

The **German Marine Research Consortium (KDM)** was founded in 2004 as a non-profit association of the largest marine research institutions in Germany. It pools the expertise of German marine and coastal research to strengthen the bottom-up strategic capabilities of the community, to network within the international community and to represent the interests of marine research vis-à-vis national, EU and international decision-makers as well as the public.

The **International Ocean Institute** is a non-profit organization founded by Professor Elisabeth Mann Borgese in 1972. It consists of a network of operational centres located all over the world. Its headquarters are in Malta. The IOI advocates the peaceful and sustainable use of the oceans.

The bimonthly German-language magazine **mare**, which focuses on the topic of the sea, was founded by Nikolaus Gelpke in Hamburg in 1997. mare's mission is to raise the public's awareness of the importance of the sea as a living, economic and cultural space. Besides the magazine its publisher mareverlag also produces a number of fiction and non-fiction titles twice a year.

The **Decade of Ocean Science for Sustainable Development (2021–2030)** is a global campaign, launched by the United Nations, to gather stakeholders in creating the ocean we need for the future: healthy, full of life, with protected areas and sustainably managed. The aim is to develop and implement knowledge-based solutions to the most urgent problems affecting the ocean. This immense challenge relies on input from marine research, but also requires champions from all sectors of society.

9 Marine Biodiversity – Vital Essence of Our Oceans



Published by **maribus**
in cooperation with



mare





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Marine Biodiversity – Vital Essence of Our Oceans

Preface

Since the first edition of the *World Ocean Review (WOR)*, one insight has taken centre stage: the state of our oceans is not only a scientific issue, but a reflection of social and political developments. The previous reports, over the years, have shed light on the multitude of challenges facing humankind as a result of overexploitation, pollution and accelerating changes in the oceans. They have repeatedly emphasized that what is lacking is not knowledge but resolute action, integrated solutions and international cooperation – challenges that are more relevant than ever, as *WOR 9* shows.

The ocean – the largest and most diverse habitat on Earth – remains caught in the tension between rising global demands and its own limited resilience. Social and political decisions influence how we use, protect and assign value to the ocean. The growing importance of sustainable use of the marine environment is reflected in the UN Decade of Ocean Science for Sustainable Development and numerous global initiatives – and yet equitable and sustainable ocean governance is still a long way off. The integration of local and indigenous knowledge systems, a fair balance between diverse interests, and rigorous attention to hitherto neglected values are the main focus here and are the subject of fierce debate in international bodies and in the context of national agendas.

Previous editions of the *World Ocean Review* have repeatedly analyzed the gaps in marine conservation and the serious consequences of political inaction. It has become increasingly clear that climate action, species diversity and the safeguarding of vital natural resources are inseparably linked – and require an internationally coordinated, equitable and inclusive approach. Past experience has shown that participatory management strategies, mandatory conservation provisions and public acceptance are the key success factors for achieving genuine progress. The current challenges require innovative, flexible solutions that reflect the rapid changes taking place within ecosystems and society.

WOR 9 therefore particularly emphasises that the conservation of marine biodiversity requires not only accurate analyses by natural scientists, but also farsightedness on the part of society and commitment from policymakers. The ocean is more than just a resource – it is the basis of our future, our identity and global justice. The coming decades will determine whether we strike a new balance between use and protection – and thus succeed in preserving the ocean as the source of our vital natural resources.

This report aims to inspire a new vision for the oceans – as a global common good, as the key to sustainable development, and as the touchstone for the social and political transformation that we so urgently need at this time.



Nikolaus Gelpke
Managing Director of maribus gGmbH, mareverlag publisher and Patron of IOI

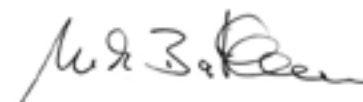
Biodiversity is complex. The diversity of species within a single habitat is only one component. Other factors also come into play: the interaction between species, but also their embeddedness in the inanimate environment. And ultimately, our own subjective views have a bearing on biodiversity as well – and this is where controversy creeps in: which measures should be implemented at the international level in order to stabilize marine biodiversity? After all, even organisms which we tend to dislike, such as pathogenic viruses and stinging jellyfish, form part of intact ecosystems.

This ninth *World Ocean Review (WOR 9)* focuses on the vital foundation of our oceans and explores all these aspects of marine biodiversity. The major marine science institutes in Germany, represented in the German Marine Research Consortium (KDM), have contributed their collective scientific knowledge of marine diversity to this latest edition of *WOR*. Together, they analyze the functions of species in various habitats in order to identify patterns and decode their causes. General principles are then defined on this basis.

What purpose do these findings serve? Human communities make a great diversity of claims on the sea: the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) assigns people to four archetypes according to whether they are living from, living with, living in or living as nature. However, key figures in politics and the economy generally only consider a small number of mostly market-based values of nature. This is reflected in the decisions they take, which lead, among other things, to overfishing, pollution and ocean warming, at the expense of future generations. The knowledge we produce is therefore intended to generate more respect for the largest habitat on Earth.

There are safety nets for ocean life, however, as *WOR 9* convincingly demonstrates. Marine species and habitats that were once severely degraded or close to extinction due to human activity are recovering as a result of conservation measures. The recovery potential of marine ecosystems is high, which means that a substantial proportion could be restored by 2050. Active global partnership is essential here.

Indigenous knowledge plays a key role in ensuring the success of this marine management approach, as does the recognition that some marine regions will have to be intensively used in future, although damage should be kept to a minimum wherever possible. Conflicts of interest between conservation and use should be resolved by involving all user groups in planning, implementing and monitoring measures relating to the exploitation of marine resources. The prospects of success increase if this takes place within the framework of international agreements and an integrated system of ocean governance, the aim being to think holistically about marine conservation and management. Short-term economic interests must be set aside if they harm the ocean's most important biological communities. This is the goal to which German marine research remains committed.



Prof. Dr. Ulrich Bathmann

Chair of the German Marine Research Consortium (KDM)

and member of the Executive Board of the German Marine Research Alliance (DAM)



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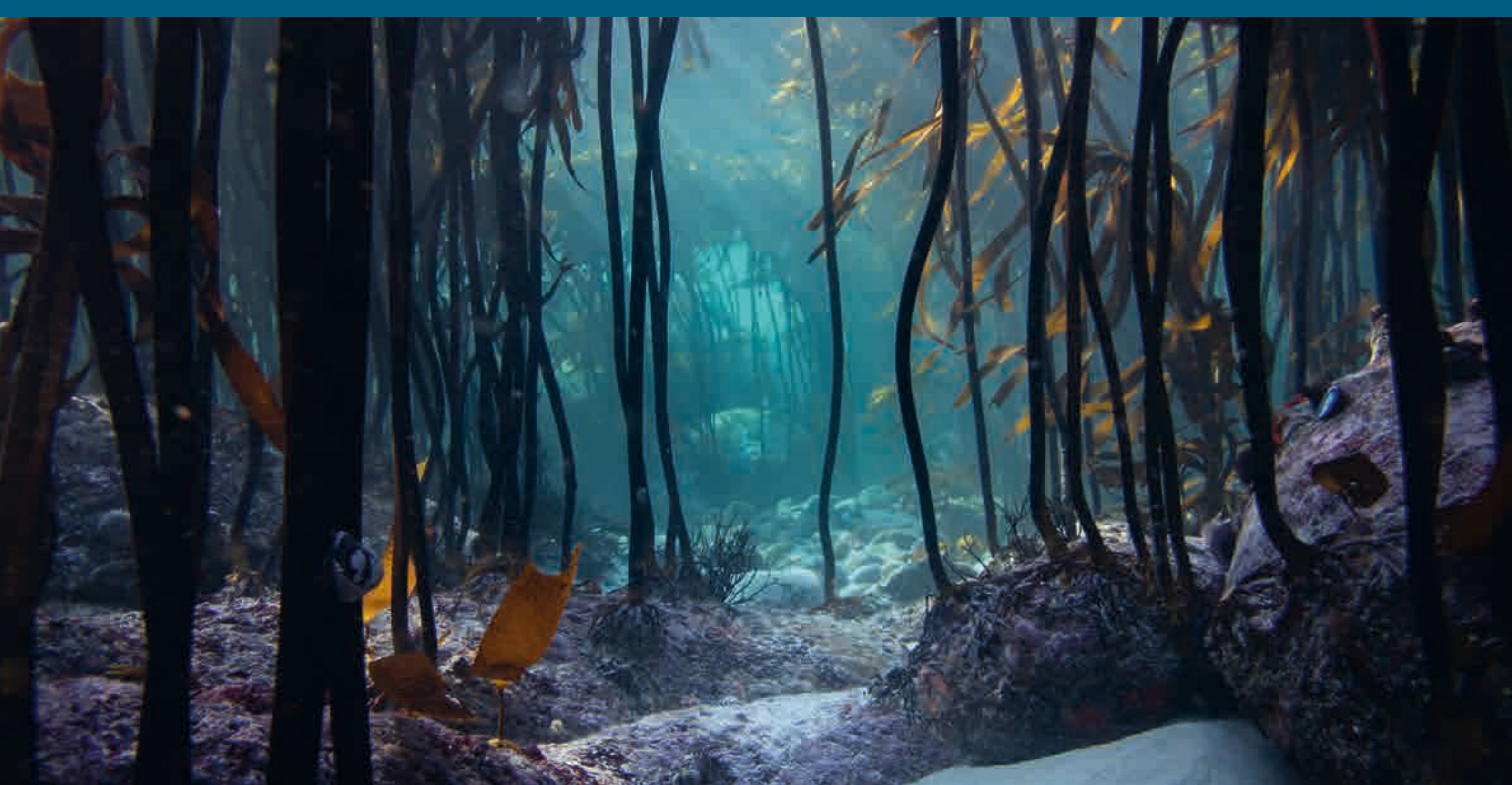
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1 Life in the ocean – species richness that counts

> As a habitat, the ocean exceeds all dimensions. No other habitat on the planet is as vast, diverse and unexplored as the global ocean. The variety of shapes and colours displayed by marine life is unparalleled. Measuring, understanding and, above all, conserving and enhancing this diversity is a major challenge in an era of climate change and natural resource overexploitation.



A constant stream of new discoveries

> It is estimated that between one and two million different species live in the ocean – from bacteria and archaea to plants, animals and fungi. Ten to 25 per cent of these have been scientifically described. All other marine organisms are considered to be as yet unknown. It is therefore not surprising that some 2300 new species are discovered in the oceans every year. Scientists are increasingly resorting to molecular analysis to identify them. These analyses can detect traces of marine life that have remained hidden until now.

Nothing is outlandish enough

Life in the sea has no standards: any size, any shape, any colour is allowed – no matter how bizarre. Anything and everything is included, from the tasselled wobbegong, a shark that actually looks like a bedside rug, to sea spiders with legs as long as a grown human, to jellyfish that glitter like disco balls or worms shaped like miniature Christmas trees.

The list of oddities and superlatives goes on and on, including creatures of all sizes and from all corners of the

global ocean, but especially from extreme habitats such as the deep sea or polar oceans. These harsh environments require their inhabitants to develop highly sophisticated adaptation mechanisms, so that over the course of evolution, the shape, colour and functions of organisms have served one sole purpose: to survive as best as possible and reproduce.

None of the beauties and presumed absurdities of marine life are just nature’s whimsy. Rather, every feature and trait is meaningful and has evolved through the process of evolutionary selection. But we humans have only



1.1 > The body appendages of the firework jellyfish (*Halitrephes maasi*) appear bright red in the remotely operated underwater vehicle’s spotlight. This deep-sea species has been sighted in the Pacific and Atlantic oceans and the Mediterranean Sea. It also appears to be able to survive in low-oxygen waters. But not much more is known about the species.

just begun to fathom their meaning in individual cases, and to understand the role individual species play in the marine food web and network of relationships. And sometimes we don’t even properly put on our thinking cap – like when we voted for the world’s ugliest animal in 2013.

The blobfish (*Psychrolutes phrictus*) won the title because, in the photos shown, this deep-sea dweller resembled a grumpy-faced large boulder. However, in their natural environment, the deep waters of the North Pacific Ocean, the grayish to anthracite-coloured blobfish look just like ordinary fish. Only their head is slightly broader because it is armoured with bone plates. When brought to the surface, however, the loss of pressure distorts the appearance of the up to 70 centimetres long fish into a depressed-looking droopy mess. The image of the odd-looking fish impressed the voters more than the fact that blobfish can live to be over 100 years old and are threatened with extinction by deep-sea fishing.

The largest habitat on planet Earth

The blobfish, the tasselled wobbegong, the Japanese giant spider crab and the Christmas tree worm are among the approximately 248,000 marine species (as of August 2025) officially listed in the World Register of Marine Species (WoRMS). They are all considered “known”. On average, 2332 new species are discovered each year, and the list keeps getting longer with no end in sight. This is probably due to the sheer size of the global ocean.

It is by far the largest habitat on planet Earth. While its dimensions can be described in numbers and units, they really are beyond human imagination. The global ocean contains 1.3 billion cubic kilometres of water, covering a seabed area of 361 million square kilometres. This represents 71 per cent of the Earth’s surface, or an area more than eight times the size of the largest continent, Asia. The average water depth is around 3700 metres. However, in deep ocean trenches, such as the Challenger Deep in the western Pacific Mariana



1.2 > *Spirobranchus giganteus* is commonly known as the Christmas tree worm. It owes its trivial name to its striking tentacle “crowns”. The calcareous tube it builds around its body serves as its home. It uses its tentacles to filter microalgae and micro-organisms from the water.

Trench, the distance between the sea floor and the water surface can be as much as eleven kilometres. Compared to such depths, even the world’s highest mountain, Mount Everest (8848 metres), appears merely medium-sized.

This space harbours life literally everywhere, from the deepest depths of the ocean trenches to the intertidal zones of the Wadden Sea and beneath the floating glacier tongues in Antarctica. Marine organisms brave the cold of the polar oceans as well as the extreme temperatures at hydrothermal vents, the so-called “black smokers”. Animal life is thriving even where humans have long thought it impossible – for example, on the sea floor of hypersaline deep-sea basins such as can be found in the Mediterranean. In the pore water between the sediment grains there is no oxygen, and salt concentrations are high: living conditions in the sea could hardly be more extreme. Nevertheless, scientists were able to identify three different species of tiny sediment-dwellers called Loricifera (from Latin, *lorica*, corselet [armour] + *ferre*, to bear) that colonize the upper layer of the sea floor.

Experts attribute the enormous resilience and specialization of marine organisms to the long evolutionary



1.3 > The sea anemone *Edwardsiella andrillae* could hardly have chosen a colder place to live than the underside of the Ross Ice Shelf in Antarctica. This is where researchers discovered it, burrowed deep into the ice. Only their tentacle tips peek out of the ice.

history of life in the sea. Some four billion years have passed since the once hot planet Earth cooled to below 100 degrees Celsius, liquid water first appeared and the first oceans formed. Not much later, the first life appeared on Earth. How and where is not known, but it is likely that the earliest life forms evolved near terrestrial hot springs and were single-celled organisms.

The primordial ocean then played an important role in their survival, as the Earth was repeatedly exposed to powerful meteorite strikes. The surroundings of the black smokers in the deep sea would have provided a safe haven for bacteria and archaea. Experts therefore believe that deep-sea regions were crucial to the development of life on Earth at that time.

No more than a quarter of all marine species are known

It is estimated that the oceans host between one and two million different species today – from microscopic archaea and bacteria, to single-celled algae and fungi, to 30-metre-long whales and seaweeds. If we compare these figures with the WoRMS species list, we currently know only about ten to 25 per cent of all marine species. For the remaining 75 to 90 per cent, there is no written information, partly because humans have not yet explored many marine regions, ecosystems and groups of organisms in any detail.

By the end of 2023, scientists had mapped only a quarter of the world’s sea floor. Moreover, some of the least studied groups of marine organisms are thought to contain thousands, if not hundreds of thousands, of undescribed species. These include, for example, the marine isopods (Isopoda), the marine snails and slugs (Gastropoda) and the tanaids (Tanaidacea). The enormous diversity of protozoa, probably the largest and most diverse group of organisms in terms of taxonomy and evolution, is also poorly understood.

Moreover, surprising observations and research findings continue to show that we still have only a rudimentary understanding of how life is distributed in the oceans, what metabolic processes take place, and how the many

Taxonomy: What’s that?

Taxonomy is a branch of biology that involves the systematic study of living organisms and their classification into groups (taxa) and hierarchical categories based on their physical structure, genetics, or relationships. It is also the science that regulates and analyzes the principles of classification of organisms. The term is derived from the Greek words *táxis* and *nomos*, meaning “order” and “law” respectively.

The system of taxonomic categories

When experts taxonomically classify an organism, they place it in a system of various hierarchical levels. You may be familiar with this “classification”, or “biological systematics”, from Wikipedia. The online encyclopedia refers to it in almost every background article on species of flora and fauna.

The main taxonomic levels and the corresponding exemplary categorization of the great white shark are as follows:

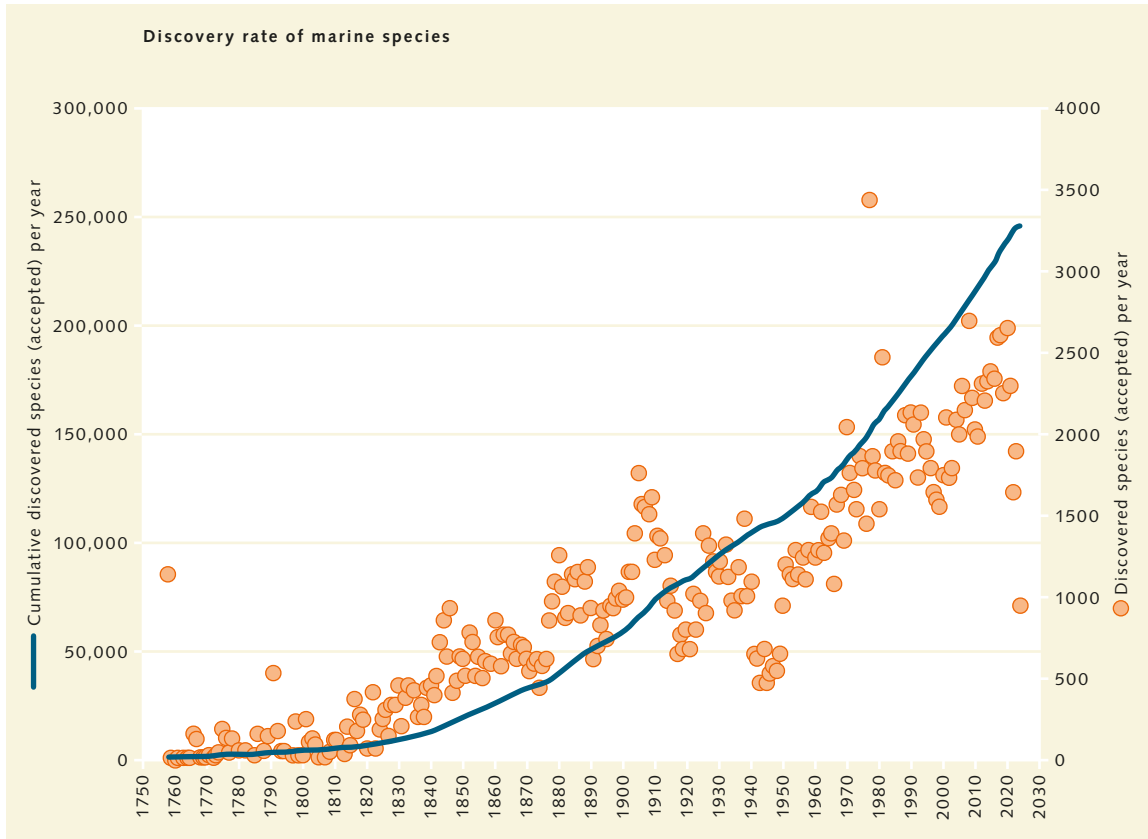
Taxonomic level	Systematics, using the great white shark
Domain	Eukaryota
Kingdom	Animalia (animals)
Phylum	Chordata
Subphylum	Vertebrata (vertebrates)
Class	Elasmobranchii (modern sharks, rays, skates, and sawfish)
Order	Lamniformes (mackerel sharks)
Family	Lamnidae
Genus	Carcharodon
Species	Great white shark (<i>Carcharodon carcharias</i>)

In terms of phylogeny, there are many more subdivisions than can be represented by the major taxonomic ranks and other possible subdivisions. In addition, groups of organisms that are assigned to a particular taxonomic rank (e.g. phylum) are not necessarily at the same hierarchical level in the phylogenetic tree.

For this reason, experts emphasize that any grouping of organisms is a simplification of their true relationships.

1.4 > Experts working on the World Register of Marine Species (WoRMS) keep a record of all newly discovered species. While the number of known marine species has now risen to almost 248,000, we still only know a small proportion of marine biodiversity.

Species
The “species” is considered to be the basic unit of biological systematics, but is not clearly defined. The biological concept of species is often used. According to this concept, a “species” is defined as a group of populations whose members have the potential to interbreed with one another and produce fertile offspring. It is important to note that the group referred to as a “species” should not be able to reproduce with other groups (criterion of intrinsic reproductive isolation).



different marine biocoenoses succeed in continuously driving the wheel of life – both in the sea and on Earth as a whole.

The ocean in crisis

Experts are of the opinion that the problem with our lack of understanding of marine life is that we have accepted this lack of knowledge as the status quo, and as a result we have lost sight of and forgotten about much of the ocean. Yet some 3.2 billion people, or 40 per cent of the world’s population, get a significant proportion of their animal-based food from the sea and are therefore directly dependent on functioning marine ecosystems.

But instead of conserving the marine habitat, we are systematically exploiting its resources. We are destroying marine ecosystems in many different ways and are

weakening the ocean to such a degree that this threatens our well-being as a society.

There is increasing evidence of marine species extinctions. In recent decades, humans have fished sharks and rays to such an extent that more than three out of four of these predatory fish species are now threatened with extinction. Their disappearance has devastating consequences for marine biocoenoses. Many tropical coral reefs are in a similarly precarious situation. Together they are home to around a quarter of all known marine life. However, as a result of climate change, marine pollution, coastal defences and overfishing, warm-water reef-building corals in almost all regions are already dying at such a rate that by 2019 they covered only half to a quarter of the area they did in the 1980s.

If we are to halt these species extinctions and thus also safeguard a cornerstone of human existence, we need to understand marine life. We need to know which



1.5 > These marine creatures are among the most popular new discoveries of 2023: the worm-like mollusc *Dorymenia boucheti*, the bristle worm *Alaysia solwarawarriors*, the deep-sea sponge *Abyssocladia falkor* (top row, left to right), the sea daisy *Xyloplax princealberti*, the deep-sea jellyfish *Santjordia pagesi* and the Caribbean ribbon worm *Tetranemertes bifrost* (bottom row, left to right).

creatures live where in the sea, how they respond to man-made impacts, and how we can minimize the negative effects of marine exploitation. Experienced marine advocates sum up the current situation with the words, “People don’t protect what they don’t know”. This *World Ocean Review* therefore sets out to summarize the current state of knowledge about marine life and to identify solutions that will enable us to conserve the ocean’s biodiversity and restore it where it has already been destroyed.

Biodiversity, species richness and other key terms

The ocean is considered healthy and resilient when its biological communities support a large number of species that differ in their genetic make-up, appearance, characteristics and functions. If this is the case, experts

speak of “high biodiversity” – a term derived from the words *biological* and *diversity*. Over the past 30 years, biodiversity has become one of the most important concepts in environmental protection and environmental management, and it’s now on everyone’s lips in politics, society, the media and the scientific community. However, people understand “biodiversity” in different ways.

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) defines “biodiversity” as the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part. This includes variation in genetic, phenotypic, phylogenetic and functional attributes, as well as changes in abundance and distribution over time and space within and among species, biological communities and ecosystems.

Population
“Population” refers to the individuals of a species that occur together in a given geographic area, interact with each other and form a reproductive community.

Terms such as “species diversity”, “species richness” or “biological diversity” are often used synonymously with biodiversity. However, as the definition shows, the concept of biodiversity is much broader. Species diversity and species richness are both simply measures of the number of species, be that in a particular ecosystem, habitat or even a scientific sample. Strictly speaking, therefore, they represent only one aspect of biodiversity.

Diversity at all levels

When experts speak of marine biodiversity, they mean the diversity of life in all components of marine ecosystems and at all levels of biological organization – from genes and populations to individual species, biological communities and ecosystems.

Genetic diversity and individual trait differences

Genetic diversity and individual trait differences within populations allow marine species to adapt their behaviour

and lifestyles to local environmental conditions. The North Sea three-spined stickleback provides an interesting example of how marine organisms indirectly pass on traits or characteristics across generations. When water temperatures rise, females of this species pass on trained mitochondria to their offspring that are adapted to the environmental conditions the females have experienced. In this way, the juvenile fish receive information about their mother’s living conditions and are to some extent better able to cope with the warmer waters. This gives them a clear adaptive advantage.

Differences between individual species

The differences between individual species are evident as organisms differ in appearance, have different evolutionary histories, colonize different habitats and take on different roles and functions within them. Particularly successful in this respect are the widespread cephalopods (Cephalopoda), a class that includes squid, cuttlefish, octopus and nautilus (Nautilidae). Together this class con-

tains approximately 1000 species that live in all areas of the global ocean, from coastal waters to the deep sea. Only nautilus are restricted to the tropical waters of the western Pacific and Indian Oceans.

The various cephalopods have different appearances, behaviours and abilities. While the vampire squid (*Vampyroteuthis infernalis*), for example, takes a leisurely approach to foraging in the deep sea, stretching out its arms like a large umbrella to catch microplankton, sinking algae and faecal particles, cuttlefish are all about speed. They have a torpedo-like shape and use their mantle as a kind of nozzle through which water can be forced out of the mantle by powerful muscle contractions. This jet propulsion allows the squid to accelerate to speeds of up to 80 kilometres per hour. They then use their ten tentacles to grab their slower prey.

Differences between communities and ecosystems

In turn, the diversity of communities and ecosystems is based on species living together or alongside each other in different assemblages as well as influencing or depending on each other in different ways (interaction). For example, blue whales and Antarctic krill have a predator-prey relationship, meaning that one species eats the other. But two or more species may also compete for the same food source or live together in a symbiotic relationship, in other words one of mutual benefit. Well-known examples of such interactions in the ocean include the coexistence of clownfish and sea anemones, the symbiosis between large marine organisms and cleaner fish, and the close coexistence of corals and their unicellular algae symbionts.

The interaction of species in an ecosystem can, in turn, change local environmental conditions. Where kelp forests and seagrass beds grow, they influence local ocean currents. Flounders, worms and other seabed dwellers rummage through the top sediment layer, stirring up particles and sometimes altering the chemical balance of the upper seabed. Parrotfish nibble on coral stalks and excrete their remains as fine sand, determining the shape of coral reefs and the living conditions for themselves and all other reef inhabitants.

These examples show that the concept of marine biodiversity is multidimensional and opens up different perspectives from which to view and analyze the structure of life. There is widespread agreement among experts that a high level of biodiversity helps to stabilize the processes and interactions within communities over long periods of time. Species composition, in terms of the diversity of species traits, also plays a crucial role.

For example, if a coral reef contains several species of fish fulfilling similar ecological roles, these reef dwellers can fill any functional gaps that may occur if individual fish species are lost due to disease, overfishing or ocean heat waves. Under these conditions, ecosystems such as coral reefs are better able to cope with short-term environmental disruption or damage. Conversely, a loss of biodiversity can disrupt an ecosystem’s internal interactions. The productivity of the affected biocoenoses then often declines, rendering them unable to deliver the usual ecosystem services.

Earth’s biodiversity in numbers

Scientists quantify life on Earth in very different ways. The three main approaches are:

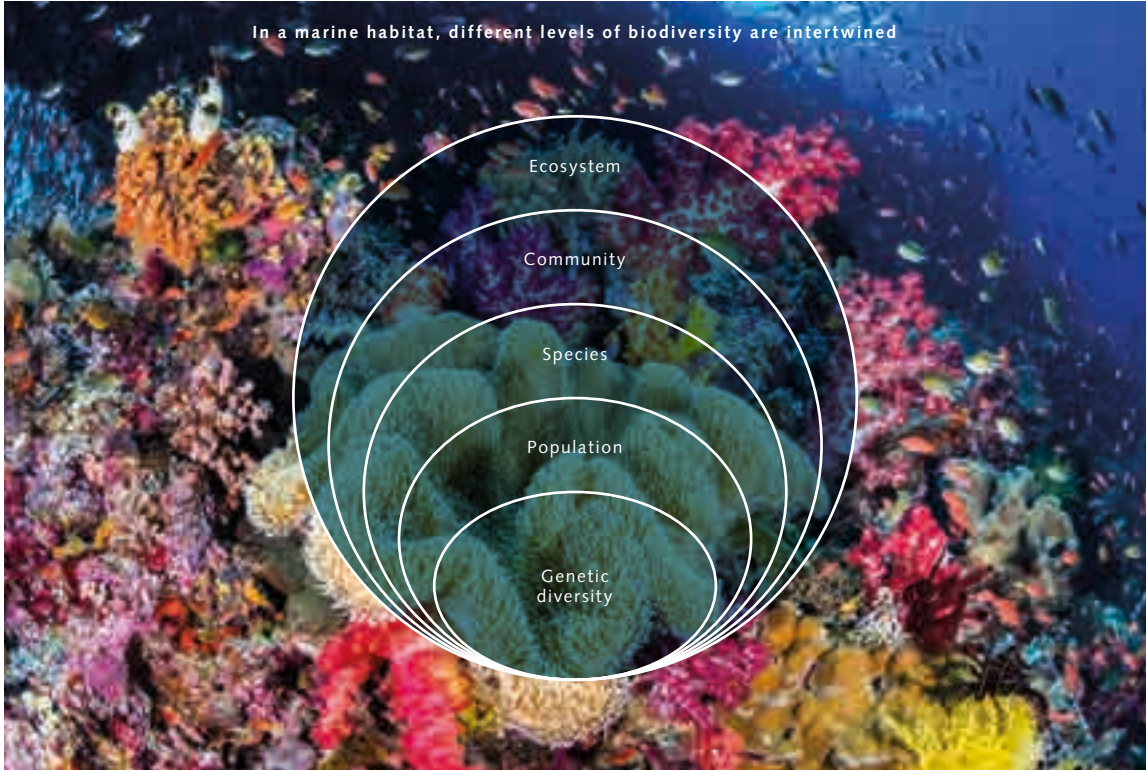
- to estimate or measure species richness (total number of species) in a given region,
- to calculate the total biomass of a species or group of species (e.g. all species in a genus), and
- to consider the phylogeny and lineage of a group of organisms, or in other words, whether this group is a separate branch on the “tree of life” and how many branch points the tree has.

Estimates of species richness

To understand the data on Earth’s biodiversity, it is important to know that taxonomists classify every living organism into one of three major categories of life on Earth, called domains. Their Latin names are *Archaea*, *Bacteria* and *Eukaryota* (living organisms with differentiated cells and nuclei). Archaea and bacteria are also known as prokaryotes because their cells have a relatively simple struc-

Biodiversity
“Biodiversity” refers to diversity within species (genetic diversity), between species and between habitats and ecosystems.

1.6 > In the ocean, diversity can be found at all levels of biological organization – from genetic diversity to ecosystems. Importantly, all levels are interconnected and facilitate the range of services provided by marine life.



1.7 > The diversity of marine life at different levels of organization is the result of different structural and functional traits. This table summarizes the characteristics that are of particular interest to science.

Level of biological organization/compositional level	Structural diversity	Functional diversity
Genes/molecular level	Genetic structure, gene pool; molecular and biochemical structure	Genetic variability over time, changes in the gene pool; biochemical changes in space and time
Species/individual level	Morphological variability, size-biomass spectrum	Physiological variability; changes in environmental tolerance; variability in growth
Species/populations	Population structure, population growth, biomass variability	Population dynamics, changes in production and productivity; changes in intra-species relationships
Biological community	Community composition	Changes in interspecific relationships; organism-habitat variability; competition within the habitat; interactions within the food web
Ecosystem	Ecosystem structure	Ecosystem processes, changes in predator-prey relationships, competition between ecosystems
Landscape type	Habitat structure; seascape mosaic	Variability of the interplay of physical and biological factors in space and time; changes in the mosaic of the marine landscape in space and time

ture. Eukaryotic cells contain more sophisticated components called organelles, including a cell nucleus.

The domain of eukaryotes is divided into several supergroups. By far the greatest diversity and evolutionary variety is found in unicellular organisms, which include protozoa (meaning “first animals”).

There are only two supergroups of true multicellular organisms: Archaeplastida, which includes land plants, and Opisthokonts, which includes fungi and animals such as jellyfish, fish and whales.

Currently around two million described species constitute the domain of Eukaryota. Of these, roughly half are insects and an estimated fifth are vascular plants. The remaining species represent an eclectic mix of life forms. About seven per cent are fungi and only four per cent of all known species are vertebrates.

Only estimates can be made as to how many living organisms remain undiscovered and undescribed. Ex-

perts generally use their knowledge of species richness and relationships within better understood groups to infer the number of species in less well-studied groups. According to this approach, our planet should be home to an estimated 8.7 million eukaryotic species. Of these, 8.1 million would be plants and animals, with insects constituting the largest group with an estimated 5.5 million species.

If all undiscovered species were to be identified and described using conventional methods (manual identification of differences in shape and body structure), it would take more than 300,000 taxonomists about 1200 years. But that’s not all: initial analyses using new molecular biology methods suggest that the domain of eukaryotes might, at an extreme, contain up to a billion species.

According to current knowledge, terrestrial ecosystems are much richer in species than marine communi-



1.8 > Guardians of biodiversity: The droppings of Adélie penguins fertilize the Antarctic coastal areas where they raise their chicks. In this way, the birds provide the nutrients nitrogen and phosphorus that microorganisms in the soil, as well as mosses and other plants, need to survive.

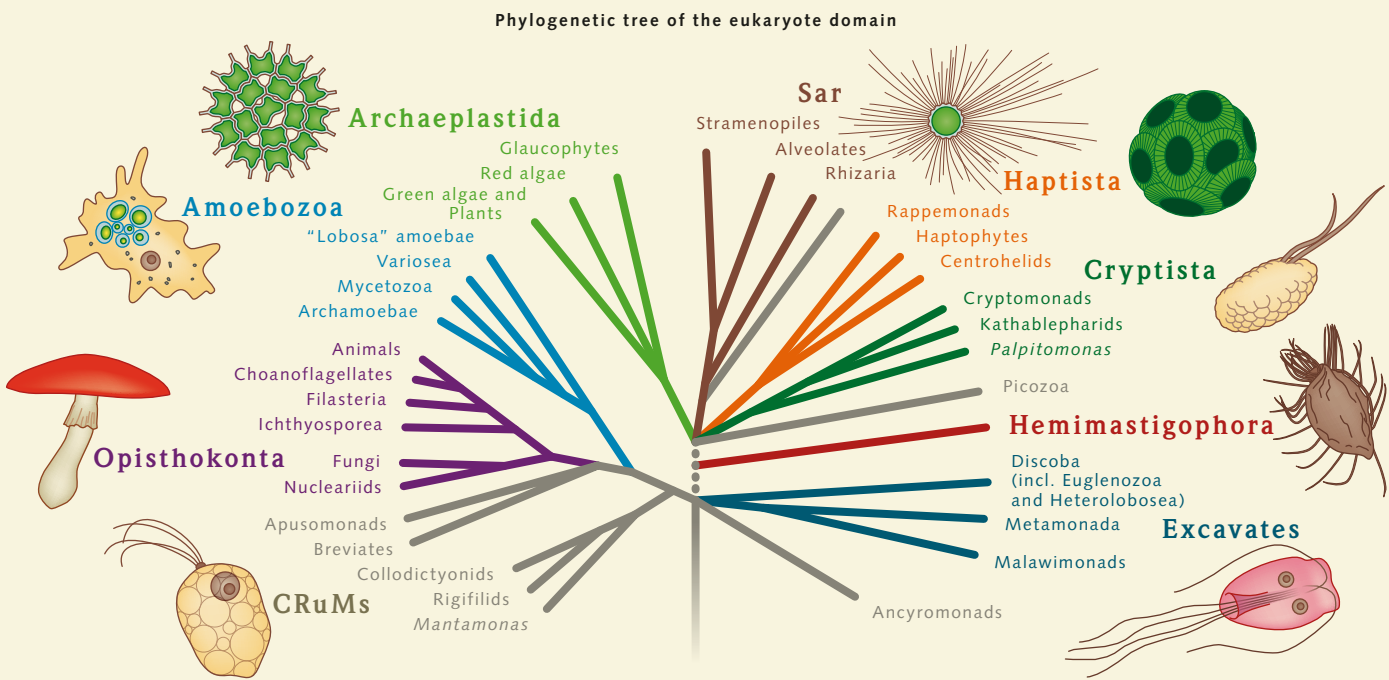
ties. About 77 per cent of the approximately two million described and thus known species live on land, about twelve per cent in the ocean and eleven per cent in lakes, rivers, streams and ponds. This difference is due to the fact that, in the course of their evolutionary and dispersal history, terrestrial organisms have been forced to specialize much more frequently. Where barriers such as mountains, valleys, rivers or an island location prevent the dispersal of living organisms, new species or communities that only occur in a particular area of the world (endemic species) develop more quickly. Moreover, flowering plants and pollinators have co-evolved on land and many insect species only pollinate very specific flowering plants, which is why there are so many different terrestrial insect species. In the ocean, however, flowering plants are rare.

Experts also point out that marine biological communities have been affected by mass extinctions throughout Earth's history. They may have been slow to recover, which could be one reason why the biodiversity of the oceans is significantly lower than that of terrestrial ecosystems.

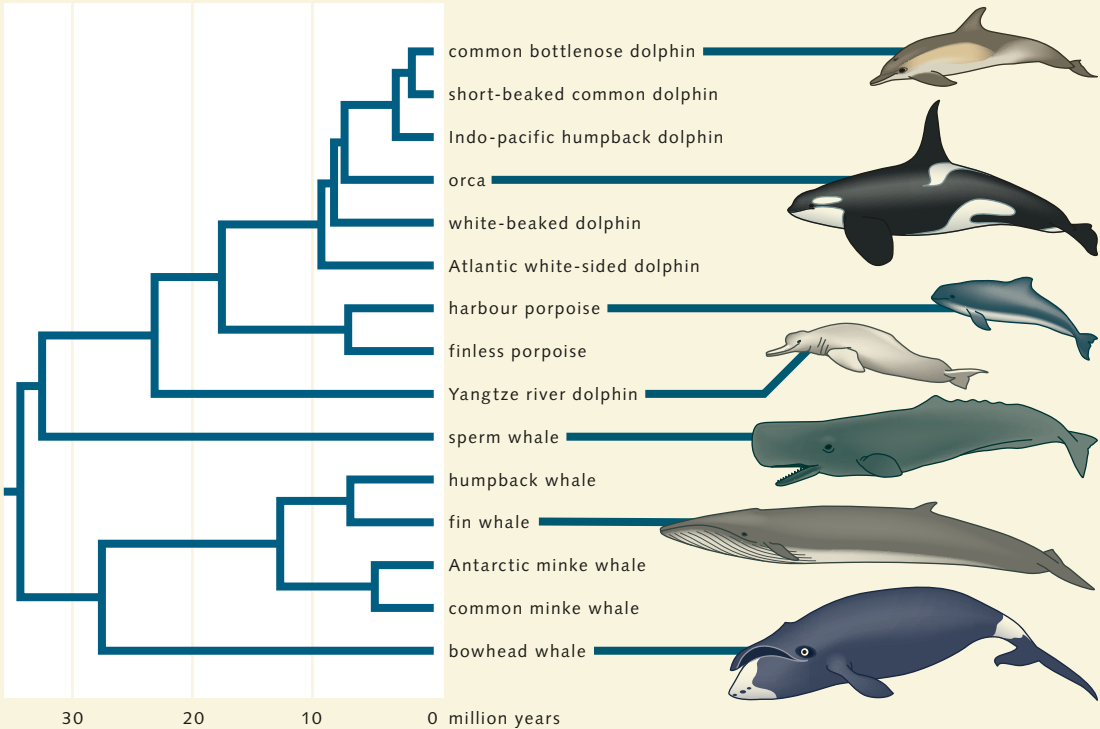
Living biomass quantities
A different picture emerges when experts analyze which living organisms have the most biomass. At 80 per cent, plants make up the vast majority of the Earth's biomass. They account for a total weight of around 450 gigatonnes of carbon, with land plants contributing the largest proportion. However, when researchers only consider animal biomass, they find that marine arthropods top the list of animal groups with a total weight

Estimated total number of species on Earth					
Domain	Evolution began	Organism structure	Number of species (total)	Number of species (marine)	Number of species (terrestrial)
Bacteria (bacteria, prokaryotes)	3 to 4 billion years ago	unicellular	1,250,000 (0.8 to 1.7 million)	no information	no information
Archaea (archaea, prokaryotes)	3 to 4 billion years ago	unicellular	105,000 (70,000 to 140,000)	no information	no information
Eukaryota (eukaryotes)					
Protozoa (protozoans)	1.5 billion years ago	unicellular	36,400	36,400	0
Chromista (chromista)	1.2 billion years ago	unicellular	27,500	7400	20,100
Fungi (fungi)	1 billion years ago	unicellular or multicellular	611,000	5320	605,680
Animalia (animals)	700 million years ago	multicellular	7,770,000	2,150,000	5,620,000
Plantae (plants)	500 million years ago	multicellular	298,000	16,000	281,400
Totals			10,100,000	2,210,000	6,540,000

1.9 > The total number of species on Earth is still a matter of estimation. This is mainly because the diversity of terrestrial and marine bacteria, prokaryotes and archaea is difficult to quantify.



Family tree and evolutionary history of whales, based on molecular analyses (as of 2016)



1.10 > New molecular methods of analysis have contributed to the fact that the phylogenetic tree of the eukaryote domain now has many more major branches (supergroups) than it did 25 years ago. Our diagram is a simplified representation of the state of knowledge in 2020.

1.11 > Results from molecular biology studies allow scientists to reconstruct the evolutionary history of related groups of animals – whales in this case – and to pinpoint more precisely at what point in time new species arose.

1.12 > The family of scarab beetles contains 30,000 to 40,000 different species, including many well-known beetles such as the dung beetle, rose chafer, cockchafer, stag beetle and the Hercules beetle (centre), the world's largest beetle with a body length of more than 15 centimetres.



of around one gigatonne of carbon. Marine arthropods, for example, include more than 30,000 different species of crustaceans, with some marine “species of fame” such as the European lobster (*Homarus gammarus*) and the Antarctic krill (*Euphausia superba*), approximately 500 different species of sea spiders and five different species of horseshoe crab. The huge shoals of Antarctic krill alone are estimated to weigh in at 500 million tonnes.

Fish make up the second largest animal group in terms of total biomass. They weigh in at around 700 million tonnes of carbon. Those inhabiting the mesopelagic zone, i.e. fish living at depths of 200 to 1000 metres, account for the largest proportion by weight. Molluscs (Mollusca) and annelids (Annelida) share third place with 200 million tonnes of carbon each.

Phylogenetic history and phylogenetic diversity

A third way of measuring diversity is to look at the evolutionary or phylogenetic history of species or groups of species. Essentially, this involves asking how many branches and branch points (forks) there are in the family tree of a group of organisms, and how long each branch is. Each branch point represents a split in the species. The length of the branches and the number of branch points reflect how far back in time the split occurred and how many different traits have developed. Although this method provides different information than the consideration of species diversity, phylogenetic diversity largely correlates with the number of species within particular groups. This is because for each additional species, the group’s own branch in the phylogenetic tree receives an additional branch.

A look at the tree of life shows that the phylogenetic diversity of our planet is dominated by bacteria. This is hardly surprising, as bacteria and archaea are among the oldest and most widespread forms of life on Earth. Moreover, their enormous diversity of species and functions provides essential metabolic processes and cycles, such as the nitrogen and sulphur cycles, without which life on Earth would not be possible.

Depending on which approach to quantification the scientists employ and from which perspective they analyze the diversity of life on Earth, different players come to the fore: animals dominate in terms of known species diversity, plants in terms of biomass and metabolic activity, and bacteria in terms of phylogenetic diversity and metabolic innovation.

From microscopes to genes: New biodiversity research methods

Up until now, researchers have had to go to great lengths to understand which organisms live in a particular area of the ocean. They cast nets of different mesh sizes to catch, count and identify fish, microalgae and microfauna. They scraped mussels, sponges and other sessile creatures from the ocean floor, dived into deep waters with ROVs or research submarines to take samples, or used photo and video cameras to document any creature at loose in the water column or on the seabed.

Particularly time-consuming was the counting of organisms and the identification of individual species based on their body shape, internal structure, behaviour and reproduction and other special characteristics. Moreover, the analyses were usually limited to those organisms that could be seen with the naked eye or at least displayed clear characteristics under the microscope.

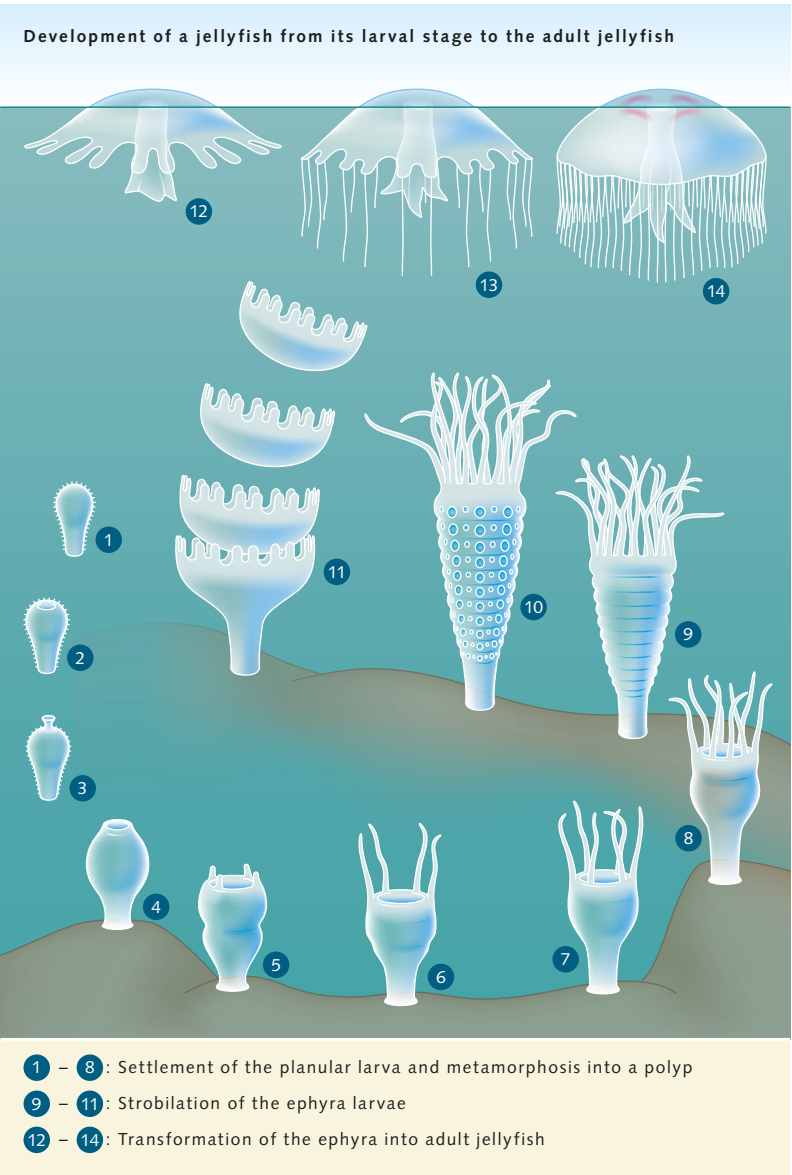
However, it is difficult to distinguish bacteria and other single-celled organisms by their shape. They often have no distinctive morphological features. The same is true of the larval stages of many marine invertebrates. Even experts find it difficult to distinguish between the tiny juveniles of bivalves, echinoderms

and crustaceans, such as oysters, sea urchins and lobsters.

We also now know that the different shapes of living organisms do not necessarily mean that they belong to different species. Sometimes the organisms simply go through different life-history phases. Common jellyfish, for example, spend most of their lives as a small cup-shaped polyp on the ocean floor. This polyp grows over the winter and then releases small, free-swimming

1.13 > Biodiversity can be quantified in a number of ways. Here you can see the distribution of global biodiversity across the major kingdoms of life using the metrics of species diversity, phylogenetic diversity and biomass.





1.14 > Umbrella jellyfish belong to the cnidarians and appear in two different forms after the larval stage – as a medusa and as a polyp. Their transformation from polyp to medusa is known as metagenesis or alternation of generations.

juvenile jellyfish in the spring. This free-swimming form of jellyfish is called a medusa and usually dies a few months after sexual reproduction. Despite their completely different appearances, the jellyfish polyp and the medusa are one and the same creature. They are genetically identical.

The opposite is true of orcas. Once thought to be a single species, researchers have now identified three, if not four, distinct populations, or ecotypes, that differ

in their behaviour and appearance and may represent more than one species, even if they look very similar. In a February 2024 publication, US scientists first reported on the fourth population. According to the study, the 49 animals live far off the west coast of North America. They hunt sperm whales, sea turtles, elephant seals and other marine mammals and have both pointed and rounded dorsal fins. In the other populations, however, the whales have uniform dorsal fin shapes. In two populations they are rounded, in the third they are pointed.

Therefore, marine organisms that look similar may or may not belong to the same species. It is quite common for unrelated beings living in the same environment to have developed similar or identical body shapes, features and traits over the course of evolution. This principle is known as convergent evolution. An example of convergent evolution is the development of shovel-shaped forelimbs which both the European mole (*Talpa europaea*) and the Australian marsupial mole (*Notoryctes*) use to burrow through the ground. But the two species are not related. Body morphology can therefore no longer be the sole criterion for identifying different species.

One barcode for every species

To be on the safe side, researchers are increasingly using molecular methods to describe and differentiate between species and to identify their functions in the ecosystem. This involves analyzing the organisms’ genetic information, or more precisely, sections of their DNA molecules. These DNA segments, known as genes, form a species-specific blueprint of life and allow scientists to precisely differentiate species and their functions in the ecosystem.

Genetic material can be found in any cell. Skin flakes, mucus, hair, individual microalgae, bacteria, faecal particles or even urine are often sufficient to extract the DNA of their originators. Selected areas of the DNA molecule are then amplified and read (sequenced) using high-throughput techniques. Researchers focus primarily on selected molecular markers. These are short gene

fragments found in the DNA of the highest possible number of organisms.

The special feature of these molecular markers is that on the selected gene segment, the four nucleic acids – adenine, guanine, thymine and cytosine – are uniquely arranged for each species. At the same time, their sequence is so similar that the gene sequences of different species can be compared.

For example, DNA regions for the production of ribosomes, which are required for protein synthesis, can be used as molecular markers. Ribosomal gene fragments are mainly used to identify unicellular organisms such as microalgae, archaea and bacteria. In animals, however, experts usually sequence a gene segment called “cytochrome c oxidase subunit 1”. It encodes information for

energy generation in the mitochondria, the powerhouses of the cell.

For each gene sequence read, the researchers create a barcode of nucleotides, similar to the barcodes on supermarket products. This process is called *barcoding* when the analysis is performed on a few specific DNA molecules. If the environmental sample analyzed contains an assortment of genetic material (environmental DNA, eDNA), so that thousands of different DNA fragments from different organisms need to be amplified and sequenced, experts speak of *metabarcoding*.

The barcodes are then compared to the millions and millions of gene sequences that scientists have already collected and catalogued in digital reference databases.

1.15 > This shows the rich diversity of shapes in the plankton community of Australia’s Great Barrier Reef. It includes fish eggs, hydromedusae, copepods and larvae of sea cucumbers, mantis shrimp, snails, prawns and decapods.



Environmental DNA
Environmental DNA (eDNA) is the total set of biological remains found in a water sample, the genetic analysis of which provides insight into the biodiversity of a specific marine area. Experts also refer to this as “free-floating DNA”.

If a code is found in the database, the DNA owner can be identified immediately. However, if the gene sequence is unknown, individual analyses must be carried out. This requires that the unknown organisms are available as individuals, so that taxonomists can identify them based on their appearance and at least, as a first step, assign them to a taxonomic group or genus. Their genetic material is then sequenced, a reference barcode is created and all available information is transferred to the appropriate database for cataloguing.

