the inland towns, for example. Nevertheless, in Europe the attempt is made to gauge the proportion of tourists staying in coastal regions. It is estimated that in 2009 some 28 million bed spaces were available in total (in holiday apartments, hotels, hostels or on campsites) in 27 European countries. Of these, around 60 per cent were located in the coastal regions. According to a survey conducted in the European Union (EU), 46 per cent of EU citizens spend their annual

2.10 > In the past, Iranian Lenj wooden boats were used along the Persian Gulf for trading, pearl diving or fishing. UNESCO wants to preserve the tradition of Lenj boat-building.

holiday as beach tourists. These statistics did not take account of tourists who head for the sea to pursue diving or other sporting activities. This in turn means that the total number of EU maritime holidaymakers may be even higher.

The UNWTO cites whale- and dolphin-watching tours as an example of the sea's popularity with tourists. This is one segment of tourism for which sufficient data exists. Whale-watching expeditions were first offered early in the 1950s on Point Loma peninsula in California. In those days the sea mammals were only observed from the shore. Even at that time the whales attracted around 10 000 visitors a year. It turned out that people elsewhere found the large animals equally fascinating, and eventually this tourist attraction spread around the whole world. Today whale- and dolphin-watching tours are offered in 119 countries. Around 13 million people per year take up such offers, spending around 800 million US dollars on the pastime. Once the costs of accommodation, travel and meals are taken into the calculations, the expenditure of these tourists amounts to 2.1 billion US dollars per year.

2.11 > The limestone caves on Mexico's Yucatán peninsula are very popular with divers.

Supporting services

Biological, chemical and physical processes that take place naturally in the environment and are thus the basis of life on Earth are categorized as supporting services. This category also includes the dynamics of the marine food web. Its finely balanced coexistence of predators and prey is ultimately of great benefit to humans, too, since fish is a valuable foodstuff.

Even the biodiversity of habitats and the different habitats themselves are classified as supporting services. Scientists have established that species diversity is extremely important for the stability of marine ecosystems. This has been demonstrated in various ways including experiments in macro-algae forests. In one field experiment, for example, the number of macro-algae species was artificially reduced by removing several species at the beginning of the growth period. In this species-impoverished habitat the overall algae biomass did actually diminish – reducing the availability of food for consumers and the number of available habitats.

One significant supporting service for marine life is the process known as primary production, the basis of which is photosynthesis by phytoplankton. Photosynthesis is the way in which plants make use of sunlight to create energy-rich molecules like sugar and starch. With the right light intensity and food supply, algae can grow and multiply very quickly. The service provided by marine algae is remarkable: all in all they produce around 50 per cent of the plant biomass worldwide.

Primary production is the basis of the food web. Unicellular algae are eaten by fish larvae and micro-crustaceans, which in turn become food for larger fish or sea mammals. The importance of primary production in the sea is shown by studies which have investigated the degree to which the size of fish stocks correlates with primary production. It emerged that in areas of periodically high primary production, the quantity of fish caught could rise by up to 30 per cent, whereas in other regions it decreased by up to 40 per cent in times of low primary production.

Primary production is bound up with the various biochemical processes and biogeochemical cycles of the sea.

Region	Whale and dolphin watchers in 2008	Countries in 2008	Direct spending (USD million)	Total spending (USD million)
Africa and Middle East	1 361 330	22	31.7	163.5
Europe	828 115	22	32.2	97.6
Asia	1 055 781	20	21.6	65.9
Oceania, Pacific islands, Antarctica	2 477 200	17	117.2	327.9
North America	6 256 277	4	566.2	1 192.6
Central America and Caribbean	301 616	23	19.5	53.8
South America	696 900	11	84.2	211.8
GLOBAL TOTAL	**12 977 218**	**119**	**872.7**	**2 113.1**

2.12 > Whale- and dolphin-watching are an important segment of the tourism industry. In 2008, almost 13 million people worldwide went on such safaris, spending 2.1 billion US dollars on these tours including travel and accommodation.