Barcoding methods can be used to detect all living organisms that have left genetic traces in the sample being analyzed – from bacteria to whales or seabirds – provided their gene sequences are known. This is increasingly but not invariably the case. On German marine biology expeditions to the Arctic Ocean, for example, 30 to 70 per cent of the microalgae species sampled cannot immediately be identified using molecular methods. For this reason, there are always taxonomists on board who pick out unknown algae species cell by cell and then analyze these using both conventional and novel methods.

Using barcoding, scientists are increasingly able to trace the evolutionary history of organisms or determine the dates of evolutionary milestones. For example, researchers have only just recently been able to use molecular methods to pinpoint more accurately the origin of vertebrates. The corresponding gene changes took place between 530 and 505 million years ago. For this study, the team of scientists sequenced the genome of the eel-like brown hagfish (*Eptatretus atami*) and the jawless sea lamprey (*Petromyzon marinus*), among others.

In addition to purely scientific species identification, barcoding can also be used for other, more extensive purposes. For example, it can be used to identify illegally caught sharks. An international team of researchers recently developed a compact test kit that allows even lay people to determine within an hour whether a sample of fish meat originated from selected endangered shark species. The test is sensitive to gene sequences from three species: the bigeye thresher (*Alopias superciliosus*), the

pelagic thresher (*Alopias pelagicus*) and the shortfin mako shark (*Isurus oxyrinchus*).

Metabarcoding can tell us which species are present in a given marine area at what time of year, including organisms that cannot be seen or distinguished with the naked eye or caught in nets. However, it does not provide information on the number of individuals, nor does it reveal the functions of individual species within an ecosystem or how these functions are changing. Shifts in community composition only become apparent through metabarcoding if the analyses are repeated at regular intervals and certain species are detected at higher or lower frequencies.

Inferring functions from genomic information

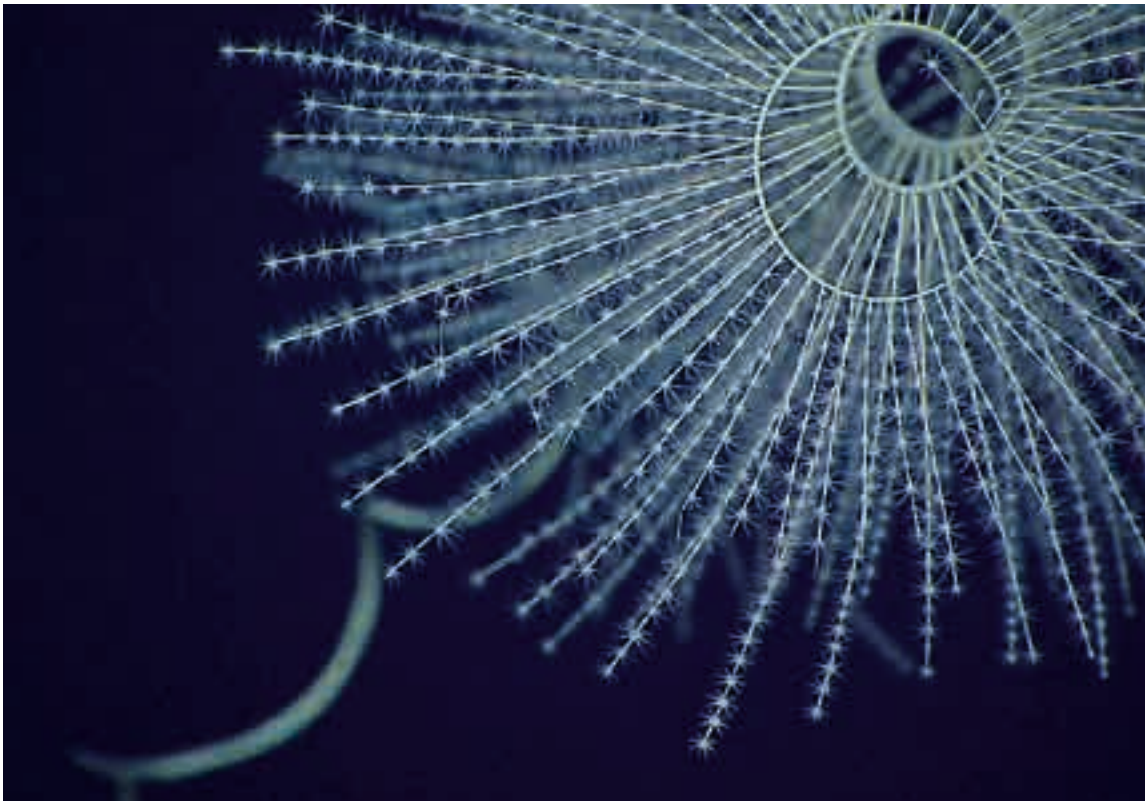
In the field of marine microorganisms, scientists are therefore going one step further with their molecular analyses. They no longer sequence only selected gene fragments, but the entire DNA contained in an environmental sample. All the gene sequences are then sorted into so-called *metagenomes*. In this way, the researchers can also identify functional genes, which, for example, reveal the metabolic processes in which certain types of bacteria are involved. This in turn allows them to deduce the microorganisms’ function in the ecosystem being studied.

A study of the *Global Ocean Gene Catalogue 1.0* shows the insights that researchers are gaining using this method, termed metagenomics. The digital database contains gene sequences obtained by scientists who analyzed 2102 water samples from different regions and depths of the global ocean. They then used supercomputers to identify more than 308 million groups of genes. They were able to assign just over half of these to the three domains of bacteria, archaea or eukaryotes, with bacteria accounting for the largest proportion of the global ocean’s microbial genome, followed by eukaryotes and archaea. The researchers were also able to visualize the distribution of microorganisms across ocean regions and depth zones, and use functional genes to identify the metabolic tasks performed by specific groups of micro-

1.16 > Caribbean reef sharks (*Carcharhinus perezii*) are an endangered marine species. To better understand the distribution and population structure of these predatory fish, and to be able to make recommendations for their conservation, scientists take a small piece of the shark's fin and use molecular techniques to analyze the genetic information it contains.



1.17 > The soft coral *Iridogorgia magnispiralis* can produce light signals on its own – a property known as bioluminescence, which has been present in the animal kingdom for 540 million years.



organisms in each ocean region. For the first time, the researchers were also able to show that more than 50 per cent of the genetic material analyzed came from fungi in the twilight zone, at depths of between 200 and 1000 metres.

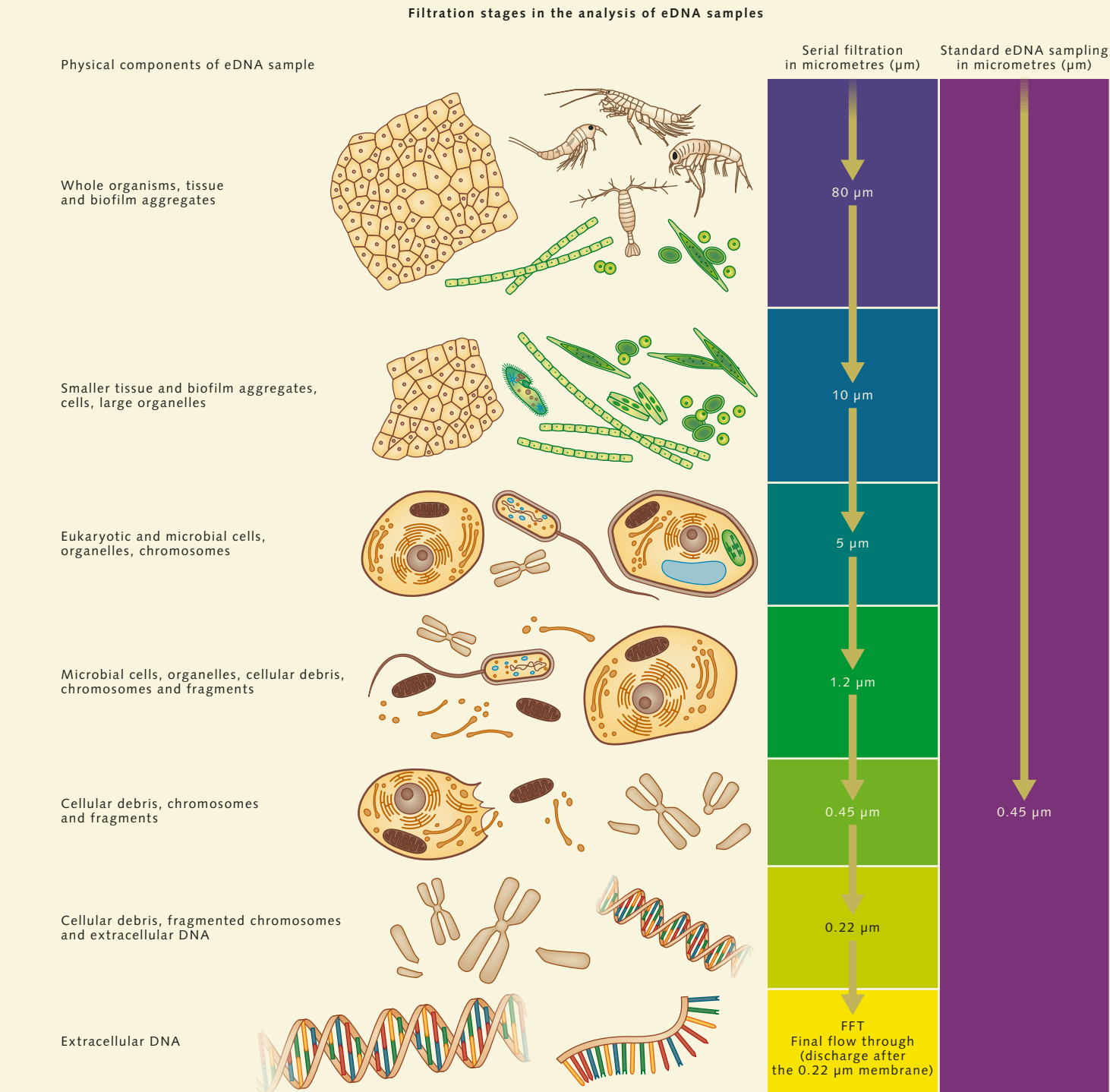
Other researchers used functional genes to discover that soft corals (Octocorallia) were able to independently emit light signals as early as 540 million years ago – a trait now termed bioluminescence. To this end, they reconstructed the evolutionary history of soft corals using a large dataset of genetic sequences and fossil remains of relevant species. A computer model was then applied to analyze the large amount of data.

But molecular methods have a lot more to offer. A third method, known as *metatranscriptomics*, allows scientists to identify the species-specific traits that help marine microbes thrive in their habitat. In this context it is important to know that certain gene markers are switched on or off in an organism depending on environ-

mental conditions, such as when an organism acclimatizes to rising water temperatures. Metatranscriptomics can be used to identify such adaptation strategies. For example, tropical coral experts are using this method to find out why some microalgae that live in symbiosis with corals and provide them with nutrients survive ocean heat waves better than others, with the result that their symbiont corals bleach more rarely.

These and other detailed insights from research on molecular biodiversity are urgently needed to understand the functioning of marine life. Knowing which marine organisms live where, what functions they perform, and what traits enable them to do so, will help us to understand how climate change and other stressors are likely to change marine communities and what services they will be able to provide in the future.

However, it is also true that there are not enough taxonomists in the world to identify unknown marine organisms and carry out the many survey counts that



1.18 > When looking for environmental DNA (eDNA), the pore size of the seawater filter determines which organisms, cell components or even extracellular DNA fragments are filtered out and then amplified and read for metabarcoding.

Artificial intelligence: A technology revolutionizes marine research

Video and still cameras have become an integral part of marine biology research. Coastal researchers use drones to record organisms living in the intertidal zone; deep-sea scientists document in HD any living being caught in their ROV’s spotlight. These and many other activities generate millions and millions of photos and countless hours of video footage that are too much for humans to process and analyze. For this reason, marine researchers are increasingly turning to artificial intelligence (AI). The term refers to intelligent – in the sense of self-learning – computer programmes that have been created by humans and are therefore called artificial.

No performance without training

AI systems are revolutionizing the way researchers explore and observe marine life. Their strength lies in their ability to analyze huge amounts of data at lightning speed. This is made possible by computers with high processing power and programmes that learn from many examples to perform tasks without being explicitly programmed to do so. This technology is called “machine learning”. Just like humans, AI systems need to practice and train to satisfactorily perform their tasks going forward. To this end, experts feed them annotated data – for example, thousands and thousands of images in which mussels are marked that they want the AI to recognize in aerial photographs of coastal areas.

To facilitate the learning of marine biological AI systems around the world, the Monterey Bay Aquarium Research Institute (MBARI) in the USA and partners launched an online platform named *FathomNet* in 2022. It contains, among other things, some 28,000 hours of annotated deep-sea video footage and more than a million photographs in which MBARI taxonomists have identified the depicted species. Scientists are pursuing similar goals with the *Global Library of Underwater Biological Sounds (GLUBS)*, which will one day bring together underwater sound recordings from around the world and make the recordings of known and unknown marine species freely available. Interested parties can then use these as learning material for AI algorithms.

A study from northern Brazil shows how successful AI can be at identifying species-specific underwater sounds such as clicks or whistles. For the first time, researchers were able to track the migratory movements of two species of river dolphin – the pink Amazon river

dolphin (*Inia geoffrensis*) and the tucuxi (*Sotalia fluviatilis*) – using sound recordings.

Neural networks make AI programmes more powerful

But AI systems do not just work with images, video and sound. Researchers at the Plymouth Marine Laboratory (PML) on the south coast of Britain have trained AI to predict the occurrence of toxic algal blooms using optical satellite images and water samples from coastal waters. To this end, the IT experts equipped their AI system with a so-called “neural network”.

Neural networks are a method of machine learning in which a series of “neurons” are connected to each other. IT specialists use this approach to mimic the way the human brain works, where nerve cells are connected and electrical signals are sent between them. A neural network in AI works in a similar way. It allows scientists to develop more complex computer programmes. The scientists at PML also aim to feed their system with data on, for example, water temperature and chlorophyll content to improve their algal bloom predictions. In this way, the researchers hope to be able to detect and predict blooms of a variety of toxic algae.

AI systems are not only used to identify species. Autonomous underwater vehicles equipped with sensors, cameras and AI-driven navigation systems are now able to decide on their own which creatures to follow, which course to take to explore an area of the ocean, or where to take samples. AI-powered camera systems record the amount of plastic debris that is floating on the ocean surface or in the water column, and new AI-powered models allow fisheries experts to calculate the size of remaining fish stocks based solely on catch data. Thanks to AI, the latter can be done much more accurately now than with any other model used to date.

Every deployment needs to be well considered

Despite the euphoria, it is important to remember that the use of AI needs to be carefully considered. Questions of research ethics are just as important as those of data protection. Scientists also need to ensure that AI-driven systems do not cause damage when deployed in sensitive marine habitats. If scientists and other users can overcome these hurdles, AI-driven systems will soon make a significant contribution to our understanding of marine ecosystems.



1.19 > Not just on Earth: Autonomous AI-powered underwater vehicles will explore the ocean on Jupiter's moon Europa.

Marine fungi – the overlooked composters

Fungi are among those marine organisms whose role and distribution in the oceans has only become clear with the increasing use of molecular analysis. Science now recognizes approximately 2000 species. However, this number probably represents less than five per cent of the species that actually exist.

Most marine fungi are microscopically small. Some are known to live in the stomachs of fish and sea urchins. Others have been found inside corals or on black smokers, and still others float in the water column as unicellular or filamentous fungi. Sometimes, however, marine fungi form fruiting bodies not unlike mushrooms we see in the forest or supermarket. This can happen even at depths of 500 metres, as an experiment off the coast of Taiwan has shown. When scientists there brought a wood log back to the surface after more than three and a half years on the ocean floor, the log was covered with many small black fruiting bodies of the deep-sea fungus *Alisea longicolla*.

Only a small number of researchers are systematically studying marine fungi at present. But their initial results are astonishing. Apparently, there is no clear distinction between fungi that live on land and those that live in the ocean. Instead, the scientists keep finding fungal species that occur in both habitats, or whose terrestrial and marine forms are very similar. And apparently fungi perform the same function in both environments: they decompose organic matter. This assumption has now been confirmed by genetic analyses of marine fungi.

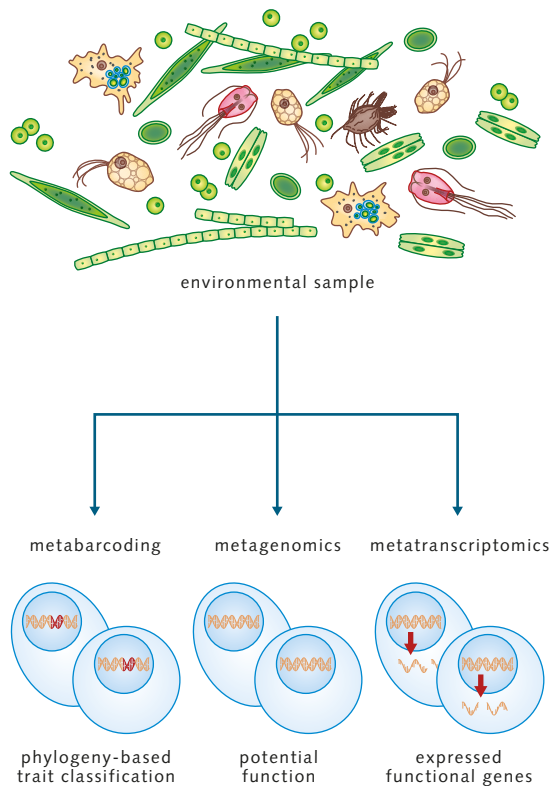
Marine fungi target driftwood and dead algae, as well as fish faeces, whale bones and mussel shells. Once the fungi have broken down the biomass, bacteria follow to process the remains. The bacteria in turn are eaten by zooplankton, which then serve as prey for fish. Fungi therefore play an important role in the oceanic food webs and biogeochemical cycles.

Unlike green plants, fungi do not photosynthesize. Instead, they feed on the living or dead biomass of other organisms. This reliance on external sources for nutrition is termed heterotrophism; it is the reason why fungi such as *Alisea longicolla* can survive in deep-sea environments.



1.20 > Sac-like reproductive organs of a variety of marine sac fungi.

Molecular methods at a glance



1.21 > Using high-throughput molecular techniques such as metabarcoding, metagenomics and metatranscriptomics, researchers can identify species, infer their phylogeny and determine the function of specific genes.

have become necessary as part of fine-scale marine monitoring. Experts therefore believe that molecular methods will soon become the standard for marine monitoring. And sometimes the results of molecular analyses highlight problems that have yet to be solved, such as when genetic material from land animals such as chickens or cattle suddenly appears in water samples from the German North Sea. Rainwater probably washed their faeces off the fields. Rivers then carried them to the sea, thus contributing to the eutrophication of coastal waters. Their presence in the North Sea is further evidence that our lives on land have a major impact on the health of marine ecosystems.

CONCLUSION

The ocean:
Diversity in every nook and cranny

The ocean is the largest habitat on planet Earth. It covers 71 per cent of the Earth’s surface and reaches depths of up to eleven kilometres. There is life everywhere in this vast space – even in places where nobody would have thought it possible.

The total number of marine species is unknown. Scientists estimate that there are between one and two million different species in the oceans, but there could be many more. Only a quarter of the estimated number has been scientifically described.

The large proportion of unknown marine species explains why researchers make new discoveries on almost every expedition. Identifying newly discovered species and assigning them to a group or family of organisms is a very complex process. It is time-consuming and requires tremendous expertise.

For this reason, experts are increasingly turning to molecular methods such as barcoding, metabarcoding and metatranscriptomics.

These methods analyse the genetic information of organisms or, more precisely, selected regions of their DNA molecules. This information can be used to uniquely identify species, infer their functions and phylogeny, and identify successful adaptation strategies.

This basic knowledge is needed to make statements about the biodiversity of a selected marine area – be it an individual ecosystem, a marine region or the entire ocean.

Scientists use “biodiversity” as a catch-all term embracing various kinds of diversity: within spe-

cies, between species and between habitats and ecosystems. Diversity includes variation in genetic, morphological, phylogenetic and functional traits, as well as changes in abundance and distribution over time and space.

The concept of biodiversity is hence multidimensional and not easy to understand. As a further complication, researchers use a great variety of methods to quantify the biodiversity of any particular region. Such methods involve estimating or measuring the region’s species richness, calculating the total amount of biomass present and its distribution among species and species groups, examining the phylogeny of the organisms living in the region and analyzing the relationships between the different species.

Marine habitats displaying a high level of species richness as well as high functional and phylogenetic diversity are generally more resilient than low-diversity ecosystems. When the biodiversity of a marine region declines, the productivity of the biological communities affected tends to decline as well. These communities of organisms are then no longer able to deliver all the services they usually provide.

Experts are currently observing such a decline in performance as a result of drastic losses of biodiversity in many marine regions. In some places, populations are in decline, while in others species are vanishing altogether.

The drivers of these trends are man-made. Through climate change and the continued destruction and overexploitation of marine habitats, we are weakening marine ecosystems to the point where their survival and the many services they provide to us humans are no longer guaranteed.

2 The distribution of life in the ocean

> Finding answers to the question as to why marine organisms occur in their ancestral habitats and not elsewhere is a major challenge for science. The factors and mechanisms that determine the distribution of species in the ocean are not yet fully understood or documented. For marine animals, water temperature, food supply and interactions with other species are particularly important. But there are other factors at play that need to be considered.



Patterns of marine biodiversity

> Thousands upon thousands of species around the warm equator and just a few “masters of the cold” in the polar seas: For a long time, this was how experts imagined the distribution of species in the global ocean. Today we know that habitat choice is primarily determined by water temperature and food supply. In some cases, however, habitat depth and structure play just as important a role, as do the number and voracity of cohabitants and neighbours.

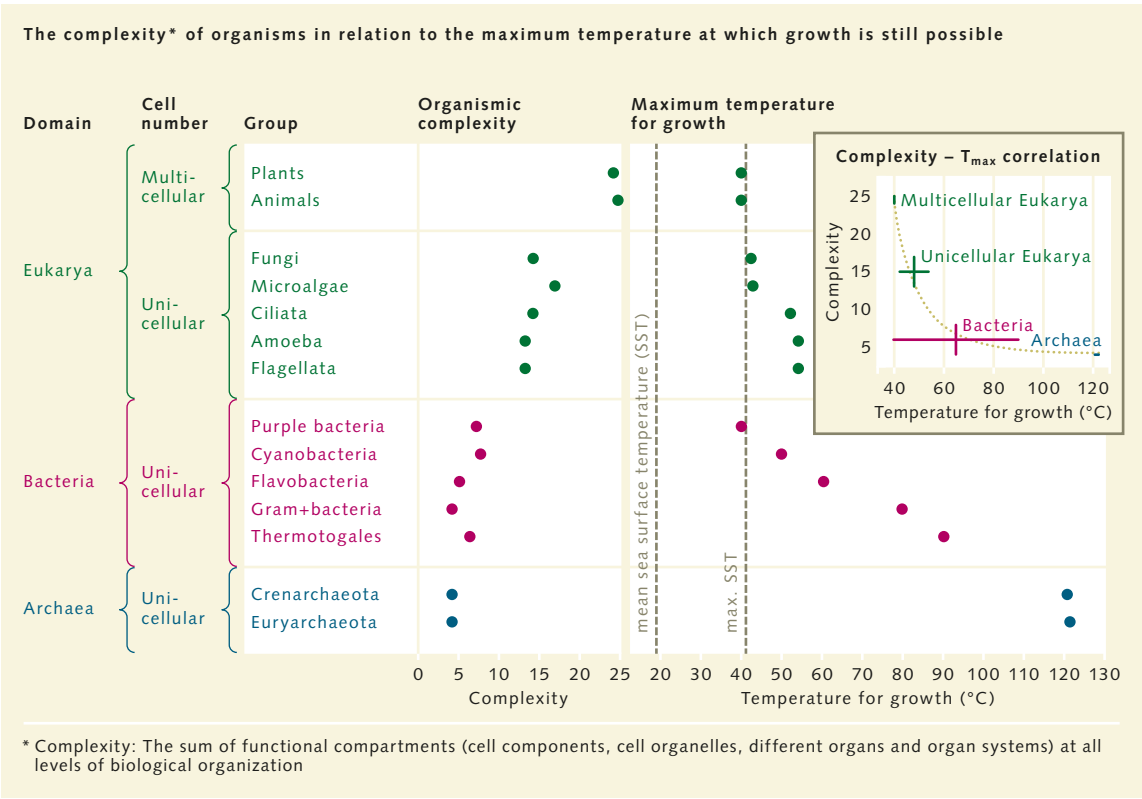
Key factors determining the distribution of marine life

The Coral Triangle in the Western Pacific is a marine region of superlatives. The island-studded waters around the Southeast Asian nations of Indonesia, Malaysia, Papua New Guinea, the Philippines, Timor-Leste and the Solomon Islands are recognized as the most biodiverse marine communities in several categories. The region hosts near-

ly 600 different species of coral and more shellfish species than can be found anywhere else in the world’s oceans. Experts have identified more than 2000 different species of reef fish, many of which are endemic. The Coral Triangle is also home to more species of sharks, more crustaceans and more species of anemones, macroalgae and sea squirts than any other region of the global ocean.

But why is this tropical marine region in Southeast Asia more species-rich than any other? What are the envi-

2.1 > These various stony corals grow terrace-like in the Coral Triangle. Their horizontal, almost table-like growth form has the advantage that all the coral polyps receive sufficient sunlight and can use their tentacles to feed on zooplankton (small animals) floating in the water column.



2.2 > Generally, the more complex the structure of a marine organism, the lower the maximum temperature at which it can grow. For this reason, simple single-celled organisms such as bacteria or archaea can survive at or in hot springs, but more complex animals such as fish cannot.

ronmental factors that drive marine life and thus determine which single-celled organisms and species of flora and fauna occur where in the ocean and at what population densities? Science has some initial explanations and has already been able to confirm these for many marine organisms through experiments and measurements. However, it is not yet clear whether these mechanisms apply to all known groups of organisms.

Best understood is the geographical distribution of marine animals. Which species can settle where in the ocean and find sufficient food is determined by the following key factors:

- the temperature and availability of oxygen,
- primary production and thus the total supply of food in a habitat, and
- the complexity of the marine habitat (this category includes parameters such as habitat structure, local currents, and also interactions between species).

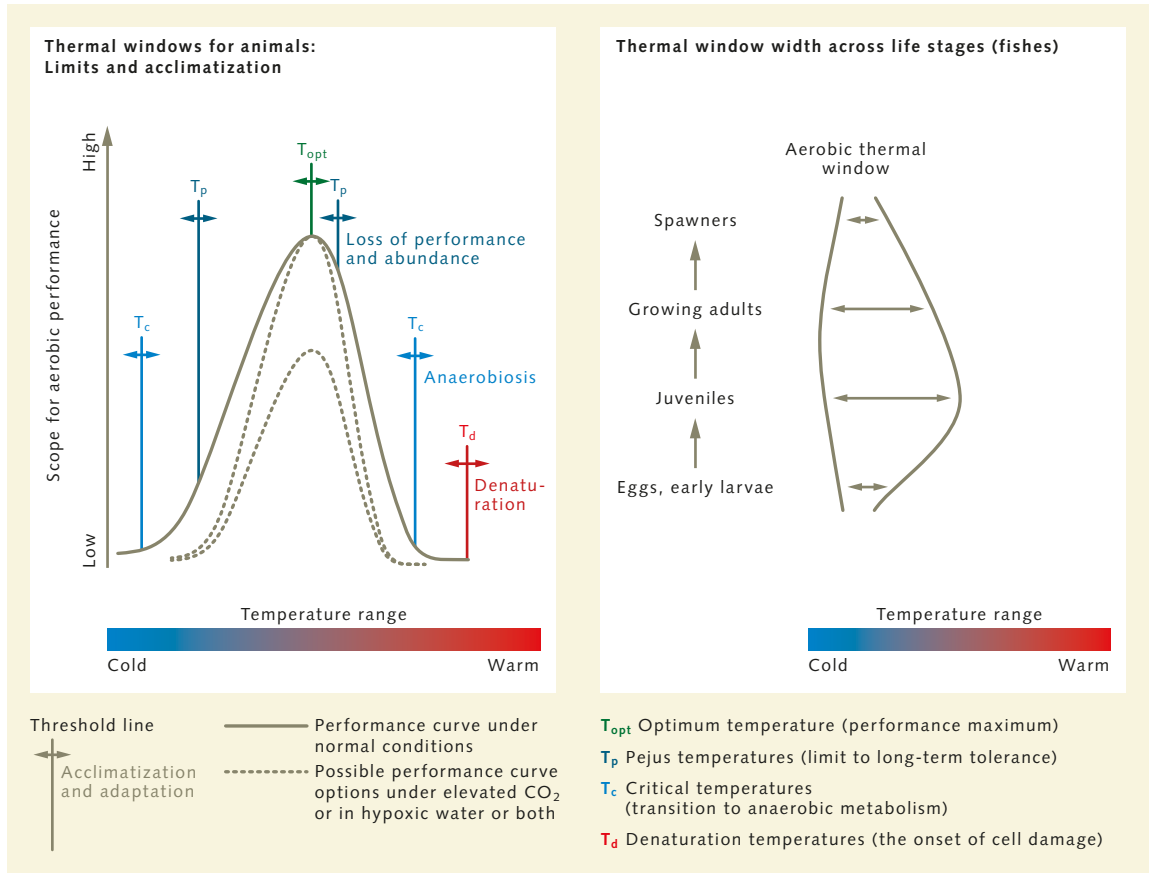
Temperature and oxygen

Ambient temperature is the most important driver of biodiversity, because all living organisms on Earth can only live and function in the long term within very specific temperature ranges. This applies to viruses and bacteria as well as single-celled algae, macroalgae and plants, animals and humans. This range is termed the thermal tolerance window or thermal niche.

The width of this window or range varies from species to species. For oxygen-breathing marine organisms, if the ambient temperature is within their species-specific optimal range, they can provide enough energy to maintain all their bodily functions long-term by absorbing oxygen and food. However, if the temperature falls below the lower limit of the thermal tolerance window or rises above the upper limit, the body’s functional mechanisms fail and the organism’s life is at risk.

Moreover, we know of cold-blooded marine organisms such as fish that the width of the thermal tolerance

2.3 > Every living organism has a limited temperature range in which it can function and exist. This range is termed the thermal tolerance window. An organism exhibits the greatest performance when the ambient temperature is at the average value of its thermal tolerance window. As the organism gets warmer or colder, its performance declines.



window, and thus the individual's heat tolerance, changes over the course of an animal's development. Both parameters increase from the embryonic stage to young adulthood. However, as fish reach sexual maturity and increase in body size and mass, the width of the thermal tolerance window and hence the heat tolerance decrease again. Embryos and individuals ready to spawn therefore have the lowest tolerance to temperature fluctuations.

If we now compare all species and groups of organisms in the sea, we can see that the more complex organisms, such as animals and plants, not only have the narrowest thermal tolerance windows but they also reach their upper tolerance limit much sooner than other marine organisms. While unicellular bacteria and archaea can live in hot, oxygen-poor waters, marine organisms with a more complex structure reach their growth limit

at a water temperature of 41 degrees Celsius at the latest. This upper temperature limit is evidently an insurmountable obstacle for their highly developed metabolic systems.

With the exception of birds and mammals, most marine animals are cold-blooded, meaning that their body temperature is determined by the ambient temperature. If a marine region heats up significantly in the summer and cools significantly in the winter, the organisms living there need a wide thermal tolerance window to be able to cope with both the warm summer temperatures and the cold winter. This is the case in the North Sea, for example. Long-term measurements off the North Sea island of Helgoland show that the average sea surface temperature there is below zero degrees Celsius during extremely cold winters, rising to 20 degrees Celsius in warm summers.

In tropical seas, however, seasonal temperature variations are much smaller. In the Philippine Sea, a marginal sea of the western Pacific Ocean and the most biodiverse region of the Coral Triangle, the sea surface temperature is around 20 degrees Celsius in winter. For the rest of the year, it averages between 24 and 28 degrees Celsius. As a result, the marine organisms living there only have to compensate for comparatively small temperature differences.

Furthermore, the performance of organisms also varies within their own thermal tolerance window. It rises towards the centre of the window and then drops again, resulting in a parabolic performance curve. This means that most organisms are only capable of long-term maximum performance when the ambient temperature is roughly in the middle of their own thermal niche and there is sufficient oxygen. If the air or water is warmer or colder, or if the organisms lack oxygen, they will not be able to perform optimally and will lose out in the competition between species. An example from Japan illustrates the form such a temperature-related defeat can take.

The waters off the east coast of Japan are home to both Japanese sardines (*Sardinops sagax melanostictus*) and anchovies (*Engraulis japonicus*). Both species form large shoals, but never occur in very large numbers at the same time. Instead, at times anchovies dominate, while a few years later Japanese sardines take over. This interplay can be explained by naturally occurring fluctuations in sea surface temperature in the western North Pacific and the different heat tolerances of the larvae of the two species.

Japanese sardine larvae grow best at a water temperature of 16.2 degrees Celsius. Anchovy larvae, in contrast, prefer 22 degrees Celsius. This gives the latter an advantage when the currents of the North Pacific bring warmer water to Japan's east coast. But when the seawater cools down again, the sardine larvae find better growth conditions. The anchovies lose out during these cooler periods.

In addition to the temperature-dependent performance of marine organisms, there is a second way in

which the water temperature of a marine region affects biodiversity. Warm temperatures, such as those found in the Coral Triangle, accelerate the metabolism of all organisms living there. This shortens the lifespan of individual generations. Offspring are produced at shorter intervals, thus increasing mutation rates. Scientists argue that this makes the emergence of new species more likely, and that the region's biodiversity will increase in the long term as a result of evolutionary development.

They cite the abundance of species in tropical seas as evidence for this theory. Unlike the polar oceans, their water temperatures have remained stable over the past 15 million years. Moreover, the Coral Triangle and other tropical marine areas were never iced over or glaciated – events which could have caused species extinctions. Spared from climatic extremes, the shallow waters interspersed with coral reefs instead became a source of biodiversity and, experts note, gave rise to many of the more advanced marine organisms we know today.

This raises two questions that science has yet to answer: Is there an upper limit to the species diversity of a marine area? Is there a saturation point? And secondly, do stable higher temperatures allow for greater species diversity? All considerations in this regard probably start with the question of how much food and oxygen are available to the organisms in a given marine area, and whether both quantities are sufficient to meet the marine organisms' temperature-dependent basic needs.

Primary production as the key to species richness

Living organisms need food to grow and reproduce. Those that cannot find food must migrate or die. The food supply in a marine region therefore has a direct impact on biodiversity. In many places, algae, marine plants and cyanobacteria, also known as primary producers, provide the basis for a rich food supply. They absorb carbon dioxide and nutrients such as nitrogen, phosphorus, iron and silicon from the sea and use photosynthesis to create

2.4 > Brittle stars are not ascetics: They use their long, tubular arms to grab small organisms and animal or plant remains that are suspended or drifting in the water. They then sweep their prey to their mouth with its five toothed jaws on the underside of their central body disc.



new carbon-rich biomass. For this reason, primary production is particularly high in marine areas where sufficient nutrients and sunlight are available, such as coastal waters. The greater availability of nutrients in such areas is also the reason why important primary producers such as unicellular calcareous algae or diatoms are much more likely to grow and form algal blooms around large land masses than far out in the open ocean.

Primary producers in the Coral Triangle benefit from the region’s many islands and regular rain showers. The rain washes much-needed nutrients from the land into the sea. As these are immediately absorbed and used in the highly productive coastal waters, the primary production of the world’s oceans declines with increasing distance from land and increasing water depth. The same generally applies to species diversity.

Submarine mountains or continental slopes, where nutrient-rich water masses often rise from the depths, are

an exception. These provide primary producers in the light-filled surface water with nutrients so continuously that they grow and die steadily and biomass sinks from the sea surface to the depths in sufficient quantities. Under such conditions, deep-sea biodiversity can be relatively high, even in temperate and high latitudes, as researchers have found in a study of the global distribution of 2100 species of brittle stars.

When the scientists analyzed their data, they found that the greatest species richness of brittle stars was found in the deep sea far from the tropics, at the foot of continental slopes in the mid-latitudes of the northern and southern hemispheres. This observation may indicate that the geographical distribution and species richness of brittle stars at great depths is mainly dependent on food availability and only marginally on water temperature, which at very great depths is roughly the same everywhere – in polar seas as well as in the tropics. The situation is different for brittle stars living at depths of up to 2000 metres. Here, the highest numbers of species are found in the tropics and subtropics.

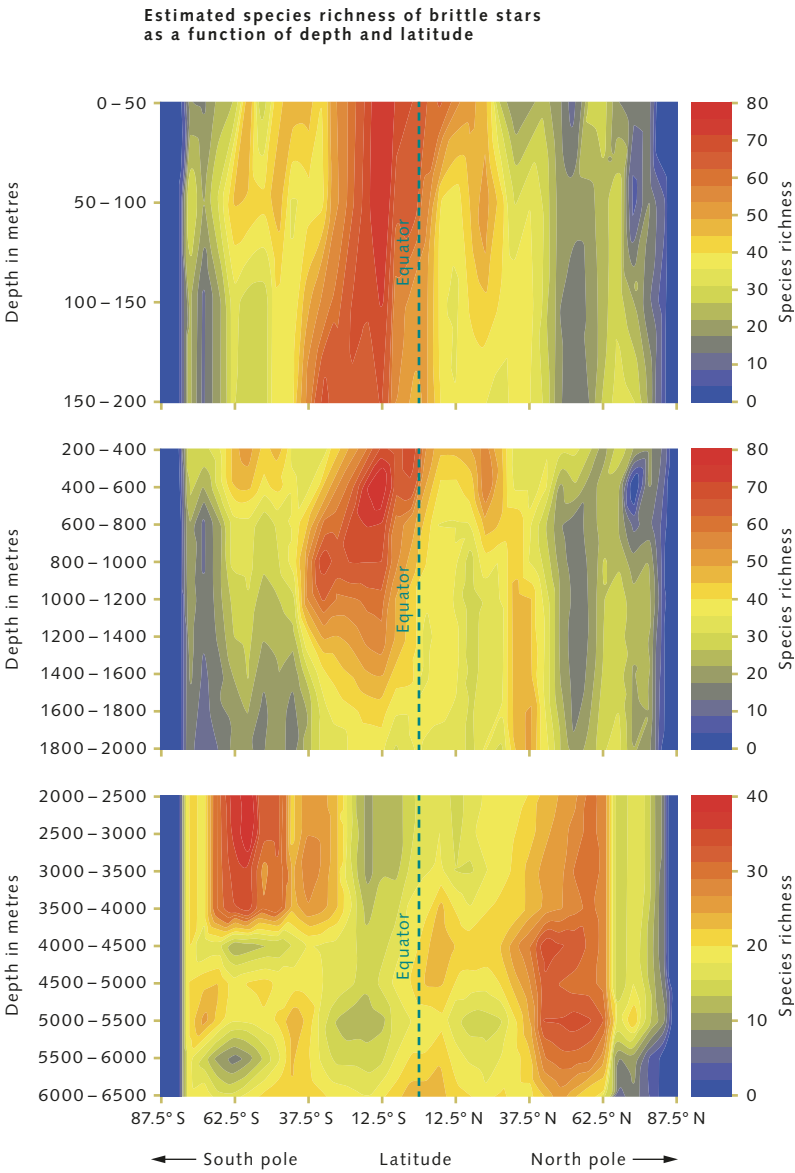
The role of structurally rich habitats and the coexistence of species

The Coral Triangle’s communities also owe their biodiversity to the many coral reefs, each of which is a habitat in its own right that, so to speak, forces its inhabitants to adapt to local conditions. Structurally rich habitats such as reefs, mussel beds, seagrass meadows and kelp forests provide many species with food, shelter and a wide choice of potential mates. They are therefore among the most species-rich marine ecosystems.

For organisms, it is always a risky business to colonize new habitats. If they leave their own coral reef, for example, they run the risk of being swept away by one of the ocean’s many currents or of being exposed to predators. And yet, throughout evolution, species have had to conquer new habitats. This is usually because competition for food in their original territory has become too great, local environmental conditions have changed, or animals have to find mates. Movements



2.5 > Off the coast of the Swedish island of Gotland in the Baltic Sea, wind and currents swirl large accumulations of shimmering green phytoplankton through the water. Microalgae are the first link in almost all oceanic food chains.



2.6 > The distribution and abundance of brittle stars changes with increasing water depth. From a depth of 2000 metres, the echinoderms live mainly at the foot of continental slopes in the mid-latitudes, as that is where they find the best food supply.

of the continental plates have also played a role in the history of the Coral Triangle. For example, where there are now large areas of shallow water supporting diverse marine life, about 20 million years ago there was a deep rift between the Southeast Asian plate and the Australian plate. As the two plates moved closer together, the shallow water areas were created that are so important today, allowing species to migrate and fill new niches.

In order to minimize the risks associated with species migration, many marine species continue to follow one of three proven survival strategies:

- They stay relatively small and are carried to new habitats by local ocean currents. This saves energy.
- They grow to an impressive size to scare off predators, or they become master swimmers so that predators cannot follow them.
- They invest less energy into growing, leaving their safe shelters only at night to forage in the dark. This keeps them hidden from predators that hunt by sight.

This allows marine organisms to colonize habitats for the first time or repeatedly, to undertake long migrations (e.g. gray whales, sea turtles, sharks, etc.), or to exist in marine areas where there are many predators. The end result is that more organisms survive and the likelihood of new species emerging increases. The latter is especially true when organisms colonize habitats where strong currents, deep water, ice barriers or other obstacles prevent them from returning to their place of origin.

In the long term, environmental factors such as the sea level also play an important role in the distribution of species and ecosystems. Sea levels determine which coastal areas dry up or are permanently flooded, and where sunlight-dependent organisms such as corals can colonize. Scientists have also developed a growing understanding of how the balanced coexistence of different species in an ecosystem can strengthen the community as a whole. A famous example is the interaction between sea otters (*Enhydra lutris nereis*), sea urchins (*Strongylocentrotus purpuratus*) and giant kelp (*Macrocystis pyrifera*) off the west coast of North America.

Kelp forests are a biodiversity hotspot and provide a habitat for many marine organisms, including sea urchins, which normally hide on the seabed and feed on dead algae floating by (passive feeding). Under certain circumstances, however, they emerge from their burrows and switch to an active feeding mode, feasting on healthy algae. Researchers do not yet fully understand what

makes them do this. However, it is known from observation that sea urchins in active feeding mode are capable of destroying large areas of kelp forest.

Healthy sea otter populations are the most effective defence against this. These marine mammals hunt the sea urchins and thus keep them from leaving their hiding places. In this way, the kelp forest remains largely intact – or so experience has shown. For almost a decade, however, scientists in Monterey Bay, California, have been observing that the interplay of the kelp forest species community is a lot more complex and that other species also play a role.

In 2014, the marine region was hit by a heatwave. This coincided with the outbreak of a starfish disease that caused mass mortality. Sunflower sea stars (*Pycnopodia helianthoides*) were among the victims. With an arm span of up to one metre they are among the

world’s largest starfish – and they eat sea urchins. Their sudden disappearance and the heat stress caused the sea urchins to come out of hiding and actively attack the giant kelp, devouring the forests in many places except for a few remaining areas and reproducing extremely rapidly.

The increasing number of sea urchins meant more food for the sea otters, which benefited their young in particular. They survived in higher numbers, so that the otter population also grew. However, the sea otters only hunted sea urchins in the few remaining patches of kelp forests, effectively protecting them from overgrazing. The otters spurned the many sea urchins on the grazed residual areas, presumably because the echinoderms found less to eat on the bare areas and were therefore less nutritious than the well-fed sea urchins in the residual kelp forests.

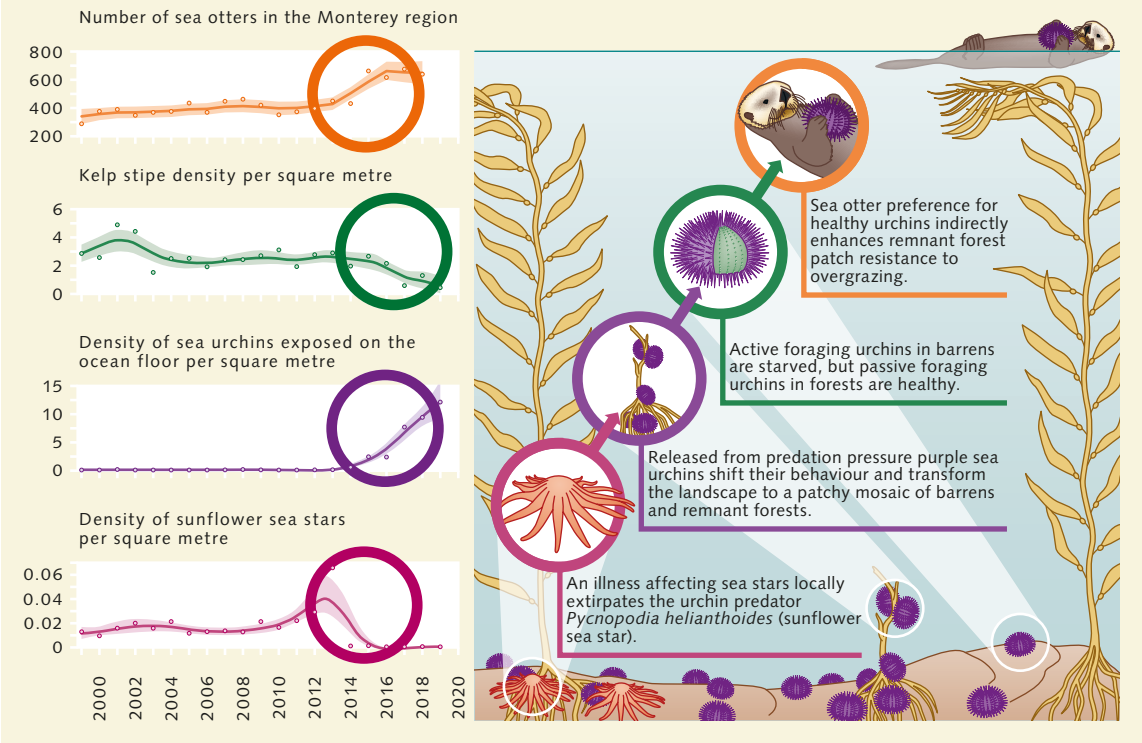


2.7 > Gray whales spend the summer building up fat-reserves in the waters off the coast of Alaska, then migrate south in the autumn to give birth in the Gulf of California. Due to their enormous size only orcas hunt them.



2.8 > A group of ravenous Pacific purple sea urchins (*Strongylocentrotus purpuratus*) head for a bull kelp forest (*Nereocystis luetkeana*) off the coast of Mendocino, California. After such an attack, all that is usually left is bare rock.

The interplay between sea otters, kelp, sea urchins and sunflower sea stars in the observation period from 1998 to 2020



2.9 > The subtle interplay between sea otters, sea urchins, brown algae (kelp) and sunflower sea stars (starfish) off the coast of California shows how species in a habitat influence each other and thus stabilize their eco-system.

Contrary to expectations, the sea otters did not contribute to any rapid depletion of sea urchins in the overgrazed areas, and the giant kelp was unable to recolonize these areas. This was a huge loss for the coastal ecosystem. It remains to be seen what will happen next.

This example demonstrates that the stability and functionality of marine ecosystems and their biodiversity also depend on the behaviour and coexistence of their inhabitants. When these relationships change, the communities reorganize, which can also mean that the species richness of a previously diverse marine region declines.

Maps showing the distribution of marine life

Our knowledge of the abundance and distribution of marine life has increased dramatically over the past

two decades. This is largely thanks to databases such as the Ocean Biogeographic Information System (OBIS), where researchers from all over the world contribute data sets on the occurrence of marine species. Looking at the ocean regions covered by the data sets, it is clear that experts in China, Australia and Europe have a particularly good overview of the species found in their waters. The waters of the tropical western Atlantic, the tropical eastern Pacific and the Canadian part of the Arctic Ocean are less well surveyed. In addition, there are marine ecosystems for which little or no information is available. These include deep-sea communities in particular, but also biotic communities in permanently ice-covered regions, as yet unstudied coral reefs, and chemosynthetic communities. The latter are low-oxygen deep-sea ecosystems in which bacteria use methane or sulphides as an energy source for primary production.

Marine biodiversity hotspots

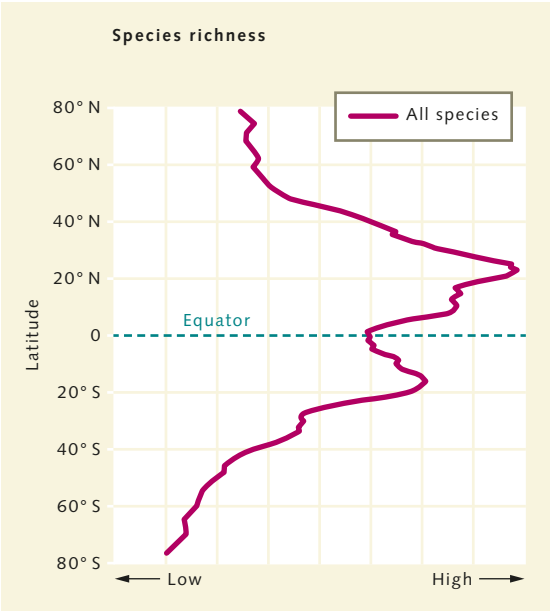


2.10 > In its Sixth Assessment Report, the Intergovernmental Panel on Climate Change identified 43 marine hotspots of biodiversity and species diversity. These are marine regions with particularly high species richness, including particularly rare species or organisms that only occur in these particular areas.



2.11 > Selected marine biodiversity hotspots. Top (from left to right): the seagrass meadows in the Northeast Atlantic, the Agulhas upwelling area off the coast of South Africa, the coastal areas of the Antarctic Peninsula; Middle (from left to right): the Humboldt Current with its fur seal colonies off the coast of Chile, Chesapeake Bay on the coast of the US state of Maryland, a coral reef in Indonesia; Bottom (from left to right): another Indonesian coral reef, the kelp forests off the coast of Norway and the reef communities in the waters of the Philippines.

2.12 > Patterns of marine biodiversity: The number of known marine species increases from the polar regions towards the equator. It reaches a maximum in the transition zone between the tropics and subtropics and then slightly declines towards the equator.

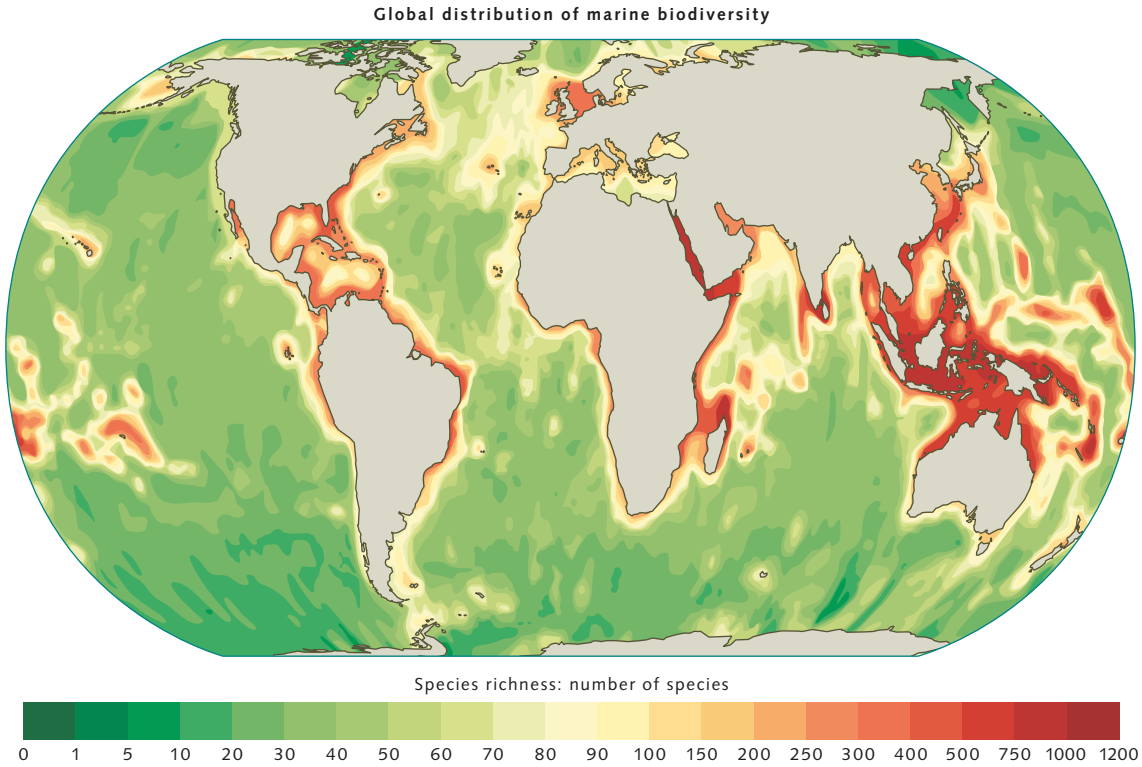


Not surprisingly, researchers know more about the abundance and distribution of commercially important

marine species such as tuna, squid and mussels than they do about species that are not caught and sold. More research has also been done on larger marine organisms than on smaller species. In 2020, an international team of experts summarized that sufficient comprehensive data to track their global distribution are available for a mere 50,000 marine species. These well-researched marine organisms once again are mainly those of commercial interest, as well as marine organisms that are very popular with the public, such as whales and other marine mammals.