One example of these fundamental processes in the ocean is the carbon cycle. Carbon is the basic component of the human body and constitutes the vast majority of animal and plant biomass. Land-based plants and sea algae take it up from the atmosphere or the water in the form of carbon dioxide (CO_2). The plants then make use of the CO_2 as a component for sugar and starch production during photosynthesis. Through the metabolism of organisms and by means of natural chemical processes, carbon is constantly changing its state. In the sea, for instance, large quantities of carbon in the form of dead and decaying biomass, e.g. algae or micro-crustaceans, drop down into deep waters, but even while it is sinking some of this carbon is already being re-used by bacteria as food, and thereby metabolized.

Alongside the carbon cycle, a range of other cycles are significant to life. One example is the nitrogen cycle.

Regulating services

The protection from storms and floods afforded by mangrove forests, dunes, or coral reefs come into the category of regulating services, as does protection from erosion, i.e. the loss of sand from the coastline caused by storms and currents. This kind of protection is provided by intact ecosystems, such as the dense vegetation on dunes which holds down the sand during storms, or **seagrass meadows** and mussel beds in the water which prevent the fine sediment from being carried away by waves.

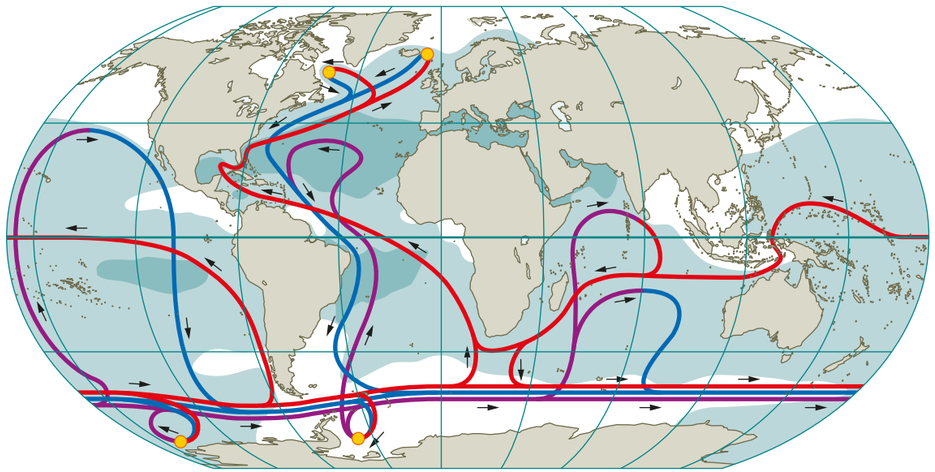
Large quantities of waste and excrement find their way into the sea from rivers or are piped from the sewage system directly into coastal waters in many places. Biodegradation of this matter is likewise considered a regulating ecosystem service, as is the absorption of toxic substances released by humans, e.g. heavy metals or persistent chlorine and fluorine compounds. Single-celled organisms and bacteria are the main biodegraders of this organic pollution load. When they die and drop to the sea floor, the pollutants settle along with them, accumulate in the sediment and are thus removed from the water. Naturally, the toxic substances in the sediment still persist in the environment for a long time, but had they remained

in the water many marine organisms would have been directly exposed to them. Plankton organisms especially would have absorbed these pollutants from the water along with tiny particles of food and then passed them on to other organisms in the food chain.

Engine of the climate system

The sea has a decisive influence on the climate. Scientists even refer to it as the engine of the Earth's climate system. Firstly, the sea exerts a regional influence. Since it can store heat for long periods, in winter it heats up the atmosphere and thus brings warmer air onto dry land in coastal areas. Because a great deal of water evaporates over the sea, in many regions the oceans also supply a large proportion of the rain that falls over the land.

Secondly, the sea has a global climate effect. The seawater in the tropics absorbs large quantities of solar energy and transports this towards the poles. Water can store heat energy for long periods so that the energy is transported over many thousands of kilometres. But the sun over the tropics is not the only driving force. Physical processes at the poles also keep the global climate machine in motion: There the water cools drastically so that ice forms. Since ice contains no salt and the salt is left behind in the seawater on freezing, in areas of sea ice the salt content of the water rises. The high salt content and the chilling make the seawater denser and thus heavier. Consequently the water begins to sink downwards. This phenomenon, which occurs in just a few polar sea regions, is known by experts as convection. Below about 2000 metres the water stratifies into the deep water masses and flows very slowly back towards the equator. This completes the loop of the large ocean currents, which begins in the tropics. Since these currents which encircle the globe are driven by temperatures and salt content, scientists call this phenomenon thermohaline circulation (*thermo*: driven by temperature differences; *haline*: driven by salt-content differences). But thermohaline circulation is not the only influence on ocean currents; the winds also have an effect.



2.13 > The global currents that flow around the world are complex and connect all the oceans. The diagram shows the thermohaline overturning circulation in simplified form. The yellow circles represent the most important areas where water sinks to a great depth. The purple and blue lines radiating from them mark the paths of the surface and deep-water currents. On their way through the ocean, these currents are mixed and warmed until they finally rise upwards. The paths of the warm return flows, which are close to the surface, are shown in red. Surface salt content is higher in the dark areas and lower in the white areas. Since the Atlantic is more saline than the Pacific on average, deep water can form there more easily. The circumpolar current shows that all oceans are interconnected.

Winds arise because sea areas or different landmasses heat up unevenly. This gives rise to differences in atmospheric pressure which are evened out by wind currents. The trade winds, which blow from the same direction for several months in the tropics and subtropics, are a major influence. In certain areas the trade winds drive the surface water away from the coasts. Consequently cold and nutrient-rich water from the depths rises towards the surface along the coast. Experts call these sea regions upwelling areas. Examples are the coastal waters off Peru and South Africa. Since the upwelling water brings many nutrients from the deep sea to the surface, primary production is particularly high in these waters, and they are especially rich in fish.

Exchange of gases

Not only the climate but also gases are regulated by the sea; the oceans and the atmosphere are permanently exchanging large volumes of gases. Every day, for example, seawater absorbs quantities of carbon dioxide equivalent to the weight of four million mid-range cars. Since the beginning of the Industrial Revolution, the oceans have swallowed up around half of the total carbon dioxide (CO_2) released by the burning of natural gas, petroleum and coal. Without this constant CO_2 uptake, the atmosphere would have been subject to far greater warming than has actually occurred.

Apart from CO_2 a range of other gases pass back and forth between ocean and atmosphere; for example, nitrogen and methane.

Algae odour acts as cloud seed

For the last few years researchers have also been taking an interest in a gas that was long disregarded: dimethyl sulphide. It arises when dead algae decompose, and causes the typical odour given off by algae on the beach. Scientists have found out that dimethyl sulphide is emitted in large quantities from the sea into the atmosphere, where it plays an important part in cloud formation as a condensation nucleus. Since clouds reflect sunlight and to some extent also thermal radiation, scientists suspect that dimethyl sulphide has a significant bearing on the climate. This is why producing dimethyl sulphide and exchanging it between water and air is now also considered to be one of the ocean's regulating ecosystem services.

Responsibility for future generations

The regulating and supporting services of the sea are particularly significant for life on Earth because they are comprised of some fundamental biological, biochemical and physical processes. These processes have been going on for millennia and some of them respond very sluggishly to changes. This is particularly true of the ocean's role as the engine of the climate system.

Ocean currents are constantly turning over immensely large water masses but move very slowly for the most part – often at slower than walking pace. The deep water that has sunk to the poles during thermohaline circulation moves so slowly that it remains at depth for several hundred to 1000 years. As a result of this, so far the human-induced changes to the climate which are causing the seawater to warm up are mainly detectable at the sea surface. It will still take some time before climate change really penetrates the ocean depths. Not that this is any reason for complacency. It means that changes affecting regulating and supporting ecosystem services of the ocean carry special weight as an intergenerational issue. Changes caused by human activity today could still be affecting people's lives in several hundred years time.

In view of the great importance of the sea's regulating and supporting ecosystem services, sustainability experts are now making the case that the Gulf Stream or the carbon cycle might also be considered as critical natural capital or critical services. The most important task for the future is therefore to develop strategies to safeguard these critical and other marine ecosystem services for the future, in the context of sustainable development.