Using the OBIS datasets and other databases, several research teams have attempted in recent years to visualize marine biodiversity on a world map and to identify the most species-rich marine areas. This is not an easy task, as the first step was to check the comparability and applicability of a billion data sets. Some, for example, lacked precise location data, while in others, marine organisms had not been clearly identified or records had been entered twice. It is also well known that there is signifi-

2.13 > Species richness is generally higher in coastal areas than in the open ocean. Researchers have documented the highest levels of biodiversity in the Indo-Pacific Coral Triangle, the central and western Indian Ocean, the Red Sea and around the islands of the Southwest Pacific.



cantly more research data available from the oceans of the northern hemisphere than from southern or tropical regions. This creates a disruptive bias in the data, which also had to be corrected.

After several data processing steps a relatively clear picture of species richness in the global ocean emerges. The map presented here is the result of an analysis carried out in 2020. It captures taxonomic information and distribution data for 41,625 species across all groups of organisms, representing 17 per cent of known marine species at the time of publication.

The map shows that the marine regions with the greatest biodiversity are located at the edge of the tropics. This is particularly true of coastal waters. At the equator itself, there are significantly fewer species than 2000 kilometres further north or south. Scientists explain this significant dip in the diversity curve by the fact that fewer and fewer marine organisms are able to tolerate the increasing warmth at the equator. Thousands of species have migrated north or south since the 1950s to avoid dying of heat exhaustion in constant water temperatures of 28 degrees Celsius or more.

Major differences in species richness are also apparent when travelling around the globe along the equator. While the central marine regions of the Atlantic and Pacific Oceans can be described as species-poor, species richness increases as one approaches the Caribbean or the Coral Triangle in the Indo-Pacific. Other marine hot-spots include the central and western Indian Ocean and the Red Sea. Researchers have also documented large numbers of species in parts of the Northeast Atlantic and the North Sea.

It must be said, however, that these general patterns do not apply to all groups of organisms. Seals, sea lions and walruses, for example, are mammals that produce their own body heat and have evolved to develop a thick, insulating layer of fat. Especially in cold regions this gives them a distinct advantage. This is why they are most abundant in polar and subpolar waters. In contrast, seagrasses prefer the water temperatures of temperate latitudes and are most abundant in their coastal waters.

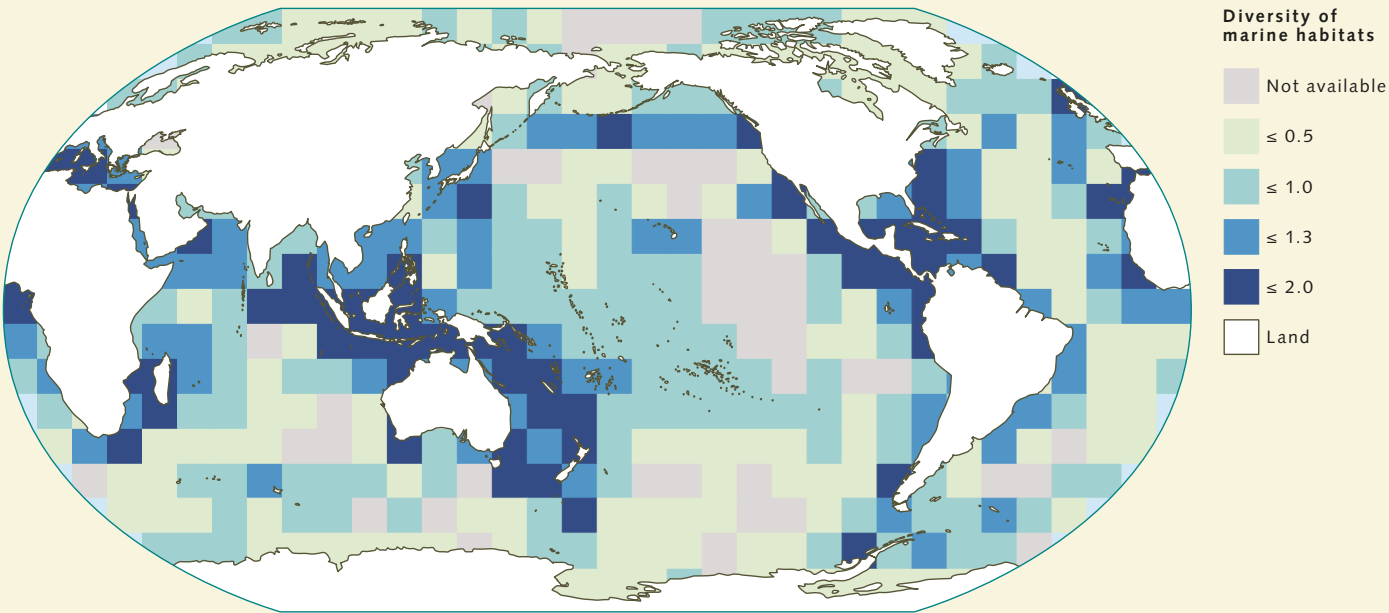
Far out in the open ocean, researchers have documented the greatest biodiversity in marine areas between 30 and 40 degrees north and south latitude. These regions are home to most species of zooplankton, such as copepods, foraminifera and krill, as well as large numbers of whales and deep-sea fish such as tuna and sharks. Comprehensive data on the distribution of single-celled algae (phytoplankton) and marine bacteria were not yet available in 2020.

The diversity of habitats and biogeographical areas

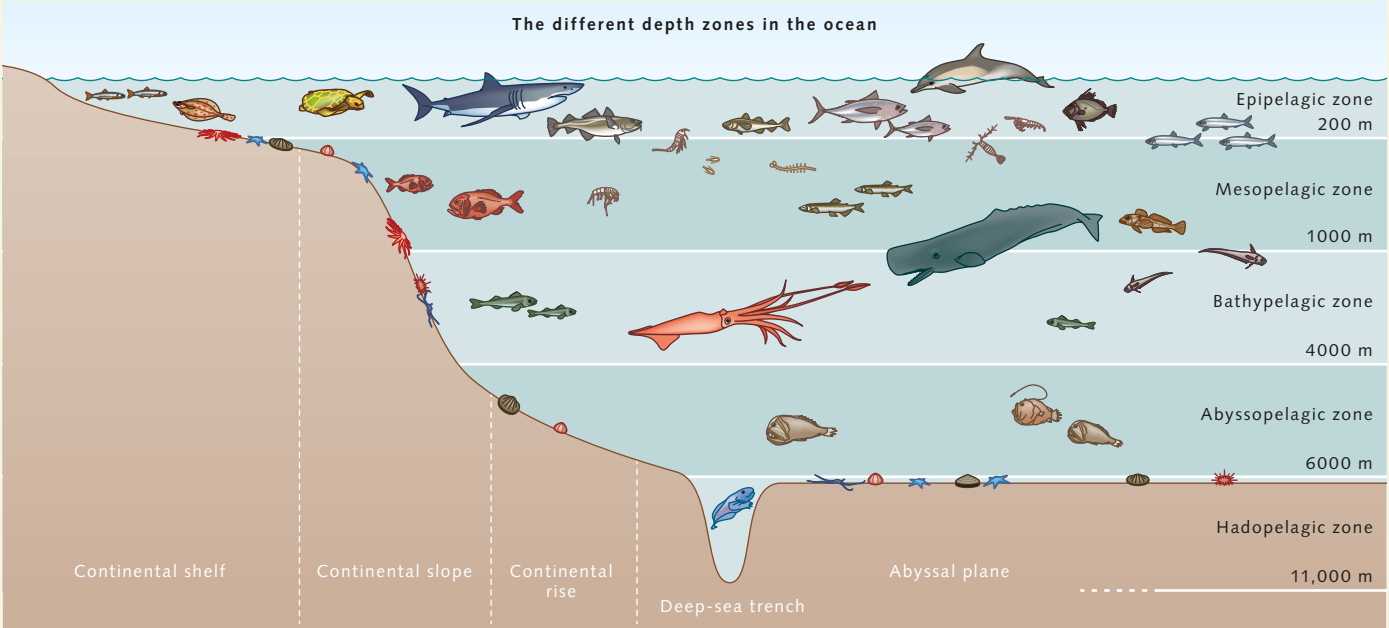
The researchers also looked at where the twelve best-known marine ecosystems occur in the global ocean, and whether there are regions in the global ocean where different ecosystems coexist in close proximity. The ecosystems analyzed included the biotic communities of river estuaries, mangrove forests, tidal marshes, sea-grass meadows, coral reefs, continental-shelf incised valleys and deep trenches, cold-water coral reefs, seamounts, deep-sea trenches, hot springs and submarine mountain ranges. The results of the analyses confirmed the findings on the species diversity of the oceans: the number of ecosystems, and therefore the diversity of different biotic communities, was found to be highest in the Coral Triangle, the Caribbean and off the east coast of Australia.

Three years earlier, in 2017, another team of researchers had published a map dividing the world's oceans into 30 different zones, known as biogeographical regions. For this classification, the scientists had analyzed OBIS data on the distribution of 65,000 marine species and used statistical methods to examine how similar marine communities were in terms of their species composition. Where there were clear differences between neighbouring communities, the scientists drew a boundary.

Using this zonation, they were then able to answer a number of questions about the distribution of marine life. They found that of the 100 most widespread marine species, 72 were plankton and only 27 were what are known as marine megafauna. These are large inhabitants of the



2.14 > This map shows which marine regions host the highest number of different marine habitats, such as seagrass meadows, coral reefs, estuaries or trenches. The darker the colour of each box, the greater the number of habitats that can be found in that region. The corresponding numerical values have been calculated using a diversity index. Such indexes are applied to compare the biodiversity or habitat diversity of two regions. The two best-known diversity indices are the Shannon-Wiener index used here and the Simpson index. Both take into account the number of species or habitats and their distribution in a given area.



2.15 > Water temperature and the availability of light and food determine the depth distribution of marine life. Researchers distinguish five depth zones.

seas such as whales, sea turtles, seabirds and sharks, some of which are known to migrate over long distances. According to the study, the foraminifera *Globigerinita glutinata* has the largest habitat. This tiny single-celled organism was found in 28 per cent of the marine area surveyed.

The analysis also showed that marine organisms swimming in the water column are generally more widespread than those living on the ocean floor. The marine area with the highest proportion of endemic species is the Black Sea: 84 per cent of the species living there were not found in any of the other zones. The researchers explain this leading position with the inland sea's low salinity. Due to the high level of freshwater inflow, freshwater and brackish water species can also live in the Black Sea.

The study also provided new insights into the depth distribution of species. Based on their data, the researchers were unable to detect any depth zones other than those already known. These include the surface layer flooded with sunlight (euphotic zone), where algae and their predators thrive. It extends from the ocean surface to depths of around 200 metres.

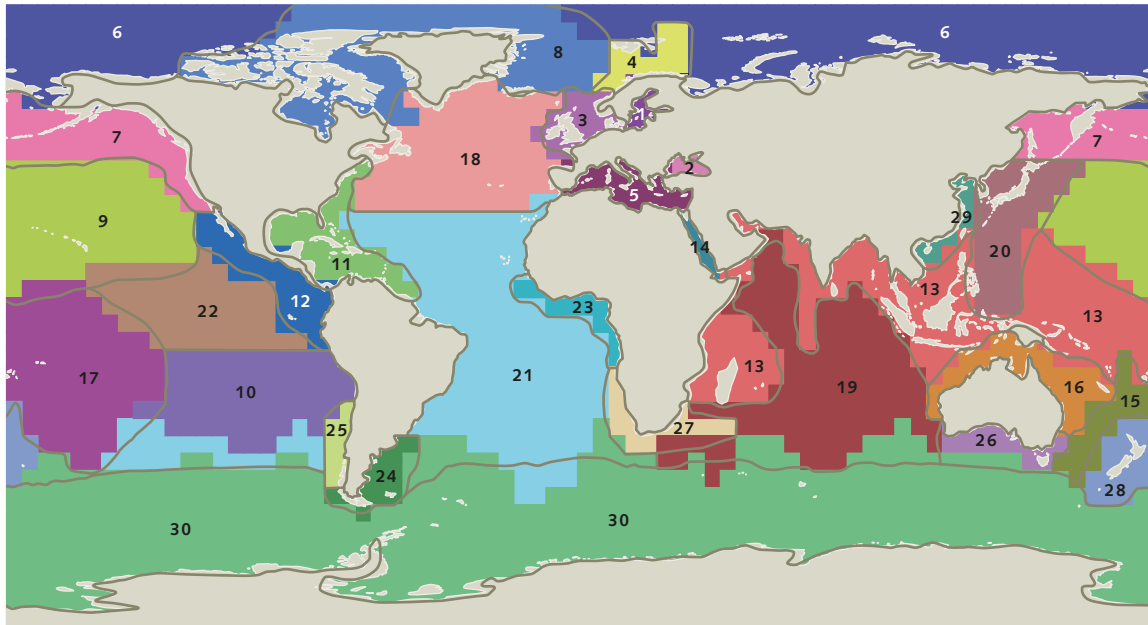
Below this is the twilight zone (mesopelagic zone), where plants no longer thrive. It extends from 200 to 1000 metres and provides a daytime refuge for organisms that only come to the surface at night to feed. Below the twilight zone is the deep sea (bathypelagic and aphotic zones), where communities of organisms have to cope with low food availability, constant cold and permanent darkness.

The scientists hope to use this knowledge of the distribution of marine life to help protect it – for example,



2.16 > The foraminifer *Globigerinita glutinata* lives in the water column and is one of the most widespread marine organisms in the world. The shell of adult animals consists of three distinctive chambers. It is less than half a millimetre in diameter.

2.17 > The biogeography of marine life: After analyzing data on the distribution of 65,000 species of flora and fauna, researchers were able to divide the global ocean into 30 different biogeographical zones. Each of these zones is home to a marine species community that differs in its composition from the communities in the neighbouring zones.



Ocean region	Number	Endemic species (in %)	Number of species
Inner Baltic Sea	1	63	458
Black Sea	2	84	192
Northeast Atlantic	3	27	7117
Norwegian Sea (in parts)	4	43	1345
Mediterranean Sea	5	45	3096
Arctic seas	6	19	1907
North Pacific	7	27	5535
North Atlantic and subarctic waters of Canada and Greenland	8	31	1492
North Pacific (mid-tropical)	9	47	2859
South-eastern Pacific	10	59	1618
Caribbean and Gulf of Mexico	11	30	13,281
Gulf of California	12	30	3279
Indo-Pacific seas and Indian Ocean	13	31	16,508
Gulfs of Aqaba, Aden and Suez, Red Sea	14	74	997

Ocean region	Number	Endemic species (in %)	Number of species
Tasman Sea	15	57	1468
Coral Sea	16	33	10,349
Central tropical South Pacific	17	44	2818
Central Northwest Atlantic	18	26	7591
Central Indian Ocean	19	43	3486
Central Western Pacific	20	40	4678
Central South Atlantic	21	33	5512
Central Middle Eastern Pacific	22	36	1217
Gulf of Guinea	23	57	992
Waters of the Río de la Plata	24	45	1651
Waters off Chile	25	68	584
Waters off South Australia	26	40	2158
Waters off South Africa	27	45	6700
Waters around New Zealand	28	33	3126
Northwest Pacific	29	47	2551
Southern Ocean	30	17	4256

by using the biogeographic zones to determine the best possible location, size and connectivity of marine protected areas.

The distribution map and associated database will also be used as a benchmark for future observations of marine biodiversity.

Reports of species migrations and ecosystem shifts as a result of climate change are now coming in from all regions of the global ocean. This is no surprise, as

the Earth’s climate directly regulates the key factors that determine the distribution of marine life. These primarily include water temperature, the oxygen content of the water masses, their degree of acidification (pH), terrestrial nutrient inputs as a result of precipitation, the strength of ocean currents, sea levels and, in the case of the flora and fauna of the polar seas, the extent, thickness and lifetime of the sea ice that protects and sustains them.

CONCLUSION

Determinants of success for marine biodiversity

If we want to conserve marine biodiversity, we need to understand which environmental factors significantly influence the distribution of species in the oceans. Scientists approach this question from two directions: Firstly, they collect and analyze data on the occurrence of species and habitats. They produce distribution maps and seek to recognize patterns and decipher the local conditions to which these patterns are attributable. At the same time, they look at the principles of how microbial, animal and plant life works and try to derive laws. However, whether or not these conceptual explanations do apply to all marine organisms must then be thoroughly tested. This is a task that has not yet been fully accomplished. Our knowledge of the key drivers of species richness and the geographical distribution of marine life is therefore still incomplete. Empirical evidence of the interactions between different environmental factors and the mechanisms behind them is still lacking in some cases or is the subject of controversial debate in the scientific community.

The geographical distribution of animals in the ocean is best understood. Which species can settle

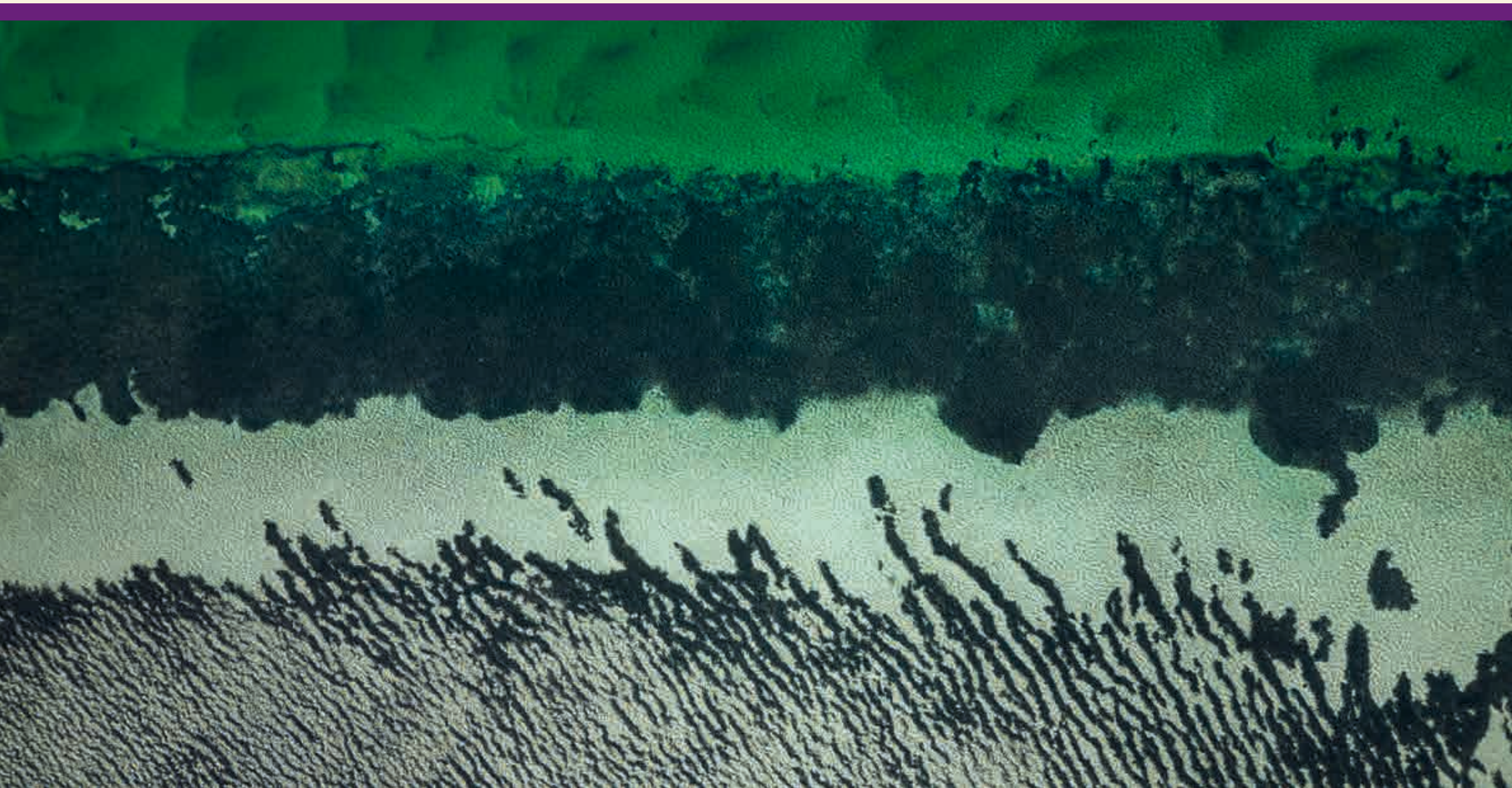
where in the sea and find sufficient food is determined by the ambient temperature and availability of oxygen, the overall food supply in the habitat and its complexity. This refers in particular to parameters such as habitat structure and interactions between its inhabitants.

The interplay of all these key factors provides ample explanation of why a much higher number of species live in the light-filled coral reefs of the marginal tropics than in the surface waters of temperate latitudes or the polar seas. At the same time, it is clear that there are exceptions to this rule – such as marine mammals, for example, whose bodies are not dependent on the ocean temperature, and the special case of deep-sea organisms. Because the latter live in marine regions with comparatively stable water temperatures, the food factor plays a much more existential role for them than for organisms in surface waters.

Such detailed knowledge of the geographical distribution of marine species, communities and ecosystems is urgently needed. It helps in the planning and implementation of conservation measures and provides a starting point for the early detection of climate-related changes in marine biodiversity and for the implementation of the best possible adaptation measures.

3 What marine nature and marine life mean to us

> Marine biological communities are a part of nature, to which people assign very different values. Depending on where we were born, the culture we grew up in and how close we live to or with the oceans, we assign different meanings to marine life. Different perspectives result in disparate approaches to nature, which explains why successes in marine protection up to now are few and far between.



Time for rapprochement

> Social science research shows that the less people’s well-being depends on nature in a direct and tangible way, the less they will tend to care about the environment and the oceans on their doorstep. People in industrialized nations in particular have become alienated from nature and have little understanding of why healthy marine ecosystems are vital to our survival. It is time we change that. However, this requires a departure from the prevailing belief that the oceans should serve us profitably.

Not monsters, but indispensable hunters

When two people were killed in shark attacks in Hawaii in the early 1990s, the fear among beachgoers and surfers was palpable. There were immediate calls for targeted hunts of large sharks to protect the tourism economy. It would not have been the first shark cull in the US state. Between 1959 and 1976, the Hawaiian authorities carried out a total of six shark control programmes, catching 4700 predators and killing most of them – mainly tiger sharks (*Galeocerdo cuvier*), sandbar sharks (*Carcharhinus plumbeus*), blacktip sharks (*Carcharhinus limbatus*), Galapagos sharks (*Carcharhinus galapagensis*), great white sharks (*Carcharodon carcharias*) and various hammerhead sharks.

Local shark populations plummeted by an estimated 50 to 90 per cent as a result of these campaigns, prompting some experts to proclaim that people were now safer in the ocean. The large, allegedly more dangerous sharks had been removed after all. However, a 1994 study contradicted this assessment. Firstly, the number of shark attacks during the cull period remained virtually unchanged from previous years. During both periods, the Hawaiian authorities recorded an average of 0.6 attacks per year. Secondly, it was already known in the 1990s that the frequency of shark attacks depends primarily on how many people use the sea for work, sport, fun and recreation, rather than solely on how many sharks reside in coastal waters.

But beyond the statistics, experts say there is a second argument against another mass cull: As predators, sharks play a key role in marine ecosystems. Tiger sharks, for example, like to hunt in seagrass meadows, and their appetite for sea turtles, dugongs and other grazers ensures

that seagrass meadows are not overgrazed, preserving them as shelter, nursery and habitat for hundreds of other marine species, including those that humans catch and use. Killing sharks in large numbers may upset the balance of marine life, the authors wrote at the time.

Thirty years on, in 2024, this is one of the key messages from an international team of researchers after analyzing the ecological roles of more than 500 different shark species worldwide. Their study states: Sharks contribute to the health of the ocean in such diverse and sometimes still misunderstood ways that their dramatic decline is an urgent concern.

In particular, open-ocean shark species such as oceanic whitetip (*Carcharhinus longimanus*), mako and hammerhead sharks have been fished so intensively over the past six decades that their populations have declined by more than 70 per cent between 1970 and 2018, and by as much as 84 per cent in the Indian Ocean. Where once ten of these impressive predators patrolled the seas, there are now fewer than three. Moreover, almost a third of all shark and ray species are now threatened with extinction. Healthy and functioning shark populations are needed to ensure the long-term survival of marine life. Researchers are therefore calling for a change in the way we think about sharks: We have to get away from seeing them as monsters or an inexhaustible source of food, and towards seeing them as vital health watchdogs for the oceans.

A key question: What are people’s attitudes towards nature and the oceans?

The change in thinking that scientists are calling for requires us to be aware of how we think about nature

and marine life, the importance we attach to each living being, and how our views influence our behaviour and decisions about the protection and utilization of nature and the environment.

In 2022, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) explored these questions scientifically in its *Values Report* (“Assessment report on the diverse values and valuation of nature”).

For this report, some 100 experts from around the world analyzed more than 13,000 scientific articles from a variety of disciplines, as well as a large body of indigenous and local knowledge, to examine how people from all over the world and from different backgrounds characterize their relationship with nature. It found that

people experience nature in very different ways and perceive the non-human environment differently. For example, while one group of people may see humans and nature as inextricably linked, others see the two systems as separate and independent of each other.

Such differences in turn explain why people develop different understandings of the role that healthy ecosystems play in their own well-being and attach different values to them. The main determinants are:

- *people’s world-view* – this refers to the way in which people perceive and interact with the world;
- the *knowledge system* in which people grow up – this includes social and environmental knowledge, and the practices and beliefs that relate to the rela-

3.1 > Mangrove forests provide people with timber and food. They protect coastlines from erosion and attract tourists. But the forests are declining in area in many places, driven by people’s hunger for land.



Sharks: (predatory) fish with a wide range of ecological roles and functions

Sharks as we know them today have populated the global ocean for around 150 million years. The group includes more than 500 species. Some are barely longer than a student ruler. Others, with a body length of up to 18 metres, are longer than a classic travel coach. Sharks can be found in all marine ecosystems, from the deep sea to the shallow waters of tropical coral reefs, in the open ocean as well as close to beaches. Some species, such as bull sharks, migrate up rivers and can live in brackish or fresh water.

Sharks feed in very different ways. While whale sharks and basking sharks filter microalgae and zooplankton from the water, smaller species hunt for worms and crustaceans. And of course there are the apex predators such as the great white shark, tiger shark or oceanic whitetip shark, which, once they reach a certain age, prey not only on other fish, including other sharks, but also on cephalopods and marine mammals.

Given this great diversity of species and behaviours, it is not surprising that sharks play a number of different ecological roles. As predators at the top level of the food web (apex predators), they keep their prey populations in check. They thus contribute to the balance of power within important coastal ecosystems such as seagrass beds and kelp forests, helping to ensure their existence.

At the same time, the very presence of sharks influences the behaviour of their prey and, indirectly, the fate of other marine organisms that are impacted by their prey. For example, in the vicinity of protected coral reefs, when reef sharks or other predators patrol nearby, fish feeding on seagrass and macroalgae are so intimidated that they leave their home reefs only for short periods, if at all.

As a result, they do not have the opportunity to graze the seagrass and macroalgae beds away from the reefs. This means in turn that there are far fewer and smaller overgrazed areas on the seafloor than on reefs where large predators are absent due to overfishing and grazers can also forage away from the reefs without fear. Such cause-effect mechanisms from the top to the bottom of the food web are called “top-down effects”.

But sharks also have a bottom-up effect. For example, they transport nutrients and biomass over long distances. This is the case when reef sharks hunt and feed in the open ocean, but deposit their faeces in the coral reef to which they return between hunting trips. A similar transport of nutrients or biomass occurs when sharks grow up as juveniles in one ocean region, but later migrate and are eaten or die of

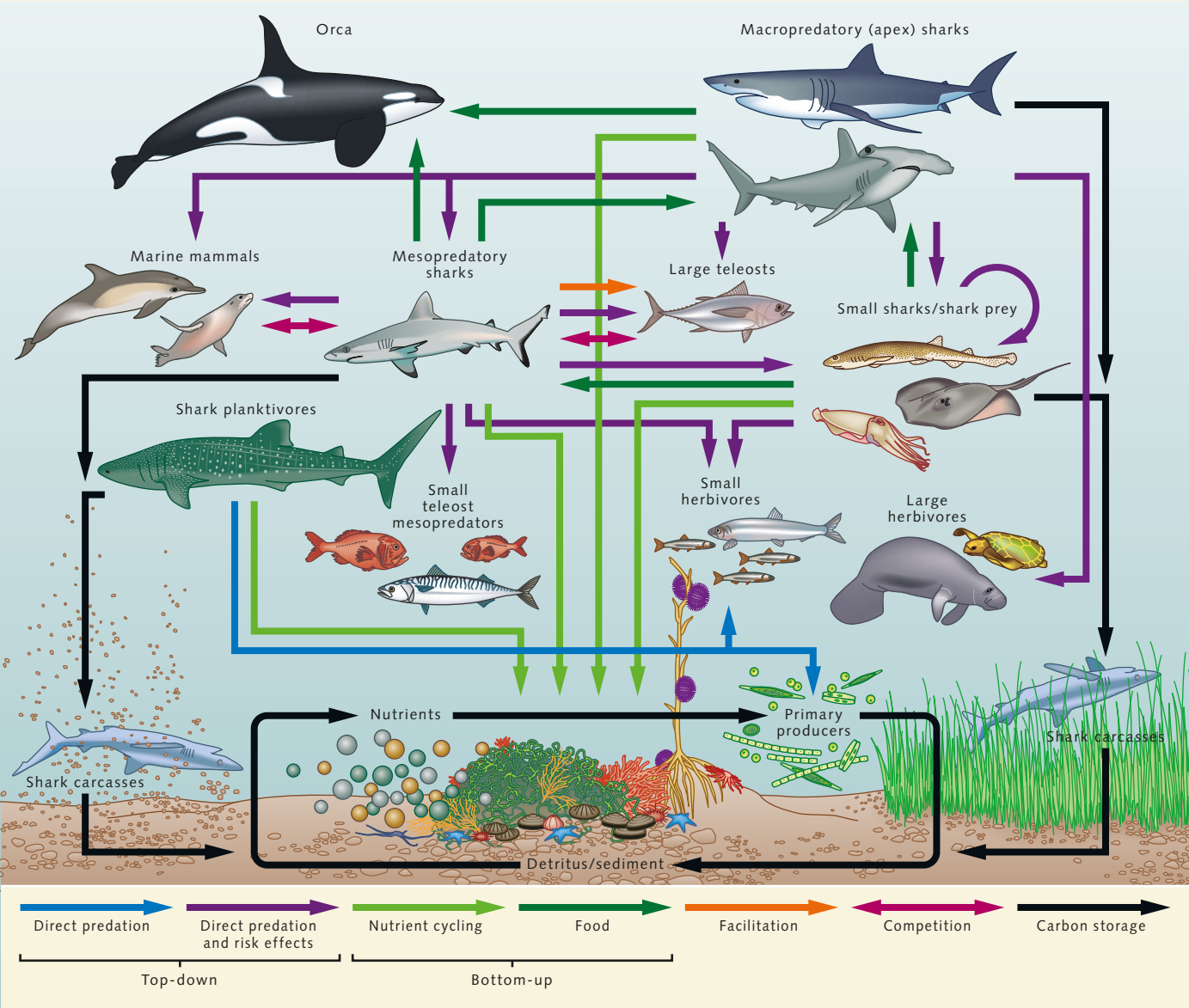
natural causes elsewhere. Their bodies then sink to the bottom and serve as a food source for other marine organisms.

Remains may be stored in the seabed, sequestering the carbon they contain. However, these processes have not been studied in detail, nor has the role of sharks as feed processors. White sharks, for example, act as processors when they feed on whale carcasses floating at the ocean surface, making them accessible to smaller predators. Deep-sea sharks perform a similar role on the ocean floor.

Another, often forgotten, aspect is that sharks themselves are hunted and eaten by other marine predators. So they also serve as food. In this context, top predators are particularly vulnerable as juveniles. However, some families of orcas also hunt adult great whites.



3.2 > Great white sharks patrol a seagrass meadow off the Southern Neptune Islands, Australia. The predators mainly hunt Australasian fur seals (*Arctocephalus forsteri*), which give birth on the islands.



3.3 > Sharks play multiple roles in marine ecosystems. While they act as predators and have a top-down effect through various processes, they are also prey themselves, allowing for bottom-up effects in the food web.

3.4 > The artisanal fishermen on Bangladesh's south coast still use their traditional boats to fish the Bay of Bengal. Their livelihoods depend directly on healthy and functioning marine ecosystems.

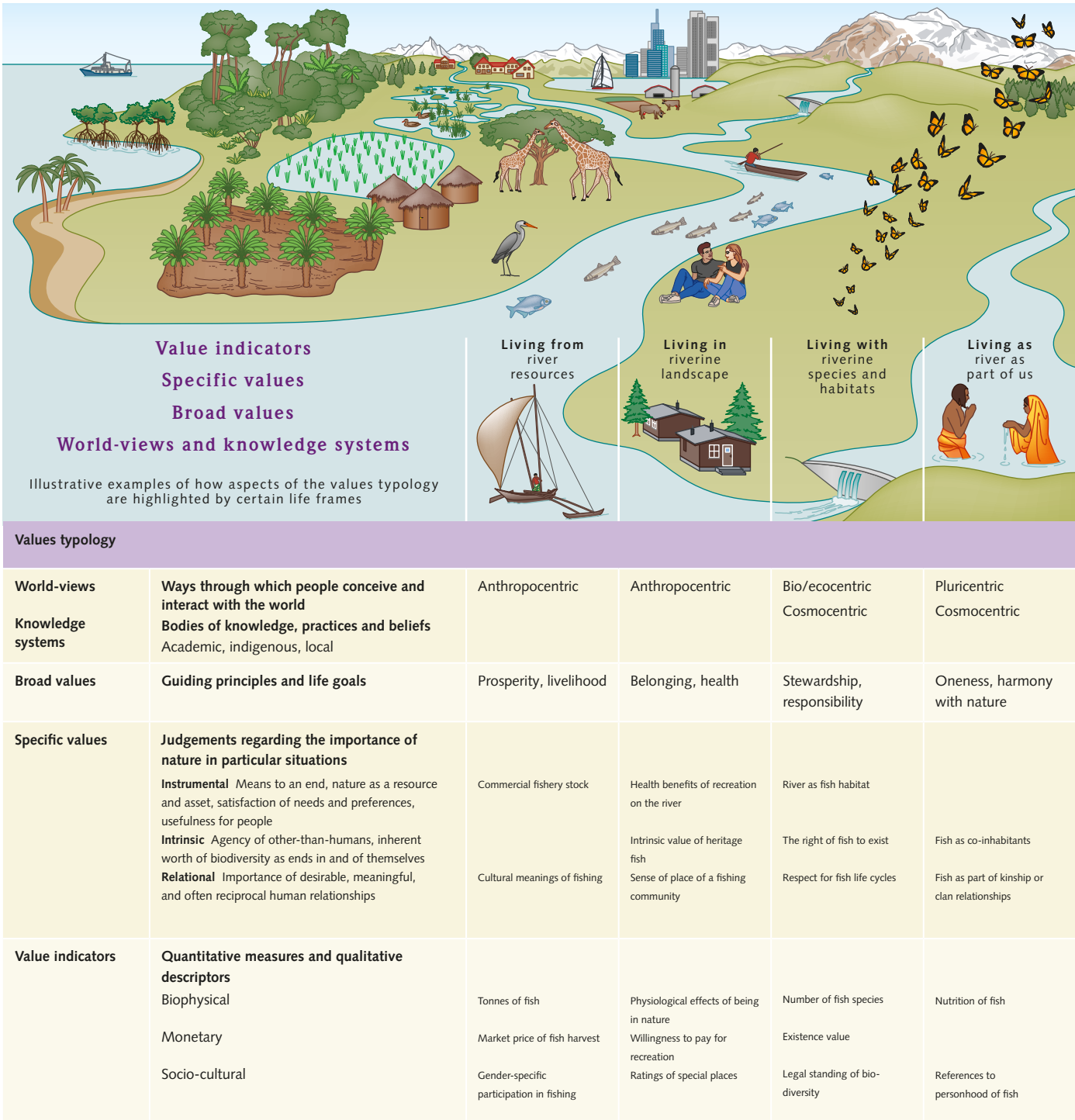


tionships of living beings, including humans, to each other and to their environment. Well known knowledge systems include, for example, academic learning and thinking, but also indigenous or local knowledge;

- *broad values* that guide people in their world-view and in their interaction with nature. Examples include moral principles such as justice, belonging and freedom, but also life goals such as the pursuit of pleasure, health and prosperity;
- *specific human values* that reflect opinions or judgments about the importance of certain things in par-

ticular situations and contexts. These include 1.) *instrumental* values, which state that something has value as a means to an end and is in principle substitutable; 2.) *relational* values, which denote something the value of which arises from people's relationships with nature or with other people through nature; and 3.) *intrinsic* values, which state that something has value as an end in itself or has an inherent or moral value that is not tied to human ends;

- *value indicators* – these are economic, biophysical or socio-cultural parameters by which people mea-



3.5 > People define their relationship with nature in terms of world-views, broad values, specific values and value indicators. This overview illustrates how these can differ between people, depending on their individual life frames.

sure, describe or compare the value of nature. A group of commonly used value indicators for marine fish stocks, for example, are indicators such as the catch quantity measured in tonnes (biophysical indicator), the market price received for the catch (economic indicator) or the proportion of women among the fishers involved in the catch (socio-cultural indicator).

Our own native tongue also has a major influence on our perception of nature. If people have many different words for the oceans and their inhabitants, as is often the case with indigenous peoples living in coastal regions, they are in the best position to engage more deeply with the oceans and their biological communities.

To handle the difficulties in categorising the many ways of looking at nature, the IPBES experts propose a typology that illustrates how world-views, knowledge systems, values and value indicators together influence the way people interact with and value nature. Their typology asserts that there are:

- People who *live from nature*;
- People who *live with nature*;
- People who *live in nature*, and
- People who *live as nature*, i.e. people who see themselves as *part of nature* and act accordingly.

People who say they live from nature communicate that nature is important because it supports human life, needs and well-being through the uses, goods and services it delivers. For example, an ocean is valued by these people for the fish it provides for consumption.

People who live with nature see the cycles of nature, its life-sustaining processes, and the many species that have a right to flourish regardless of their contribution to human well-being. These people recognize the right to life of the fish in the sea, regardless of their own human needs.

The “living in nature” category includes people who understand physiographic regions as settings for their

own lives, practices and culture. As a result, they value the sea and its coastal landscapes as areas that strengthen their own sense of place and identity and shape their own personal narratives.

However, humans can also see themselves as part of nature, or live as part of nature, perceiving it as a physical, mental and spiritual part of themselves. In this case, the sea is seen as sacred or familial, for example because it fosters a sense of unity, kinship and interdependence.

The IPBES experts stress that none of these categories or perspectives is better than the others but, rather, that they are not mutually exclusive and people can harbour different combinations of these “life frames” at different times and in different contexts.

Understanding the different categories not only helps to understand the world-views, knowledge systems, values and value indicators that are important to people. They also make it easier to understand policy decisions.

In their values assessment report, the IPBES experts stress that the global decline in biodiversity on land and in the oceans is due to the fact that political and economic decision-makers primarily see the economic value of natural assets and focus on short-term financial gains. Long-term changes to the natural resource base on which our lives depend, such as nature’s contribution to climate regulation, are not or only inadequately taken into account. As a result, political and economic decisions are leading to a clear overexploitation of terrestrial and marine ecosystems.

In contrast, policy processes that respect, recognize and integrate the world-views, values and traditional knowledge of indigenous peoples and local communities would lead to decisions that deliver better outcomes for people and nature. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) therefore concludes that both the causes of the global biodiversity crisis and possible solutions are closely linked to the way nature is valued in political and economic decisions at all levels.

Brazil: Granting waves the right to exist

In August 2024, the Brazilian municipality of Linhares became the first local authority worldwide to adopt a law that grants own rights to a part of the ocean on its coast. The law stipulates that the waves in and at the mouth of the Doce River, on which Linhares is located, will henceforth have the right to their own, unqualified existence, in a manner similar to human individuals.

By adopting the law, the municipality further commits to protecting and restoring the form and configuration of the river estuary, and to maintaining and restoring the natural cycles that purify the water and ensure that the river can flow without hindrance and ocean waves can roll into shore as accustomed. The law also underscores the cultural and economic importance of the waves for the local community. Moreover, the municipality had appointed four local ocean activists to acts as representatives and advocates of the waves. They are charged with representing the interests of the ocean in public debates and in policy-making processes.

The Doce River estuary is a major attraction to surfers. The waves here are long and have, when they break, the tubular shape so prized by surfers. About eight years ago, however, the surfing community noticed first changes. Large amounts of sediment had been deposited in the river estuary, making the river’s flow rate change. In two places the waves eventually stopped breaking altogether.

This was caused by the collapse of a dam far inland that had been built to hold back the waste of an iron ore mine. During the Mariana dam disaster in November 2015, more than 40 million tonnes of sludge and mine tailings surged into the river. This torrent devastated towns downstream and killed 19 people. In Linhares, at the Doce River’s mouth, the waves stopped rolling. They only returned after a major flood in 2022 had carried the sludge deposits away.

Conferring legal standing on components of the ocean is a way to improve protections for certain marine areas or their inhabitants. If these rights are infringed, appointed marine advocates are entitled to take the originators of the damage to court. Where appropriate, local authorities may also conduct investigations. The decision taken by the municipality of Linhares is not unique. Half a year previously, in March 2024, representatives of the indigenous peoples of the Southwest Pacific (New Zealand, Tonga, Tahiti, Hawaii, Cook Islands) decided to confer legal status on whales and dolphins. This status comprises, among other aspects, the right of these marine mammals to a healthy environment and to free movement.

The decision is not internationally binding. Nonetheless, in the island states involved the courts can recognize the new legal status of the marine mammals as customary law even if it is not yet enshrined in

the statutes of the countries. Similar conferrals of rights occurred in recent years at various policy levels for rivers (e.g. in Colombia, Bangladesh and New Zealand) and for Lake Erie in the US state of Ohio.

In Ecuador, rights of nature have even been enshrined in the constitution. The new constitutional provisions state that nature has a right to respect for its existence and maintenance and regeneration of its life cycles. They further stipulate that every person, community, people or nationality in Ecuador can call upon the competent public authority to enforce the rights of nature.



3.6 > A surfer rides the waves of Brazil’s Doce River in the rainy season. The local authority of Linhares, the town on this river, has now granted the waves an unqualified right to exist.

On the difficulty of valuing marine ecosystem services

Much profit is gained from the services of the oceans and seas. Yet to this day there are no comprehensive, universally recognized calculations or uniform statistics of the economic value of the world's oceans. This is partly because a plethora of methods and approaches is used to determine and valueate the many different values of nature, and thus of the oceans.

In its *Values Report*, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) lists more than 50 different methods drawn from diverse disciplines and knowledge systems that are used and characterized in the literature worldwide to capture the values of nature. IPBES notes that none of them is suited to be used as a uniform valuation method for all purposes – the social, economic and ecological settings that determine the choice of a suitable method are too diverse, the IPBES scientists stress.

Nonetheless, experts do frequently seek to calculate the economic value of marine ecosystem services – often in the hope that the sums calculated in this manner may influence policy decisions governing the way oceans are used. The available science-based valuation methods can be grouped in four families: nature-based, behaviour-based, statement-based and integrated valuation methods. They differ essentially in which aspects of nature are assessed, which sources of information are used, how information about the values of nature is generated, which value indicators are taken into account and which valuation products finally emerge (see table).

	VALUED METHOD FAMILIES				Considerations for valuation by indigenous peoples and local communities
	Nature-based valuation	Statement-based valuation	Behaviour-based valuation	Integrated valuation	
What is assessed? What is the source of information?	Nature, physical or ecological components of nature and nature's contributions to people	What people say or express when asked about the importance of nature and nature's contributions to people	What people do in or with nature, for nature, to nature, or to use nature's contributions to people	Different outputs from one or more methods to support decision-making	Indigenous peoples and local communities gauge nature and its interdependencies with people by gathering information from ancestors, future generations, non-human beings, the cosmos and the spiritual world
Examples of methods and approaches	Biodiversity inventory, mapping of ecosystem services, Delphi method, participatory mapping of ecological values	Group discussions, Q-methodology, contingent valuation, choice experiments, deliberative methods	Participant observation, travel cost method, cost-based methods, hedonic pricing, livelihood dependence, photo-series analysis	Ecosystem service valuation, cost-benefit analysis, multi-criteria decision analysis, integrated modelling, scenario building, deliberative decision methods	

3.7 > The numerous different methods used to value nature can be classed in four non-disciplinary families. The table summarizes their key features. Each valuation method is suited to assessing quite specific types of values of nature and contributions made by nature to humankind. Moreover, each method has specific capabilities and is subject to specific limitations.

The IPBES authors stress that the choice of method has a major impact on the outcome of any assessment.

The overview of methods reveals the truly massive difficulties that arise when undertaking to assign economic values to the seas and oceans and their ecosystems and species diversity – an undertaking only currently feasible for narrowly defined aspects. Researchers in Great Britian, for example, calculated in 2016 how much money the British public health system saves because people like to engage in sports on coasts or in other bodies of water and therefore lead a healthier life. They found savings amounting to 176 million British pounds.

Two years later, experts at the Irish Environmental Protection Agency published a report setting out the financial value attributable to selected coastal and marine ecosystem service benefits for Ireland's inhabitants and guests. Their calculations showed that just tourism travel to the Irish coasts generates financial flows amounting to 1.6 billion Euros. The Irish fisheries and aquaculture sector derives annual profit from the seas amounting to 664 million Euros. Finally, to name but a third example, the experts appraised the CO₂ absorption and storage of the oceans at a value of 819 million Euros annually.

However, the experts noted that the figures they presented would not allow calculation of a total value of marine ecosystem services for Ireland. This is because the services valued in their report only represent a small proportion of the livelihood bases and thus values that the seas and oceans, in their entirety, provide for us humans.

How is information about values generated?	Directly measuring nature, remote sensing, consulting experts Consulting users/experts/ local communities and knowledge holders	Asking people questions (interviews, surveys), undertaking activities with people (games, discussions, arts), analyzing narratives (e. g., Twitter posts)	Observing people, assessing records of people's behaviors (e. g., park visits, house purchases), assessing records of policy choices, assessing (non-) market exchanges	Synthesizing, comparing, contrasting, deliberating, consolidating or aggregating multiple values for decision-making or decision support	Information gathering through territory patrols, natural resources monitoring or communal assemblies can entail rituals and ceremonies undertaken by specialized traditional experts.
“Specific values” elicited and examples of value indicators	Mainly intrinsic and instrumental values Species counts, carbon stored, ecological health indicators	Instrumental, intrinsic and relational values Subjective well-being indicators, narratives of human-nature relationships, willingness to accept compensation for setting aside land, willingness to pay for access to nature	Mostly instrumental values Time spent, share of household income, prevalence of disease, price of a hectare of land, use of indigenous plants	Instrumental, intrinsic and relational values Strength of support or objections to policy options, welfare gains or losses from projects of indigenous plants	Valuation is often a collective process that considers all members of a community (including children or those who are not visibly present), as legitimate generators of information. Understanding the richness and depth of indigenous peoples' and local communities' valuation approaches implies deconstructing disciplinary definitions of methods and concepts such as “evidence” and recognizing that integration of knowledge systems is not always possible, desirable or necessary.
Type of stakeholder inclusion	Inclusive methods exist (e. g., community monitoring of biodiversity) but most methods do not include stakeholders	All methods include stakeholders to some extent (e. g., surveys) and inclusion is often integral to the methodology (e.g., deliberative valuation)	Most methods have limited or no stakeholder inclusion (e. g., analysis of market accounts), but encompass observations of diverse stakeholders	Some methods can be non-inclusive (e. g., desktop multi-criteria decision analysis), but often inclusion is key to the decision support aspect (e. g., participatory scenario building)	
Examples of typical valuation “products”	Biodiversity indices, maps of priority areas for policy management action Improved understanding of the importance of components of nature	Ranked importance of nature's contributions to people Monetary value for protection of areas of biodiversity significance Explanations for why people value nature	Ranked importance of nature and nature's contributions to people Additional costs due to degradation (e. g., changes in time to collect fuelwood) Explanations for how people value nature	Ranked policy options Evaluation of socio-economic and environmental impacts of policy options Improved understanding of conflicts and shared uses of nature	
Limitations	Impact on people assumed but not assessed Dependence on nature is not assessed by those directly living from, living in and living with nature	Potential large variability in the reliability of statements (i.e., do people respond truthfully?) Power disparity can reduce the validity of group-based (e. g., deliberative) methods Representativeness in selection of respondents biases results	Requires conceptual and empirical understanding of the relationships between behaviour, nature and its contribution to well-being Cannot reveal in-depth understandings of motivations behind behaviour	Aggregation of values across groups of people can reduce representation of values Combining multiple value types creates incommensurability concerns	

Strengths and weaknesses of the concept of ecosystem services

The recognition that people place different values on nature is not new. Experts in science and politics have been working for several decades to develop concepts and methods that can be used to quantify the extent to which nature affects us humans, both positively and negatively. It is also clear that decisions affecting nature can be made more effectively if it is known what values are affected – in other words, what is at stake for whom.

One of the best-known and most widely used valuation schemes in science, policy and administration is the 1997 concept of ecosystem services, which aims to show how nature’s services improve people’s quality of life. It does this by dividing nature’s processes and services into four categories:

- *Provisioning services:* These include the oceans’ functions and processes that humans use to supply themselves with products such as food and raw materials, with the help of labour and technical tools. It also includes the spaces and areas that the sea provides, for example for shipping or for the production of renewable energy.
- *Regulating services:* This category captures the benefits and utility that humans derive from the oceans’ regulating effects. It therefore includes services such as marine climate regulation (heat transport and heat exchange); coastal protection by mangrove forests, dunes, seagrass beds and reefs; the provision of oxygen for respiration by phytoplankton and other marine plants; and keeping water clean by breaking down nutrients and pollutants released into the oceans.
- *Cultural services:* These include numerous functions that serve human well-being in an intangible way. They may have special social, religious or spiritual significance or be part of the traditions of a people. This category includes services such as the pure aesthetics of a seascape, its recreational and leisure

value, or the inspiration that artists, scientists, architects and many other people draw from the oceans.

- *Supporting services:* These are the fundamental biological, chemical and physical processes that occur naturally in the environment and form the basis of life on Earth. In the oceans these include, for example, the production of biomass by algae and aquatic plants, the marine nutrient cycles, the oceans’ contribution to the global water cycle, predator-prey relationships, as well as species diversity and the different habitats themselves. Humans generally benefit indirectly from all these supporting services as they provide the basis for the cultural, regulating and provisioning services mentioned above.

The *Millennium Ecosystem Assessment* published by the United Nations in 2005 made the concept of ecosystem services well known worldwide. The success of the concept resides in the way it illustrates how economic development and human well-being depend upon healthy ecosystems. However, experience has shown that the concept can make people tend to characterize the value of nature and its services mainly in terms of economic benefit. The focus is then frequently narrowed to how much financial profit can be gained from natural assets, or which financial damage is prevented by specific ecosystem services such as the flood protection services provided by healthy mangrove forests, seagrass meadows and salt marshes. This perspective has led to economic interests playing a dominant role in many individual, corporate and governmental decisions on the use of nature and the oceans. It thus manifests the life frame of living from nature, frequently promoting the overexploitation of terrestrial and marine ecosystems alike.

In response to this situation, IPBES developed its own concept of “nature’s contribution to people”. This aims, for one thing, to give more explicit consideration to values such as responsibility, reciprocity and respect for nature. For another, it takes account of knowledge systems that conceive of humans as being part of

3.8 > Whoever lacks awareness, when gazing at the sea, of what lives below its surface and how many vital services these organisms provide for us humans will be unlikely to commit to the protection and sustainable use of the oceans.



3.9 > Tourist deluge: a cruise ship at anchor off a small island in the Caribbean Sea. For one day, its passengers will eat, drink, swim and sunbathe on the island.



nature – such as the perceptions of indigenous peoples, local communities and new movements striving for the holistic well-being of people and nature.

In this manner, the IPBES experts hope, decisions on approaches to nature can be underpinned by diverse value indicators and will in the best case also take account of disparate perspectives on what constitutes a good life on Earth.

Widening disconnection from nature

IPBES has identified another barrier on the path towards better decisions for people and nature: the increasing disconnection between the two. In most industrialized countries, the experts note, people have lost any direct, sustained contact to nature in less than two generations.

Today they live in cities, work in sectors entirely separate from fisheries, agriculture and forestry, and most of them no longer cultivate their own fruit and vegetables.

As a result, the preservation and functionality of nature no longer have any immediately tangible, existential importance for many of these people. The further welfare rises and urbanization advances, the less interest people have in animals, plants – and the oceans. This disconnection, combined with a loss of access to nature, impacts across generations on people’s understanding, values, attitudes and actions, IPBES concludes. The outcome is further degradation of nature.

Rethinking alone will therefore not suffice to halt the overfishing of sharks or put an end overall to the destructive exploitation of the oceans. Transformative change is needed. This implies a fundamental departure

Utilizing indigenous and local knowledge

Integrating local knowledge: While this call to action sounds highly abstract in the IPBES *Values Report*, an international team of mangrove experts has taken it to heart. Together with local partners, scientists grouped in the Global Mangrove Alliance have produced best practice guidelines in which they explain how local people can help to make mangrove conservation and restoration projects deliver successful outcomes.

The authors of the guidelines stress that local and indigenous communities know their mangroves better and more comprehensively than external visiting researchers, even if the latter come from nearby cities or research facilities. The 21 examples of best practice presented in the guidelines highlight particularly the following strengths of local communities and knowledge-holders:

- *Extremely good knowledge of the locality:* In Colombia, the initiators of a mangrove conservation project learnt from local people the sites where parts of the mangrove forest were salinizing due to sediment deposits and insufficient seawater input. On this basis, project participants jointly planned new channels and excavated these by traditional means. Salination was halted, and new mangroves were planted.
- *Broad knowledge of the species diversity of local ecosystems:* On Madagascar, local people accompanied a group of researchers during their species inventory surveys of the area. The local knowledge-holders saw and identified 18 bird species which the scientists could not have named and listed.
- *Very special knowledge of the species diversity of local ecosystems:* In Kenya, a local crab fisherman helped the initiators of a reforestation project to select the right mangrove species. He knew exactly which two mangrove species the crabs, which do not occur everywhere, prefer, and recommended the corresponding species to the planners. He also assisted in selecting the site for planting the mangrove saplings.
- *Valuable knowledge of the history of coastal regions:* On the Philippines, the local community took part in the search for stretches of coast to be reforested with mangroves in order to protect the coasts better from storms. Among other things, the people knew that an old fish pond was once a mangrove area. They recommended this area and subsequently helped to remove the embankments and plant saplings.
- *Excellent local networking and range:* In Brazil, many coastal communities organize a Green July each year – a month devoted to mangrove conservation. At various events, the older community

members pass on to children and youths their knowledge about seasonal changes in the mangroves and fish stocks. They further demonstrate the methods that can be used to prevent forest logging, pollution and other disruptions.

To harness all these capabilities for new conservation projects, initiators need a great deal of sensitivity, time and intercultural competencies. It is essential to become acquainted with local people, listen to them and involve them from the outset – including in potential research findings. For interest in ideas about how to conserve mangrove forests and their ecosystems and utilize them sustainably is greatest among those people whose livelihoods and very survival depend upon the well-being of these coastal ecosystems.



3.10 > Women check the growth of young trees in a newly planted mangrove forest on the coast of the Philippine region of Central Visayas.



3.11 > The sea shimmers green to brownish where macroalgae are cultivated off the coast of the Philippines. Some 200,000 fisher families gain a livelihood from this – mostly in economically less developed regions.

from values and attitudes focused on short-term, individual material gains. Instead, such concepts of value should be prioritized that are geared towards sustainability and are concerned with the well-being of all. In such a perspective, knowing which numerous and

impressive services the more than 500 shark species provide may at least contribute to making fatal culling campaigns, such as those that have been carried out to protect bathers on Hawaii and elsewhere, a thing of the past.

CONCLUSION

A new awareness of the value of the oceans and their populations of species

People’s perceptions of nature, and thus of the oceans, take manifold forms. They experience natural spaces, animals and plants in diverse ways and therefore interact with them in a great variety of manners. For instance, while some people view tiger sharks as nothing other than terrors of the seas, others lobby for the conservation of the majestic predators whose hunting forays safeguard flourishing seagrass meadows in many tropical and subtropical regions of the oceans.

The different perceptions of and interactions with nature give rise to disparate views of nature’s role as the very foundation of people’s lives and their quality of life. This, in turn, results in a multitude of types of value attributed by people to nature.

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has found that people often have one of four types of relationship to nature. They either live from nature, with nature or in nature, or see themselves as an intrinsic part of nature. To which of these types an individual belongs depends on that person’s world-view and on the knowledge systems used and the values and value indicators applied by that person.

While all this sounds highly abstract on paper, it exerts huge practical relevance. After all, it is

people’s very own relationship to nature and the oceans that determines their decisions on how to treat nature – at all levels, individual, political and economic.

IPBES concludes in its *Methodological Assessment Report on the Diverse Values and Valuation of Nature* that both political and economic decision-makers up to now only take account of a narrow set of largely market-based values of nature. This is why their decisions are frequently at the expense of nature and thus also at the cost of society and future generations.

This is amplified by the circumstance that, in the course of advancing industrialization and urbanization, people are losing direct contact to the natural environment. The result is a disconnection from nature, in tandem with a severe loss of knowledge about the species diversity, the roles and the needs of natural biotic communities on land and in the oceans. To halt species extinction and bolster the integrity of the natural environment, it will be essential that decision-makers at all levels, in the private sector and in public policy alike, shed past convictions and develop a new awareness of nature. Neglected values and local and indigenous knowledge need to be given consideration in decisions, and the vital role of healthy natural spaces needs to be communicated across all sectors of society. For the fact is: people will only protect and preserve what they know and understand.

4 Pressure from all sides

> Marine wilderness that is untouched by humans is almost a thing of the past. Be it underneath the Antarctic ice shelves or in remote deep-sea trenches, traces of human activity can be found everywhere, in the form of noise, plastic particles or rising water temperatures. What makes this so fatal is that humanity's demands on ocean resources are increasing while the number of stressors threatening marine life is rising in tandem.



An unprecedented downward spiral

> Marine life is currently one of the biggest losers. Marine biocoenoses are shrinking due to the large-scale removal of organisms, changing due to climate-related species migration, or being destroyed by direct interventions such as sand and gravel extraction. The result is that many places now have unstable ecosystems characterized by species decline that provide only a fraction of the services we humans need for a liveable future.

Species decline from earliest human history onwards

Ever since humans have existed on Earth, we have been altering the ecosystems and biodiversity of the places we inhabit. Archaeological finds in Africa suggest that *Homo erectus*, an ancestor of the modern *Homo sapiens*, exterminated the first animal species after learning to cook game over a fire one to two million years ago. The first modern humans lived in Africa between 100,000 and at most 300,000 years ago. They also learnt to cook meat

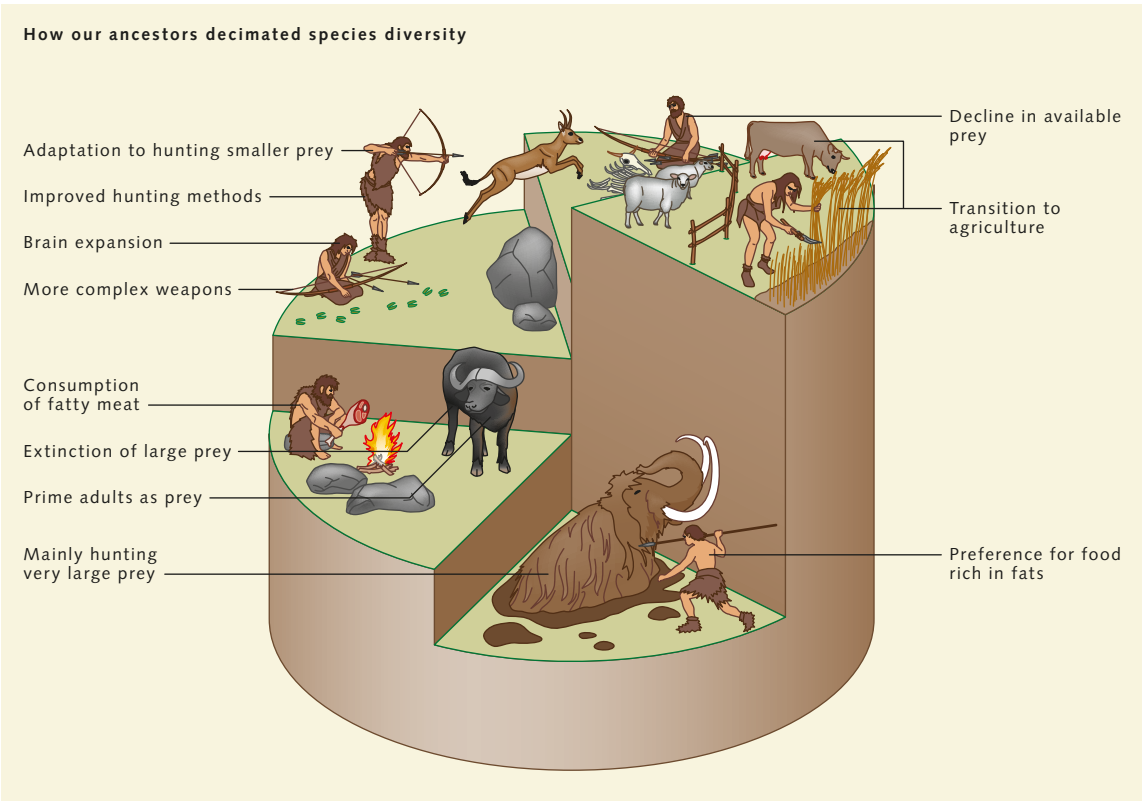
using fire. As socially organized omnivores, our ancestors hunted in groups. They mainly hunted large game together, taking selected plant species and some domesticated animals with them when they searched for new habitats. Both these behaviours altered the original ecosystems of newly colonized areas.

By the beginning of the Holocene around 12,000 years ago, modern humans had colonized three-quarters of the world’s terrestrial areas. By then, large game animals only persisted in sparsely populated regions. In what are now Israel, Egypt and southern Syria, for example, 10,500-year-old human remains demonstrate that people hunted much smaller animal species than their ancestors had many years earlier. Their hunting yield was just 1.7 per cent, a small fraction, of the animal biomass killed by the ancestors of modern humans in the same region 1.5 million years ago, as revealed by archaeological excavations in the region. The researchers also investigated possible reasons for this significant loss of biomass. They concluded that the decline could not be explained by climate fluctuations or sudden climate change. It is much more likely that humans and their ancestors in the Middle East decimated or even wiped out all large land creatures within 1.4 million years. People in the Mesolithic period (around 10,000 to 8000/6000 years before present) therefore had no choice but to prey on smaller wild animals and start arable farming a little later.

Between the 7th and 14th centuries AD, the colonization of islands in the southern and western Pacific resulted in further demonstrable species extinctions caused by humans. In Polynesia, for example, it is estimated that some 1000 local bird species disappeared after humans arrived. Many of these extinct birds belonged to the rail family, which includes crane birds. These birds mostly



4.1 > Extinct giant bird: When humans first settled in New Zealand in the early 14th century, some 58,000 moas lived on the two islands. Just 120 years later, the settlers had wiped out these flightless birds, which could reach a height of up to 3.6 metres.



4.2 > The first modern humans mainly hunted big game. In doing so, they caused the extinction of many species. They also deprived themselves of an important food source, forcing them to adapt their way of life several times over the course of history in order to survive.

only lived on the islands and, over the course of evolution, had lost the ability to fly. Unable to fly, these ground dwellers were easy prey for hungry humans and their “entourage” – dogs and pigs they had brought with them. These animals preyed on the birds, as did rats which arrived on the islands as stowaways.

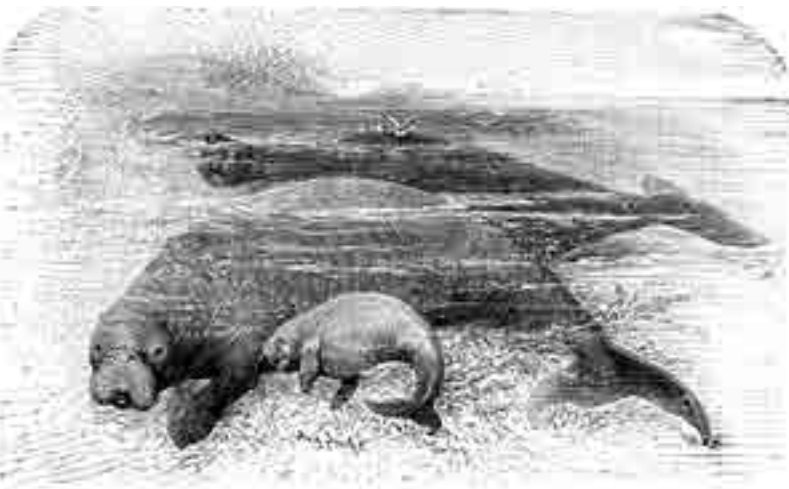
Despite the consistently negative outcomes, humans have also always played a role in preserving species diversity and biodiversity, for instance by breeding new species of flora and fauna or preserving heritage species through targeted breeding programmes. However, a region’s species diversity can also benefit from small, targeted interventions in healthy ecosystems. For instance, when individual trees are removed from a dense forest, small clearings are created, providing a habitat with new conditions. A variety of species settle there more quickly than in the neighbouring forest, resulting in an overall increase in species diversity. Structurally rich gardens and parks have a similar effect.

All over the world, ethnic groups as well as traditional agricultural practices preserve certain habitats, and thus species, that would not exist without targeted intervention. Examples include heathlands grazed by sheep and high-altitude summer pastures in the Alps that are farmed extensively. These areas are home to many rare vascular plants, but only as long as the grasslands are regularly grazed or mown.

Initial cases of marine overexploitation

Although humans had already overfished coastal areas and decimated populations of marine mammals in ancient times, there was no mass extinction of marine species comparable to that of species on land. One decisive factor was that marine species generally inhabit larger areas than terrestrial animals and plants, and another factor was that humans were not yet able to reach every corner of the global ocean. This left marine life with sufficient

Population
The term “population” refers to a group of individuals of the same species that live together in the same location or area at the same time, interact with each other, and form a reproductive community. The development of a population is influenced by the various interactions between its members and their animate and inanimate environments.



4.3 > Steller's sea cow (*Hydrodamalis gigas*) could grow to 7.6 metres long and was hunted to extinction by humans just a few years after it was discovered. This species lived in the cold, shallow coastal waters of the North Pacific, primarily in the Bering Sea.

refuges, particularly for species that were heavily fished or hunted. At the same time, humans for the longest time only fished and hunted as much as they needed to feed their clan or family.

This changed as the human population grew and markets for luxury items such as furs, feathers and ivory developed. People also began to earn a living by selling fish, mussels and other marine resources. Experts agree that the increasing destruction of marine habitats, and the subsequent collapse of marine populations and coastal ecosystems, has primarily been caused by the commercialization and subsequent industrialization of resource use and marine exploitation.

Just as on land, humans initially targeted the largest and most valuable species of marine mammals, fish and invertebrates. Once these populations had been depleted by intensive hunting and their slow reproductive cycles, the focus shifted to smaller, less valuable species. However, there had also always been smaller species that were fished. The hunt for the largest fish, seals, king crabs and other marine organisms continues to affect marine life today. First, large individuals disappeared from local biological communities, and shortly afterwards, entire populations of large organisms. The remaining populations quickly developed smaller body sizes and reached sexual maturity earlier. As a result, heavily fished marine organisms generally tend to be smaller today than they were in the past.

The first evidence of a large-scale collapse in European fishing dates back to the High to Late Middle Ages (11th to 15th centuries). During this period, the Christian Church prohibited the consumption of meat. However, believers were permitted to eat fish and seafood on up to 130 days a year, which increased demand for seafood. At the same time, towns were growing, farmers cleared forests to create arable land, and rivers were dammed to power mills. All these developments led to significant changes in streams, rivers, lakes and estuaries. Water quality declined. The combination of increased fishing pressure and deteriorating water quality caused the populations of sturgeon and salmon to decline. Both species of fish disappeared from many European waters and coastal ecosystems. The European sea sturgeon (*Acipenser sturio*) vanished from Central and Eastern Europe in the 12th century. Atlantic salmon (*Salmo salar*) stopped returning to their spawning grounds from the late medieval period onward.

In response to declining fish stocks in inland waters and along the coast, fishermen in the North and Baltic Seas began to target nearshore fish. New shipping, fishing and preservation methods and technologies allowed them to venture further out to sea and catch larger quantities of fish. The main species caught were cod and herring.

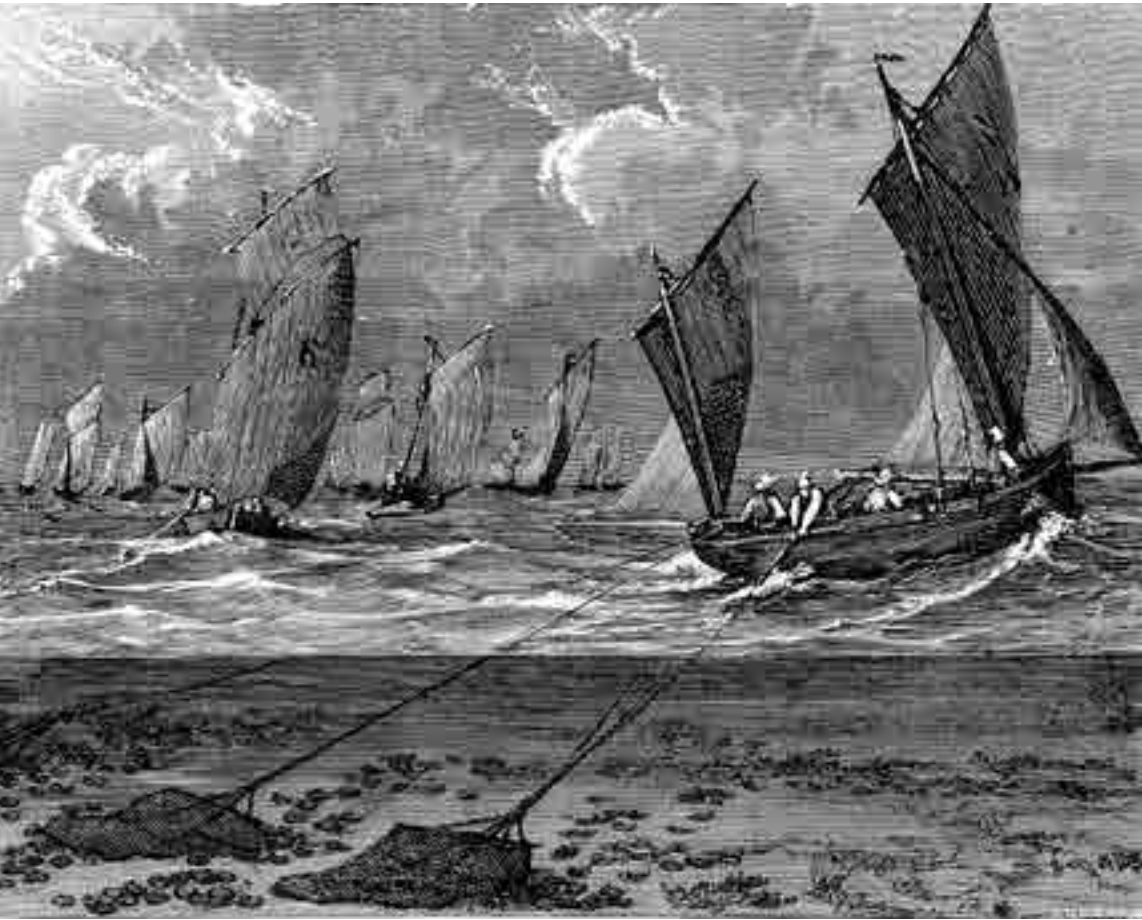
The practice of catching fish and selling them at local markets, and later across regions, developed into a distinct business sector and became one of the driving forces behind the medieval trade revolution of the 11th and 12th centuries. The Hanseatic League, a powerful trading alliance of the time, amassed considerable wealth through the sale of herring. The price of salted herrings rose steadily during the Middle Ages. While 1000 of them cost 15 sous (or sol) in the coastal town of Calais in 1268, by 1300 the price had risen to 30 sous, reaching 75 sous just 42 years later. By that time, hundreds of millions of herrings were being caught in the North Sea and Baltic Sea every year, salted, stored in barrels, and shipped. However, the combination of intensive fishing, declining water quality and climate fluctuations gradually led to the collapse of important fish stocks in

the late Middle Ages. By the late 13th century, herring shoals had disappeared from the southern Baltic coast. In the southern North Sea, herring stocks began to collapse from 1360 onwards.

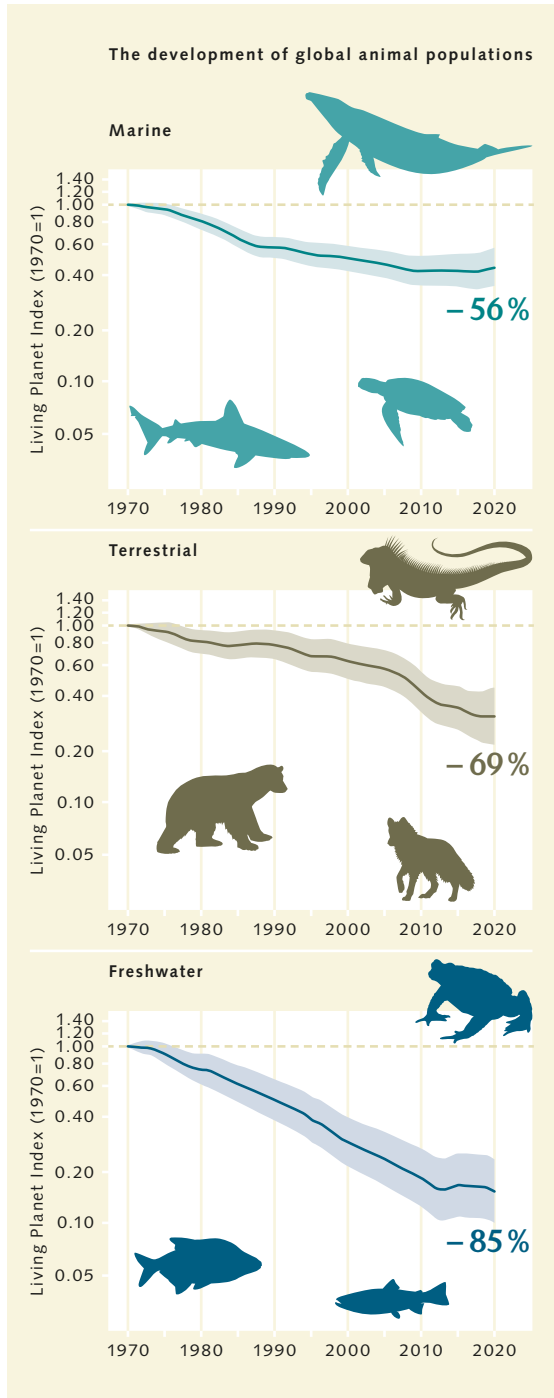
Compared to Europeans, other cultures at that time were more careful with their marine resources. In Japan, for instance, fishing families developed various targeted methods to enhance the living conditions of marine organisms in coastal waters, thereby increasing their productivity and species diversity. They replanted destroyed seagrass meadows, for instance, and cultivated bivalves and macroalgae to improve water quality. This form of sustainable coastal and marine management is known as “Satoumi”. This approach, which deliberately rebuilds weakened coastal ecosystems for future sustainable use, is now internationally recognized as an important tool in

the fight against marine species extinction, and is therefore more relevant today than ever before.

In the 18th century, the first marine species went extinct as a result of human exploitation. Steller's sea cow (*Hydrodamalis gigas*), which inhabited the North Pacific, was hunted so intensively after its discovery by Europeans that it became extinct within 27 years. As the colonial powers advanced into North America and Australia, they began to overfish local stocks of fish and bivalves there as well. As a result, huge oyster beds in Europe and off the coast of North America disappeared after the 19th century development of machines that could mechanically detach and collect bivalves from the sea floor. The total area of oyster beds lost in European seas amounted to at least 1.7 million hectares – an area twice the size of the Mediterranean island of Crete.



4.4 > Until the 19th century, people used sailing boats to fish for oysters off the European coast. However, the subsequent introduction of motorized steamships led to the overfishing of oyster beds, causing them to disappear from an area of at least 17,000 square kilometres.



4.5 > The three ecosystem categories of the Living Planet Index reveal a dramatic decrease in the number of wild animal populations. The index covers 1816 marine species, 2519 terrestrial species and 1472 freshwater species inhabiting lakes, streams, rivers and ponds.

The Great Acceleration

When fishermen began to replace their sailing ships and boats with steam-powered vessels in the 1880s, the range over which they could operate expanded once again. Motorized fishing boats could remain at sea for longer periods and use larger trawl nets in deeper waters. Further technological advances, such as larger and more powerful ships, new fishing gear, freezing and preservation techniques, and navigation and sonar equipment, led to a sharp increase in global fishing after the Second World War. Consequently, some of the world’s largest fish stocks collapsed. Moreover, between 1925 and 1975 whalers killed 1.5 million baleen whales in the Southern Ocean alone.

In hindsight, experts describe the period since the 1950s as the “Great Acceleration”. However, this term refers not only to the increase in global overfishing since the Second World War. It now represents the drastically increasing pressure that human activities are placing on all of the planet’s natural systems, including materials cycles, the climate, and species diversity on land and in the oceans.

The Age of Extinction

Today, more than 70 years after the start of the Great Acceleration, biodiversity on Earth is worse off than ever before. More than one million species of flora and fauna worldwide are at risk of extinction. The latest Living Planet Report by the World Wide Fund for Nature (WWF) and the Zoological Society of London found that the size of some 35,000 wildlife populations studied had declined by an average of 73 per cent over the past 50 years. This means that in an area that held 100 fish, amphibians, reptiles, birds and mammals in 1970, on average there are now only 27. The experts documented the highest population declines among freshwater species. Their populations have shrunk by 85 per cent on average. Terrestrial wildlife populations declined by 69 per cent, while marine species declined by an average of 56 per cent.

How are changes in biodiversity measured?

Scientists use a variety of indicators and indices to assess the state of and changes in Earth’s biodiversity. They need to combine these indicators and indices to understand the extent and pace of global species loss, and to determine the effectiveness of conservation measures in curbing this loss. Any single indicator or index is too limited in its significance to allow informed conclusions to be drawn.

Frequently used biodiversity indices include:

Global Living Planet Index (LPI)

Developed by WWF and the Zoological Society of London, the index shows the latest changes in nature from 1970 to the present day. It does this by tracking the size of almost 35,000 animal populations and the changes therein. Therefore, the LPI is an early warning indicator of increasing extinction risk and potential loss of ecosystem function and resilience. It examines populations of 5495 species of fish, amphibians, reptiles, birds and mammals. The index values given represent the average rate of change over time.

Red List Index (RLI)

Based on data from the Red List of Threatened Species, the RLI shows how the overall risk of extinction for species is developing, i.e. whether a group of species is becoming more or less threatened with extinction. The lower the RLI value, the greater the risk of extinction for the species in this group. Governments use the RLI to track their progress in achieving biodiversity loss reduction targets. As of October 2024, the global RLI value for the marine species group is composed of Red List data for 133 mammal species, 865 bird species and 842 coral species.

Biodiversity Intactness Index (BII)

This index measures changes in terrestrial biodiversity using data on the abundance of plants, fungi and animals worldwide. It expresses the proportion of the original number of species remaining in a given area despite human influence, as well as their frequency of occurrence, as a percentage. The underlying database, which is held at the Natural History Museum in London, contains information on some 58,000 species, including birds, mammals, plants, fungi and insects. Unlike

other biodiversity indicators, BII experts can predict how the index would change in response to future management decisions. Such information is required by companies and policymakers to evaluate different management strategies and options.

Marine Trophic Index (MTI)

MTI measures the level at which a country’s fishermen operate within the food web, allowing for conclusions to be drawn about the state of local marine ecosystems. Countries with a higher MTI tend to catch larger (predatory) species from higher trophic levels. Conversely, lower MTI values indicate catches from the lower levels of the food web. A decline in the MTI over time may indicate that countries have overfished and depleted their fish stocks at higher trophic levels, turning to smaller, less commercially valuable species at lower levels instead. This process is referred to by experts as “fishing down the marine food web”.

Biodiversity indicators for the Baltic Sea

While the four biodiversity indices outlined above are primarily employed in international negotiations, agreements and targets for marine and nature conservation, researchers conducting everyday scientific research require a comprehensive set of region-specific indicators to document the state of biodiversity and potential changes within a specific area. Experts from the Commission for the Protection of the Baltic Sea, also known as the Helsinki Convention (HELCOM), use 26 core indicators to assess the health of life in the Baltic Sea. These include the extent of ocean acidification, by-catch rates in fisheries, seabird reproduction rates, the abundance and distribution of porpoises, gray seals and ringed seals, the sizes of important coastal fish populations, the diatom-to-dinoflagellate ratio in the spring algal bloom, and the average size and total abundance of zooplankton in the Baltic Sea.

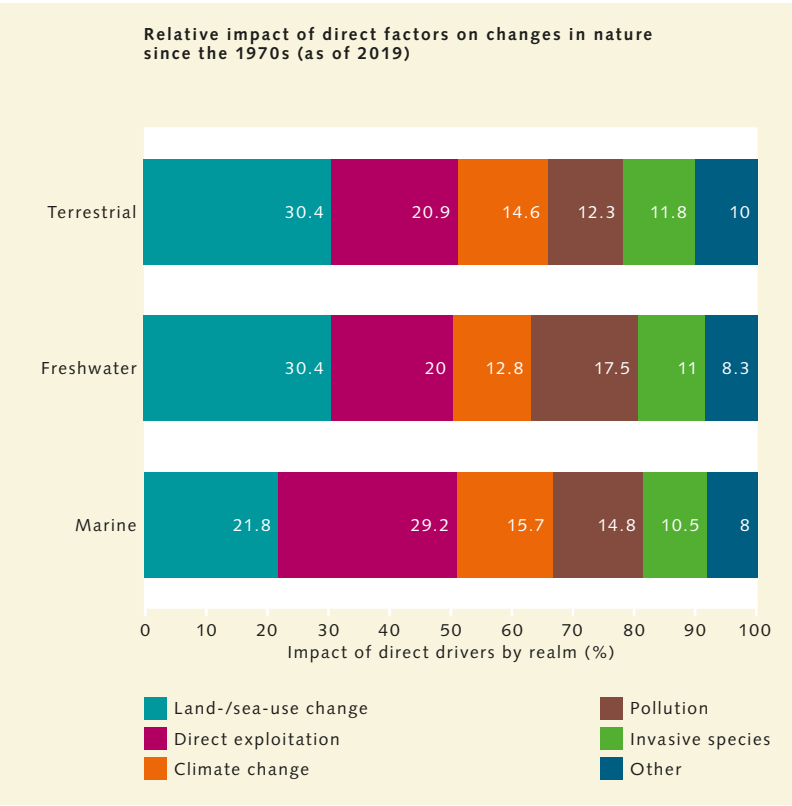
Recently, scientific analyses of these indicators did not allow for a positive overall assessment. The 2023 HELCOM status report states: “The biological diversity of the Baltic Sea is deteriorating due to pressure from various human activities, the effects of which are exacerbated by climate change. Currently, most fish, bird and marine mammal species, as well as seabed and water column habitats in the Baltic Sea, are not in a healthy state.”

Experts attribute the somewhat reduced rate of decline in marine life to the composition of the populations studied. The main species observed here are fish whose populations are regulated by catch quotas and other management measures. While some of these regulated

fish stocks have recovered in recent years, others have remained stable. WWF experts note that this trend is also evident in current statistics on marine organisms.

However, the situation facing marine life is illustrated by the plight of hawksbill sea turtles (*Eretmochelys imbr-*

4.6 > In 2019, experts at the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) analyzed the extent to which direct factors were driving biodiversity loss on Earth. The oceans were found to be most affected by overfishing and other forms of resource overexploitation.



cata), which nest on Milman Island in the northern part of the Great Barrier Reef in Australia. Although the island is located in a nature reserve with the highest protection standards, the number of female turtles nesting there has declined by more than half in just 28 years (1990 to 2018) – presumably because the turtles were illegally caught outside the protected area or killed as by-catch in fishing nets. Experts predict that this important sea turtle population could be wiped out completely by 2036. The hawksbill sea turtle would then be locally extinct.

WWF experts cite the destruction and loss of natural habitats caused by the expansion of food production for humans as the main cause of the dramatic decline in wild-life populations worldwide. This includes agriculture, as well as the fishing and hunting of wild animals. Other causes include overexploitation of natural biological communities, introduction of alien species, spread of disease, and the consequences of climate change and environmental pollution on land and at sea.

The drivers of marine species turnover

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) deals in even greater detail than the WWF with the factors and forces that drive human-induced species turnover. Scientists use the term “drivers”, but it is not fully elucidated what this encompasses. IPBES distinguishes between direct and indirect drivers of species turnover. The latter include the factors, values and behaviours that cause humans to make decisions which ultimately affect nature.

In its 2019 assessment report, IPBES identified the following as the most important direct human influences on marine biodiversity: the direct extraction of raw materials and organisms; changes in the use of coastal areas and oceans; climate change and its consequences for marine life; coastal and marine pollution; and invasive species. The most significant indirect drivers are population growth and demographic changes, such as migration and urbanization, as well as socio-cultural changes, economic and technological developments, and changes in political, regulatory and administrative approaches (governance), as well as conflicts and epidemics.

All of these factors have an impact, both individually and in combination with other influences. For example, the growth in the world’s population, alongside global economic growth and technological change, has led to changes in people’s lifestyles. Consequently, the demand for food, energy and natural resources such as rare earths, sand and metals has increased. At the same time, more greenhouse gases have been released into the atmosphere every year, accelerating climate change. Rising plastic production has caused more waste to be generated; in agriculture the use of fertilizers and pesticides has increased. Both these developments have contributed significantly to marine pollution in recent decades.

The direct removal of organisms

The main causes of species diversity loss in the oceans are overfishing and destructive fishing methods such as bottom trawling. Since the 1960s, the marine fishing industry has grown faster than any other marine industry.

Seafood is one of the world’s most traded foods, with an estimated 61.8 million people currently employed in the global fishing industry. This growth, which has accelerated since the late 1990s, is mainly due to the increased farming of fish, mussels and other marine organisms in aquaculture. Wild catches officially peaked at around 82 million tonnes per year during this period. Since then, catches have stagnated at a high level, but fishing activities have expanded to greater depths and more remote regions.

According to the Food and Agriculture Organization of the United Nations (FAO), approximately 115 million tonnes of fish and seafood were landed in 2022. Of these

marine organisms, 79.7 million tonnes were caught in the wild. Meanwhile, 35.3 million tonnes came from marine aquaculture – a new record high. However, the FAO emphasizes in its accompanying report that there are gaps in its catch statistics. For instance, catches from illegal fishing as well as by many artisanal fisheries and catches by recreational and sports fishers are not included. In order to accurately assess the extent to which fishing threatens marine biodiversity and the effectiveness of conservation measures, these removals must also be surveyed fully.

The FAO regularly monitors and documents the consequences of intensive oceanic fishing, using 445 fish

Species extinction: A three-step process

To assess biodiversity, and therefore nature’s health status, it is not enough to know which species exist, where they are found and how common they are. It is also crucial to understand the risk of these species becoming extinct within the next few decades. In most cases, species do not disappear suddenly, but gradually.

The process begins with the *functional extinction* of a species. This becomes apparent when members of a species become increasingly scarce in certain areas. At this stage, the population is still large enough to survive in the long term. However, at the same time, there are too few individuals to fully perform this species’ ecological functions.

The next step is *local extinction* (*extirpation*). This means that it disappears from a certain part of its geographical range, but survives in other areas. A species is considered globally extinct when it disappears completely, with no living individuals remaining anywhere on Earth (*global extinction*).

While the first two stages of the *extinction process* are undoubtedly important, most scientific information on species extinction focuses on the risk of their worldwide disappearance. This is usually referred to as extinction risk or extinction rate.

Extinction risk indicates the likelihood of a species becoming extinct worldwide. It is calculated for clearly identified species and considers both their biology and the external threats to which they are exposed. Individual species are usually assessed according to the standards used by the International Union for Conservation of Nature (IUCN) for its Red List of Threatened Species. The risk categories for species that are still found in the wild range from “least concern” (no special conservation measures are required) to “critically endangered”

(there is a 50 per cent probability that the species will become extinct within the next ten years).

Two further categories relate to extinct species. Here, the IUCN distinguishes between species that are completely extinct and those that are extinct in the wild.

In contrast, an *extinction rate* indicates the speed at which species disappear within a certain period of time. This rate is often estimated retrospectively, i.e. once the species have already become extinct. It does not usually refer to specific species, but rather to large groups of species or entire habitats. To compare extinction rates from different time periods or for different groups of species, a standardized method is used to determine their value. Extinction rate is measured as the number of extinctions per million species per year. Experts then compare this rate with the background extinction rate. This indicates the average extinction rate due to non-human causes, which is estimated to be one species per million species per year. Current human-caused extinction rates, on the other hand, are between 100 and more than 1000 times higher.

Experts speak of *mass extinction* if at least 75 per cent of all species die out within a geologically short period of time. Whether the current extinction rates already meet this definition is the subject of debate among scientists. However, there is consensus on three points: Firstly, current extinction rates are higher than the average seen throughout human history. Secondly, a mass extinction of species in the coming centuries cannot be ruled out. Thirdly, mass extinction is not an unstoppable process. Through our actions, we humans can influence whether such high extinction rates will be reached or not.

4.7 > Researchers found 403 pieces of plastic in the digestive tract of a flesh-footed shearwater that was found dead on the Australian coast. When seabirds accidentally ingest plastic waste, the particles can cause cuts to the gastrointestinal tract, as well as leading to kidney and liver damage and dementia-like brain damage.



populations as case studies. While 90 per cent of these populations were considered to be fished at “maximally sustainable levels” in 1974, this figure had fallen to 62.3 per cent by 2021. Conversely, the proportion of overfished stocks rose during this period from ten per cent in 1974 to 37.7 per cent in 2021. This means that according to FAO data more than one third of the stocks surveyed is now demonstrably overfished.

However, pressure on fish populations is growing not only because of the demand for fish meat, which is sold as food or used to produce fishmeal. In the coastal waters of Mexico, parts of Africa and Southeast Asia, fishermen have for some time now increasingly targeted species of fish with large swim bladders. These are removed, dried and sold to Asia as a luxury food, status symbol and alternative medicine for more than 15,000 US dollars per kilogram. The state of the affected fish stocks is only being investigated in a small number of locations.

Given the growing problem of overfishing, fish farming in marine aquaculture has gained increasing significance. Experts predict that this sector will continue to

grow and occupy more ocean space in the future. Therefore, sustainable solutions are needed to address the environmental issues associated with aquaculture. These include the spread of diseases and parasites from farmed to wild fish stocks, increased water pollution from feed residues, faeces and pharmaceuticals, and the sourcing of feed (krill and fishmeal).

Antarctic krill (*Euphausia superba*) are mainly fished in the waters north of the Antarctic Peninsula and in areas further to the northeast. Since 1993, catches have quadrupled, causing particular problems where penguins, seals and an increasing number of baleen whales feed. Experts are therefore calling for stricter catch quotas and fishing bans in certain regions. Otherwise, they say, the increasing competition for these nutritious little crustaceans could jeopardize the recovery of baleen whale populations and threaten the survival of many other krill predators. Similar competition for food exists in the waters off South Africa, where the overfishing of anchovy and sardine shoals for fishmeal has led to a significant decline in the remaining African penguin colonies.

4.8 > The hawksbill sea turtle (*Eretmochelys imbricata*) lives mainly in tropical coral reefs, where its diet consists of sea sponges, sea anemones and jellyfish. However, the number of these turtles has declined sharply due to illegal capture and destruction of their clutches of eggs. The species is now considered at risk of extinction.



4.9 > “The World” is the name given to this string of artificial islands in the Persian Gulf. Built between 2003 and 2008, they are shaped like a world map and are located off the coast of Dubai. The islands are mainly made up of sand dredged from Dubai’s shallow coastal waters.



*Direct extraction of raw materials
and its consequences*

The ocean provides human societies with a wide range of raw materials, including oil, natural gas, minerals, metals, sand and gravel. The combination of rising global demand, technological progress and dwindling land-based sources has made the extraction of an increasing number of marine raw materials not only feasible but also economically viable. The industries involved have high expectations, as evidenced by the ongoing international negotiations on deep-sea mining, for example. However, the extraction of marine materials incurs significant initial costs and poses numerous environmental risks.

Researchers describe the dredging of sand and gravel as one of the most dangerous and harmful activities that can be carried out on a coast or in a river. This activity causes irreversible and irreparable damage to the land, water and biological communities of coastal and marine environments. It also often destroys entire ecosystems, such as beaches, dunes, spits and seagrass meadows. As a result, seabirds and sea turtles lose their habitats and

nesting sites. As a consequence of the disappearance of seagrass meadows, vital refuges for the offspring of many marine organisms are also lost. According to the United Nations Environment Programme, sand extraction has tripled since the beginning of the 2000s, driven by population growth, urban expansion, economic growth and measures to protect against the effects of climate change. It is estimated that human societies currently use 40 to 50 gigatonnes of sand per year, and this figure is rising. This far exceeds the amount that the Earth system can replenish through the weathering of rocks.

Dredging is not only carried out at sea for the purpose of extracting sand. Dredgers are also used when installing oil and gas platforms, wind turbines, pipelines and other offshore infrastructure. In all cases, the seabed must be levelled to stabilize and secure these structures. For offshore wind farms, dredgers often remove the upper layer of sediment from the ocean floor, which can be up to ten metres thick. When constructing oil or gas production platforms, a rock platform is often created instead. Before laying underwater pipelines and cables, the ocean floor



4.10 > In Hong Kong, dried fish swim bladders are sold in sacks. Business is booming because swim bladders are considered a luxury food and a status symbol. Furthermore, many buyers believe that consuming fish bladders will slow down their ageing process.

4.11 > Marine biologists on a research vessel approach a dead blue whale (*Balaenoptera musculus*) floating on the ocean surface in California's Santa Barbara Channel. The giant whale had been struck by a ship and died from its injuries.



must be cleaned and levelled, a trench dug or a rock bed constructed to reduce the load on the structure. This process completely destroys the biological communities on the ocean floor.

Changes in coastal and marine use

There are more than 1.6 million kilometres of coastline on Earth, spread across 123 countries. The coastal zone includes coastal waters, the associated ocean floor, adjacent land, estuaries, and other nearby bodies of water. It is estimated that between 23 and 37 per cent of the world's population lives within 100 kilometres of the sea. This currently equates to between 1.86 and 2.99 billion people.

Due to population growth, increasing urbanization and economic development, coastal areas are being used more and more intensively. These areas serve as residential areas, transport hubs, industrial zones, economic centres and recreational spaces for an ever-growing population, and are being extensively redesigned to accommodate the requisite buildings and infrastructure. Expanding coastal metropolises such as Singapore, Hong Kong,

Manila, Jakarta, Lagos and Mumbai are prime examples of this trend. At the same time, waste, sewage and pollutants, including those released further inland, are concentrated in coastal areas via rivers.

When millions of people live in confined spaces, the remaining coastal marine ecosystems are exposed to intense, chronic stress. In particular, biological communities suffer from the overloading of coastal waters with waste, sewage, nutrients and pollutants. This often results in low-oxygen zones where few marine organisms can survive. In Jakarta Bay (Indonesia), for example, the number of fish declined by 80 per cent as the city grew. In 2015, corals covered only one tenth of their original range. Off the coast of Hong Kong, scientists have shown that the degree of water pollution determines which organisms survive on the ocean floor. Areas with heavily polluted water are primarily settled by mussels that are unaffected by the poor water quality and large quantities of particles stirred up by construction work. In contrast, in regions with less polluted water, macroalgae, bryozoans and other molluscs, which are sensitive to sinking particles and sediments, also survived.

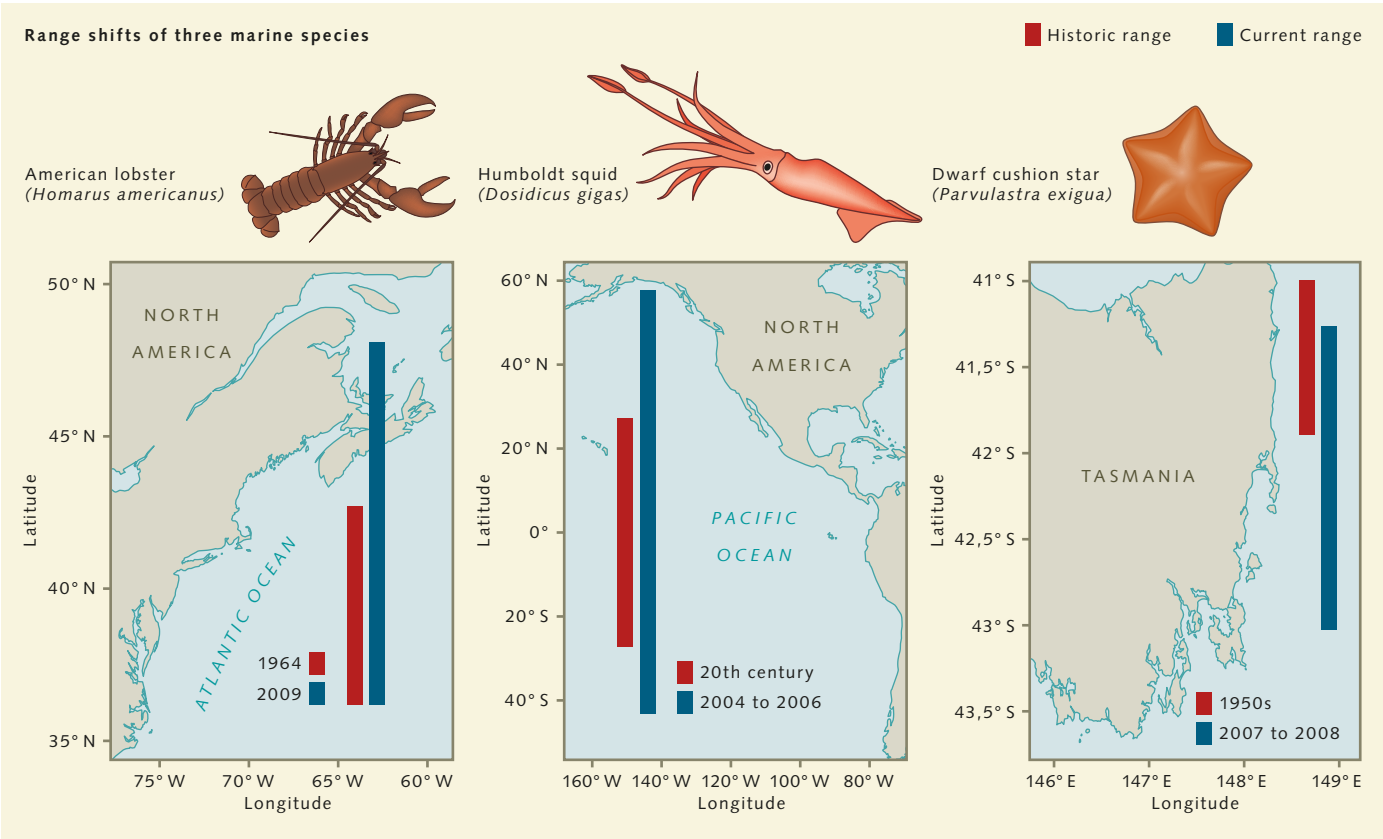
Our increasing reliance on the sea is placing new stresses on marine organisms, including noise pollution from construction work for wind farms and other infrastructure, as well as from the growing volume of shipping traffic. For example, on the west coast of the Canadian province of British Columbia, 300-metre-long natural gas tankers will soon be sailing through the narrow Kitimat fjord system to load liquefied natural gas at a new shipping port and transport it to Asia. This archipelago has long been considered a safe haven for fin whales and other baleen whales. Local whale researchers fear that it could soon become a death trap for these marine mammals.

The consequences of climate change for marine species diversity

Climate change is altering the living conditions of marine organisms in many unprecedented ways. Rising water temperatures force cold-blooded organisms to invest

more energy and oxygen in their metabolism, thus requiring them to expend more energy to maintain their bodily functions. This is possible as long as there is sufficient food and the ambient temperature remains within the species-specific comfort range, enabling individuals to acclimatize. However, if the temperature rises above this range, the organisms are at risk of circulatory collapse. Warmer seawater also stores less oxygen than cold water. This means that heat-stressed organisms find it more difficult to mitigate that stress by increasing their respiratory rate. In addition, heat increases the number and size of low-oxygen zones at mid-water depths and shifts the biological calendar of many species. This can occur in such a manner that the calendars of different species drift apart: in the western Baltic Sea, for instance, due to warming phytoplankton blooms only occur after cod and herring larvae have hatched. As a result, the juveniles are at risk of starvation.

4.12 > Due to ocean warming, many marine species are moving to cooler waters, albeit to differing extents and at different speeds. This has been proven to be the case for species such as the American lobster, the Humboldt squid and the Tasmanian dwarf cushion star.



The drivers of oceanic species change

Changes in land and marine use

- 1 Coastal development and construction
- 2 Construction of offshore wind farms
- 3 CO₂ storage deep beneath the ocean floor
- 4 Military exercises
- 5 Maritime traffic
- 6 Submarine cables and pipelines
- 7 Expansion of agricultural activities
- 8 Inputs of fertilizers and pesticides used in agriculture
- 9 (Mass) tourism
- 10 Leisure and recreation
- 11 Land reclamation
- 12 Construction of coastal protection structures
- 13 Discharge of pollutants and untreated wastewater
- 14 Waste disposal (including plastics)
- 15 Marine-based methods for targeted CO₂ removal
- 16 Discharge of pharmaceuticals via wastewater
- 17 Invasive species
- 18 (Underwater) noise

Resource extraction

- 19 Deep-sea fishing
- 20 Bottom trawling
- 21 Fish farming in marine aquaculture
- 22 Algae farming (food/raw material)
- 23 Krill fishing
- 24 Sand and gravel extraction
- 25 Mining of ores and rare earths in coastal waters
- 26 Oil and natural gas extraction
- 27 Drinking water production through desalination
- 28 Test runs for deep-sea mining
- 29 Exploitation of genetic resources

Impacts of climate change

- 30 Ocean warming
- 31 Ocean acidification
- 32 Increasing water stratification
- 33 Marine heatwaves
- 34 More intense cyclones
- 35 Sea-level rise
- 36 Increasing oxygen depletion
- 37 Sea ice decline
- 38 Effects of forest fires on coastal and marine ecosystems
- 39 Spread of disease
- 40 Species migration

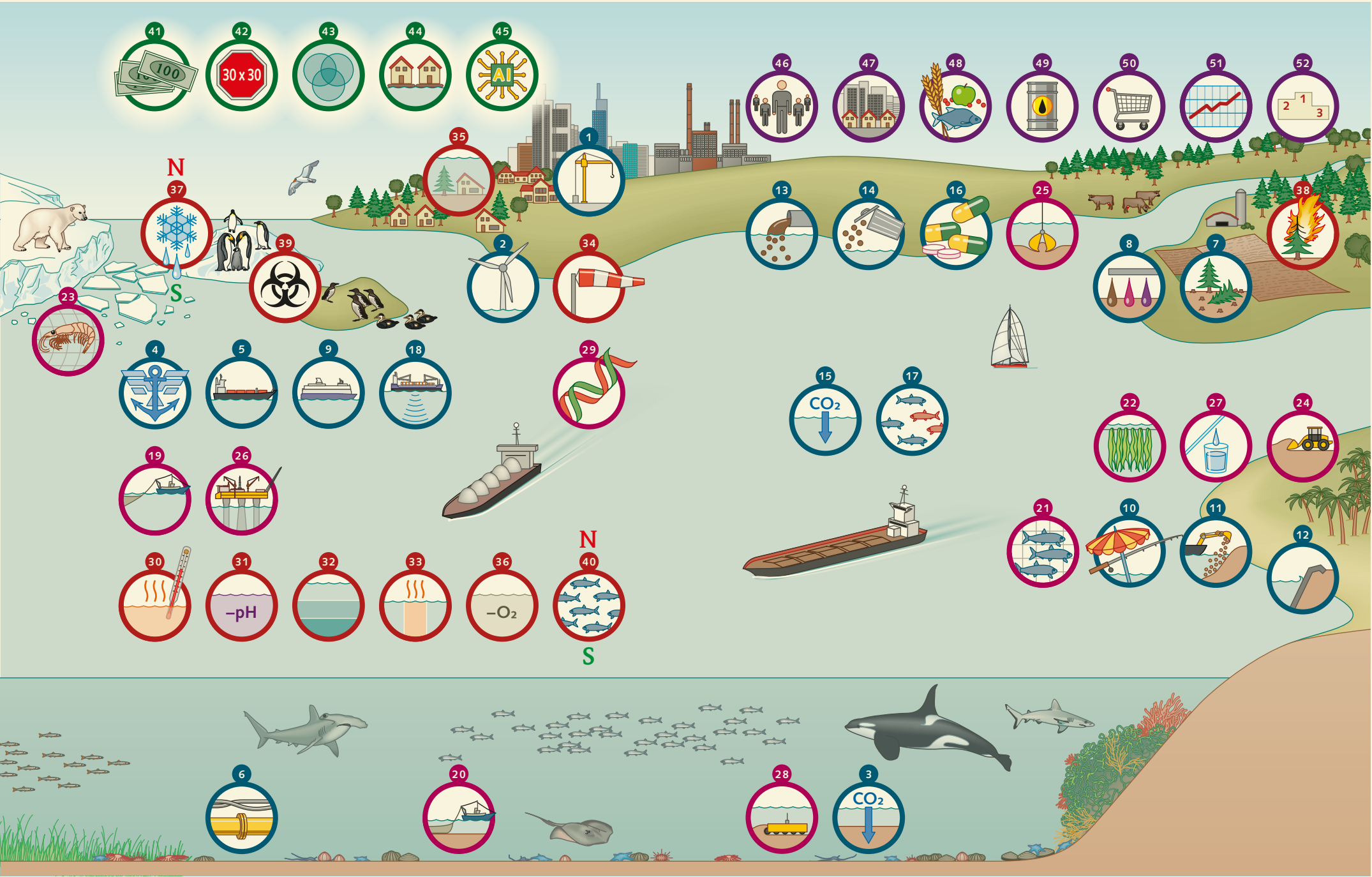
New technologies and political strategies

- 41 Subsidies for deep-sea fishing
- 42 "30-by-30" protection target
- 43 Multiple use of marine areas
- 44 Floating cities
- 45 Artificial intelligence

Indirect drivers of species turnover

- 46 Population growth
- 47 Urbanization
- 48 Rising demand for food
- 49 Rising demand for raw materials
- 50 Rising consumption
- 51 Aim of constant economic growth
- 52 Increasing competition for land, raw materials and terrestrial resources

4.13 > Drivers of oceanic species change: Humans alter marine ecosystems mainly by exploiting fish and other resources, using coastal and marine areas for their own purposes and driving climate change.





4.14 > Storm damage: A year on from Hurricane Ian sweeping across the US state of Florida, this fishing boat remains stranded in a mangrove forest ravaged by wind and waves. As hurricanes become stronger, coastal ecosystems such as mangroves, tidal marshes and seagrass meadows are increasingly at risk.

Climate change is also altering ocean chemistry because atmospheric carbon dioxide dissolves in the surface waters. This acidifies the ocean, making life difficult for many organisms, especially calcifying species such as bivalves, true conchs and calcifying marine algae. These organisms must expend far more energy building their protective shells and skeletons, as well as repairing acidification-induced damage.

Last but not least, climate change is causing sea levels to rise and the area of sea ice to decline. These developments have far-reaching consequences: breeding and nesting areas in low-lying coastal regions are flooding, and mangrove forests are becoming permanently inundated, resulting in the trees dying off. The disappearance of sea ice not only means the loss of a key habitat in the polar seas. It also means the loss of the most important food source, as nutritious polar diatom communities form the foundation of marine food webs in the Arctic and Antarctic.

The impacts of climate-induced warming, acidification and increasing oxygen depletion on marine life are mutually reinforcing and having an increasingly disruptive effect: mobile species are leaving their traditional territories, migrating towards the poles or to deeper waters. Among the many species fleeing the increasing heat is cod. The cod population in the North Sea is shrinking, while the heat-loving European hake (*Merluccius merluccius*) is migrating northwards from the south into the North Sea. Hake are more cunning hunters than cod. Experts therefore assume that the newcomers to the North Sea will put much greater hunting pressure on native species and could permanently alter the ecosystem.

Depending on whether ocean currents carry their eggs, larvae or juveniles to new, suitable habitats, organisms attached to the ocean floor, such as warm-water corals, will either die out locally or become extinct as the oceans warm and acidify. The remaining habitat of cold-adapted organisms such as penguins, Arctic cod and Antarctic krill in the polar seas is declining in area due to the reduction in seasonal sea ice cover and absence of permanently low temperatures.



4.15 > Antarctic krill swim underneath ice floes to feed on polar diatoms growing in the cracks and channels of the sea ice. Krill are a key-stone species in the Southern Ocean food web. They are a vital food source for penguins, fish, whales, seals and many other animals.

Extreme events such as marine heatwaves and severe cyclones pose a particular threat. Due to their scale and destructive force they quickly exceed the stress limits of organisms. Therefore, extreme events can cause immense damage to marine ecosystems within a short period of time, especially if they occur at increasingly shorter intervals, preventing ecosystems from recovering from previous shocks.

The structure of local biological communities, and with it their ability to perform certain ecosystem services, changes when species disappear or new species arrive. Off the coast of Japan, for instance, the migration of algae-consuming reef fish from tropical waters due to rising temperatures has led to a decline in native kelp forests. This has had negative consequences for the many species that previously relied on the macroalgae forests

for their survival. However, at the same time, the fish have allowed for the establishment of corals that prior to the ocean water warming up had only been found in coastal areas further south.

Such dramatic changes to marine ecosystems have a direct impact on the people who depend on them for their livelihoods. Fishing grounds are shifting geographically and becoming inaccessible, especially for artisanal fisheries. This is particularly true of tropical and subtropical waters, where significantly fewer species will be able to survive in the now warmer waters.

In Alaska, fishing for opilio snow crabs (*Chionoecetes opilio*) was banned in 2022 after a prolonged marine heatwave caused stocks in the Bering Sea to collapse by more than 90 per cent. Prior to this extreme event, fishers landed annual catches worth 200 million Euros. It is uncertain whether this level can ever be reached again. The probability of the water temperature in the Bering Sea exceeding the snow crab's arctic cold comfort zone is now 200 times higher than in the 1850s. Researchers also found that the snow crabs died during the heatwave due to a lack of food. In the warm water, they required far more food than the Bering Sea ecosystem could provide.

This example underscores that climate change has enormous consequences for marine biological communities, making it more difficult for us to sustainably utilize and preserve them in the long term.

Coastal and marine pollution

Human-induced pollution of the oceans and coastal areas is increasingly contributing to the decline in marine biodiversity. Today, oceanic pollution encompasses not only the deposition of chemicals, silt and contaminated wastewater, but also the contamination of marine ecosystems by artificial light, pharmaceuticals, anthropogenic noise and plastic waste in all its forms. The effects on ecosystems are correspondingly diverse. For example, pharmaceuticals and environmental toxins can cause reproductive issues and increased mortality rates. They may also reduce the food supply for certain species. Artificial light can irritate nocturnal marine organisms. For instance, if lamps are lit in the immediate vicinity of sea turtles'

beach nests, the fresh hatchlings can't find the most direct path to the ocean. Underwater noise caused by humans can drive marine organisms away from their habitats and make it difficult for them to hunt, find mates and communicate. In extreme cases, it can injure or kill them.

The millions of tonnes of plastic waste in the sea are destroying marine habitats, with plastic debris accumulating on a massive scale. Carelessly discarded fishing nets pose a risk to marine life, as animals can become entangled in them and die. Marine organisms may also mistake plastic waste for food and ingest it. These animals then virtually starve to death with full stomachs. Microplastics particles are a particular danger. Researchers have now shown that more than 1300 different terrestrial and marine animal species ingest microplastics particles, including invertebrates, insects, fish, birds and mammals. The adverse impacts of this pollution are felt at all levels of biological organization, from the cellular level to the food web and entire ecosystems.

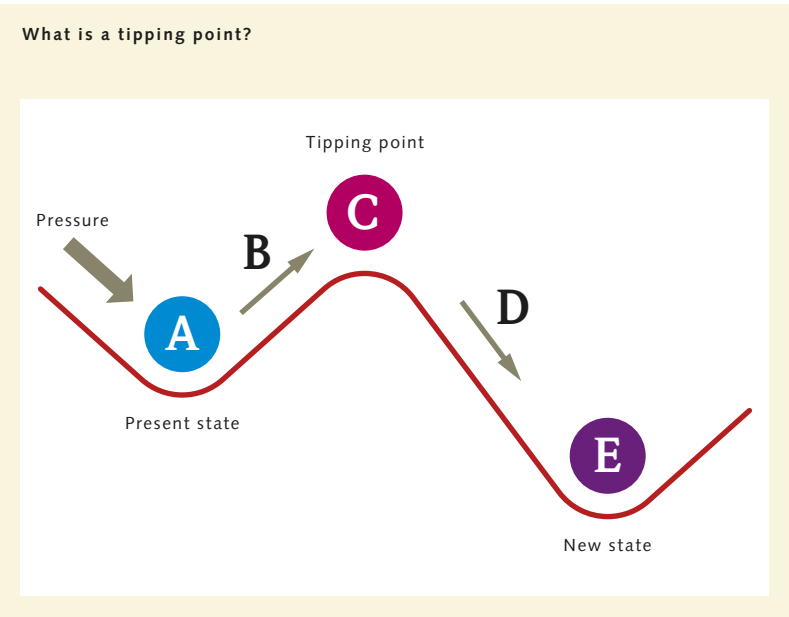
Greater damage occurs when many stressors combine

Human activities and interventions in the ocean affect marine organisms in different ways. The intensity of individual stress factors varies between marine regions and depending on the water depth at which organisms live. For example, the inhabitants of shallow coastal seas feel the effects of rising water temperatures, increasing ocean acidification and the direct consequences of marine pollution much more acutely than deep-sea biological communities far out at sea. Nevertheless, the following applies to the entire ocean habitat: if stress factors occur simultaneously, they may interact and thus increase their destructive power. Stressors reinforce each other, creating a cascade effect.

This intensifying effect is particularly evident in tropical coral reefs. Those that are already weakened by water pollution and intensive fishing bleach more quickly and extensively during periods of extreme warmth than those that are not exposed to additional stresses. The latter also recover much faster. Additionally, reefs in over-fertilized

4.16 > The population of African penguins has plummeted over the past 35 years. While there were still around one million penguins living on the coasts of South Africa in the early 1990s, by 2023 this figure had dropped to fewer than 10,000. This decline is due to the overfishing of sardines and anchovies, as well as an increase in floods and heatwaves during the breeding season causing the penguins to abandon their nests.





4.17 > Scientists use the term “tipping point” to describe the point in time at which the cumulative effect of many small changes or pressures causes a system to exceed its stress limit. The system then changes in a fundamental way and assumes a new state. A return to the original state is usually impossible.

coastal waters are more susceptible to destruction by voracious crown-of-thorns starfish. The nutrients deposited from land-based sources promote the growth of microalgae. These, in turn, serve as food for the starfish larvae during the first six to twelve months of their lives. If microalgae are available in large quantities, the starfish grow in large numbers and, once sexually mature, prey on the polyps of stony corals. Each spiny starfish can destroy up to ten square metres of coral per year.

Critical tipping points are nearing

The Living Planet Index and other indicators of global species diversity reveal the alarming rate at which the Earth is losing its wild animal and plant species, either through extinction or drastic population decline. This decline is particularly evident in the ocean, where there has been a widespread loss of seagrass meadows, tidal marshes, kelp forests and coral reefs, as well as a dramatic collapse in shark and ray populations. Hunted and fished by humans for centuries, populations of sharks and rays have declined by a further 71 per cent since 1970. According to the Red List, more than one third of the approximately 1200 shark and ray species are threatened

with extinction – a disaster of inconceivable proportions for the marine environment.

Although human activities often cause small-scale changes in species diversity, the cumulative impact of these interventions can be highly significant. The pressure on the affected ecosystem, or even the entire ocean, can increase to such an extent that the change originally driven by humans suddenly continues of its own accord. This results in further, very abrupt changes that may be irreversible. Moreover, they usually pose enormous additional risks to humans and nature. In such instances, experts speak of reaching a tipping point. If crossing this tipping point jeopardizes the survival of large numbers of people and species of flora and fauna, it is referred to as a global tipping point.

The most prominent global tipping points include the melting of the Greenland and Antarctic ice shields, the collapse of the Atlantic meridional overturning circulation in the North Atlantic, and the thawing of permafrost worldwide, which could result in the release of huge quantities of carbon dioxide and methane. In terms of the oceans, the worldwide extinction of tropical coral reefs would constitute a global tipping point. Their complete disappearance would lead to the collapse of important fisheries. Moreover, many tropical islands and coastlines would lose their natural breakwaters, not to mention the impact on marine species diversity. It is estimated that tropical coral reefs harbour a quarter of all known marine species.

Although it is difficult to prove that global tipping points have been exceeded, there are now many signs of local or regional tipping points. In 2023, for instance, many of the remaining coral reefs in the Caribbean bleached during an exceptionally intense and prolonged marine heatwave. Researchers witnessed, powerless to respond, the affected stony corals dying on a scale never before seen by coral experts. The consequences of this massive die-off for species diversity in the region are thought to be far-reaching but scientific proof will take time. This is partly because stony corals that survive a bleaching event can take up to a year to recover from the heat shock and resume growth and reproduction.

CONCLUSION

Disruptions and damage at all levels

Just like us humans, marine organisms need a safe natural resource base on which they can draw for their growth and healthy reproduction. This primarily includes an intact, unpolluted habitat, ambient temperatures within their specific comfort zone, and sufficient food. However, none of these cornerstones of marine life are considered to be secure today. The direct and indirect interventions of human societies in the global ocean are too far-reaching and severe.

The most important direct drivers of the decline in marine biodiversity are the extraction of raw materials and organisms, changes in the use of coastal areas and oceans, climate change and its consequences for marine life, coastal and marine pollution, and the migration or introduction of invasive species. Indirect impacts are caused by factors such as human population growth, demographic shifts (e.g. urbanization and migration) and socio-cultural, economic, technological and political developments. These factors influence the decisions we make as societies, which ultimately affect nature and marine life.

The overexploitation of marine ecosystems in European waters began as early as the Middle Ages, driven by the growing commercialization of goods, raw materials and marine ecosystem services. This continued in other marine regions of the world in colonial times. The present development trajectory can be termed as the industrialization of marine resource use and exploitation. Its extent has increased rapidly since the 1950s, resulting in the damage, destruction or disappearance of many original marine ecosystems and a decline in the popu-

lation numbers of particular animal populations by more than half since 1970. The loss of marine species diversity is now so severe that a global mass extinction can no longer be categorically ruled out.

It is also a fact that our demands on the sea and its biological communities continue to increase, despite all the species and habitat losses in the ocean. New or drastically intensifying forms of utilization include energy generation at sea, shipping traffic, and fish farming and algae cultivation in aquaculture installations. Meanwhile, marine pollution by waste, microplastics and other pollutants is also mounting.

The consequences of climate change for marine life are a significant source of uncertainty. Not only are they driving thousands of species to leave their traditional ranges, tearing apart food webs and bringing biological processes to a standstill, they are also weakening the health and resilience of many marine organisms. Weakened or stressed organisms usually lack the energy to withstand further disturbances, so the consequences of climate change exacerbate the damage caused by other stressors. Experts speak of a cascade effect, which occurs when several disturbance factors impact in the same place at the same time, reinforcing each other's effects.

However, there is one piece of good news: selected marine organisms and biological communities in some marine regions are now being systematically monitored, with their condition being regularly assessed by means of a number of different biodiversity indicators. This enables experts to determine whether or not measures to reduce human-induced pressures are effective and whether or not marine life may slowly be recovering.

5 Newcomers on board

> The immigration and spread of non-indigenous species is one of the drivers of species turnover. In many parts of the global ocean, newcomers have already altered established biological communities by preying on keystone species, displacing native species, or introducing diseases. But not everything is black and white. In the Wadden Sea of the south-eastern North Sea, newcomers and long-established species live in mutually beneficial coexistence.



Non-indigenous species: Curse and blessing

> They migrate on their own, arrive as stowaways, or are deliberately introduced and released by humans: Immigrant or introduced animals, plants and microorganisms have been changing life in the oceans for centuries, especially in coastal seas. Local biodiversity can decline as a result of such new arrivals. But there are exceptions. In the species-poor Wadden Sea, newcomers have not yet displaced native species. In fact, they sometimes strengthen local ecosystems.

The Suez Canal as a gateway

The silver-cheeked toadfish (*Lagocephalus sceleratus*) must be handled with extreme caution. This spotted fish, a member of the pufferfish family, can grow up to a metre in length. It not only bites through fishing nets and metal hooks with ease, but also produces its own venom, called tetrodotoxin, which is found on the fish’s skin as well as in its internal organs. One to two milligrams of this neurotoxin is said to be enough to kill a person, the University of Pula, Croatia, warned in the early summer of

2024. Shortly before the warning was issued, a Croatian fisherman had caught a silver-cheeked toadfish for the first time in the Adriatic Sea and thus in the northern part of the Mediterranean where this fish species does not belong at all.

The silver-cheeked toadfish normally lives in the tropical Indo-West Pacific, in the equatorial waters south of India and the Asian continent. Thousands of kilometres, as the crow flies, lie between its home and the Adriatic Sea. Nevertheless, these squid-eating predators can now be found in large parts of the Mediterranean.

5.1 > The Suez Canal on the eastern edge of the green Nile Delta allows marine organisms from the Red Sea and the Indo-Pacific region to autonomously migrate into the Mediterranean Sea and establish themselves as non-indigenous species.



In recent decades, this and many other species of flora and fauna from the Red Sea and the Indian Ocean have managed to migrate to the Mediterranean via the Suez Canal.

The shipping lane in Egypt proved to be an easy gateway. Since its opening in November 1869, the way has been clear for Pacific marine organisms to autonomously spread into the Mediterranean Sea. Even today, more than 155 years after the canal’s official opening, species from the Indo-Pacific are still migrating into the Mediterranean, driven by ocean warming and the widening and deepening of the canal – some for the first time, others repeatedly. Particularly in the eastern part of the Mediterranean, and especially in the coastal waters of Israel and Palestine, marine biologists now recognize more than 450 non-indigenous species of flora and fauna that have migrated through the Suez Canal and settled in the Mediterranean. These include cnidarians such as the nomad jellyfish (*Rhopilema nomadica*), which occurs in large swarms, more than 160 species of bivalves, and an armada of more than 100 species of fish.

An influx with serious consequences for local biodiversity

Experts have not yet been able to conclusively assess the impact that this invasion has had on native Mediterranean life. However, there is clear evidence that some of the immigrant species are changing native biological communities. These include the rivulated rabbitfish (*Siganus rivulatus*) and its relative, the squaretail rabbitfish (*Siganus luridus*). The former was first discovered in Israeli coastal waters in 1924, followed by the latter 31 years later. Since then, the two algae-consuming species have spread to the waters of France and Tunisia.

The two rabbitfish species now make up 95 per cent of the fish biomass in the rocky coastal areas of the Mediterranean. Because of their predilection for certain types of brown algae, they have overgrazed the underwater algal forests in many places. Researchers report that instead of lush macroalgae forests, sponges and bare rocks now dominate the affected coastal areas.



An important question: Do the newcomers harm the established ecosystem?

The observations from the Mediterranean are one of many examples of how non-indigenous species, also known as neobiota, are changing the structure and functioning of established marine biological communities. The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) therefore lists species of flora and fauna that have been introduced into new habitats by humans or whose autonomous immigration has been facilitated by humans as one of the five direct drivers of global biodiversity decline.

Experts are particularly concerned that the global dispersal of species will increasingly harmonize biological communities in different marine areas. The fear is that a few robust species will become ubiquitous, while specialists will be pushed back. In the long term, this could lead to a global decline in biodiversity. Whether these fears will one day be realized is a matter of debate among scientists.

5.2 > The jellyfish *Rhopilema nomadica* is native to the east coast of Africa and the Red Sea. It was introduced into the Mediterranean in the late 1970s via the Suez Canal. Since then it has spread along the Levantine coast from Egypt to Turkey and Greece.

Making way: How humans pave the way for non-indigenous species

How humans introduce non-indigenous species or enable them to immigrate		
Pathways	Sub-pathways	Description
Corridor	Interconnected water-ways/basins/seas	Species spreading to new regions along infrastructure such as canals or other artificial waterways interconnecting previously unconnected water bodies, basins and seas
Escape from confinement	Aquaculture/mariculture	Species that have escaped from confinement or controlled situations in either freshwater or marine environments to produce food or other agricultural type products including bioenergy products
	Botanical garden/zoo/aquaria	Species that have escaped from confinement and that were kept for public display, public education or conservation breeding programmes
	Horticulture	Species that have escaped from confined or controlled environments where they were commercially cultivated for purposes other than aquaculture/mariculture
	Live food and live bait	Species that have escaped from confinement or controlled environments where they were kept and/or transported as live food or live bait
	Ornamental	Species that have escaped from confined or controlled environments where they were introduced for decorative or ornamental reasons excluding commercial horticulture
	Pet/aquarium species	Species that have escaped confinement or controlled environments where they were kept by private collectors or hobbyists for recreation
	Research	Species that have escaped confinement or controlled environments where they were kept and/or bred for use in research
Release in nature	Biological control	Species released into the (semi)natural environment with the purpose of controlling the population(s) of one or more organisms
	Erosion control	Species released into the (semi)natural environment to control the environment or to act as physical barriers
	Fishery in the wild	Fish and other aquatic animals (e.g. invertebrates) released into the (semi)natural environment to provide additional or alternative subsistence and/or commercial or recreational fishing opportunities
	Other intentional release	Species released into the natural environment for reasons other than those covered in any other release in nature pathways

How humans introduce non-indigenous species or enable them to immigrate		
Pathways	Sub-pathways	Description
Transport (contaminant)	Contaminant on animals	Species introduced unintentionally as contaminants on animals transported through human related activities (e.g. aquaculture)
	Contaminant on plants	Species introduced unintentionally as contaminants on plants or plant products transported through human related activities
	Contaminated bait	Species introduced unintentionally as contaminants in/of bait
	Parasites on animals	Unintentional introduction of parasitic species transported by a host animal or an animal that acts as a vector
Transport (stowaway)	Angling/fishing gear	Species introduced unintentionally as stowaways on equipment used by recreational anglers or commercial/professional fishermen, including aquaculture gear
	Ballast water	Species that have been introduced unintentionally via the ballast tanks of ships and boats, within ballast water, ballast sediments or solid ballast materials
	Container/bulk	Species introduced as accidental stowaways in or on shipping containers and bulk cargo
	Hitchhikers on plane	Species that have been introduced unintentionally by being a hitchhiker in or on airplanes and other aircraft
	Hitchhikers on ship	Species that have been introduced unintentionally by being a hitchhiker in or on ships, boats or other watercraft but excluding species transported in ballast tanks or via ship fouling
	Organic packaging material	Species that have been introduced unintentionally by being a stowaway in or on packing materials such as wooden pallets
	Ship fouling	Species that have been introduced unintentionally as biofouling organisms on underwater surfaces of ships including the hull and niche areas
Unaided	Rafting on anthropo-genic debris	Species that spread to new regions attached to marine litter and other anthropogenic materials drifting in natural water currents

5.3 > There are several ways in which humans enable species to reach new habitats and potentially colonize and spread in such areas. Experts distinguish between the pathways listed in this table.

5.4 > After the last ice age, the sand gaper *Mya arenaria* was only found on the east coast of America. It was then introduced into the North Sea by the Vikings 800 years ago. Juvenile sand gapers in particular have been an important food source for crabs and seabirds there ever since.



The importance of non-indigenous species in altering established ecosystems and their services is now so great that the IPBES Member States commissioned the IPBES Expert Panel to produce a special report on the subject. The report, published in September 2023, makes a clear distinction between non-indigenous species and invasive non-indigenous species. Non-indigenous species are all organisms that have been introduced into new regions as a result of human activity. The term “invasive”, on the other hand, is restricted to those non-indigenous species that have colonized and spread in their new home and are having a negative impact on local ecosystems, their species and biodiversity.

The proportion of invasive species can be surprisingly low. European waters, for example, are now home to more than 800 neobiota – and according to current knowledge, only a small number of these are harmful to native biological communities and the services they provide.

Immigration pathways: Marine organisms on the move

Humans intentionally and unintentionally enable marine organisms to cross the boundaries of their traditional

range and migrate to new marine regions. For example, the many stowaways that are transported across the world’s oceans clinging to the hulls of boats and ships or floating in ballast water represent unintentional introductions. Once they reach their destination, the organisms fall off or are disposed of with the ballast water in their new home. The Vikings already introduced non-indigenous species such as the North American sand gaper (*Mya arenaria*) into the waters of the Kattegat 800 years ago.

The risk of introducing neobiota by ship increased with the development of modern cargo ships and the globalization of trade. Whereas in 1750 wooden merchant ships could carry an estimated 120 species of marine biofouling and boring organisms, 200 years later international merchant fleets transported more than 10,000 different marine species from one region to another in their ballast tanks. But then, as now, coastal insects and plants were also added to the mix, starting their long journeys hidden among the pebbles, sand and coastal debris forming part of ships’ ballast.

In February 2004, the International Maritime Organization (IMO) adopted the International Convention for the Control and Management of Ships’ Ballast Water and Sediments to reduce the introduction of such unwanted species. The Convention, which came into force on 8 September 2017, stipulates that ballast water can only be discharged if certain limits or requirements are met. For example, ship crews must keep detailed records of when and where they discharged or took on ballast water. Ballast water must also be treated to remove or render harmless any harmful aquatic organisms and pathogens it may contain, or to prevent their ingestion or introduction. For example, one of the regulations states that ballast water may only be discharged into the sea if less than ten viable organisms with a minimum size of 50 micrometres can be detected per cubic metre of water.

Nevertheless, shipping continues to contribute to the spread of species. This applies both to existing transport routes, where traffic is increasing, and to regions such as the Northeast Passage through the Arctic Ocean, where



5.5 > The Russian cargo ship *Iohann Mahmastal* is waiting for permission to dock at the Yamal 2 natural gas terminal in western Siberia. The ship is carrying food and construction materials for the new natural gas production facility. The ship had to sail through the Northeast Passage to deliver its cargo. Each such voyage increases the risk of species being introduced into the fragile ecosystems of the Arctic Ocean.



5.6 > The polyps of the orange cup coral (*Tubastraea coccinea*) only extend their tentacles in the dark to catch food. Originally from the Indo-Pacific, this stony coral has spread across the Caribbean to the east coast of Brazil, where it now competes with native Atlantic corals.

tankers and cargo ships have only recently begun to operate regularly.

Escapes of non-indigenous species from aquaculture cages or other marine breeding facilities are expected, but unintentional. It is estimated that between 1993 and 2012, more than one million Atlantic salmon (*Salmo salar*) and silver salmon (*Oncorhynchus kisutch*) escaped into the South Pacific every year from farms in Chile alone. The escapees then mixed with native fish species. The extent to which the farmed salmon compete with the native wild species has not yet been clearly established. This is mainly due to a lack of baseline knowledge as to the species composition and functioning of fish stocks in Chile's rivers, lakes and fjords. Nevertheless, there has been a human-induced change in species composition with unknown consequences.

In addition to increasing competition for food, farmed fish outbreaks pose two other risks to local biodiversity. Firstly, fish farm escapees can carry viruses, lice and other pathogens that can be transmitted to wild fish and other native marine organisms. Secondly, escaped fish may reproduce locally and establish their own populations. However, for such colonization to be successful, many species-specific environmental conditions must be met. At least in Chile, despite the high numbers of outbreaks in the 1990s and 2000s, there have been no reports to date of escaped Atlantic salmon or silver salmon being able to reproduce in the wild and establish permanent populations.

The situation is different in the Amazon region: Intensive fish farming has contributed significantly to the establishment of 41 non-indigenous fish species in the river and its estuary, more than half of which are predatory or omnivorous. With these research results from 2021, the researchers involved have also disproved the classic assumption that non-indigenous species find it more difficult to colonize species-rich habitats than species-poor ones.

Observations from European coastal waters highlight the extent to which non-indigenous aquaculture species can carry hitchhikers. Around 60 different pathogens, parasites and fouling species such as tunicates have spread

with introduced farmed bivalves such as the Manila clam (*Ruditapes philippinarum*) and the Pacific oyster (*Magallana gigas*).

When humans build artificial waterways, such as the Suez and Panama canals, the subsequent immigration of non-indigenous species is considered unintentional. Experts do not refer to this as active alien species introductions, but rather as the removal of one or more barriers to dispersal.

Interestingly, when new corridors open up between two marine habitats, species always migrate from the species-rich region to the species-poor region, not vice versa. This explains the immigration of Pacific species to the Mediterranean. Almost no species have migrated in the other direction.

When people deliberately release non-indigenous species, there are clear agendas behind their establishment, such as the desire to locally hunt or fish these species. For example, the edible mouthless crab *Cardisoma crassum*, which is native to Ecuador, ended up in the coastal waters of the Galapagos island of Santa Cruz in this manner.

A profitable fishing industry has developed in Norway's Barents Sea since the red king crab (*Paralithodes camtschaticus*) from the North Pacific was deliberately released there in the 1960s. In the absence of natural predators, the large crabs have since spread along the Norwegian north coast – to the delight of local fishers. Today, they export red king crabs worth the equivalent of 100 million Euros per year.

Humans are partly to blame when species drift into new ocean regions, for example by attaching themselves to plastic debris. The Pacific sun corals *Tubastraea coccinea* and *Tubastraea tagusensis*, for instance, have been spreading along the Atlantic coast of Brazil using this pathway. The two Pacific species have extensive defence mechanisms, reproduce rapidly and, due to the lack of predators in the South Atlantic, are well placed to displace native corals such as the reef-building stony coral *Mussismilia harttii* from their home reefs.

However, experts consider the introduction of non-indigenous species by flotsam and jetsam to be immigra-

tion without direct human assistance. Moreover, immigration as a result of climate-induced ocean warming plays a special role. In these cases, organisms autonomously expand their range. They are therefore not considered active introductions of alien species by humans, even if climate change is caused by humans.

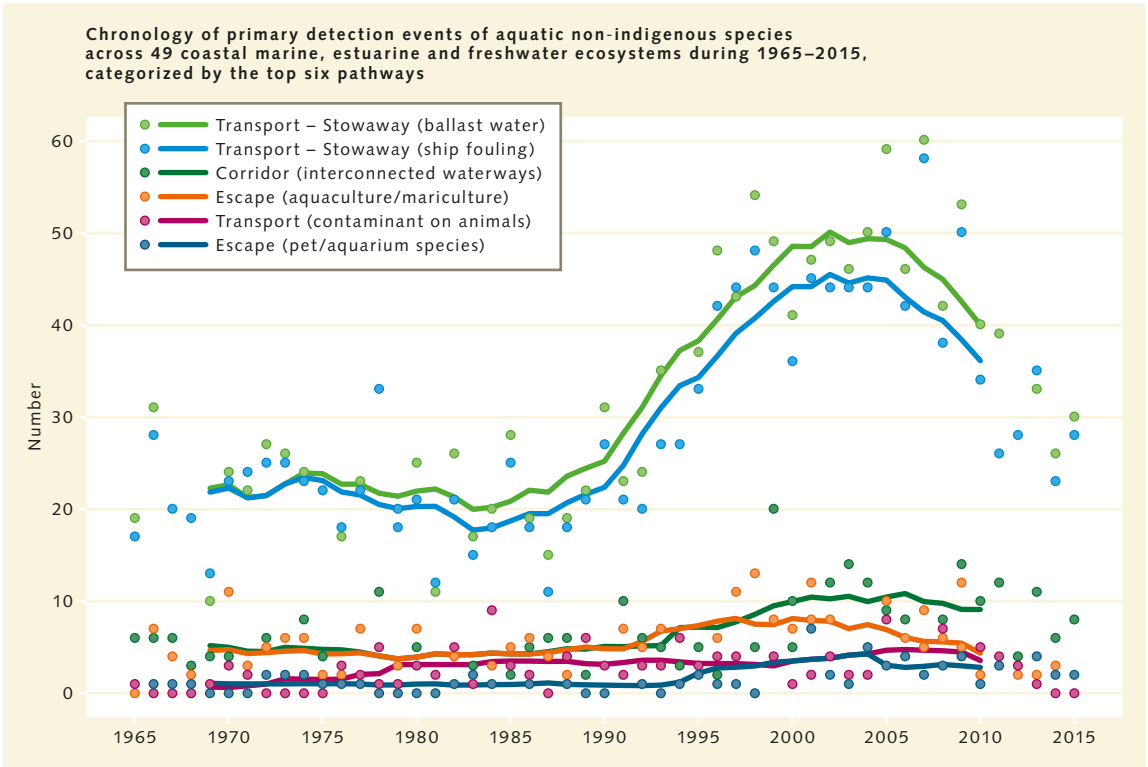
How many non-indigenous species are in the ocean?

The first reports of colonisation by non-indigenous marine organisms date back to the early 19th century. Since then, the number of known immigrant or introduced species in the global ocean’s various ecosystems has increased steadily, partly because there has been an increase in the amount of research undertaken on the topic since the 1970s. In 2020, a team of scientists analyzed a large number of existing datasets on non-indigenous aquatic organisms. They found that between 1965 and 2015, an average of 43 primary detection events for new

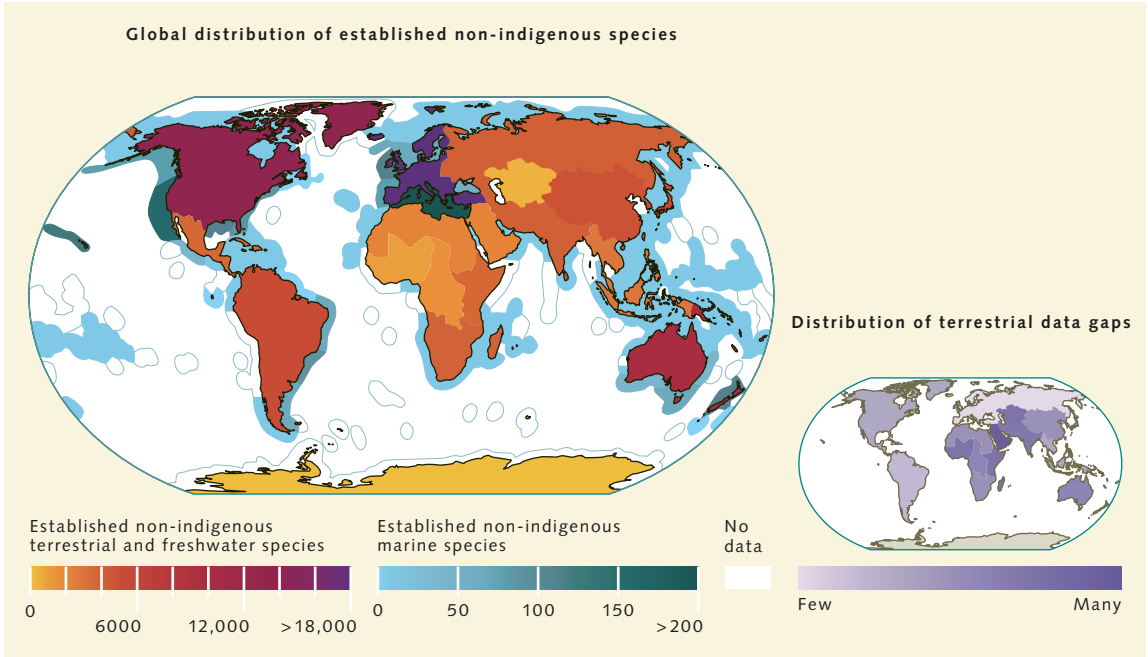
non-indigenous species had been recorded per year in marine and coastal waters around the world and in the Great Lakes of North America.

In total, the researchers counted 1442 introduced or immigrant species in 39 marine and freshwater ecosystems. The newcomers primarily included organisms from the arthropod, bivalve and fish phyla, as well as red algae, annelids, tunicates, and also bryozoans and cnidarians.

Detailed analysis also showed that the rate of detection of newly established non-indigenous species was relatively stable during 1965 to 1995. On average, 32 non-indigenous species were newly detected each year. In subsequent years the detection rate increased steadily, reaching 51 primary detections annually by the year 2000 and 66 primary detections per year during 2005 to 2010. Possible reasons for this are the increase in shipping on the world’s oceans, the expansion of fish and shellfish farming in aquaculture, and better monitoring programmes in some of the world’s coastal regions.



5.7 > Global shipping is a major cause of the immigration and introduction of non-indigenous species. This fact is highlighted in this graph, which shows the pathways through which newly discovered non-indigenous species in marine habitats and onshore waters were found to have arrived.



5.8 > Researchers have been able to detect many more invasive species on land than in the oceans. However, the number of introduced marine organisms has also been increasing. This is due in part to an increased likelihood of new introductions. At the same time, new monitoring programmes mean that new arrivals are more likely to be detected.

However, the researchers believe that their data greatly underestimate the true number of neobiota, partly because the datasets they analyzed cover only 73 per cent of the world’s most important aquatic ecosystems. Secondly, in many places it is not at all clear which species have always lived in the region, and which organisms arrived when and how.

As a result, the comparatively young field of marine invasions research still has knowledge gaps at the global level, particularly with regard to standardized methods, comparative time periods and comprehensive observation efforts. For example, there is a lack of information on the extent to which non-indigenous species have invaded the open ocean and water depths greater than 200 metres. Most of the species listed in the study are thought to have entered the ecosystems studied with the help of ships (biofouling, ballast water, etc.). Only a small proportion of the detected introductions were due to escapes from aquaculture installations.

Since the late 1990s, however, scientists have documented an increase in non-indigenous species that have either migrated through new corridor pathways or lived in aquariums until their ill-considered release.

The adverse effects of the release of marine organisms have been demonstrated by the rapid and uncontrolled spread of the Indo-Pacific red lionfish (*Pterois volitans*) into the tropical regions of the western Atlantic. The fish were probably introduced into Florida’s coastal waters by hobbyist aquarium fishkeepers in the mid-1980s. With no real local enemies, the predatory fish spread across the Gulf of Mexico to the Caribbean within 30 years. These solitary fish are found mainly in coral reefs, where they prey on young reef fish. Scientific experiments in the Bahamas have shown that a red lionfish can significantly reduce the number of juvenile fish in the coral reef it inhabits.

Neither good nor bad

Non-indigenous species not only benefit from the fact that they often do not have to face natural enemies in their new habitats. Successful newcomers frequently have a high physiological tolerance to abiotic factors such as temperature, allowing them to adapt quickly to the conditions in the newly colonized habitat. This permits them to spread rapidly after successful establishment.

5.9 > Hunting is currently the only way to stop the Indo-Pacific red lionfish (*Pterois volitans*) from spreading further into the tropical western Atlantic. The first of these invasive fish were probably released by hobbyist aquarium fishkeepers in Florida's coastal waters in the mid-1980s.



However, it is too narrow a view to categorize the introduction, establishment and subsequent spread of non-indigenous species as a good or a bad thing as such. Nature knows no such labels.

In nature, change means that some groups of organisms benefit, while others may lose out. For others still, things remain as they are. When non-indigenous organisms invade a habitat, the key question is whether they perform ecological functions similar to native species and whether the range of ecosystem services is maintained. If this is the case, the species inventory changes, but not the ecosystem's functional diversity.

Compared to terrestrial forests and grasslands, many marine ecosystems are more open beyond their boundaries. As a result, native marine organisms are much better able to avoid introduced species than terrestrial organisms would be. In many instances, native species also come to terms with the immigrants. Studies in the European Wadden Sea, the world's largest contiguous system of intertidal sand and mud flats, located in the eastern and south-eastern North Sea, show how this coexistence

of native and introduced species can actually increase the biodiversity of a marine habitat.

The Wadden Sea as an outdoor laboratory

Researchers are now aware of more than 100 non-indigenous species that have colonized the Wadden Sea, either living on the seabed or as free-swimming organisms in the water column. Twelve per cent of the newcomers arrived directly from remote marine areas. The majority, however, first migrated to neighbouring regions and then made the leap to the Wadden Sea – often because man-made structures such as harbours made it possible for the new organisms to settle.

The Wadden Sea as we know it today is less than 8000 years old. It is therefore a comparatively young habitat that has always been home to many organisms, but only a comparatively small number of species. In other words, its biodiversity is rather low. However, with the increase in shipping since the beginning of the 20th century, the number of introduced species has steadily

increased, partly because seawalls and other structures were built along the coast to which stowaways could attach themselves.

Earlier, in the 14th century, the American sand gaper (*Mya arenaria*) had migrated from the Kattegat. The Vikings had brought it there. Juvenile sand gapers are an important food source for crabs and seabirds in the Wadden Sea to this day. Adults can live for up to 20 years. By then their shells will have grown to a length of up to 15 centimetres, making them one of the largest bivalves in the Wadden Sea.

The Chinese mitten crab (*Eriocheir sinensis*) is another non-indigenous species. It arrived in the early 20th century when ships started using ballast water for stabilization. It is now the most common crab in the rivers flowing into the Wadden Sea. However, the mitten crab has not yet had any impact on the intertidal ecosystem.

The same cannot be said for the Pacific oyster (*Magallana gigas*). This fast-growing species spread to the Wadden Sea after fishermen first grew it in oyster farms in

France, the Netherlands and the UK. Since 1986, it has also been cultivated as an aquaculture species in net bags off the island of Sylt and thus directly in the Wadden Sea. Oyster larvae only settle on solid ground, which in the Wadden Sea they found in the form of the native blue mussel beds. The juveniles settled on the shells of the mussels and quickly overgrew the beds they form.

However, what initially looked like a hostile takeover followed by displacement turned out over the next 20 years to be a beneficial coexistence. The oysters began to grow only on top of each other, no longer using the mussels as a hard substrate. They quickly formed a new “overstory” on top of the mussel beds.

The mussels made their home in the much muddier level below. While nowadays they have less space than in the past and compete with the oysters for food, the top layer of oysters protects them from predators, such as the green shore crab, and from other organisms harmful to the mussels, such as barnacles, which attach themselves to the mussels' shells. All in all, there are now many more

5.10 > This is what a successful coexistence of introduced and native species looks like. In the Wadden Sea, mussels and immigrant Pacific oysters form multi-storey mussel-oyster beds that withstand weather extremes better than pure mussel beds.



organisms living in the same area, although not all mussel beds are colonized by oysters. Another advantage is that oyster-mussel beds appear to be so robust and stable that they can withstand strong storms much better than mussel-only beds.

And there is another thing the researchers learnt from their observations in the North Sea and the Wadden Sea: the immigration of the same non-indigenous species into different ecosystems can have very different effects. This is shown by the experience with Japanese wireweed (*Sargassum muticum*). On the rocky coast of the Heligoland archipelago, this macro-algae, which can grow to more than four metres in length, competes with native seaweeds in places. When it wins, it performs the same ecosystem functions as its predecessors, providing a habitat for all the species that used to live in the other algal thickets. In contrast, in the sandy Wadden Sea the Japanese wireweed colonizes the newly formed mixed mussel-oyster beds and forms true algal forests of a size and complexity never before seen in the Wadden Sea. These forests in turn attract other smaller algae, invertebrates and many fish that hide among the kelp. This provides a new habitat and increases the mussel beds’ species diversity.

Such details are known because there are established programmes both in the Wadden Sea World Heritage Site and beyond its borders in which researchers monitor the development of non-indigenous species. Along the German North and Baltic Sea coasts, for example, 16 stations document the occurrence of non-indigenous species and their abundance.

Observations so far only cover short periods of time

Many introduced species exhibit a “boom and bust” development pattern, meaning that after initial mass development, the number of individuals decreases as the species adapts to the new ecosystem. In contrast, other species behave inconspicuously at first and occur in low numbers for a long time. But when climatic or hydrographic conditions change, these “ecological sleepers” may multiply

explosively, increasing their impact on the ecosystem. However, all these observations have been limited to periods of only a few decades. As a result, little is known about the long-term effects of non-indigenous species on native ecosystems and biological communities. This is particularly true for the long-term consequences of viruses and diseases that non-indigenous species introduce into new habitats. These have been the subject of little research to date.

For this reason, experts argue that everything possible should be done to prevent new introductions of marine non-indigenous species. Once an invader has established itself in a new habitat, it is almost impossible to push it back, precisely because marine habitats cannot be sealed off. The European Marine Strategy Framework Directive from 2008 therefore includes non-indigenous species as one of the parameters for assessing a marine region’s environmental status. In this context, a quantifiable indicator is being developed to capture the status of a marine area with regard to neobiota.

In its special report from 2019, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) concludes that the introduction of non-indigenous species is a complex process, intertwined with the transport of goods and other components of global change, such as land-use change, climate change and human disturbance. This ecological complexity, the diversity and abundance of non-indigenous species and the difficulty of identifying invaders in new environments have made their prevention and management challenging. However, both are essential to maintaining the natural development of ecosystems.

The IPBES experts conclude that there is now almost nowhere on Earth where non-indigenous species have not migrated or been introduced. They write that research also shows that the number of invasive non-indigenous species is increasing in all regions of the world. At the same time, however, there are major gaps in our knowledge, and valid data are not always available. As a result, the long-term consequences of immigrant species for biodiversity on land and in the oceans are being underestimated.

CONCLUSION

Non-indigenous species: Immigrations caused by human activity

An important driver of marine species turnover is the immigration and spread of non-indigenous species. These are organisms that have either been introduced into an ecosystem by humans or have been able to migrate on their own after humans removed barriers to their spread.

Non-indigenous species can migrate, for example, when the construction of a canal connects two marine areas that were previously separated. Species migrations also occur when climate change warms the ocean and warm-blooded species find suitable conditions in previously cold areas.

In contrast, researchers speak of alien species introductions when organisms are brought into new habitats by ships, when they are deliberately released by humans, or when they colonize new areas because they are kept in cages or net bags for food production and manage to escape – whether through accidents, storm damage or the release of larvae.

Non-indigenous species that spread into a habitat and disrupt the normal interactions of native animals, plants and micro-organisms are called invasive species. Such adverse effects occur, for example, when newcomers increase predation pressure on keystone species, displace native species or introduce diseases to which local marine life is vulnerable.

There are several examples of marine invasive species. However, their numbers are much smaller than on land because marine habitats are more open at their edges. When newcomers outcompete long-established marine species, the latter are more likely to migrate or retreat into niches than many species

inhabiting terrestrial habitats, such as forests or meadows. Nevertheless, scientists fear that globalization may one day cause marine biological communities to become too similar world-wide, with the overall result that global biodiversity declines. Whether this will actually come to pass is a matter of debate, even among experts.

In species-poor marine areas such as the Wadden Sea in the south-eastern North Sea, the more than 100 known non-indigenous species have so far not displaced any of the native species. In fact, some of the invaders have actually strengthened local ecosystems. For example, the colonization of blue mussel beds in the Wadden Sea by introduced Pacific oysters has made the mixed reefs more resilient. When storms whip across the North Sea, the oyster-mussel beds tend to suffer less damage than beds formed by blue mussels alone.

Researchers have also been able to document examples in which non-indigenous species have replaced established species in their function. Although this has changed the species composition in the ecosystems concerned, importantly their range of functions has remained the same.

Nevertheless, everything humanly possible should be done to prevent the spread of non-indigenous species, as it is also clear that many of the long-term consequences of human-induced species migrations are not yet fully understood.

While intensive and, in many places, systematic research is now under way, it is often unclear which species have been present in the area under investigation for what length of time and whether that time span is long enough for them to be considered “native”. Moreover, it is still too rarely possible to compare the results of observations made in different regions.

6 Scenarios conducive to rebuilding marine life

> Although many marine habitats are severely overexploited and degraded, experts are convinced that it is possible to rebuild marine flora and fauna by 2050. Their optimism rests on the many minor successes achieved in marine conservation and the lessons learned from them. However, a genuine comeback of marine ecosystems will only be within reach if the international community takes resolute action and human interventions in the ocean do much less damage in future.



The good news: Making a successful comeback

> The return of schools of bluefin tuna in the Pacific, the recovery of the fin whale population in the Southern Ocean: the many minor successes achieved in marine and species conservation show that the recovery of marine life is possible. It will take time, however, as well as appropriate conservation action, close-knit scientific monitoring networks and a rethinking of how we plan to use the ocean in future. Ultimately the effort will pay off – for a species-rich, well-functioning ocean that provides us with much of what we need for a secure and liveable future.

Fin whales, sea turtles and other returnees

It must have been a breath-taking sight: on 20 March 2019, a group of marine biologists on board a research vessel in Antarctica sighted not five or ten but some 150 southern fin whales (*Balaenoptera physalus quoyi*) hunting for food off Elephant Island. Their mouths gaping wide, the rorquals dived and surfaced again and again, the jets from their blowholes forming a wall of dancing fountains on the surface of the sea.

Never before had the researchers seen so many southern fin whales congregating at a single site. For too long, the population of these ocean giants – a subspecies of fin whale that can reach an average length of up to 22 metres – was far too small for that. During the era of commercial whaling, stocks had been depleted, the whales hunted almost to extinction. Between 1904 and 1976 alone, whalers slaughtered more than 700,000 fin whales in the Southern Ocean – mainly in the waters around the northern Antarctic Peninsula, where



6.1 > In the waters off Antarctica's Elephant Island with their abundance of krill, southern fin whales now gather again in their hundreds to feed together.

krill and other prey are in plentiful supply. Fin whales have gathered at these feeding grounds since time immemorial.

In the two decades after commercial whaling ended, however, observers from the International Whaling Commission (IWC) only sighted southern fin whales in this area in isolated cases. It seemed that the rorquals had vanished from their traditional feeding grounds. It took almost 40 years for the whale population to recover to such an extent that the fin whales were able to return to their traditional feeding grounds in their hundreds again.

The example of the southern fin whales proves that even depleted populations can recover if the causes of their decline are eliminated. And there have been reports of similar successes elsewhere in the past two decades: of humpback whales off the east coast of Australia, of sea otter populations in the Canadian province of British Columbia, of leatherback sea turtles nesting in the Virgin Islands, and of coastal areas where degraded or vanished mangrove forests, salt marshes, kelp forests or seagrass beds have been successfully re-established or replanted at their original sites.

The key pillars of successful marine biodiversity conservation

Experts have analysed many of these individual cases to determine which conditions must be put in place in order for heavily overexploited marine biocoenoses to recover. They found, firstly, that species and habitat loss can be halted only if all the causal stressors – not just one – are eliminated or substantially mitigated. This in turn requires holistic solutions that ultimately aim to fully satisfy all the basic needs of the marine organisms once more. These basic needs include clean water, adequate nutrition and an intact and protected habitat in which species can reproduce and raise their young.

Secondly, successful biodiversity conservation requires the help and support of a multitude of stakeholders at various levels. It is therefore more likely to involve coordinated action than one-off initiatives. The analysis also showed that restoring heavily degraded habitats or



depleted populations is a more promising approach than attempting to re-establish species and ecosystems that have vanished completely.

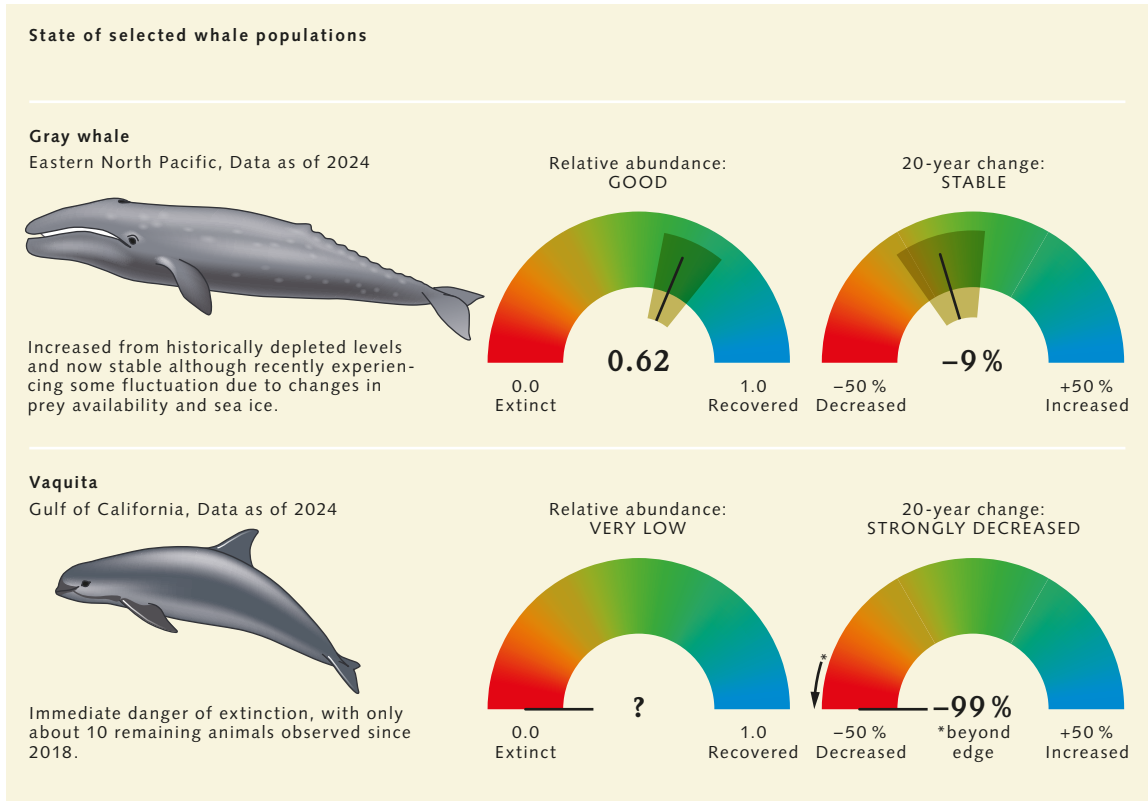
Factors which have contributed to successful marine biodiversity conservation in recent decades include measures such as banning or strictly regulating the hunting of marine organisms, various sustainable fisheries management strategies, and measures to reduce marine pollution and protect and restore significant coastal and marine ecosystems.

Regulating the hunting of marine organisms

The population of southern fin whales was able to recover because in 1982, the parties to the International Convention for the Regulation of Whaling (ICRW) voted by a majority to impose a moratorium on the hunting of great whales. The moratorium came into force in 1986 and soon spelled the end for commercial whaling. Nowadays, the International Whaling Commission (IWC) – the ICRW's governing body – keeps a precise record of the trajectories of various whale populations. It also collects and evaluates information about current risk factors such as underwater noise, ship strikes (collisions), marine pollution, diseases, entanglement in fishing lines, traps or nets, and the impacts of climate change.

6.2 > On 2 December 1946, government representatives from 42 nations met in Washington D.C. in the USA to sign the International Convention for the Regulation of Whaling. Since then, a further 46 countries have signed this international treaty.

6.3 > The International Whaling Commission's Scientific Committee monitors the trajectory of individual whale populations using computer modelling. The results show that the number of gray whales in the Eastern North Pacific is slowly decreasing, while the vaquita is in immediate danger of extinction.



Strict international rules also apply to the trade in captured marine organisms; these rules are set out in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (Washington Convention – CITES), which entered into force on 1 July 1975. Its purpose is to ensure that international trade in specimens of wild flora and fauna does not endanger the species' survival. To that end, CITES monitors international trade in wild flora and fauna on one of three species lists in the Appendices to the Convention. Traders wishing to import or export specimens of these species must apply for a CITES permit. A permit may be refused, depending on which of the three protection categories applies to the species concerned.

Also important for the survival of threatened marine species are measures that mitigate major sources of risk. Such measures can include new-style fishing nets with built-in escape hatches for sea turtles (bycatch), a speed limit for boats and ships crossing whale migration routes

(collision risk), or artificial bubble curtains that reduce infrasound from marine construction or piling works (underwater noise).

The corresponding regulations and standards are generally adopted at the national level. One of the best-known rafts of legislation is the USA's Marine Mammal Protection Act (MMPA), enacted in 1972, which aims to protect marine mammal species from localized extinction. The European Union's Habitats Directive is broader in scope. In force since 1992, it requires EU member states to maintain and restore natural habitats and wild flora and fauna by establishing a coherent network of special areas of conservation on land and at sea.

Sustainable fisheries management

With the aid of various measures to regulate fishing, it has been possible to rebuild depleted local and regional fish stocks in some regions of the world. Limited fishing quotas and fishing periods, fishing bans in selected zones,

6.4 > To maintain native populations of the hawksbill sea turtle and green sea turtle, the Royal Thai Navy operates sea turtle nurseries around the country. The turtles that are bred here are regularly released into the wild.



6.5 > Selected marine species that appear on the three species lists in the Appendices to the Washington Convention (CITES).

Appendix I	Appendix II	Appendix III
Species that are threatened with extinction. CITES prohibits international trade in specimens of these species except when the purpose of the import is not commercial, for instance for scientific research.	Species that are not necessarily now threatened with extinction but may become so unless trade is closely controlled. International trade may be authorized by the granting of an export permit or re-export certificate.	Species included at the request of a Party that already regulates trade in the species and that needs the cooperation of other countries to prevent unsustainable or illegal exploitation. International trade in specimens of these species is allowed only on presentation of the appropriate permits or certificates.
Sea turtles; manatees and dugongs	All stony coral species; all seahorse species; all giant clam species; all black coral species	Walruses (Canada)
Sperm whales; Baird's beaked whales; bowhead whales; North Atlantic right whales; humpback whales; fin whales; sei whales; other baleen whales	All dolphins not listed in Appendix I	Clipperton angelfish (France)
Irrawaddy river dolphins; Australian snubfin dolphins; dolphins belonging to <i>Sotalia spp.</i>	All requiem shark species; great white sharks; whale sharks; all hammerhead sharks; other species of shark and ray	Brown sea cucumber (Ecuador)
Totoaba fish	West Greenland stock of minke whales	Red corals (China)

regulations on permitted fishing gear, and agreements on the integrated and sustainable management of marine regions and their resources have proved particularly effective in this context.

It was sustainable fisheries management that laid the foundation for the return of bluefin tuna (*Thunnus orientalis*) in the northern Pacific Ocean, for example. As a result of heavy overfishing in the 1990s and 2000s, stocks of this coveted predatory fish had declined to such an extent that the few remaining specimens amounted to just two per cent of its potential unfished level in 2009 to 2012. In 2011, the fishing nations concerned responded to this dramatic decline by reducing their catch of both juvenile and larger bluefin and henceforth coordinating their approach. As a result, more juveniles reached sexual maturity and were able to reproduce. Stocks experienced a remarkable recovery: by summer 2024, the population had rebounded to around 20 per cent of the potential unfished stock – ten years earlier than originally projected.

Measures to reduce marine pollution

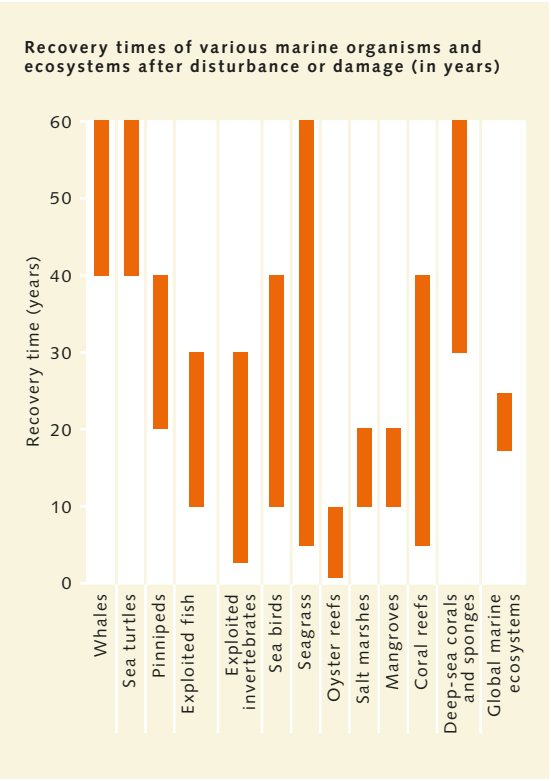
Various national provisions aimed at improving water quality in rivers and inshore waters have helped to reduce pollutant and nutrient inputs to coastal waters, mitigating the risk of unwanted algal blooms and hence the formation of oxygen-depleted zones. International agreements such as the Stockholm Convention on Persistent Organic Pollutants (POPs) have resulted in the banning or strict regulation of the use of certain chemicals that accumulate in the environment, so less of these pollutants enter the sea.

The International Convention for the Prevention of Pollution from Ships (MARPOL) has also had an effect. The Convention and a protocol thereto entered into force on 2 October 1983. It includes regulations aimed at preventing and minimizing pollution from ships – both accidental pollution and that from routine operations. The 1992 amendments to Annex I require shipping companies and shipbuilders, from 1996, to construct oil tankers with double hulls in order to increase safety in

the transportation of crude oil and petroleum products by ship. If the outer hull is ruptured in a collision or stranding, the second hull is there to prevent oil spillage. The MARPOL Convention also includes specific provisions on the construction, equipment and operation of chemical tankers.

In addition to technical provisions and legislation aimed at improving water quality, projects to restore marine habitats that naturally filter particles, nutrients and pathogens out of water bodies have also proved their worth. These are, specifically, mussel beds, seagrass meadows, salt marshes and mangrove forests.

In the extended harbour area of the US metropolis of New York City, for example, an environmental organization is attempting to reintroduce American oyster (*Crassostrea virginica*) at 18 sites. At one time, the natu-



6.6 > How quickly do marine species recover from harmful impacts or events? That depends on their reproductive cycle. Oysters reproduce rapidly, but it takes 20 to 40 years for a few individual seals (pinnipeds) to develop into a colony.



ral oyster reefs here covered almost 900 square kilometres – 100 square kilometres more than the area of the city. The oyster reefs vanished in the 1920s, however, killed off by overfishing over the course of more than a century and by severe pollution of the rivers discharging into the sea.

Although rainwater and road runoff still enter the harbour via the city's drainage system, the situation has been gradually improving over the last 20 years or so. Oysters can now survive along the New York shoreline again, and if the reintroduction is successful, water quality is likely to further improve. As suspension feeders, the American oyster removes nutrients from the water column that would otherwise drive algal growth and the formation of oxygen-depleted zones. The oysters filter surplus nutrient-rich particles out of the water, as well as microalgae that have grown as a result of eutrophication. Targeted oyster cultivation is thus seen as an innovative and cost-effective measure for coastal and water resources management.

6.7 > Volunteers from a marine conservation organization, the Billion Oyster Project, start work on restoring an oyster reef in the harbour of the US city of New York. Healthy oyster reefs filter water, provide food and habitat for hundreds of species and protect the shoreline from storm and flood damage.



6.8 > In 2016, the government of the Australian state of Queensland purchased large tracts of land within the Normanby River catchment in order to halt overgrazing. The conservation measures aim to reduce the sand and other sediment inputs from the river that cause turbidity of the water masses on the Great Barrier Reef.

Meanwhile, on dry land, the government of the Australian state of Queensland was seeking a solution to the high sediment and nutrient inputs to the Great Barrier Reef, caused mainly by overgrazing on a large cattle station in the northern part of the state. In areas where overgrazing had exposed the soil, runoff of sand and other particulate matter frequently occurred during rainfall. These particles were then washed down the Normanby River into the northern coastal sea, reducing its water quality, with particularly adverse impacts on seagrass beds and the numerous corals in this marine region. To overcome the problem, the state of Queensland purchased the cattle station in May 2016. It phased out livestock farming, transformed the grazing land into a nature refuge and implemented various on-site measures to control erosion. In addition, since 2017, the government has been pursuing a specially designed programme to improve water quality on the Great Barrier Reef and, among other things, provides funding for training and research on minimizing erosion in farming.

Conservation and restoration of significant habitats

Over the past 30 years, countless initiatives have been launched to conserve and restore marine habitats around the world. They focus particularly on coastal ecosystems such as mangrove and kelp forests, seagrass beds and salt marshes, and mussel and tropical coral reefs. The most successful were conservation and restoration projects that were planned and implemented jointly by experts and local communities, covered as large an area as possible and whose funding was secure. These projects not only take scientific and indigenous knowledge into account; they also factor in that coastal communities need to harvest a certain amount of fish, shellfish, timber and other resources from the ecosystems in order to generate income. What is needed, therefore, is an adequate knowledge base, mutual agreements, and powerful incentives for local communities to act prudently and only extract as much food and material as the ecosystems can spare.

There is no “one-size-fits-all” solution for restoring marine habitats. In the past, many attempts to replant mangrove forests failed, either because they were planted

in the wrong place or the wrong species were used. The experts therefore advise against actions of an ad hoc nature. Instead, each restoration measure should be well thought-out and planned and implemented in line with local conditions and needs.

An impressive success rate of 88 per cent has been chalked up by projects that have attempted, over the last 50 years, to free islands from the scourge of invasive rats. Wherever these efforts have been successful, not only have seabird colonies recovered: numbers of lizards and insects have also increased. Eradication campaigns of this kind have been carried out on the Galápagos island of Floreana, for example, as well as on South Georgia in the South Atlantic, one of the most important breeding sites for king and macaroni penguins.

How long do marine organisms and habitats take to recover?

The more extensive the human-induced damage sustained by a marine ecosystem or population of marine organisms, the longer it will take for them to fully recover. In numerous cases, the extent of the degradation or population decline is severe.

6.9 > Seabirds such as the gray-headed albatross (*Thalasarche chrysostoma*) have benefited from the systematic eradication of rats from the island of South Georgia in the South Atlantic.



6.10 > Staghorn corals (*Acropora*) are keystone marine species: with their many tiny “antlers”, they provide habitat and hiding places for other small marine organisms. Tropical coral reefs host an estimated 25 per cent of all marine species.



Seabird counts in the United Kingdom and Ireland have revealed that populations of eleven of 21 native seabird species – in other words, over half – have declined by more than ten per cent since 2002. The ornithologists recorded population increases for just five species. The number of threatened warm-water coral species increased from 33 per cent to some 44 per cent between 2008 and 2024. This means that of the 892 known reef-building tropical coral species, at least 340 species now fall into one of the three IUCN Red List categories of threat. Among these, 56 species are “vulnerable”, 251 are “endangered” and 33 are “critically endangered”. An important point for any reader wishing to check the figures here: coral species for which the experts had deficient observation data were also classed as “vulnerable”.

How quickly can populations start increasing again? That partly depends on the speed at which the species reproduce. This then raises other questions: how many young are born in each reproductive cycle? How many of them ever reach sexual maturity? And how many older members of the population die within the same period? The great whales, for example, reach sexual maturity

later than seals. In part, this explains why fin whales, blue whales and related species need more than 100 years of intensive protection to rebuild healthy populations after the calamitous whaling era, whereas elephant seals and fur seals, which were also hunted intensively, were forming large colonies again after just a few decades.

Sea turtles also take up to 100 years to recover from population decline. However, experience has shown that some populations are capable of far more rapid growth. In Hawaii, for example, the number of green sea turtles (*Chelonia mydas*) – strictly protected since 1974 – had increased sixfold by 2016. Two years after this reported success, however, a hurricane hit the turtles’ main nesting site, and wind and waves washed away large areas of the low-lying atoll. Will the turtles recover from this setback? Only time will tell.

Planning for present and future impacts of climate change

The example of the green sea turtles illustrates the extent to which increasingly frequent weather extremes and

other climate change impacts are jeopardizing the recovery of marine species and impeding effective conservation measures. The scale of these extremes and impacts also explains why the increase in great whale populations in the Southern Ocean does not, by any means, imply that their survival is guaranteed. The future of these recovering populations is uncertain, experts at the Scientific Committee on Antarctic Research note; they too identify climate-related changes in the ecosystem of the Southern Ocean as the cause.

In regional and global research networks and programmes, scientists from various disciplines are monitoring climate change and its impacts on the marine environment and forecasting the changes that can be expected in the next decades and centuries, depending on how quickly the Earth heats up.

In the international Fisheries and Marine Ecosystem Model Intercomparison Project (FishMIP), climate and ecosystem modelling experts combine the results of nine global ecosystem models with climate models that project changes in variables such as greenhouse gas emissions,

water temperature, biomass production and the strength of the major ocean currents.

Among other things, they have found that by 2050, many of the world’s marine regions could see their fish biomass drop by more than ten per cent if humankind continues to produce such high greenhouse gas emissions and climate change continues apace. By 2100, the decline could even reach 30 per cent or more if there is no reduction of emissions and global temperatures rise by three to four degrees Celsius above pre-industrial levels.

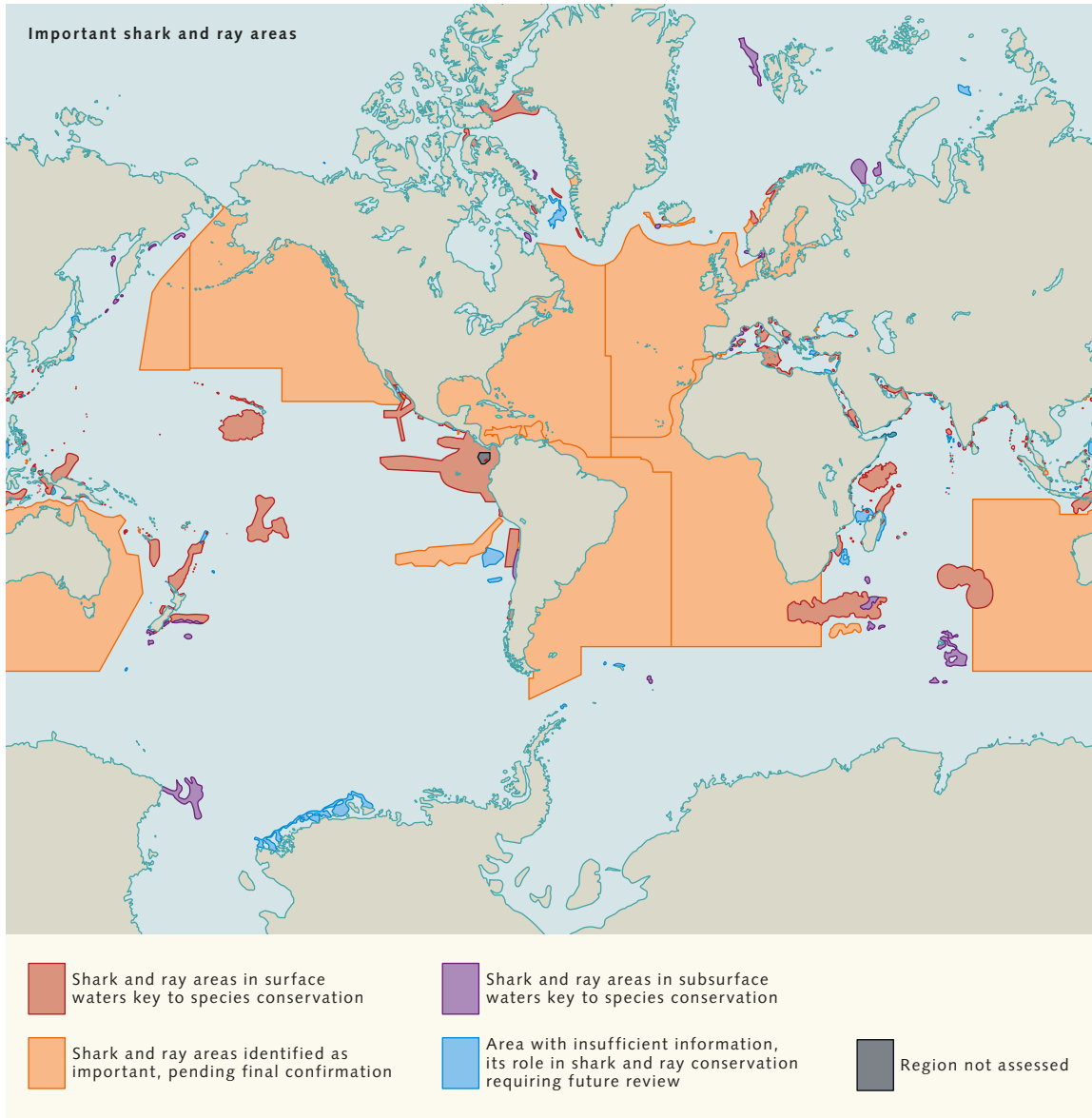
Detailed projections such as these are urgently needed so that fisheries and other planned uses of the ocean can be adapted to the anticipated changes in environmental conditions. Identifying areas of the sea where marine heatwaves will occur more frequently in future or where ocean acidification and sea levels will rise dramatically also enables experts to decide where investment in costly restoration of salt marshes and other coastal ecosystems is worthwhile – and where projects of this kind would be very likely to fail due to climate change.

Population recovery
Experts identify various stages of recovery, depending on population growth. A partial recovery means that population figures increase by ten to 50 per cent. A rise of 50 to 90 per cent is described as a substantial recovery, while a full recovery requires population growth of more than 90 per cent.



6.11 > During the summer drought in 2018, the surface of the German Wadden Sea’s tidal flats dried out completely in some places. These arid conditions put ground-dwelling organisms under extreme stress.

6.12 > In order to protect sharks and rays effectively, it is essential to know which regions of the world's oceans are frequented by these predatory fish. An international team of experts took on the task of identifying and mapping these areas of the sea.



Restoring marine flora and fauna – some guidance

Due to the resilience of many species and the successes achieved in restoring marine ecosystems, researchers are hopeful that marine flora and fauna can be rebuilt if simultaneous efforts to limit global warming and mitigate the impacts of climate change are successful. The experts recommend that every effort be made, above all,

to increase the abundance of important marine habitats and keystone species and halt the degradation of biocoenoses on the seabed (bottom trawling, filling, laying of pipelines, cables, etc.).

A defining characteristic of significant habitats is that they serve as a breeding ground, nursery, refuge and food source for many species associated with the ocean. Examples are coral reefs, seagrass beds, mangrove forests, salt marshes and kelp forests, as well as many

areas of the seabed at various water depths, including on submarine mountains. A keystone species, in this context, means a species that has a disproportionately large impact on the environment relative to its abundance and plays a key role in maintaining the functions of marine ecosystems.

If keystone species vanish from their ecosystem, this can lead to dramatic shifts within the community and radically change ecosystem dynamics. Identifying and preserving keystone species is therefore crucial for ecosystem resilience and stability – on land and in the ocean. Unfortunately, experts do not always agree on a definition of “keystone species” or which species should be described as such. In essence, however, keystone species fall into the following three categories:

- *Habitat-forming species, also known as ecosystem engineers:* Through their growth and distribution, they contribute to the creation of new three-dimensional habitats that can be colonized by other species. This category includes seagrasses, macroalgae, corals, mangroves, salt marshes, reef-building mussels and glass sponges.
- *Prey species:* They generally occur in large schools and serve as a food source for a wide variety of predators. Without Antarctic krill, for example, baleen whales, penguins, fish, seals and other seabirds in the Southern Ocean would starve. Other typical prey species are schooling fish such as herring, anchovy and sardine. In Arctic waters, copepods play a key role in the food web.
- *Predatory species that have a disproportionately large impact on the structure of their community's food web:* In simple terms, these are predators that keep other species in check and thus maintain a balance within their habitat. They include sea otters, which feed on sea urchins; limpets (Patellidae), which graze on algae on rocky shores; sea stars, which hunt mussels in the intertidal zone; and orcas – predators which patrol Prince William Sound off the west coast of North America, where sea otters are their preferred prey.

There is, however, also some discussion as to whether keystone species should, perhaps, be defined as a species complex on which the structure, functioning and all the various characteristics of the entire ecosystem depend. This refers to core species within an ecosystem that interact with each other in predator-prey relationships and on whose interaction all the other species are dependent. An example of a species complex is the interplay between microalgae, seagrass, zooplankton, invertebrates, hogfish (*Lachnolaimus maximus*), snappers and other predatory fish on the Media Luna Reef off the coast of Honduras.

What action needs to be taken to strengthen keystone species and habitats in the ocean? There is a wealth of knowledge and a consensus among experts here.

Firstly, it is essential to preserve the remaining intact marine and coastal areas and protect them from more intensive use. In densely populated coastal areas, this may prove challenging because very few healthy, unaltered biocoenoses still exist. On the remote shores of North and South America, in the Arctic and Antarctic, and in parts of Africa and Australia, however, there are certainly still some intact species-rich marine ecosystems that should only be used sustainably, if at all.

Secondly, all the conservation measures that have already been initiated and are proving effective must be continued and their scope expanded. There is a particularly urgent need for action to combat the contamination of the marine environment by new persistent pollutants such as “forever chemicals” and plastic. Due to the slow recovery of many keystone species and habitats, it may take many decades for the hoped-for successes to be achieved.

Thirdly, for all degraded key marine ecosystems, rapid and mutually reinforcing conservation and rebuilding measures must be taken – also to avoid potential tipping points. If these tipping points are crossed, there is a risk of irreversible ecosystem collapse. The packages of measures must aim to protect and restore species and habitats in all their diversity and functionality, limit all forms of use to a sustainable level, reduce all forms of marine and coastal pollution or prevent them entirely,

Scenarios conducive to achieving the best aspirational outcomes towards rebuilding marine life

Rebuilding wedges	Seagrass	Coral reefs	Fisheries	Megafauna
Protect species	Low	Low	Critical	Critical
Harvest wisely	Low	High	Critical	Critical
Protect spaces	Medium	High	High	High
Restore habitats	High	Medium	Medium	Medium
Reduce pollution	Critical	Critical	Medium	Medium
Mitigate climate change	High	Critical	High	High
Recovery targets by 2050	Substantial to complete	Partial to substantial	Substantial to complete	Substantial
Key actors	Government, civil society and NGOs	Government, tourism operators, fishers organizations, civil society and NGOs	Government, fishers organizations and civil society	Government, fishers organizations, NGOs and civil society
Key actions	Reduce nutrient inputs, protect, avoid physical impacts, and conduct restoration projects	Ambitious reduction in greenhouse gas emissions, reduce excess sediment and nutrient inputs, improve water quality, protect reefs, rebuild food webs and restore damaged reefs	Reduce overfishing, bycatch and incidental mortality, ban destructive fishing practices, protect spawning/breeding areas and nursery grounds, and remove perverse incentives	Protect, reduce bycatch, reduce incidental mortality (ship strikes, entanglement, ghost gear), reduce pollution (noise, debris, chemical), protect breeding/haul-out sites, safeguard migration routes and reduce competition with fisheries

Rebuilding wedges	Seagrass	Coral reefs	Fisheries	Megafauna
Key opportunities	Blue Carbon and coastal defence strategies against storms and sea-level rise, links to management for enhancing water quality, food provision and biodiversity strategies	Link to coastal defence, food provision and biodiversity strategies	Sustainable seafood, MSC-certified fisheries, develop sustainable aquaculture to reduce pressure on wild stocks	Marine wildlife tourism, cultural benefits and ethics
Key benefits	Protect shoreline from erosion and rebuilding biodiversity and fisheries	Provision of fish, protection from sea-level rise and storm surges, recreational and cultural benefits	Improved quality and quantity of seafood supply	Increased connectivity among ocean basins, enhanced nutrient cycling and ocean productivity
Roadblocks	Infrastructure (for example, areas occupied by harbours), severe and frequent heat waves with climate change	Dependence on climate change trajectories, mortality with ocean warming, ocean acidification and increased cyclone activity	Cumulative impacts from fishing, pollution, habitat alterations, changing distribution ranges, habitats and food due to climate change	Losses due to extinction, continued impacts from ship strikes, pollution, habitat alterations, changing habitats and food due to climate change
Remedial actions	Compensatory restoration, improve water quality and reduce local stressors	Ambitious efforts to mitigate climate change and manage to improve resilience	Create MPAs as refuge sites, restore coastal breeding/nursery sites to aid recovery, develop breeding programmes for critically endangered species	Create MPAs as refuge sites, safeguard migration routes, restore coastal breeding/nursery sites to aid recovery and develop breeding programmes for critically endangered species

6.13 > Preserving and restoring marine habitats is not only good for marine organisms; ultimately, and above all, it benefits humankind as well. If strategies like this are successfully implemented worldwide, the recovery of marine life could be achieved by 2050.



6.14 > A pod of humpback whales gorges on Californian anchovy (*Engraulis mordax*) in Monterey Bay off the coast of the US state of California. Once a heavily polluted stretch of coastal water, the Bay is now known as the “Serengeti of the Sea”.

and effectively mitigate climate change and its numerous impacts.

In order to achieve these objectives, responsible, integrated action by policymakers, business, the scientific community and civil society is required at all levels. With consistent, knowledge-based marine management, the researchers say, humankind may yet succeed in strengthening marine biodiversity on a lasting basis so that by 2050, many significant marine ecosystems are able to recover, with increased resilience, and life in the ocean can once again provide the multitude of services that are essential for human survival.

The need for dynamic marine management

What might sustainable, biodiversity-boosting marine management look like? There is no universally valid answer to this question. The packages of measures adopted must be tailored to local conditions – while also aligning with regional, national and international framework strategies. In view of the growing frequency of weather extremes such as storms and marine heatwaves, and with climate-related shifts in community composition, dynamic forms of marine management that facilitate prompt and far-sighted action are required.

If, for example, a coastal area is affected by a prolonged heatwave that inhibits the reproduction of native mussel beds or fish populations in full or in part, it would be sensible to cancel the planned mussel harvest or fishing season in order to prevent any further weakening of the biocoenosis. Similar decisions may be required if ocean warming causes herring or other schooling fish to spawn prematurely, before the blooming of the microalgae that serve as their larvae’s food supply. Conditions such as these can result in the loss of an entire year’s offspring – with dramatic impacts on the population as a whole.

Timely and, above all, science-based action in such scenarios is conditional upon three sets of measures, however: firstly, the environmental parameters and ecosystems in sea areas with human use must be closely monitored and all changes documented. Secondly, techni-

cal staff are required to evaluate the data and produce recommendations for action. In a third step, these recommendations must then be implemented, with monitoring of compliance – which requires other processes and rules and is, in turn, conditional upon all participants and stakeholders showing the necessary insightfulness.

Dividing the sea into zones

If marine life is to recover while human claims on the ocean simultaneously increase, the division of the ocean into separate zones is likely to be unavoidable. On the one hand, well-functioning and interconnected marine conservation areas are needed in which marine biocoenoses are genuinely protected from direct human impacts. On the other, some marine regions will have to be intensively used. Even here, however, marine biodiversity can benefit if the various forms of use are coordinated and their environmental impacts are balanced out. Monterey Bay on the Pacific coast of the US state of California shows what this sustainable use of the ocean might look like.

Around 90 years ago, the sea here was a stinking cesspool. Wastewater was discharged untreated into the ocean. The many fish canning factories dumped their waste in the Pacific. Sea otters, once native to the Bay, were now close to extinction, and the kelp forests had largely vanished. When the sardine fishery collapsed from the latter half of the 1940s onwards due to massive overfishing, and the canning factories were forced to close, it seemed that the fate of the local marine ecosystems and, with them, the region as a whole was sealed.

A change for the better began with a shift in mindset on the part of the local community. In October 1984, a new marine aquarium opened in Monterey; since then, it has kept locals and visitors informed about the importance of local marine flora and fauna. New legislation was adopted to regulate fishing, and in September 1992, the coastal waters from San Francisco in the north to San Luis Obispo in the south were designated a protected area, where the discharging of wastewater, drilling for oil and gas, marine mining and the hunting of marine mammals

6.15 > Sunlight pierces the interior of a smokehouse belonging to the Nisga'a, an indigenous people on Canada's Pacific coast. In spring, the coastal dwellers catch and process eulachon (*Thaleichthys pacificus*), which migrate in large schools from the sea into the Nass River in order to spawn there.



are prohibited. Marine research institutes were established in the Bay area.

Nowadays, fisheries experts from Monterey Bay Aquarium collaborate with local fishermen: together, they inform the public which species of fish should be eaten at which time of the year, where fish and shellfish can be purchased from local and sustainable fisheries, and which local restaurants have them on the menu.

All these conservation measures are having an effect. Not only have the fish and otter populations and kelp stocks recovered over time. Monterey Bay has now been dubbed the Serengeti of the Sea: alongside blue, gray and humpback whales, the Bay now hosts at least 525 species of fish, more than 180 coastal and seabird species, four species of sea turtle, around 450 different species of algae, and numerous and diverse invertebrates. This abundance of species, along with California's beautiful beaches, attracts holiday-makers and sports enthusiasts

from all over the world to the Pacific coast. Ocean tourism is now a major source of income for local people. The balance between marine conservation and use will only function, however, as long as the impacts of climate change on life in and near the ocean can be kept to a minimum. Sadly, it does not augur well at present.

Utilizing coastal indigenous peoples' traditional knowledge

In the search for solutions that enable the sea to be used in ways which promote biodiversity, researchers are increasingly exploring the traditional knowledge of coastal indigenous peoples, integrating these communities' expertise into research projects and involving them in decision-making processes. Many indigenous peoples have made sparing use of the ocean's resources since time immemorial and are privy to powerful lore and rules

that are not written down in any textbook or academic paper.

This new co-creation of ocean knowledge does not mean, however, that indigenous communities do not also pursue their own commercial interests in their management of marine resources. On Canada's northeast coast, for example, the indigenous-led regional government and Canada's national parks administration (Parks Canada) agreed to adjust the boundary of a newly planned marine conservation area so that local fishing families could continue to fish for mussels, shrimp and flatfish with trawl nets in their traditional fishing grounds. In the rest of the Inuit-led marine conservation area, this highly destructive fishing practice will be banned in future.

From individual to collective responsibility

Successful nature and marine conservation often starts with a growing awareness on the part of a few individuals, followed by their commitment to engage actively for the conservation of species and habitats. They may be local environmental activists who protect sea turtle beaches and eggs or protest against destructive practices. However, they may also be researchers who voice their concerns on the basis of their monitoring or research findings, or persons in leadership roles who have their own conception of what constitutes sustainable use of the marine environment and are willing to work towards, and implement, the necessary policy, legislative and management reforms.

The transformation that is required may be initiated by grassroots projects whose agenda or actions then have an impact on the political level (bottom-up), or conversely, by the adoption of reforms at the political level, whose provisions must then be implemented nationally, regionally and locally (top-down). A current example of a top-down process is the European Union's Marine Strategy Framework Directive, adopted in 2008. It requires coastal states in the EU to develop a national marine strategy to assist in achieving or maintaining good environmental status in marine waters. The national strategies and associated programmes of measures are reviewed and updated every six years.

A worthwhile investment

Protecting marine habitats and biodiversity and restoring them wherever they have been degraded requires collective action and adequate financial resources. It is estimated that the international community will need to invest at least ten to 20 billion US dollars annually in order to extend existing conservation measures to cover around half the world's ocean. Additional resources would be required to fund the necessary restoration measures. The financial return on this investment would be substantial, however, amounting to roughly ten US dollars for every dollar invested. More than a million new jobs would be created at the same time.

Investing in marine conservation pays off, as projects in Chile and Australia show. In both countries, the designation and implementation of marine protected areas have led to an increase in biological diversity, greater abundance of fish for human consumption, higher incomes for local communities and – in Australia's case – higher revenues from tourism. Worldwide, wildlife tourism – safaris, whale-watching and other wilderness experiences on land and at sea – contributed 120 billion US dollars to global GDP in 2018. Around 21.8 million people were employed in this sector over the same period.

Healthy marine ecosystems could offer additional economic benefits for fisheries and aquaculture facility operators, as well as for the insurance industry. With sustainable fishing, breeding and farming methods, the former can potentially achieve a sixfold increase in the amount of food harvested from the ocean compared with the present level – with a smaller environmental footprint. Meanwhile, the insurance industry could save many billions of dollars annually if intact coastal ecosystems were in place to lessen the impact of storm surges and thus limit the damage they cause.

A global partnership

Restoring marine ecosystems, some of which are heavily degraded, requires a global multi-stakeholder partnership. These diverse stakeholders particularly include

A third conservation goal: Genetic diversity for better adaptation prospects

Until recently, species conservation efforts focused mainly on rebuilding species with low population numbers, or at least protecting them from further decline. These days, however, experts are aware that species require not only a healthy population size for their long-term survival, but also a great diversity of genetic information. This means that individuals within a species should have slightly different genetic makeup. These genetic variations allow a species to adapt more rapidly to changes in their environment. For example, if seawater warms up as a result of climate change, or new diseases or predators appear, high genetic diversity within a species is the foundation that enables at least a small number of individuals to overcome this new challenge so that the species as a whole can survive.

With the decline of species abundance, however, genetic diversity within the remaining populations also decreases. New research findings show that as a result of the widespread overexploitation and degradation of natural habitats, even those species of flora and fauna whose population figures are still comparatively stable have lost much of their genetic diversity. This particularly applies to birds and mammals. In view of these biodiversity losses, experts are talking about silent extinction, as the genetic impoverishment of species is invisible. The research also reveals that not all nature and marine conservation measures help to rebuild species’ genetic diversity. However, this diversity does increase if, for example, successful efforts are made to expand species’ habitats and protect them effectively from human impacts; if declining populations are enhanced and strengthened with the addition of genetically different individuals from healthy stocks; or if two separate populations are connected by corridors so that the members of the two populations can come together and reproduce with partners with different genetic information.

The great importance of genetic diversity for the preservation of life on Earth has now been recognized by the international community as well. In the Kunming-Montreal Global Biodiversity Framework, the 196 Parties to the Convention on Biological Diversity (CBD), in December 2022, identified the maintenance of genetic diversity of all species as the third pillar of the long-term strategy. The other two are the conservation and restoration of habitats, and measures to halt species extinction by 2050 and increase the abundance of wild species.



6.16 > Genetic diversity helped the flat periwinkle (*Littorina obtusata*) to defend itself against a new enemy. When the common shore crab (*Carcinus maenas*) migrated into the Gulf of Maine, the local periwinkles grew thicker shells to protect themselves from the predatory intruder.

governments, businesses, artisanal fishermen and others whose livelihoods are directly dependent on the sea, as well as civil society. They must all reach agreement on a knowledge-based action plan that comprises the following elements:

- *clear guidelines for equitable marine conservation policies and related decision-making processes* (including provision for local community participation and free access to all information of relevance to the process),

- *adequate financial resources,*
- *coordinated agendas for marine research and for education providers,*
- *clearly defined objectives and measurable performance indicators,* and
- *a business plan showing how the investment will pay off in monetary terms.*

In addition, proven experts are required to provide the knowledge and technologies needed to rebuild marine biodiversity and habitats. And lastly, adequate human

resources must also be available to deliver the agendas.

Our fundamental conception of how we use the seas must also change. While this previously focused primarily on individual benefit or corporate profits, a new direction of travel is needed for the future. Human communities should utilize the ocean solely in ways which strengthen

marine ecosystems and, in an ideal scenario, create other additional benefits – namely, increasing everyone’s prosperity, or motivating decision-makers to make further efforts to rebuild marine life. The successes achieved in species conservation to date reinforce the message that healthy and intact marine habitats are an entirely realistic goal.

CONCLUSION

A safety net for ocean life

Marine conservation works. This is evident from the trajectory of numerous marine species and habitats that were almost eradicated or suffered extensive human-induced degradation but are now recovering thanks to conservation measures. Indeed, according to experts, the resilience and recovery potential of marine ecosystems are so high that humankind may succeed in largely restoring the currently severely weakened marine habitats by 2050.

For a successful recovery, a mix of proven marine conservation measures, innovative and participatory approaches to marine management and effective climate policies is required. Other prerequisites are adequate funding, multidisciplinary research expertise, clear policy frameworks and broad support at all levels of our society and across multiple countries. Experts are talking about a global partnership to rebuild marine life. This must be initiated and addressed immediately if the ambitious goal – healthy marine habitats by 2050 – is to be achieved.

Marine conservation measures previously aimed primarily to mitigate or entirely prevent the immediate risks to threatened species and habitats. This was achieved by strictly regulating or prohibiting the hunting of certain species, substituting sustainable for destructive fishing methods, and combating specific sources of marine pollution, for example.

Communities also began to restore weakened or degraded coastal and marine ecosystems and protect them more effectively.

The successes that these measures achieved certainly stand up to scrutiny. Overall, however, the outcomes by no means suffice to preserve marine species abundance and biodiversity. At a time of dramatic climate change and species turnover, coordinated and dynamic marine management is needed, with alignment of its individual elements and with all groups impacted by the potential measures involved in its planning.

Indigenous knowledge has a role to play in ensuring the success of this marine management approach, along with a recognition that some sea areas will be intensively used in future. Their total area is likely to be smaller than at present because more protected areas are to be designated in future years. However, it will also be crucial to utilize the ocean outside the protected areas in a way which inflicts minimal or zero damage on the marine environment.

If this transformation is successful, ecosystems – even in intensively used marine regions – can recover and, over the long term, provide the multiple services that we have come to expect and rely on. The requisite knowledge is available. Our task now is to set the right priorities and take action.

7 When marine sanctuaries benefit biodiversity

> Marine protected areas (MPAs) are regarded as a key tool in combating overexploitation and species extinction in the oceans. Their purpose is to protect marine organisms and their habitats by prohibiting or regulating certain human activities. Their number has increased significantly in recent years, and yet in many places, success remains elusive, for all too often, the planned conservation measures are implemented and monitored half-heartedly or not at all.



Setting up marine protected areas: Doing it right

> The vast majority of marine protected areas around the world are currently missing their conservation targets and failing to effectively protect local marine organisms and habitats. This lack of success has prompted experts to look more closely at the conditions that must be in place for ocean life to benefit from protected zones. The findings are clear: jointly developed conservation plans and a wealth of scientific knowledge, as well as funding, human resources and regular monitoring of outcomes, are needed in order to halt species decline in these marine regions.

The Dominican Republic: Leading the way

The government of the Dominican Republic had some good news for the international community on 11 April 2024, when it announced that it was granting protected status to 54,795 square kilometres of ocean on the Beata Ridge sea mount off the country’s south coast, effective immediately.

This area of the ocean plays a vital role for many species in the Caribbean Sea, particularly as a migration route and feeding ground for sperm whales (*Physeter macrocephalus*), hawksbill sea turtles (*Eretmochelys imbricata*), sharks, various species of dolphin, and seabirds, including the now rare black-capped petrel (*Pterodroma hasitata*). Many of them also give birth to their young here.

In addition, the government announced plans to enlarge the area of the Marine Mammal Sanctuary of Silver and Navidad Banks in the north of the Dominican Republic, where North Atlantic humpback whales birth their calves. The sanctuary now covers more than 64,500 square kilometres and has almost doubled in size.

With two marine protected areas (MPAs) of this scale, the Dominican Republic is one of more than 30 coastal states worldwide (as of October 2024) that have placed at least 30 per cent of their territorial waters under protection – the target agreed by the parties to the Convention on Biological Diversity (CBD). In their decision on the Kunming–Montreal Global Biodiversity Framework, adopted in December 2022, they made a joint commitment to ensure that at least 30 per cent of the world’s terrestrial and inland water areas, and of marine and coastal areas, are effectively conserved and managed by 2030 (the “30 x 30” target).

One marine protected area is not like another

Protected areas are intended to shield marine organisms and their habitats from man-made impacts by prohibiting or regulating certain human activities. The granting of protected status to marine and coastal areas is regarded as a key tool in combating marine species extinction, which humans have caused in a multitude of ways. Sanctuaries can help to increase local biological diversity, restore food webs, protect threatened species and sensitive habitats, and bolster fishing in adjacent areas – to mention just a few of the benefits.

Precisely when an area of the ocean can genuinely be characterized as a protected area or operates as such is difficult to pinpoint, however. States apply different rules when granting protected status, and the terminology that they use also varies to some extent. Protected areas consequently come in all shapes and sizes, with different conservation standards and objectives. In “no-take zones”, for example, all forms of resource extraction – of fish, oil, gas, sand, gravel, etc. – are prohibited. In multiple-use protected areas, by contrast, all conservation measures are aimed at preserving specific resources or services that the ocean provides, such as fish stocks for the fishing industry, or reefs, kelp and mangrove forests for tourism. This means that in these protected zones, certain human activities and uses are regulated and permitted as long as they have no adverse impact on conservation objectives.

According to the Kunming–Montreal Global Biodiversity Framework, the extraction of organisms or raw materials should be prohibited entirely in one third of the 30 per cent of protected coastal and marine areas. In line with this target, ten per cent of the ocean would be designated as no-take zones from 2030.



7.1 > A safe nursery for Atlantic humpback whales (*Megaptera novaeangliae*): in April 2024, the government of the Dominican Republic announced the enlargement of the Silver Bank Marine Mammal Sanctuary off the country’s north coast.

The European Union has embedded this target in its Biodiversity Strategy for 2030. It plans to expand upon the existing marine protected areas and supplement them with further national protected areas, with strict protection guaranteed for areas of very high biodiversity and climate value. In parallel, by 2030, one fifth of marine regions in the EU should be ecologically upgraded through the restoration of degraded habitats, according to a supplementary EU Regulation on Nature Restoration. The EU Birds Directive, Habitats Directive and Marine Strategy Framework Directive provide the relevant legal basis for action here.

Core objective:

To preserve species, habitats and their functions

Marine protected areas are established by various institutions and pursue a variety of goals. Their designation is therefore always a political decision and, as such, is rare-

ly uncontested. Furthermore, various approaches can be used to classify a marine region as a protected area.

Although there have been calls for the establishment of marine protected areas under the United Nations for decades, the international community was unable to reach agreement on a definition of the term “marine protected area” until 2023, when it was achieved within the framework of the new UN High Seas Treaty. Therefore, in the debate about marine protected areas, the definition adopted by the International Union for Conservation of Nature (IUCN) was and is often used.

According to the IUCN’s definition, a protected area – whether terrestrial or marine – is a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values. In line with this IUCN definition, marine areas in which fishing, mining

7.2 > IUCN experts assign terrestrial and marine protected areas to distinct categories depending on their conservation objectives and associated management plan.

or other extractive activities take place on a scale that causes harm do not qualify as marine protected areas. The same applies to marine regions in which only one species is protected or only one harmful fishing practice is prohibited. The reason is that at sites such as these, the core objective of a marine protected area – namely the long-term protection and conservation of the diversity of marine organisms and their habitats – cannot be guaranteed.

Marine protected areas, according to the IUCN, must meet six basic standards. They should:

1. focus on conservation of nature as the priority,
2. pursue defined goals which reflect these nature conservation objectives,

3. have a suitable size, location and design that will genuinely enable conservation of nature and habitats,
4. have a defined and agreed-upon boundary,
5. have a management plan which enables the conservation goals and objectives to be achieved, and
6. have been initiated by individuals or institutions with sufficient resources and capacity to implement the management plan.

If human activities are still permitted within the marine protected area, they must in all cases have a low ecological impact and be sustainable. Furthermore, all activities must be clearly regulated, and compliance with the regulations must be monitored, the IUCN stresses.

The seven IUCN protected area management categories		
Management category	Designation of protected area The name of a protected area has no bearing on the IUCN management category to which it is assigned.	Conservation objectives and measures
Category Ia	Strict nature reserve The only IUCN management category with a comprehensive ban on extractive activities – no-take zone.	Strictly protected for biodiversity and also possibly geological/geomorphological features, where human visitation, use and impacts are controlled and limited. Research may be permitted if the studies concerned cannot be conducted elsewhere.
Category Ib	Wilderness area Large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation.	Areas that are managed mainly for research purposes or to preserve large unspoiled wildness areas.
Category II	National park Large natural or near-natural areas protecting large-scale ecological processes with characteristic species and ecosystems.	Areas that are managed mainly for the conservation of ecosystems and for recreational purposes.
Category III	Natural monument or feature	Areas that are set aside mainly to protect a specific natural monument or feature (sea mount, marine cavern, etc.).
Category IV	Habitat/species management area Areas to protect particular species or habitats.	Areas that are managed through targeted interventions.
Category V	Protected landscape or seascape Areas where the interaction of people and nature over time has produced a distinct character with significant ecological, biological, cultural and scenic value.	Areas that are managed mainly to protect a landscape or seascape and serve recreational purposes.
Category VI	Protected area with sustainable use of natural resources	Protected areas with sustainable use of natural ecosystems and habitats.

The IUCN’s seven protected area management categories

Depending on the conservation objectives and the associated management plan, the IUCN experts assign marine protected areas to one of seven management categories, ranging from strictly protected areas with a ban on all extractive activities (no-take zones), to areas that continue to be fully available for human use subject to certain conditions. The higher the management category, the stricter the limits on human intervention and use of the ecosystems concerned.

How much of the world’s ocean is protected, and where?

The number of marine protected areas has increased substantially since the 1960s. Designated zones now exist in every ocean region – mostly in national territorial waters, varying in size and with various forms of protection status. For many countries and experts, a further ambition is to establish a network of marine protected areas covering a range of ecosystems and biodiversity hotspots, ensuring that a representative share is protected and that species can migrate between the individual protected areas. This exchange of organisms from diverse populations is essential for the conservation of marine biodiversity worldwide at all levels – from genes and populations to individual species, biological communities and ecosystems.

Due to the variety of definitions of the term “protected area” and related standards, however, there is not one set of protected area statistics for the oceans, but several. So when figures are mentioned, it is always important to consider who compiled the statistics and which selection criteria they are based on. The two best-known databases for marine protected areas are the Marine Protection Atlas (MPAtlas) and the World Database on Protected Areas (WDPA). The former is operated by a marine conservation organization (Marine Conservation Institute), while the latter is a joint project between the IUCN and the United Nations Environment Programme (UNEP). However, the two databases use different protection categories.

OECMs: Where nature conservation is a secondary outcome

Human communities often utilize areas of the sea for purposes which are not primarily aimed at nature conservation, but which may in some circumstances have a positive and reinforcing effect on ecosystems. Examples are:

- Areas with common fisheries management;
- Marine and coastal regions that are managed for tourism;
- Wind farms and oil rigs, which contribute in various ways to increasing biodiversity around subsea infrastructures;
- Marine and coastal areas that are reserved for other purposes but may also support nature conservation, e.g. military training areas, coastal defences, protected channels for communications cables and pipelines, and areas of the sea in which, due to their significance for marine life, special regulations apply to shipping;
- Large ocean regions (e.g. the Northeast Atlantic or Baltic Sea region) in which certain species are legally protected on a transboundary basis.

If these forms of use of the oceans strengthen local ecosystems, they are known as „Other Effective Area-Based Conservation Measures“ (OECMs). Less than one per cent of the world’s terrestrial and freshwater environments and less than 0.1 per cent of marine areas are currently designated as OECMs. However, now that the international community has embraced the target of protecting and conserving ecosystems in at least 30 per cent of the ocean by 2030 and only using them sustainably, OECMs are becoming more important as a management tool – for as experience shows, marine protected areas alone will not suffice to end the climate and biodiversity crisis affecting the ocean.

According to the Marine Protection Atlas, only three per cent of the world’s ocean fell into the fully or highly protected categories in February 2025. At that point in time, the Atlas listed only 220 marine areas in which fishing and other forms of resource extraction or destructive activities were prohibited entirely or on a large scale. The two largest were located in the Southern Ocean (Ross Sea Region Marine Protected Area) and off the northwest coast of Hawaii (Papahānaumokuākea Marine National Monument). Many smaller protected areas with fishing bans were sited in tropical and subtropical waters – mostly where there is particularly high species diversity.



7.3 > Protected area status does not shield ocean regions from floating marine litter. Here, national park employees are removing a fishing net that had become entangled in a coral reef in the Papahānaumokuākea marine sanctuary northwest of Hawaii.

In addition, according to information from the World Database on Protected Areas (WDPA), there were more than 16,300 protected areas around the world in which fishing and extraction of other resources were permitted to some extent. These “less protected” zones included the marine protected areas in the German North Sea and Baltic Sea. In February 2025, according to the WDPA, a total of 8.34 per cent of the world’s oceans was protected to some degree. This equated to a total area of 30.26 million square kilometres – roughly three times the size of the United States.

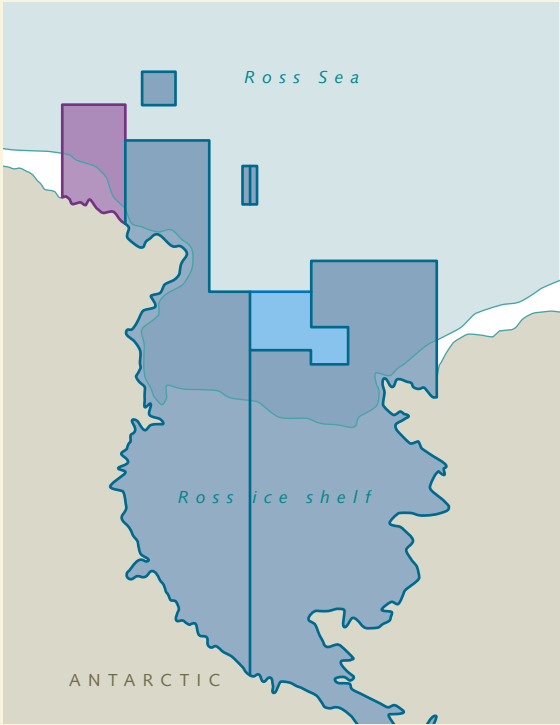
In order to achieve the conservation target of 30 per cent of the world’s ocean, however, a further 78.3 million square kilometres of coastal and marine waters must be added – in less than five years and ideally in the form of large, representative protected area networks. For this, designation of new marine protected areas would have to proceed at a much faster pace.

Little more than greenwashing?

As there is a long way to go to reach the 30 per cent target, some experts argue that the public debate should not focus exclusively on how much of the total ocean area is protected, an issue agreed at political level. Instead, there needs to be far more serious discussion of whether the areas that are important for biodiversity are indeed being protected and whether conservation regimes are being implemented and monitored effectively in all protected areas. In 2023, researchers investigated how effectively the 100 largest marine protected areas are safeguarding the living organisms that inhabit them. They found that in these areas, which cover 90 per cent of protected marine waters:

- Only one third offered a level of protection that is likely to contribute to the conservation of marine organisms and habitats;

Marine protected areas in the Ross Sea Region



	Zones	Area (km²)*	% of site
Implemented or actively managed	5	2,041,330	100
Fully protected	1	325,237	16
Highly protected	3	1,606,529	79
Minimally protected/incompatible	1	109,564	5.4
Total assessed	5	2,041,330	100

*Zones may contribute less than their total area if they are covered by zones with higher protection levels.

7.4 > The Ross Sea Region contains what is currently the world’s largest marine protected area, covering more than two million square kilometres. But even here, there are some zones with minimal protection.

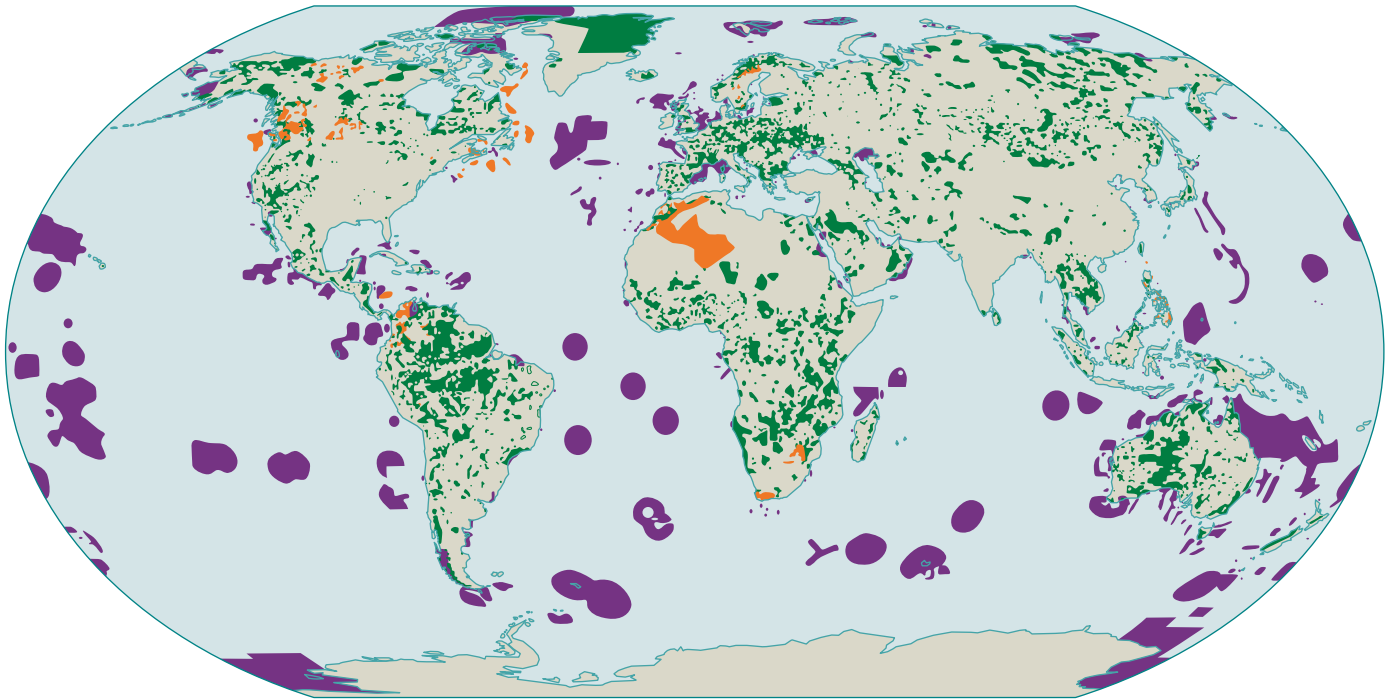
7.5 > On the online platform protected planet.net, the IUCN and UNEP publish a regularly updated map showing all the world's protected areas, both terrestrial and marine, as well as areas where nature conservation should be achieved as a secondary outcome (OECMs).

- A quarter of these protected areas (a total of 6.7 million square kilometres) were not in operation at all. In other words, the promised conservation measures had not yet been implemented and the areas were not being managed in accordance with the conservation plans. In these circumstances, protected areas offer no benefits whatsoever for flora, fauna and habitats;
- Industrial or other highly destructive activities were permitted in more than one third of the protected areas. This primarily includes industrial fishing which, along with the impacts of climate change, is the main cause of marine biodiversity loss. For the IUCN, the existence of industrial fishing operations within an area is a reason to withhold protected status;
- The majority of large-scale fully or highly protected marine areas were not located anywhere near the

nations supposedly responsible for them. Instead, they are sited in far-flung overseas regions. Areas designated by the United Kingdom and USA are examples of this.

These findings, the researchers point out, indicate that the current methods being used to survey marine protected areas and assess and report on their effectiveness are overestimating the scope and quality of the protection provided. This produces a distorted picture of human impacts on the ocean and of our progress on marine conservation – especially if protected areas which in reality have not yet been operationalized are included in current protected area statistics. Moreover, based on this and other analyses, there is reason to doubt whether increasing the coverage of marine protected areas to

Protected areas and other effective area-based conservation measures (OECMs)
(as of May 2025)



Terrestrial and inland waters protected areas Marine and coastal protected areas OECMs

30 per cent of the world's oceans will genuinely offer the marine environment the level of protection that marine life requires for its recovery. At present, marine biodiversity is declining overall – despite the conservation measures already taken and the benefits that such measures, when fully implemented, are capable of achieving.

Where should the ocean be protected?

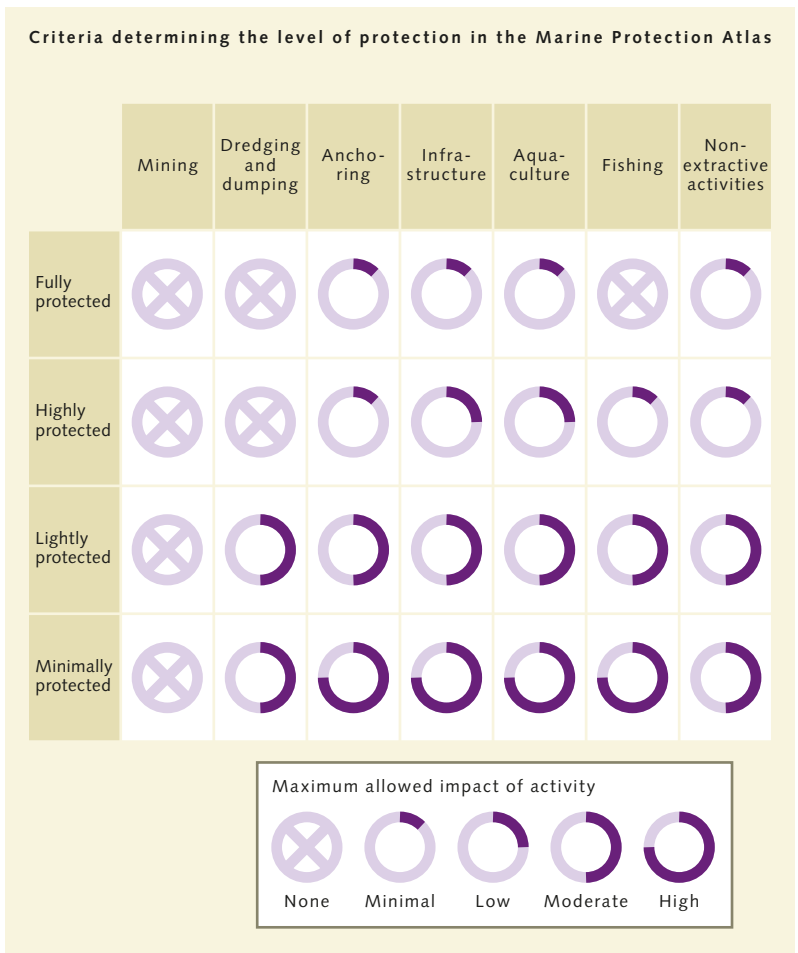
In the debate about the 30 per cent conservation target, experts have investigated, in various ways, which marine regions should be fully protected in order to yield the greatest benefits for ocean biodiversity. Politically, the most important initiative here is a process for the designation of Ecologically or Biologically Significant Marine Areas (EBSAs) within the framework of the Convention on Biological Diversity (CBD).

In this process, international marine scientists meet in regional workshops in order to assess, on the basis of current scientific, technical, indigenous and local knowledge, which areas within a given marine region are particularly worth protecting. The term “ecologically or biologically significant” applies to areas which, in the experts’ view, meet the following seven EBSA criteria:

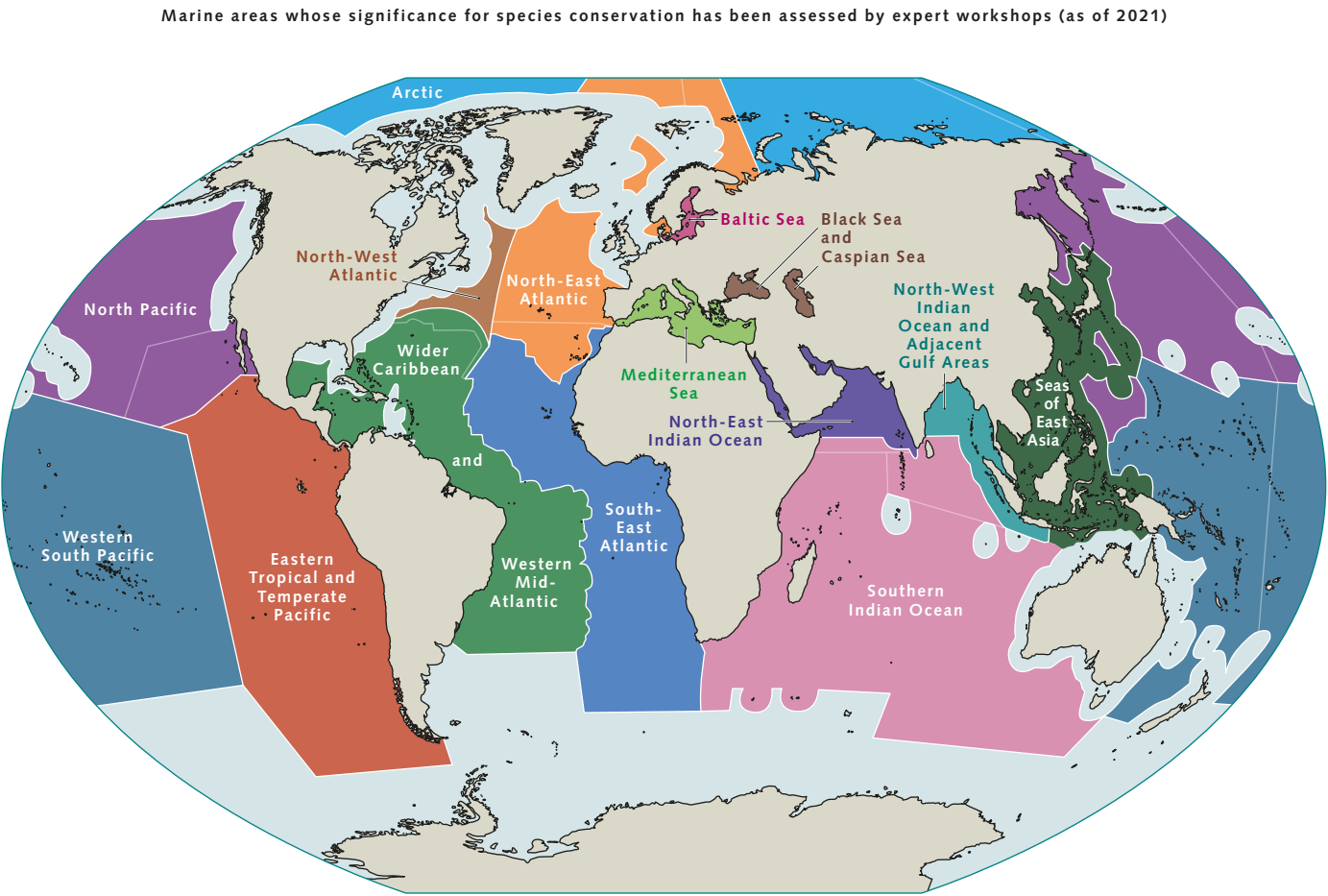
1. They are biologically or ecologically unique or rare: this means that they contain unique, rare or endemic species, populations, communities, habitats or ecosystems – or unique geomorphological or oceanographic features.
2. They have special importance for the survival of species.
3. They are critical for threatened, endangered or declining species and/or habitats.
4. They contain a high proportion of sensitive habitats, biotopes or species that are functionally fragile (highly susceptible to degradation or depletion by human activity or by natural events) or with slow recovery.
5. They contain species, populations or communities with comparatively high natural biological productivity.

6. They contain high diversity of ecosystems, habitats, communities or species, or are notable for their high genetic diversity.
7. They have a comparatively high degree of naturalness, meaning that they show a lack of or a low level of human-induced disturbance or degradation.

Marine areas which fulfil these criteria and are classed by the experts as worth protecting are then recognized as EBSAs by the bodies of the Convention on Biological Diversity and added to the EBSA database. It is a matter for policy-makers to decide whether the sites that are worth protecting are subsequently designated as marine protected areas as well. However, since they have been recognized as EBSAs, they are the first choice if a state,



7.6 > In contrast to the IUCN, the experts working on the Marine Protection Atlas (mpatlas.org) differentiate between four management categories that permit different levels of human activity, from minimal to high.



7.7 > The Secretariat of the Convention on Biological Diversity (CBD) has, to date, convened 15 regional workshops in which experts from various sectors discuss which areas of a particular region of the ocean meet the EBSA criteria and are thus deemed to be worth protecting.

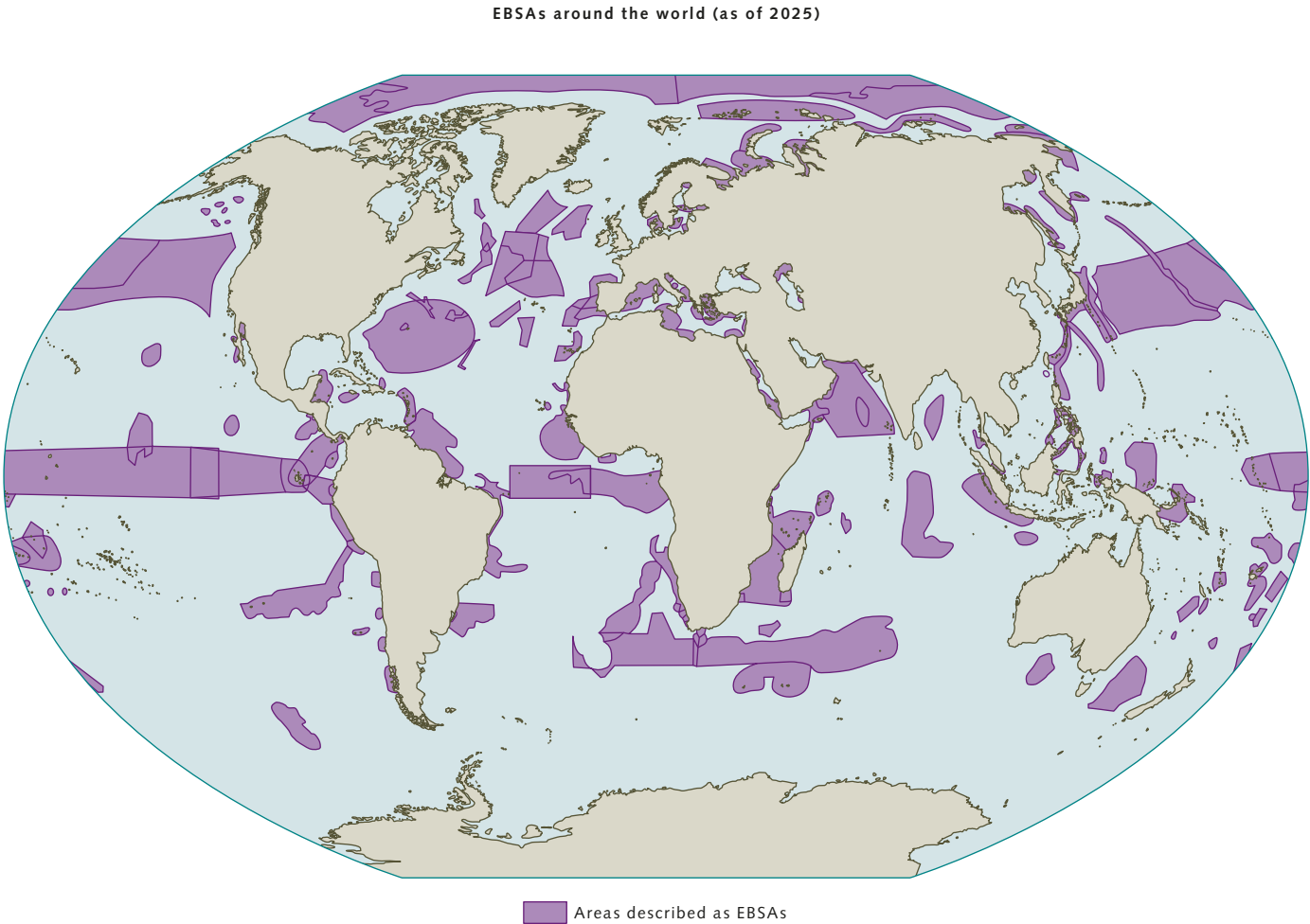
group of states or intergovernmental body is considering designating new marine protected areas, particularly in international waters.

Marine regions that have been recognized as EBSAs currently represent around 20 per cent of the world’s oceans. The smallest covers an area of just 0.95 square kilometres (in the Black Sea). The largest, in the northern Pacific, extends for 11.14 million square kilometres. Almost half of the sites are located in waters less than 200 metres deep. Others reach down to the sea floor in the deep sea. EBSAs encompass a broad array of species, habitats and oceanographic features. Some are of seasonal significance for marine organisms, while others are important all year round. The sites include submarine mountains, hydrothermal vents, coral reefs, migration corridors, seasonal fish spawning grounds and coastal up-

welling areas, as well as many other types of ecosystem. There are large EBSAs in the North Atlantic, off the southern tip of Africa, in the Arctic Ocean, in the central and northern Pacific, in the tropical waters of Southeast Asia and Central America, off the east coasts of Australia and the United States, and elsewhere.

The challenges facing marine protected areas in international waters

Most marine protected areas are currently located in national waters, for it is here that coastal states can decide independently on the granting of protected status and the related conservation objectives, as laid down in the United Nations Convention on the Law of the Sea. Protected zones in international waters (the high seas) – remote from any national coast – can only be designated on the



basis of international agreements which cover these areas of the ocean. The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) and the OSPAR Commission are examples.

The first MPA in international waters was established by CCAMLR on the South Orkney Islands Southern Shelf in 2009. This was followed in 2016 by the world’s largest marine protected area, covering 1.55 million square kilometres of the Ross Sea in the Antarctic. The OSPAR MPAs in the Northeast Atlantic cover around 460,000 square kilometres and are hence larger than Germany and Austria combined. It must be kept in mind, however, that these protected areas in international waters are recognized only by states that are members of CCAMLR and OSPAR. States that are not party to these agreements are not bound by the protected area rules. It

is hoped, however, that future marine protected areas that are located in international waters and are designated by the United Nations under the new High Seas Treaty (Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction – BBNJ) will be applicable to all, or at least the majority, of nations within the international community.

The establishment of marine protected areas in international waters is often hampered by a lack of rules and an absence of legal bases. The new UN High Seas Treaty is intended to remedy this situation. But will the Treaty genuinely have an effect? Only time will tell.

The monitoring of marine protected areas in international waters poses a further challenge because these

7.8 > Site proposals that are approved by the Conference of the Parties (COP) to the Convention on Biological Diversity are immediately recognized as EBSAs and are added to the official EBSA map. However, this does not confer protected status.

The UN High Seas Treaty:
More marine conservation in international waters

Around 64 per cent of the world’s ocean is not managed by individual states but forms part of the high seas, far away from any coastline. Previously, human interventions were largely unregulated in many areas of these international waters, with the result that rules on marine conservation were poorly implemented. However, the United Nations High Seas Treaty (full title: the Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity in Areas Beyond National Jurisdiction – BBNJ Agreement), adopted in June 2023, is intended to remedy this situation.

The Treaty enters into force on 17 January 2026 and allows states parties to create marine protected areas in international waters. It also makes provision for the granting of protected status in situations in which no consensus is reached – through a vote by the UN member states, a three-fourths majority of the parties present and voting being sufficient. It is hoped that in this manner it will be possible to protect and ensure the sustainable use of at least 30 per cent of the ocean by means of protected areas and other measures by 2030.

In order to implement the Treaty, however, many more detailed consultations are required, particularly with the regional fisheries management organizations (RFMOs) and representatives of the regional seas conventions. If a newly planned protected area is to be located in an area of the high seas for which regional fisheries management or marine conservation agreements exist, both institutions’ approval of the new protected area is required. Substantial funding will also be needed: according to one estimate, proper planning, implementation and monitoring of marine protected areas in 30 per cent of the high seas will cost around seven billion US dollars – plus a further one billion US dollars in annual operating costs. Currently, less than one per cent of international waters are protected.

It is interesting to note that in the High Seas Treaty, the UN member states have agreed on a common definition of “marine protected area” for the first time. It states: *“‘Marine protected area’ means a geographically defined marine area that is designated and managed to achieve specific long-term biological diversity conservation objectives and may allow, where appropriate, sustainable use provided it is consistent with the conservation objectives.”*

areas are located in remote parts of the high seas. Successful protection therefore depends on whether all the stakeholders concerned are able to reach agreement on how and when the implementation of conservation

measures is monitored and by whom, which scientific studies are used to document this process, and to what extent and on which scale the conservation objectives are being achieved and the protected status has a positive effect on ecosystems.

A further difficulty is that the lifespan of marine protected areas in international waters is time-limited in some cases. The decisive factor here is the international convention under which the protected status was granted. The Ross Sea Region Marine Protected Area within the CCAMLR framework, for example, has a lifespan of 35 years. An extension will likely be considered only if there is scientific evidence that the biocoenoses in the Ross Sea have clearly benefited from protected status. For this reason too, clear rules on the monitoring and evaluation of protected areas have a key role to play.

Do marine protected areas safeguard life in the ocean?

The successes achieved by a protected area can only be measured with reference to its conservation objectives – and they often vary. In contrast, the list of environmental hazards against which MPAs provide little or no protection is quite clear. This is due to the fact that ocean and air currents transport heat, water and air, and all that they contain, to the farthest corners of the seas. It follows that marine protected areas do not protect organisms from rising water temperatures, oxygen deficiency and increasing acidification or from eutrophication, pollution, diseases, sea-level rise or non-indigenous invasive species.

There are some marine regions, however, which are and will be impacted by climate change and other environmental hazards at a later stage than others. Protected areas in these regions provide havens, refuges and niches. Furthermore, researchers assume that biocoenoses and species that are not exposed to human-induced pressure from extractive activities or degradation have better prospects of adapting to the impacts of climate change than those that are highly stressed.

7.9 > Under the microscope, single-celled algae from the Ross Sea resemble planets from a distant galaxy. Growth of these microalgae occurs if, for example, melting of the Antarctic sea ice releases or redistributes nutrients in the ocean.

The effectiveness of protected areas also depends on the extent to which the proposed conservation measures are actually implemented. If a marine protected area misses its conservation targets because none of the previously announced restrictions or measures were actioned, it is said to be a “paper park” – one which exists solely on paper. Experts currently estimate that the large majority of existing marine protected areas – more than 70 per cent – are failing to meet some or all of their conservation targets. Indeed, in Europe, according to a new study, this applies to 80 per cent of the marine protected areas currently in existence.

Experts therefore argue that when it comes to marine conservation, what matters is not only the size or number of protected zones (quantity), but how well marine protected areas genuinely fulfil their conservation mission and how compliance with conservation measures is

monitored (quality). Another factor which plays a role is whether protected areas exist to preserve local habitats – above all, sedentary or territorial species (coral reefs, seagrass beds, submarine mountains, kelp forests, etc.) – or are intended to protect migratory/mobile species (e.g. fish, sharks, whales). Depending on the conservation objective, the effectiveness of protected areas can vary considerably here.

The effectiveness of protected areas is also influenced by what happens near their boundaries. Since the construction of five new wind farms in the German North Sea, for example, seabirds have been avoiding large areas of the Eastern German Bight Special Protection Area (SPA) that was created for them. One of the wind farms was even constructed within the protected area. As a new study now shows, the birds are keeping their distance – as much as ten to 16 kilometres – from the wind

7.10 > Black-throated loons (*Gavia arctica*) are among the bird species facing habitat loss following the construction of new wind farms in the North Sea.



turbines. As a result, their usable habitat within the protected area has shrunk by around half. The greatest habitat losses have been recorded for red-throated loons (*Gavia stellata*) and black-throated loons (*Gavia arctica*), but massive impacts have been documented for other breeding species on the island of Heligoland as well. The loons are now concentrated mainly in the areas farthest away from the wind farms and avoid the rest of the protected area. The experts involved in the study have therefore issued an urgent warning: constructing off-shore wind farms in or near a bird sanctuary runs the risk that its core functions as a resting area and hunting ground will be lost and its original conservation objectives can no longer be fulfilled.

Before/after, inside/out:

How researchers measure the protective effect

To be able to assess the benefits of a marine protected area on the basis of the data, researchers must first capture the baseline condition (as-is state) of the biocoenoses, so that they can then investigate which biological parameters change over the short and long term as a result of the granting of protection. They look primarily at the distribution and population density of selected species, their biomass, age and size structure, and the biodiversity of the ecosystems within the planning area.

When monitoring performance, researchers also refer to data from comparable unprotected marine areas further afield in order to identify specific protective effects. However, the unprotected areas used for comparison must, as far as possible, display identical environmental conditions (e.g. depth, currents, sediment composition) to those of the protected areas so that any consequent – and possibly confounding – differences in the findings are avoided. The ongoing challenge when measuring performance is being able to exclude other factors that may influence the findings, such as climate change or increasing marine pollution. Both these factors can cancel out potential protective effects or partly or fully distort the results of the before/after comparison.

A meta-analysis on the effectiveness of marine protected areas where bans on extractive activities are in

place has revealed an overall improvement of biological indicators – albeit, in many cases, only within the protected zones and by no means equally for all species studied. Furthermore, the successes achieved differ considerably from one protected area to another, which raises a question: why are some better at protecting marine life than others?

As a general rule, the larger the protected area and the longer it has enjoyed protected status, the more consistent the enforcement and monitoring of all prohibitions and the greater the distance from fishing grounds, the stronger the recovery of its inhabitants will be, particularly if bans on fishing and the extraction of gravel and other resources are in operation. At present, however, very few studies focus on changes in the ecosystem as a whole or look beyond individual key species (of edible fish). As a result, information is lacking on how the granting of protected status impacts the full range of ecosystem services in the protected area and which effects can be observed within the food web.

One question which arises, for example, is how an ecosystem changes if a predator fish species at the apex of the food web is no longer fished and its numbers therefore increase over time. Marine research has a role to play here, by developing new approaches that offer clearer insights into ecosystem dynamics and marine biodiversity networks and thus enhance our overall understanding. Both are needed for a more precise appraisal of the effectiveness of marine protected areas and for better and more targeted planning of new protected zones.

The controversy over the protection of fish stocks

According to figures from the Food and Agriculture Organization (FAO), more than 37 per cent of monitored global fish stocks are overfished. Experts are therefore urgently seeking solutions that would enable the recovery of endangered fish stocks. Some are in favour of an extensive network of protected areas with a total ban on fishing, as research findings show that in protected areas with fishing bans, fish abundance increases and biocoenoses on the sea floor recover – particularly mussels,

CCAMLR & OSPAR
CCAMLR stands for the Commission for the Conservation of Antarctic Marine Living Resources, whose Contracting Parties (currently 26 states and the European Union) agreed in October 2016 to designate the Ross Sea Region as a marine protected area. The OSPAR Convention is a regional marine conservation agreement for the North Sea and the Northeast Atlantic. Its Contracting Parties are 15 European countries and the European Union.

7.11 > If offshore wind farms are constructed adjacent to or in protected areas, they can impact the areas’ effectiveness – not least because seabirds keep their distance from the wind turbines.



corals, sponges and other sedentary organisms previously damaged by bottom trawl nets.

Other experts, in turn, do not consider no-fishing zones to be expedient; instead, they favour comprehensive regulation of fishing, including strict fishing quotas, seasonally limited fishing periods and a ban on fishing technology that is destructive, or results in a high level of bycatch, in areas with particularly sensitive biocoenoses. In their view, a fishing ban would encourage fishermen impacted by the ban to switch to neighbouring areas, increasing the risks to the marine environment in the latter. They note that it is unlikely that fishing would be reduced overall.

Based on this argument, the governments of China and Russia have blocked the designation of further marine protected areas in the Antarctic for many years. According to environmentalists, however, these governments ignore the fact that while measures to restrict fishing can ensure that stocks of target species are not overexploited, they do not guarantee protection for the ecosystem as a whole. Restrictions on fishing merely regulate the Total Allowable Catch for selected target species and possibly bycatch. However, the governments of China and Russia disregard the other impacts of fishing, the environmentalists say. In the Antarctic, for example, how would the ecosystems of the Southern Ocean be affected if hundreds of tonnes of Antarctic toothfish (*Dissostichus mawsoni*) – an apex predator – were extracted from a relatively small area of the sea or if many thousands of tonnes of krill were harvested locally?

Marine research has provided arguments for both sides of the controversy, but has yet to do so on other issues: model calculations indicate, for example, that a protected area can boost fish abundance and catches beyond its boundaries – but only if fish stocks in this region were already heavily overexploited and fishing pressure is very high outside the new protected area. In such regions with little or no regulated fishing, a network of multiple no-fishing zones can support the recovery of biocoenoses in the water column and on the sea floor.

A point yet to be fully clarified, however, is whether the fish stock in a marine area increases if only parts of it

are protected, and in which circumstances this occurs. Another unknown variable is whether undisturbed fish spawning within a protected area has the long-term effect of increasing fish abundance outside the protected area as well. However, researchers have been able to prove that amateur anglers often land fish of seemingly record-breaking size closer to marine protected areas than further afield. The chances of landing a big catch also increase along with the age of the protected area. Evidence for the positive effects of protected areas is also available from tropical coral reefs. Without the existing protected zones, according to some calculations, the number of reef fish would be around ten per cent lower than it is today.

Migratory marine organisms: Genuine protection at the right time of life

Protecting migratory marine organisms is even more challenging than preserving static marine habitats such as reefs, sandbanks or seagrass beds. These migratory species primarily include whales, seals, sharks, rays, seabirds and turtles, as well as many popular species of edible fish such as tuna. The animals travel thousands of kilometres on their migrations in some cases and are therefore often found outside protected zones. Nevertheless, smaller and medium-sized marine protected areas can support their conservation. This applies particularly if the protected zones are located in areas to which the animals return at particularly significant times in their lives – to mate, to lay their eggs or to give birth and rear their young. In the case of fish, it is also essential to protect regions that eggs and larvae drift into or to which juveniles migrate.

The effectiveness of conservation measures also depends on the extent to which there is cooperation among states whose coastal waters are traversed by these animals during their migrations. In a best-case scenario, the coastal states form a network of marine protected areas, with corridors that enable the animals to migrate undisturbed from one region to another.

However, even under the most favourable conditions, a protected area can never do justice to all the various

7.12 > A member of the environmental organization Greenpeace attaches a notice with the words “Marine Protected Area” to a navigation buoy in the North Sea. By taking this action, the activists aim to protect fish stocks.



Stepping stones
“Stepping stones” are small areas or patches of habitat that are used as stopovers by species during their climate-related outward migrations from an area. They are essential in enabling organisms to reach new habitats further afield. Stepping stones therefore count as habitats of high conservation interest.

species simultaneously – their migration patterns differ too much for that. For this reason too, opponents of protected areas with fishing bans argue that fish stocks would be better protected if strict fishing regulations were implemented effectively everywhere in the ocean, not only in geographically limited protected areas. This kind of sustainable fishing would ease the pressure on the marine environment while also safeguarding the supply of edible fish and shellfish for the long term, so the argument goes.

Migratory edible fish species are covered by the United Nations Fish Stocks Agreement. It entered into force on 11 December 2001 and aims to ensure the long-term conservation and sustainable use of straddling and highly migratory fish stocks. For example, the Agreement spells out the duties of flag states related to registration and records of vessels, authorizations, monitoring and

enforcement in respect of their fishing fleets. It also obliges states whose waters host migrating schools of fish, or whose fishing fleets target these species, to engage in common fisheries management.

Marine protected areas can fuel conflicts

A marine protected area is always associated with restrictions on human activity. Fishing, for example, may be limited, permissible only at specific times, or prohibited altogether. Navigation, lying at anchor and diving are also banned in some cases, ruling out any tourism use. Local communities whose livelihoods depend on the services provided by the sea therefore find themselves at a disadvantage if one of the areas used by them (in some cases for generations) is suddenly no longer accessible in the customary way.

This can give rise to conflicts of use in which the public interest in protecting the sea clashes with the individual interest in livelihood security. Often, numerous families’ livelihoods depend on access to the sea. The designation of a protected area therefore has not only an environmental and an economic component but often social impacts as well. For every protected area, the question which arises is whether the benefits for marine and species conservation outweigh the disadvantages for affected communities and how these disadvantages can be mitigated.

Planning and implementing marine protected areas: Doing it right

Conflicts of interest exist in every marine region, particularly in intensively used coastal waters. If marine protected areas are to be established successfully, the diverse claims must be considered from the outset and affected communities must be involved in planning. Unless this happens, conservation efforts are very likely to fail.

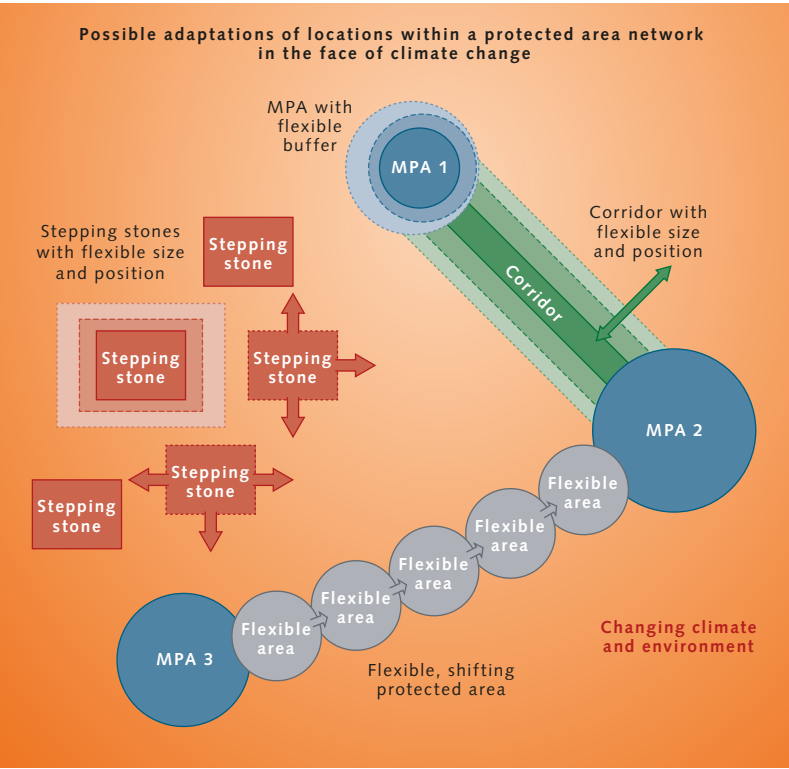
Strategies, solutions and success factors

Various approaches have proved their worth here. In the planning of smaller marine protected areas in coastal



7.13 > To safeguard its extraordinarily well-preserved coral reefs and shark populations, the Marshall Islands designated some 48,000 square kilometres of ocean as a protected area in January 2025. It covers the waters around the two northernmost islands in the archipelago.

7.14 > In the face of ocean warming, some marine species are shifting polewards or into deeper waters. To ensure that these species continue to be safeguarded, protected areas must move with them. This can be achieved if dynamic and flexible areas, stepping stones and corridors are factored into planning from the outset.



waters, there may be many benefits in having local people working with experts to reach a joint decision on which areas should be protected and to what extent, in order to achieve the best possible outcomes for the marine environment and human communities. Local fishing families are often the best source of knowledge about local resources and traditional forms of management and use. There is also more community buy-in for compliance with the rules if local people are involved in decision-making and understand the goals being pursued.

With larger protected areas in international waters, by contrast, a fruitful approach is for one or more governments to take the lead and progress transboundary cooperation under the international agreement applicable to the marine region in question. Here too, the parties to these agreements must ensure that all stakeholder groups affected by the future protected area are involved in the planning and decision-making process and can genuinely have a say. Otherwise, communities are unlikely to comply with the new rules or support their enforcement.

Experts have now identified a range of success factors for the planning and implementation of marine protected areas. They include the following:

- Involve all stakeholder groups in the planning of the protected area at an early stage.
- Ensure transparency in all discussions and decision-making.
- Identify alternative sources of income and resources for the local community.
- Offer training, upskilling and technical and financial support so that affected communities have access to alternative income sources.
- Align the planning process and conservation strategy with local conditions.

Adhering to these guidelines helps to avoid a situation in which new marine protected areas reinforce social inequalities and add to the pressure on already disadvantaged groups.

Being mindful of all the impacts of protected areas means that new scientific methods are required to analyze the interactions between the marine environment, its direct users and other stakeholders within society. Initial approaches already exist, including social-ecological network analysis, which is used primarily by experts who work on an interdisciplinary basis, enabling them to better predict and assess the impacts of economic restrictions on the various user groups and the marine environment. In addition, new remote sensing methods (satellites, drones, etc.) are useful for monitoring marine protected areas; they enable illegal fishing in MPAs or overexploitation of mangrove forests, for example, to be detected with greater accuracy.

Planning for climate impacts and adaptation

A further factor that will be decisive for the future of marine protected areas is to what extent they are able to migrate with the organisms they are intended to protect. As one of the impacts of climate change, major shifts in community composition are already being observed in the oceans. If highly endangered flora and fauna are to

Successfully protecting marine regions: Some guidance

Successfully establishing a marine protected area involves a multi-stage process which consists of two distinct phases:

The first is the **planning phase**. It starts with a rough outline of the area to be protected (planning area) and a definition of the objectives. During this phase, all stakeholder groups share their aims, claims and expectations and set joint conservation targets.

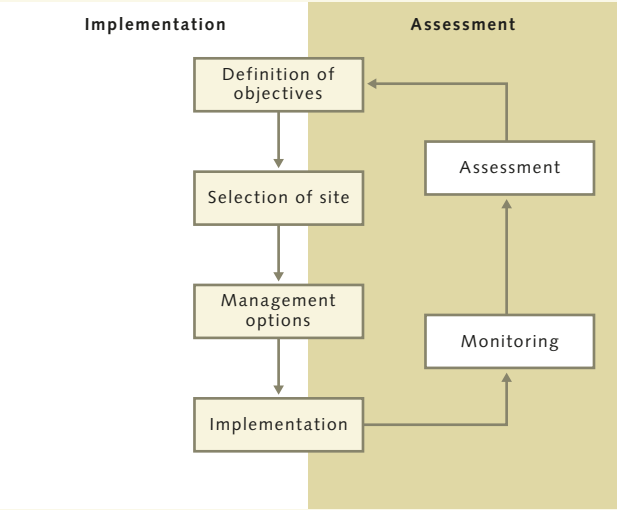
The next step is to identify an area of the sea in which the conservation objectives can be achieved through joint action. A detailed survey of the planning area is therefore carried out in order to document aspects such as the distribution of the species and ecosystems to be protected. Individual distribution maps are produced for all the collected data and indicators. In many cases, modelling is also used to assist the experts to produce a full site analysis based on the individual observations.

After that, the numerous maps are superimposed on one another and analysed with the aid of specialist software in order to identify the best location for the future protected area. This includes determining the position and size that would enable the conservation objectives to be fulfilled to the greatest possible extent while minimizing impacts on other forms of use such as fishing.

In addition, on the basis of the research results, various indicators and their baseline values are determined so that performance monitoring can be carried out at a later stage. The performance indicators generally include variables such as biomass and population size of specific target species, or population density on the sea floor. The stakeholders then draw up a joint catalogue of measures, including protection regimes and, if appropriate, a list of sanctions, solutions to potential economic and social conflicts, and proposals for funding, control and monitoring of all the various measures.

Once the marine protected area has been designated and all the regulations have been implemented, the second phase – namely **evaluation** – then follows. During this phase, experts regularly review the key indicators both within the protected area and outside and compare the trajectories (baseline condition) with the conservation objectives (target state).

If they identify any negative trends, it may be necessary to adjust the management plan or, in some circumstances, the position of the protected area accordingly.



7.15 > A protective effect is achieved solely in areas where conservation measures are implemented, evaluated and modified if necessary.

continue to be safeguarded, the protected areas established for this purpose must be planned and monitored flexibly and their position must shift to keep pace with species migration.

For example, experts are proposing the establishment of flexible buffers, corridors and so-called protected “stepping stones” in order to facilitate safe migration of marine organisms to climatically suitable zones. However, this kind of systematic, climate-smart and often transboundary planning of marine conservation requires close cooperation among states, decision-

makers, technical experts and affected local groups. One obstacle standing in the way of shifting protected areas is that other users of the ocean (e.g. the shipping or fishing industry) require clearly defined protected area boundaries in order to navigate safely and avoid these zones.

Furthermore, in view of the dramatic climatic changes that are occurring, the possibility that the conservation plans and objectives of a protected area may have to be adjusted cannot be ruled out. For example, plans for protected areas that were previously aimed at the conserva-

tion of selected species could be modified so that in future, the focus is on preserving all habitats within the protected zone. However, in order to determine whether these or other adaptations are necessary, the protected areas must be monitored on a regular and ongoing basis and any changes documented.

Growing challenges

Marine protected areas that are based on collaborative, climate-smart planning and are properly implemented will be an important and effective tool in biodiversity and marine conservation in future. Another crucial factor, however, is how sustainably we use the ocean outside the designated protected zones. In view of growing population numbers and increasing user claims on the oceans, holistic and, above all, sustainable strategies are required in order to protect and preserve marine biological diversity and ecosystems for the long term.

The option of designating the entire world ocean, or a large proportion thereof, as a marine protected area can be ruled out. Indeed, this is probably not a desirable step. Instead, humankind must learn to live with the ocean and see ourselves as part of nature. There is some evidence that the condition of marine habitats is at its best wherever the people who use them feel a close connection to their local ecosystems, are involved in all decision-making processes or, as fishing or coastal communities, are able to make their own decisions on the use of the sea.

The challenge, then, is to consider how we can implement conservation plans in marine protected areas more effectively and ensure more sustainable use of the marine environment in unprotected areas. This requires a fundamental recalibration of the way in which individuals, communities, industries and financial markets perceive the marine environment and interact with it. Rather than focusing solely on the monetary value of marine ecosystem services, as is currently the case, all stakeholders

7.16 > The entire Exclusive Economic Zone of the Cook Islands has been designated as a marine park. However, commercial fishing and marine mining are banned in selected areas only.



should consider the non-monetary services to a greater extent. Thus far, the international community has been unable to reach globally agreed targets for the conserva-

tion of biological and species diversity. This failure clearly shows that we must rethink the methods by which we seek to achieve our conservation goals.

CONCLUSION

Marine protected areas:
All too often ineffective

Marine protected areas (MPAs) are widely regarded as a key instrument in combating overexploitation of the oceans and associated species extinction. They are established in order to protect marine organisms and habitats from human impacts by prohibiting or regulating certain activities. Their number has increased significantly in recent years. However, MPAs’ conservation objectives and management strategies vary considerably. One protected area is not like another. This makes it difficult to say for sure what percentage of the ocean is indeed protected effectively.

Consistently protecting marine regions helps to preserve local species and habitats. However, the benefits of protected areas beyond their boundaries are not always scientifically proven, often due to a failure to implement planned conservation measures (paper parks). Migratory species benefit from protected zones mainly when there is large-scale connectivity between these areas and they are located in regions where marine organisms breed or rear their young. Meeting the needs of all the inhabitants of a protected area simultaneously is challenging due to the often diverse behavioural patterns of the various species.

Protected areas address some of the challenges facing the marine environment, such as the risks to and destruction of local biocoenoses by overfishing, over-extraction of resources, or mass tourism. However, they do not guard against large-scale pollution (e.g. microplastics) or climate change

impacts. They are, therefore, just one of many tools available to combat the climate and biodiversity crisis facing the oceans.

As more protected areas are designated, conflicts of interests increase – especially in areas with previously intensive human use, such as fishing. When planning a protected area, it is therefore absolutely vital that the interests of all user groups are genuinely considered. The prospects of success increase if protected areas are planned, implemented and monitored inclusively and transparently and user groups are offered alternative income sources.

In order to assess a protected area’s trajectory and performance, scientific studies are required, which must be conducted regularly over extended periods. This research should aim to determine whether the original conservation objectives are being achieved, whether the granting of protected status has a positive effect on ecosystems, and which species benefit from the protected area. Methods that enable early identification and assessment of the benefits and disadvantages of protected status for people, the ocean and society should also be utilized more frequently. These forecasts can help encourage the diverse user groups to champion the area’s protected status.

When planning, implementing and evaluating protected areas, the impacts of climate change on marine life will need to be given more consideration. New, flexible protected areas that are closely monitored and can be adapted and shifted in tandem with climate-induced species migration are required. Flexible buffers, corridors and protected stepping stones are essential to enable marine organisms to migrate into climatically suitable zones.

8 A new start for marine management

> Who is permitted to use the ocean, and how? This is determined by a diverse array of players and just as many rules, laws and agreements. So far, however, states have failed to curb the overexploitation of the marine environment and halt species decline. New governance principles and the UN High Seas Treaty help preserve and protect the remaining life in the ocean and its diversity. To succeed, however, the countless commitments must be followed by action.



Time for a genuine rethink

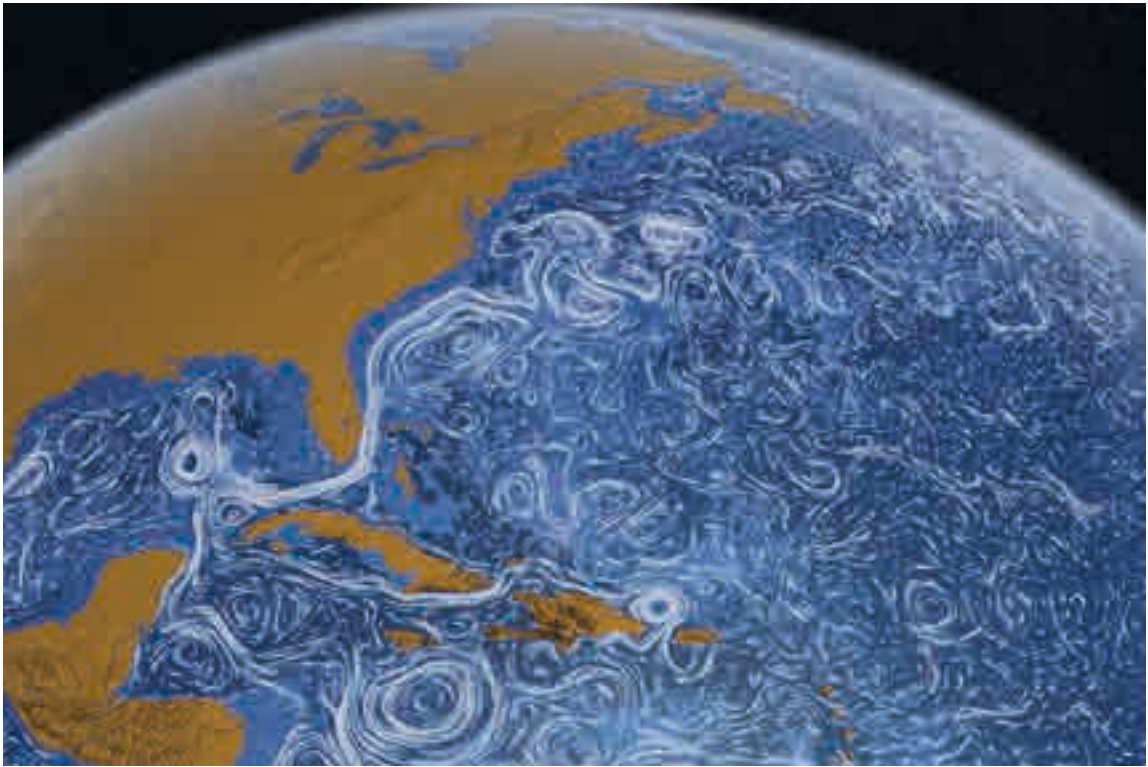
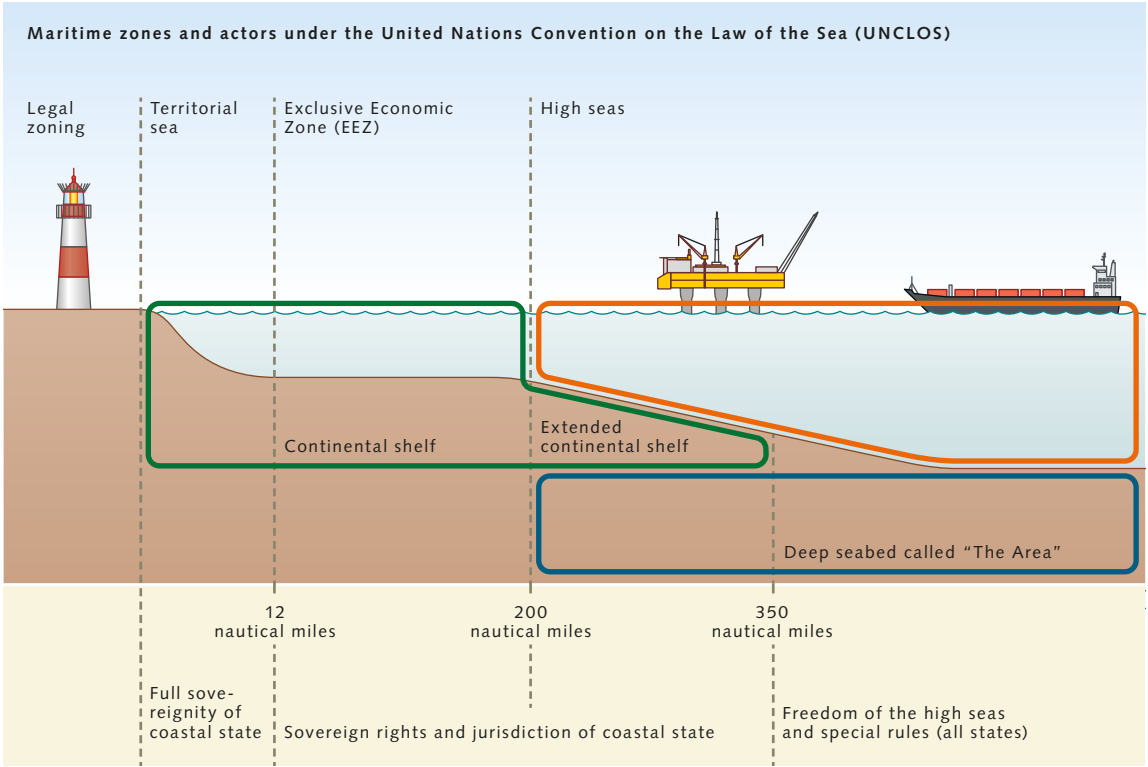
> In theory, we have long possessed the knowledge we need to use the sea sustainably and design marine management in such a way that everyone benefits from its services. Putting this knowledge into practice is failing, however, due to the governance regime – a product of history with multiple stakeholders and weaknesses – and a lack of commitment, driven by economic interests. Overcoming these barriers is one of the key challenges facing the international community. This is no longer about the future of the ocean alone. Our own future is at stake.

A global ocean – and the multiple stakeholders who decide its fate

The global ocean knows only one boundary: the coastlines of the islands and continents. In the vast space in-between, the water masses circulate, flowing from one ocean basin to another and dispersing all that the currents can carry to the furthest corner of the seas – surplus heat and carbon dioxide, but also pollutants, plastic debris and living organisms. All the regions of the ocean are thus connected – even if thousands of kilometres of the high seas separate them on the world map.

Reminding ourselves occasionally that the ocean is a vast (material) cycle where what happens in one region can have long-term impacts on many others is a fundamental prerequisite for understanding why the international community has so far failed to halt the decline of marine species and habitats. In reality, the multitude of international stakeholders and rules that determine our approach to managing the seas – known as ocean governance – do not view the global ocean as a vast unified entity in which everything is interconnected and which therefore requires collective, cross-sectoral regulation. Instead, they separate the ocean and the sea floor into

8.1 > The United Nations Convention on the Law of the Sea (UNCLOS) divides the ocean into various legal zones (spatial governance logic), with the coastal state's sovereignty decreasing with increasing distance from the coastal base-line. An overview of all the various rights and jurisdictions is provided in *WOR 7*, pp. 262–264.



8.2 > A world ocean: near-surface ocean currents such as the Gulf Stream in the western Atlantic transport water masses around the globe, dispersing heat and nutrients, but also pollutants, to the furthest corners of the seas.

zones under different jurisdictions and assign human activities in the ocean to different sectors or thematic areas.

Experts refer to two distinct regulatory approaches which have evolved over time, giving rise to the complexity of ocean governance in its current form. On the one hand, coastal states can claim exclusive rights to the marine zones surrounding them. They can thus assert sole decision-making authority over demarcated areas of the sea, which are then assigned to them under the United Nations Convention on the Law of the Sea (UNCLOS). This is known as the spatial or geographical governance logic. On the other, states regulate many uses of the oceans collectively: for example, by reaching international agreements on rules and competencies relating to specific activities, such as shipping, fisheries and aquaculture, or deep-sea or seabed mining. This is the sectoral governance logic.

The process for reaching these agreements at international level is also stipulated in part by the United Nations Convention on the Law of the Sea (UNCLOS)

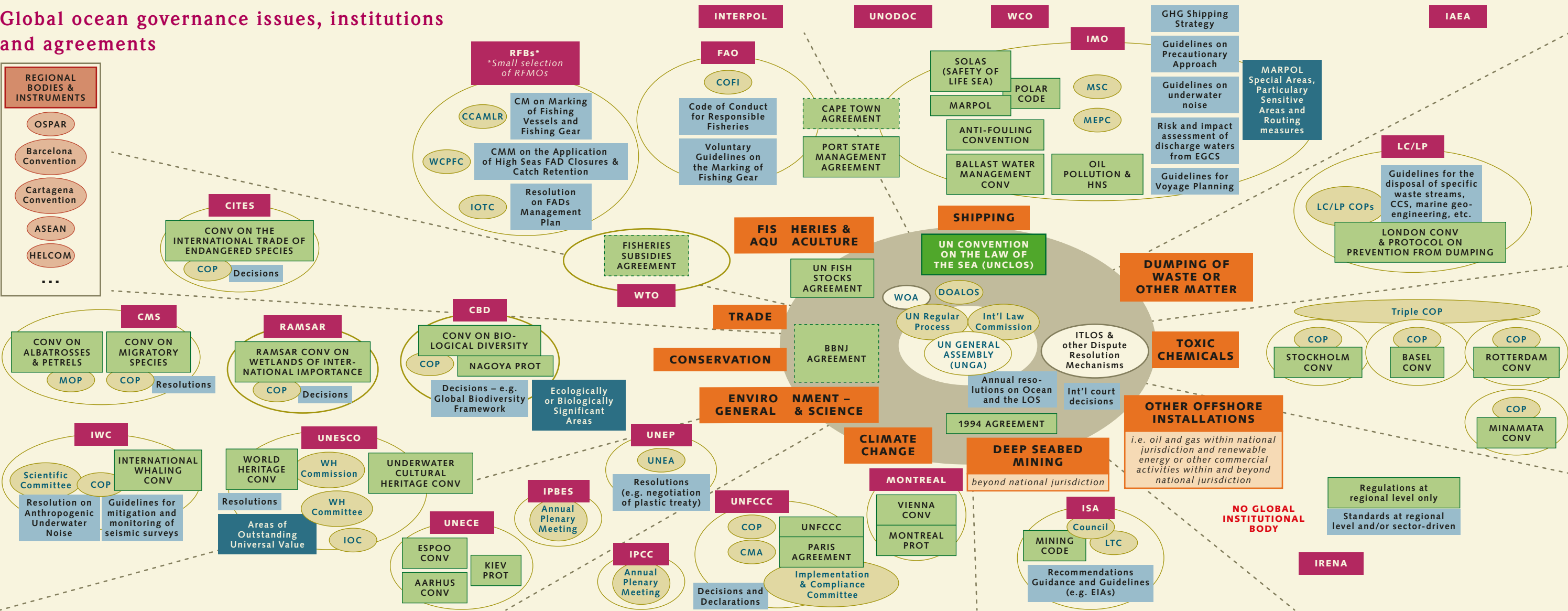
and the supplementary agreements which deal with its implementation. For historical reasons, however, each sector or thematic area has its own stakeholders, objectives and decision-making structures, making collective and coordinated global marine management almost impossible at present.

Within the United Nations (UN) system alone, there are currently more than 25 organizations dealing with the marine environment at the international level. They include the Intergovernmental Oceanographic Commission of UNESCO (UNESCO-IOC), which focuses on marine scientific research and global ocean observation. The Food and Agriculture Organization of the United Nations (FAO) also plays a key role: it monitors global fisheries and aquaculture production, supports programmes that promote sustainable fishing and fish farming and produces a regular report, *The State of World Fisheries and Aquaculture (SOFIA)*.

The United Nations Environment Programme (UNEP) is committed to the conservation and sustainable use of

Ocean governance
The term "ocean governance" encompasses the raft of regulations, laws, institutions and policy measures relating to the world's oceans and seas. It also refers to the specific area of multi-level policymaking on ocean-related topics. A multitude of governmental and non-governmental actors are involved in ocean governance at local, national, trans-regional and global level.

Global ocean governance issues, institutions and agreements



ACRONYMS

CBD	Convention on Biological Diversity	IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
CCALMR	Commission for the Conservation of Antarctic Marine Living Resources	IPCC	Intergovernmental Panel on Climate Change
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora	IRENA	International Renewable Energy Agency
CMA	Meeting of the Parties (Paris Agreement/UNFCCC)	ISA	International Seabed Authority
CMS	Convention on the Conservation of Migratory Species of Wild Animals	ITLOS	International Tribunal for the Law of the Seas
COFI	Committee on Fisheries (FAO)	IWC	International Whaling Commission
CONV	Convention	LC/LP	London Conv./Prot. on the Dumping of Wastes and Other Matter
COP	Conference of the Parties	LTC	Legal and Technical Committee (ISA)
DOALOS	Division for Ocean Affairs and the Law of the Sea (UN)	MEPC	Marine Environment Protection Committee
FAO	Food and Agricultural Organization (UN)	MOP	Meeting of the Parties
IAEA	International Atomic Energy Agency (UN)	MSC	Maritime Safety Committee
IMO	International Maritime Organization	OECD	Organisation for Economic Co-operation and Development
Interpol	International Criminal Police Organization	PPR	Sub-Committee on Pollution Prevention and Response
IOC	Intergovernmental Oceanographic Commission of UNESCO	PROT	Protocol
IOTC	Indian Ocean Tuna Commission	RFB	Regional Fisheries Body

RFMO	Regional Fisheries Management Organization	UNFCCC	UN Framework Convention on Climate Change
SDC	Sub-Committee on Ship Design and Construction	UNFCCC	UN Framework Convention on Climate Change
UN	United Nations	UNFCCC	UN Framework Convention on Climate Change
UNCLOS	UN Convention on the Law of the Sea	UNFCCC	UN Framework Convention on Climate Change
UNDP	UN Development Programme	UNFCCC	UN Framework Convention on Climate Change
UNEP	UN Environment Programme	UNFCCC	UN Framework Convention on Climate Change
UNEA	UN Environment Assembly	UNFCCC	UN Framework Convention on Climate Change
UNECE	UN Economic Commission for Europe	UNFCCC	UN Framework Convention on Climate Change
UNEP	UN Environment Programme	UNFCCC	UN Framework Convention on Climate Change
UNESCO	UN Educational, Scientific and Cultural Organization	UNFCCC	UN Framework Convention on Climate Change
UNFCCC	UN Framework Convention on Climate Change	UNFCCC	UN Framework Convention on Climate Change
UNODC	UN Office on Drugs and Crime	UNFCCC	UN Framework Convention on Climate Change
WCO	World Customs Organization	UNFCCC	UN Framework Convention on Climate Change
WCPFC	Western and Central Pacific Fisheries Commission	UNFCCC	UN Framework Convention on Climate Change
WH	World Heritage	UNFCCC	UN Framework Convention on Climate Change
WOA	World Ocean Assessment	UNFCCC	UN Framework Convention on Climate Change
WTO	World Trade Organization	UNFCCC	UN Framework Convention on Climate Change

LEGEND

	Regional organization		Binding instruments
	International organization		International and regional binding instruments – not yet in force
	Body/committee within an international organization or established by a treaty		Resolutions (incl. guidelines) and court decisions
	Lead organisation/sub-regime common name		Area-based measures and tools
	Area of implementation under UNCLOS		

8.3 > A multitude of international institutions and agreements form the global ocean governance framework. The diagram, although detailed, is not

exhaustive and does not include other influential processes that involve only a small group of states.

as of July 2025

marine and coastal areas, while the International Maritime Organization (IMO) develops and implements regulations aimed at preventing ship accidents and marine pollution by ships. Other organizations, although not part of the UN system, also contribute to the global ocean governance regime. The International Hydrographic Organization (IHO), for example, works to ensure that all the world’s seas, oceans and navigable waters are surveyed and charted, thereby supporting safety of navigation and the protection of the marine environment.

The legal framework of relevance to marine biodiversity is as complex and fragmented as the array of stakeholders and sectors involved. Currently, there are at least 24 international agreements in existence whose purpose is the conservation and protection of marine species and habitats. They include:

- the 1982 *United Nations Convention on the Law of the Sea* (UNCLOS), also known as the constitution for the seas;
- the 1992 *Convention on Biological Diversity* (CBD). Its goals are the conservation of global biological diversity, the sustainable use of the Earth’s ecosystems, and the fair and equitable sharing among countries of any benefits deriving from the use of nature’s genetic resources. Although the CBD covers all the world’s oceans, its official mandate extends solely to the regulation of marine biodiversity in Parties’ national waters. For international waters beyond national jurisdiction, the CBD may only implement and support preparatory measures;
- the 1972 *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter* (London Convention), and
- the 2009 *Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing* (Port State Measures Agreement – PSMA).

The same objectives are pursued by multilateral and bilateral agreements concluded by coastal states at regional and transregional level, which generally apply to

specific marine regions. Various European countries, for example, are Contracting Parties to the Convention for the Protection of the Marine Environment of the North-East Atlantic (Oslo–Paris Convention, OSPAR) and the Convention on the Protection of the Marine Environment of the Baltic Sea Area, with the Baltic Marine Environment Protection Commission (Helsinki Commission, HELCOM), or have signed up to the Mediterranean Action Plan of the United Nations Environment Programme (UNEP). At the same time, countries are represented in various bodies that deal with fisheries and aquaculture, some of which have regulatory powers, notably the regional fisheries management organizations (RFMOs), which differ according to whether they deal with the management and monitoring of tuna fisheries, for example, or species other than tuna. Other bodies merely perform advisory functions.

Furthermore, some coastal states have joined various voluntary initiatives to protect the seas. For example, there is broad political support for the Code of Conduct for Responsible Fisheries (CCRF), adopted by the FAO member states in 1995, and the Polar Code, which was adopted by the International Maritime Organization (IMO) and covers safety, environmental and staffing matters of specific relevance to shipping operations in polar waters.

These international, intergovernmental or voluntary agreements, in turn, are transposed into applicable law through national legislation. The degree of stringency with which domestic legislation adheres to the previously negotiated standards is a matter for the governments and parliaments concerned. The fact is that at national level too, there is usually a great diversity of stakeholders, ministries and authorities that are responsible for marine issues, creating challenges for an integrated and coordinated approach.

As this brief insight makes clear, many different stakeholders are involved in writing the rules of ocean governance. As a consequence, in many areas of the sea, a multitude of diverse provisions apply simultaneously. In the best case, they have overlapping objectives; in the worst, they contradict each other, the experts say.



8.4 > The Atlantic cod (*Gadus morhua*) is one of the most important commercial fish species in northern Europe and along the east coast of North America. It has been heavily overfished and is now classed as endangered.

CCRF
The Code of Conduct for Responsible Fisheries (CCRF) sets out principles and standards of behaviour for the fishing industry. Their purpose is the conservation of marine and freshwater living aquatic resources and ecosystems to ensure that fishing continues to be viable in future.

The weaknesses of international ocean governance

In view of the ongoing decline in marine biodiversity, experts are now investigating systematically why, within the existing legal framework for ocean governance, states are failing to protect marine organisms and their habitats effectively from overexploitation, pollution, degradation and the impacts of climate change. The research findings vary depending on the focus of study, the methods of analysis used and the participating experts’ technical disciplines. Nevertheless, the experts often arrive at similar conclusions, which can be summarized as follows:

The international community is currently unable to respond appropriately to the numerous mutually reinforcing environmental crises or collectively regulate humankind’s simultaneously increasing claims on the oceans in alignment with the interests of marine and biodiversity conservation.

Instead, the sectoral subdivision of ocean governance, which to some extent has evolved historically, is indirectly driving the loss of marine biodiversity, because economically important user claims such as shipping, the food supply, energy generation and resource extraction are given far greater priority than protecting the marine environment. Under the present conditions, the experts say, states are unable to devise joint solutions that would combat the numerous all-pervasive and interwoven causes of marine biodiversity loss simultaneously.

Researchers and marine conservationists are therefore calling for a systemic and holistic approach to marine management. Instead of sectoral decision-making, what is needed, they say, is integrated marine management which addresses all the causal factors driving marine species turnover and develops solutions that contribute in various ways to preserving, strengthening and, ideally, restoring marine organisms and habitats. In essence, it is no longer primarily about generating as much revenue



8.5 > Millions of people's livelihoods depend on the services provided by the sea – including the women from the “Mwani Zanzibar Mamas” collective in Zanzibar. For generations, they have harvested seaweed and used it to make traditional remedies and skincare products.

as quickly as possible from the ocean, its habitats and resources. Instead, on all matters relating to the ocean, humankind must take a long-term view and set new priorities. The health of the ocean and its numerous biocoenoses should be just as high on the political agenda as economic interests, along with the aim of guaranteeing fair and equitable access to the ocean for everyone.

Conservation of global biodiversity – this much is now certain – can only succeed if it is firmly embedded in the debate about the transformation and sustainable development of human societies. To guide action on the future governance of the oceans, governance experts recommend the ecosystem approach, which was developed within the framework of the Convention on Biological Diversity. The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes their conservation and sustainable use.

This approach also integrates concepts such as the precautionary principle and adaptive management. The latter, in simple terms, means a process of continuous learning and optimization. This is possible if stakeholders monitor and control the impacts of the management measures implemented by them and critically review the results. They can thus improve their understanding of systems and processes and adapt their action plans accordingly if targets are missed or external conditions change. The core objective of adaptive management in the context of biodiversity conservation is to continuously improve the measures adopted and thus increase the adaptive capacities of organisms and living resources under pressure, e.g. by mitigating human-induced stressors.

The CBD's ecosystem approach also aims to integrate modern science and indigenous and local knowledge into decision-making and to recognize that human communities, in their cultural diversity, are an integral component of many ecosystems.

All too often, the current ocean governance regime prioritizes the interests of coastal states and fishing nations and neglects the ocean's pivotal role as humankind's common livelihood base.

This criticism is aimed, inter alia, at UNCLOS. In Article 62, for example, UNCLOS calls upon coastal states to promote the objective of optimum utilization of living resources (fish and shellfish) in their exclusive economic zones. Where a coastal state does not have the capacity to harvest the entire allowable catch in its EEZ, it should enter into fishery access agreements with other countries, whose fleets may then access the surplus of the allowable catch.

In the past, these fishery access agreements were mainly entered into by African coastal states. They concluded treaties with fishing nations such as Russia, the USA, Japan and China, as well as with the European Union. However, as the African states were rarely able to monitor their partner countries' fishing expeditions or impose specific conservation requirements, as recommended by UNCLOS, this led to unsanctioned overexploitation of Africa's species-rich waters – with devastating consequences for local ecosystems and traditional artisanal fishermen in the region.

The European Union is one of the few political actors attempting to transpose the UNCLOS guidance on fishery access agreements into their own fisheries legislation. In 2013, the EU reformed the principles underlying its common fisheries policy. Since then, fishing expeditions, including in non-EU waters, have been governed by the principles of sustainable and responsible fishing, which take precedence over domestic objectives such as a secure market supply of fish and shellfish. To what extent these principles are put into practice is beyond the scope of this chapter.

Some experts emphasize, therefore, that future-proof ocean governance should no longer focus exclusively on the interests of coastal states. Instead, the ocean should be viewed in its entirety as a common good and part of the common heritage of humankind – including coastal waters currently under national jurisdiction and areas in the exclusive economic zones. As a common good, the ocean would be a non-governmental, non-private, shared resource that can only be protected if the stakeholders that depend upon it assume collective responsibility for its conservation and recovery.

Precautionary principle

The precautionary principle states that the most effective way to protect the environment is by avoiding all conceivable impacts from the start. It is a tenet of risk assessment. It comes into play from the very outset whenever there is a potential risk to the environment, regardless of scientific uncertainty about the risk's occurrence. The precautionary principle is viewed as a guiding framework for international environmental governance. However, as there is no standard interpretation or unified approach to its application, there is often controversy over which actions are compatible with the principle and which are not.

8.6 > Ghana’s fishermen are facing an uncertain future. Due to climate change and overfishing, catches of round sardinella (*Sardinella aurita*) and other schooling fish in the Gulf of Guinea decreased by more than half from 1993 to 2019.



Viewing the ocean and its ecosystems as a common good and common heritage of humankind also means that every state, economic actor, community and individual is responsible for protecting marine habitats. This holistic approach is enshrined in the Preamble of the United Nations Convention on the Law of the Sea (UNCLOS), which states that “the problems of ocean space are closely interrelated and need to be considered as a whole”. However, stakeholders’ compliance with this provision has so far been patchy at best.

The current ocean governance regime lacks consensus, coordination and clarity. Monitoring of compliance with marine conservation rules is inadequate.

Appropriate entry points exist at all levels of ocean governance, starting with UNCLOS itself. As of June 2025, 170 of the world’s countries had ratified and acceded to the Convention. At that point in time, the United Nations had 193 member states. In other words, more than 20 UN member states had not yet ratified this international treaty – including the USA. This means that these countries are not fully bound by the Convention under international law. It should be noted, however, that many of the Convention’s provisions now have the status of customary international law and are therefore binding on countries which are not States Parties.

The new Agreement on Fisheries Subsidies, adopted by members of the World Trade Organization (WTO) in 2022, has also had little impact to date. It prohibits the granting of subsidies for illegal, unreported and unregulated (IUU) fishing and for fishing of overfished stocks. It took until September 2025 for the Agreement to enter into force, more than three years after its adoption. That was how long it took for two thirds of World Trade Organization members to ratify and thereby officially accede to it.

Other frequent targets of criticism – besides states that are failing to implement UNCLOS in full or in part – are the regional fisheries management organizations (RFMOs). Their members regulate and collectively coordinate fishing in various regions of the high seas and some national waters. In the past, the RFMOs and their member states were accused of doing little or nothing to enforce international standards for the conservation of the marine environment, failing to take sufficiently resolute action against illegal fishing, developing fishing strategies without considering the ecosystem approach, and cooperating minimally or barely at all with other ocean governance stakeholders.

The situation has improved somewhat now that some RFMOs are required to undergo regular performance reviews. Environmentalists and scientists are still far from satisfied, however. At present, their criticisms mainly focus on the lack of transparency on the part of the RFMOs. For example, many RFMOs deny journalists and non-accredited observers access to their working meet-



8.7 > In the open sea off the South Orkney Islands, a Korean fishing vessel transfers its fresh catch of Antarctic krill onto a Russian refrigerated transport ship. The growth of the krill fishery in Antarctic waters poses a threat to the ecosystem in key areas of the Southern Ocean.

ings. Although reports are published after the conferences, they do not disclose, in some cases, which measures or initiatives were blocked in the negotiations and by which member states. Instead of providing transparent information, the reports merely state that no agreement was reached. The lack of detailed information arguably makes it more difficult to hold countries accountable if they fail to honour their marine conservation commitments.

The paucity of publicly accessible information about high-seas fisheries is borne out by figures from Global Fishing Watch. According to information provided by this marine conservation organization, the positional data and fishing routes taken by 75 per cent of industrial fishing vessels do not appear in any publicly accessible database. The true scale of sea fishing and hence the potential impacts on marine ecosystems are therefore almost impossible for independent observers to determine.

New forms of uses of the seas pose another major challenge for international ocean governance. Examples are marine carbon dioxide removal (mCDR) techniques, new approaches for restoring marine ecosystems, and new biotech processes based on marine genetic resources. The use of these various procedures is reportedly already in preparation and has undergone testing in many cases. However, experts note that the ocean governance regime is certainly not yet capable of addressing the risks inherent in these and other interventions; nor can it prescribe effective measures to prevent harm to the ocean and its ecosystems while guaranteeing fair sharing of potential benefits. There may be financial benefits, for example, in selling carbon removal certificates and patents. However, existing verification and approval procedures mainly focus on issues relating to technical feasibility and merely call for basic minimum standards of conservation and sustainability. Issues relating to the inter-

action between these processes and the marine environment and other forms of ocean use are rarely considered. The same applies, the experts say, to the cultural and social risks that the use of these procedures may pose, e.g. to local coastal communities, artisanal fishermen and indigenous communities.

The current rules are based on outdated assumptions.

In its day, the United Nations Convention on the Law of the Sea introduced new regulations for a multitude of previously contentious issues in marine exploitation. Its primary objective was to ensure well-ordered and peaceful cooperation among states on issues relating to the uses of the seas and oceans. The Convention is still regarded as one of the most complex and comprehensive treaties ever concluded by the international community. The negotiations were guided by the fundamental concept of a regime for the oceans and seas and achieving the equitable and efficient utilization of ocean space and resources – albeit with the proviso that the flora and fauna of the marine environment should be preserved, notwithstanding all the various uses.

This notion of the ocean as a common economic space is still current today and is reflected in Article 87 of UNCLOS on “Freedom of the high seas”. It grants all states various freedoms in respect of the high seas: freedom of navigation, freedom of overflight, freedom to lay submarine cables and pipelines, freedom to construct artificial islands and other installations, freedom of fishing and freedom of scientific research. This list reflects the still-current hierarchy of global user claims on the ocean: shipping is the top priority, followed by aviation and global communications and trade interests. Resource extraction and, nowadays, renewable energies are in third place, with fishing ranking fourth. UNCLOS thus embodies the notion that the ocean is there to serve us – in other words, we generally take from the ocean and its ecosystems rather than living in harmony with them.

This is an outdated concept, in the view of many experts. They argue that the decline of marine biodiversity

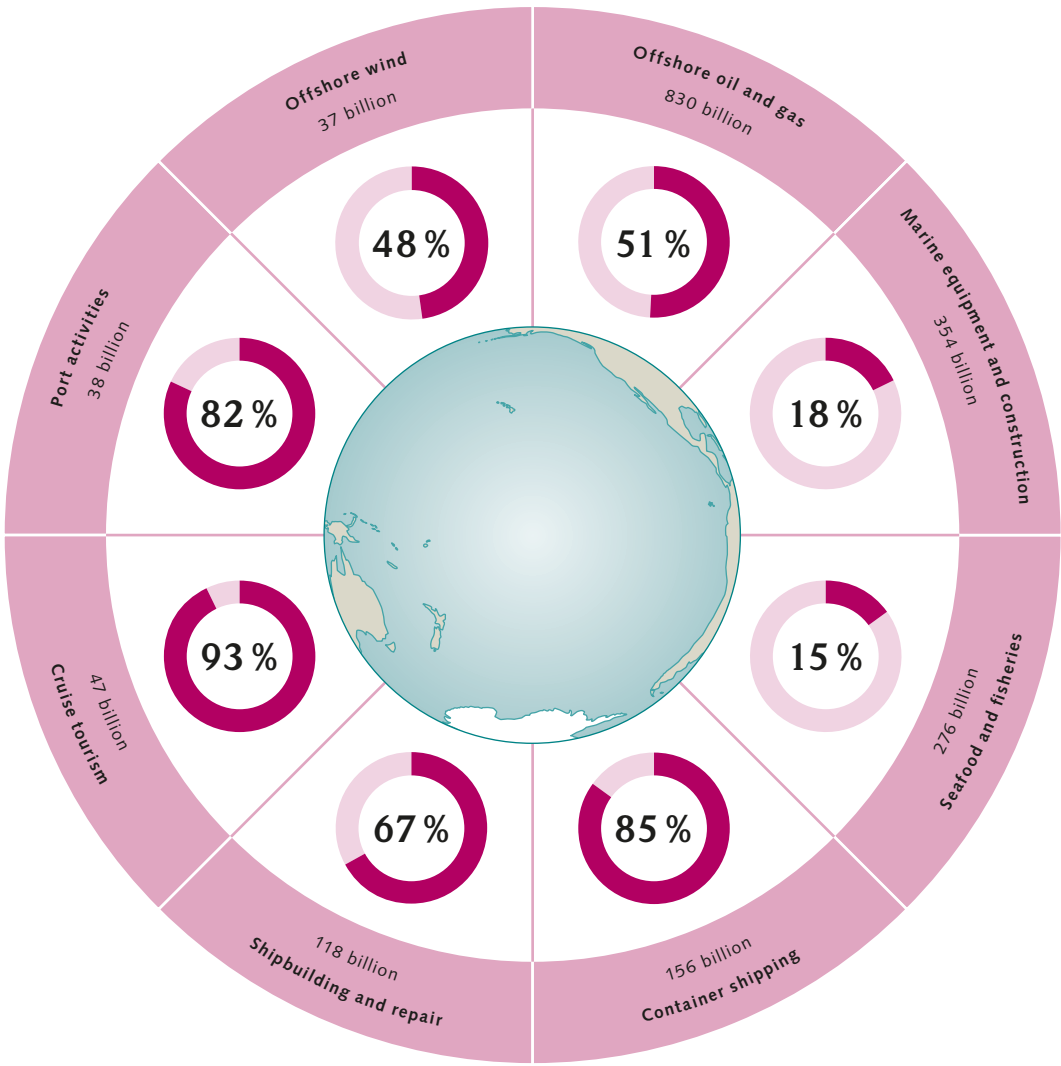
can be halted only if humankind sets new priorities in its approach to the oceans and seas. Protecting marine habitats from degradation, restoring damaged ecosystems and limiting the quantities of fish and other living resources that are extracted must, at the very least, be given equal or even, ideally, higher priority in marine management than short-term economic interests. Indeed, from a long-term perspective, sustainable use of the ocean would make more economic sense as well.

Humankind should also radically rethink the role of the oceans – above all, by defining the high seas not as a free economic space but henceforth as a protected area in which interventions are permitted only if the UN member states collectively approve them. Another option is to recognize the intrinsic value of the ocean, its ecosystems and living resources. If they were granted the legally enshrined right to exist and reproduce undisturbed, humankind would have to fundamentally overhaul its approach to marine management. This radical turn would give all stakeholders the opportunity to rewrite the legal order for the oceans and initiate the transformation that is needed to preserve life in the ocean and maintain the many vital functions that it performs for humankind.

The current regime does not allow all the world’s populations to share equitably in the benefits and participate equally in decision-making about the seas. It thus increases inequality between industrialized and developing countries.

Never before has humankind derived so much economic benefit from the oceans as in recent years. However, these economic benefits are shared in a highly inequitable manner. Research shows that in 2018, 100 companies operating in the eight core ocean industry sectors took an estimated 60 per cent of all revenues. These global corporations from countries such as the USA, Saudi Arabia, China, Norway and France collectively generated 1.1 trillion US dollars in revenues from goods and services. Total revenues from all ocean industry sectors that year stood at 1.9 trillion US dollars. The sector with the highest revenues was the oil and gas industry, which generated

Global revenue of the core sectors of the ocean economy industry, and total percentages accounted for by the top 10 companies (in US dollars)



8.8 > In five out of eight core sectors of the international ocean economy industry, the world's top ten corporations in each sector accounted for more than half of the global revenue share in 2018. As these figures demonstrate, the sharing of economic benefits from the use of the seas is highly inequitable.

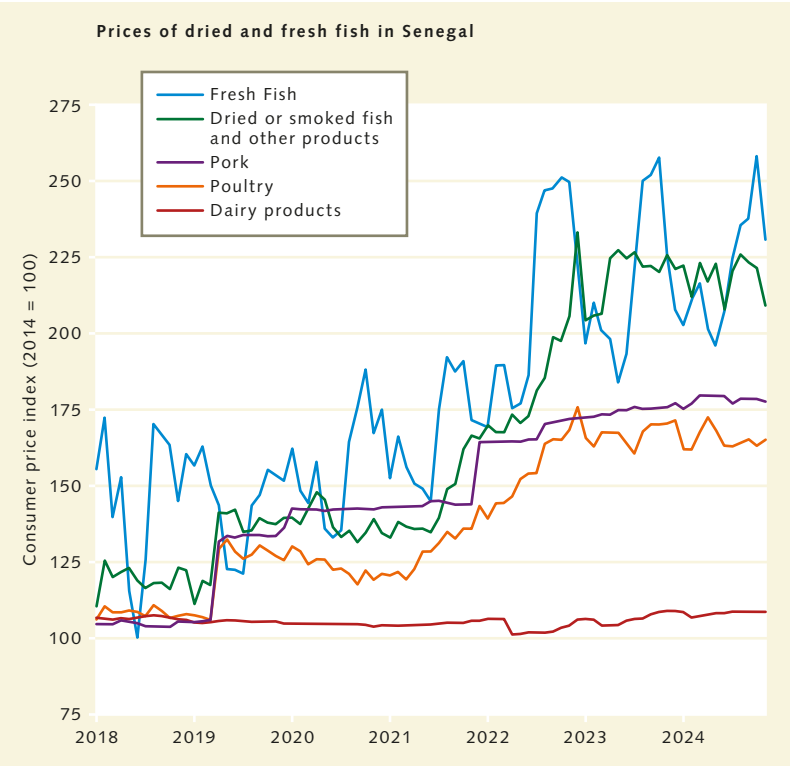
around 65 per cent of total revenue, followed by shipping (12 per cent), shipbuilding and repair (8 per cent), marine equipment and construction (5 per cent), fishing and aquaculture (4 per cent), cruise tourism (3 per cent) and port activities (2 per cent).

Staying operational and competitive in these ocean industry sectors requires a high level of technical expertise, along with substantial financial resources to fund investment in the necessary technology and equipment.

The same applies to new sectors of the ocean economy such as wind power, marine biotechnology and deep-sea mining. Smaller companies or financially weak coastal and developing countries therefore face immense challenges if they wish to break into these lucrative ocean industry sectors. As a result, there is a vast skills and funding gap between the major corporations, on the one hand, and many developing countries and small island states, on the other. The impacts of this entrench and reinforce

CCAMLR and OSPAR
CCAMLR stands for the Commission for the Conservation of Antarctic Marine Living Resources, whose Contracting Parties (currently 26 states and the European Union) agreed in October 2016 to designate the Ross Sea Region as a marine protected area. The OSPAR Convention is a regional marine conservation agreement for the North Sea and the Northeast Atlantic. Its Contracting Parties are 15 European countries and the European Union.

8.9 > Prices of fresh, smoked and dried sea fish have risen sharply in Senegal in recent years. One reason is that corporations are buying up local catches for fishmeal production.



global inequality against the backdrop of worsening environmental crises.

UNCLOS and its implementing agreements require all States Parties to share knowledge and technology on a voluntary basis with developing countries, landlocked countries, small island developing states and coastal African states, and to provide support – including financial assistance – to these nations in developing a national ocean industry and a national marine management strategy. Only then will these states be able to implement the Convention, realize the benefits of economic use of the oceans and seas, ensure the well-being of the oceans, participate as equal members in international and regional marine forums, and achieve the Sustainable Development Goals (SDGs) set out in the 2030 Agenda, according to a recent report by the UN Secretary-General on oceans and the law of the sea.

Successful transfer of knowledge and technology, according to the report, includes the provision of project funding, technical training, detailed operating manuals,

support networks, ongoing technical assistance and collaboration with academic and research institutions, and financial instruments, such as trust funds and public-private partnerships. The report further lists a number of transfer programmes and measures by individual UN institutions, intergovernmental organizations and selected states. However, it also underlines the challenges that exist.

In order to provide targeted support for developing countries’ efforts to establish a sustainable marine management regime, it is essential to start by clarifying which specific form of support is needed by the country concerned and its stakeholders and how these needs can be met. Secondly, it is necessary to regulate how progress is monitored and assessed. Thirdly, answers are needed to various questions. How can funding be secured for the planned measures? And how can good cooperation and coordination avoid duplication in problem-solving and a renewed concentration of measures on a few potentially profitable industries while biodiversity and marine conservation slip out of focus again?

Considering the effects of new developments in marine technology on the environment and local communities, the report advises all stakeholders to integrate nature-based solutions and implement appropriate independent monitoring and reporting mechanisms to ensure compliance with social and environmental standards. The precautionary principle must also be applied.

Calls for integrated, environmentally and socially compatible marine management are particularly relevant because local user groups are often at a disadvantage compared to global corporations, with their knowledge, capital and technological lead. Examples of this inequality, which has negative impacts on the marine environment and the people who depend on it, can be found in numerous places.

Off the west coast of Africa, for example, stocks of round sardinella (*Sardinella aurita*) have been fished by industrial fleets for some 15 years, the catches of this schooling fish being used to produce fishmeal. Due to overfishing and climate change, however, catches have declined dramatically – from 100,000 to 250,000 tonnes per year in the period from 2010 to 2020 to just 10,000



8.10 > How can millions of fishermen's claims to the sea be reconciled with marine and species conservation? Which solutions offer a future for human communities and ocean life? International ocean governance must act swiftly to find answers to these questions.

tonnes annually since 2021. By contrast, prices have increased. In Senegal and neighbouring Gambia and Mauritania, most of the catch is purchased by large fishmeal factories. The fishmeal is then sold to aquaculture farms all over the world as feed for seabass and other farmed fish, which generally end up on dinner tables in industrialized countries. By contrast, many of the West African fish traders who previously purchased the coastal fishermen’s catches, before salting and drying the fish for sale at local markets, have gone out of business. Fresh or dried sea fish has become a fairly expensive commodity, at least in Senegal.

High expectations of the UN High Seas Treaty

On 19 June 2023, after almost 20 years of negotiations, states participating in an intergovernmental conference on UNCLOS adopted a third implementing agreement to the UN Convention on the Law of the Sea (UNCLOS). The agreement in question is the UN High Seas Treaty (Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas beyond National Jurisdiction, BBNJ).

With the adoption of the Treaty, the international community has closed a loophole in the law of the sea. This loophole had emerged because UNCLOS itself merely contains general provisions on the utilization of ecosystems in the high seas. Granted, it imposes a duty on States Parties to preserve and protect the marine environment in the high seas. However, in view of the growing exploitation of the seas, this general provision was far from adequate. Furthermore, UNCLOS does not specifically address aspects of biodiversity conservation.

The new BBNJ Agreement contains common rules on research and utilization of marine genetic resources and addresses the issue of how the monetary and non-monetary benefits arising from the utilization of these resources (e.g. profits from patents) can be shared among all states in a fair and equitable manner. It provides the UN with a definition of “marine protected area” for the first time and specifies the conditions under which such pro-

tected areas may be designated in the high seas. It stipulates that an environmental impact assessment must be conducted prior to any project or activity carried out in international waters. It also includes provisions on transnational knowledge and technology transfer and enshrines equity for all, particularly the developing countries, as one of its guiding principles.

The fact that states were able to reach agreement on the Treaty text was celebrated by observers and negotiators as a historic success. However, many of the elements needed to implement the Agreement are still lacking. One unanswered question, for example, relates to funding; another is how various ocean governance stakeholders should work together within the BBNJ framework and how the new agreement can be integrated into the existing global and regional ocean governance system. These and other points will need to be discussed and negotiated at the first meetings of the BBNJ Conference of the Parties (COP). At the same time, states face the task of officially acceding to the Agreement by means of ratification, approval or formal adoption. The BBNJ Agreement can enter into force on 17 January 2026. For precisely 120 days previously, on 19 September 2025, Sierra Leone and Morocco announced their official accession – the two further nations needed up to then in the list of 60 required ratifications.

There are high hopes that the Agreement will enable significant progress to be made on marine conservation, justice and equitable benefit-sharing and that it will initiate a global turnaround in our approach to the seas. For example, the Agreement obliges States Parties to establish a comprehensive system of ecologically representative and well-connected networks of marine protected areas in the high seas, and to take collective decisions on how selected regions of the high seas can be protected, sustainably used and managed by means of area-based management tools (ABMTs). These area-based management agreements must aim to:

- conserve and sustainably use areas of the high seas requiring protection, including through the designation of marine protected areas,

- strengthen cooperation among all States Parties, and develop the necessary management instruments and frameworks,
- protect, preserve and restore marine ecosystems and biological diversity, including strengthening their resilience to various stressors,
- support food security and other socioeconomic and cultural values and services provided by the sea, and
- build developing countries’ capacities through targeted knowledge, data and technology transfer, and ensure their equal participation in area-based management processes.

The BBNJ Agreement must be interpreted and applied in a manner that does not undermine existing legal instruments and frameworks and relevant global, regional, sub-regional and sectoral bodies (e.g. the regional fisheries management organizations, RFMOs) and that promotes coherence and coordination with those instruments, frameworks and bodies.

How much impact will the BBNJ Agreement have under these circumstances? The experts are somewhat sceptical: if the States Parties to the BBNJ Agreement are not permitted to involve themselves in the work of existing bodies and are limited solely to making recommendations, the Agreement will be a paper tiger on many issues and in many regions, they say. However, the experts also point out that many States Parties to the BBNJ Agreement have long been represented in the RFMOs and other bodies, so a coordinated approach should be possible in theory.

The new Agreement also defines, for the first time, basic up-to-date requirements and standards for conducting environmental impact assessments (EIAs), i.e. the process by which planned human activities that may adversely affect biodiversity in the high seas are to undergo prior assessment and regulation. In terms of their scope, these provisions cover activities conducted in international waters, as well as activities in marine areas within national jurisdiction if it is determined that the activity may cause substantial pollution of or significant and harmful changes to the marine environment in areas beyond national jurisdiction.

It is entirely a matter for the state leading the project to decide whether a planned activity requires an environmental impact assessment. However, if that state determines that an environmental impact assessment is not required, it is obliged to justify its decision publicly and on the basis of the best available science and scientific information. For example, if a state determines that an environmental impact assessment is not required for a planned activity in the high seas for any reason, it must publish the grounds for its decision, along with all relevant background information, through the BBNJ Secretariat. Other states thus have an opportunity to register their views on the planned project.

If, by contrast, a full EIA is required under the BBNJ Agreement, the state conducting the assessment must make use of the best available science and scientific information and, where available, relevant traditional knowledge. The most significant environmental impacts must be considered, as well as the cumulative impacts of the planned activity. The state must also ensure that measures are identified to mitigate and manage potential adverse effects of the planned activities or, ideally, to prevent them entirely. States Parties are further obliged to notify the public of planned activities and ensure, in particular, that adjacent coastal states and other potentially affected states and stakeholders are consulted and participate in the environmental impact assessment process. The environmental impact assessment report and all related findings must be made available to all States Parties through the BBNJ Secretariat.

The BBNJ Agreement has many positive aspects and provisions. Will it ultimately meet the high expectations and effectively preserve and protect biodiversity in international waters? Only time will tell.

Translating countless commitments into action

At the Third United Nations Ocean Conference in the French seaport city of Nice in June 2025, there were endless calls for more effective protection of the marine environment. Government representatives from 130 coun-

8.11 > Delegates listen attentively to one of the many discussions at the Third United Nations Ocean Conference in the French seaport city of Nice in June 2025.



tries had gathered here to develop a framework to save the seas. Transformative measures were high on the agenda – meaning action plans to initiate radical change in our use of the seas.

“Transformation” in this context was understood to include the objective of no longer solving environmental problems solely through technological or regulatory measures: it meant addressing the root causes of the problems – for example, by reforming our values and economic system. Against this background, it is not simply a matter of starting a new debate about issues of power and legitimacy in various forms of ocean use. A successful transformation of ocean governance also requires us, as a society, to radically rethink our standards and current patterns of behaviour.

Despite the wealth of research on the transformation of ocean governance and the growing public awareness of the urgent need for effective measures, even the experts find it challenging to describe in detail the practical steps that must be taken to initiate and successfully implement the necessary process of change. There is, however, a con-

sensus on the general outlines of future marine management. If the ocean’s ecosystems are to have a future, we must ensure that:

- we support and facilitate equitable and sustainable management of the marine environment,
- all stakeholders who use the ocean or influence its status are involved in decision-making and comply with the agreements reached,
- risks such as the impacts of climate change on marine ecosystems are taken into account in management plans,
- knowledge of the sea and marine technologies is widely shared and integrated into policymaking processes,
- adequate funding is provided for the necessary measures and structures for transformative governance.

The challenge now is to translate the countless commitments into action.

CONCLUSION

Cooperation across all levels

The ocean has no national or institutional boundaries. This presents the international community with at least two major challenges in marine management and biodiversity conservation. Firstly, stakeholders across all governance levels need to collaborate on every issue of relevance to the ocean and they have to coordinate their plans for its sustainable use. Secondly, it is essential to develop solutions that strengthen biocoenoses locally or regionally without causing harm elsewhere in the ocean. Ideally, local measures such as sustainable fisheries or restoration of degraded seagrass beds and salt marshes have the ultimate outcome of promoting the health of all or much of the ocean.

Humankind, however, is still a long way from realizing this ideal of integrated ocean governance that is aligned with marine ecosystems’ needs. At present, ocean issues at all levels are dealt with by multiple stakeholders and numerous institutions which, in turn, are governed by a diverse array of agreements and legislation, depending on the topic in question. This fragmented system of ocean governance necessarily gives rise to conflicts of interests and substantial inefficiency. It limits our scope and capacity to mitigate the mutually reinforcing effects of four environmental crises: marine overexploitation, climate change, species extinction and ocean pollution.

New and, above all, holistic thinking about our approach to marine conservation and management is therefore required. It will be essential to focus strategically on the preservation, protection and recovery of ocean life and deprioritize short-term economic interests that harm the ocean’s biocoenoses.

Currently, there are high hopes of the new UN High Seas Treaty (BBNJ), which enters into force in January 2026. The Treaty regulates the criteria for designating marine protected areas in the high seas. It further obliges regional fisheries management organizations to cooperate more intensively with other ocean governance stakeholders. It also states that every project in international waters must undergo a prior environmental impact assessment. The Treaty establishes legal provisions on transnational knowledge and technology transfer and enshrines fair benefit-sharing and participation for all as a guiding principle. The latter includes the notion that all states should share in the monetary and non-monetary benefits from the utilization of marine genetic resources.

To halt the ongoing decline of marine biodiversity, a radical transformation of ocean governance will be required. Which specific steps can initiate this process? It’s difficult to say.

However, there is widespread agreement among experts about the general framework needed – a framework conducive to forms of national and international marine policymaking that are aimed at preserving and protecting ocean life effectively. It will be essential to think holistically about the needs of human communities and ocean life, to share knowledge and data, embrace collective and transparent decision-making, provide adequate funding for innovations and monitoring systems, and act with foresight to optimally mitigate the mutually reinforcing impacts of climate change and other environmental crises on ocean life.

One thing is clear: marine biotic communities are vital for our livelihoods. By investing in their conservation and protection, we will be investing in a secure future for ourselves.

9

Marine Biodiversity – Vital Essence of Our Oceans

Life on Earth is linked inseparably with the ocean. It covers around 71 per cent of the Earth's surface and reaches depths of up to eleven kilometres. The ocean is thus the largest habitat on the planet and provides a multitude of services of critical importance for human survival and well-being.

In light of this, you might then expect „that the relationship of humans to the ocean would be one of deep respect, even of reverence“, said Peter Thomson, the United Nations Secretary-General's Special Envoy for the Ocean, in his closing address at the Third United Nations Ocean Conference in Nice in June 2025. But instead, we “over-exploit ... and pollute ... and unrelentingly warm the ocean.“ Through these and other interventions, we not only deprive the ocean of its aesthetic and inspirational value; we also directly endanger the survival of marine species and therefore of humankind itself. Without a healthy ocean, there cannot be a sustainable future for us, for humanity.

We have chosen this statement to introduce this summary of *World Ocean Review 9* because it reinforces the notion that marine biodiversity is by no means a niche topic for nature enthusiasts. Today, the ocean's state of health concerns us all. And because people only protect what they know and regard as valuable, beautiful or useful, the challenge that we have taken on with *WOR 9* is to excite and inspire as many readers as pos-

sible with lasting enthusiasm for the great diversity of marine species and habitats.

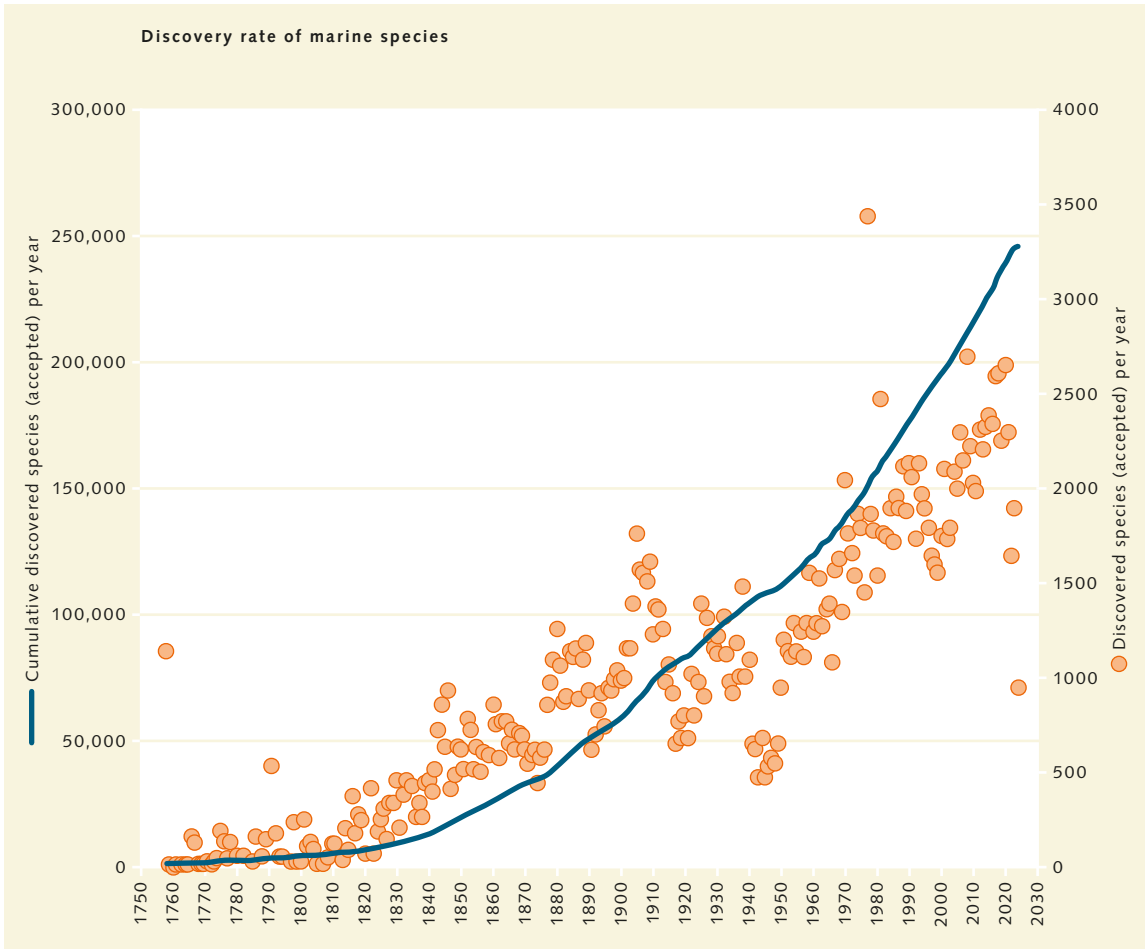
An astonishing variety of shapes, colours and functions

The dimensions of the ocean habitat are beyond human imagination. There is life everywhere in this vast space – even in places where nobody would have thought it possible: underneath the Antarctic ice shelves, for example, and in deep-sea hypersaline anoxic basins such as those found in the Mediterranean.

Precisely how many species live in and near the ocean is unknown, because we have not yet explored many marine regions, ecosystems and groups of organisms in any detail. Scientists estimate that there are between one and two million different species in the oceans, but there could be many more. Only a quarter, at most, of the estimated number has been scientifically described. And yet the variety of shapes and sizes, colours and functions of these species alone seems overwhelming – from microscopic archaea and bacteria, single-celled algae and fungi, to brightly coloured reef fish, elegant rays, darting seabirds, 30-metre-long whales and seaweeds – as well as the mysterious glass squid *Galiteuthis glacialis*, of which, incredibly, a living specimen was first filmed by scientists in the deep waters of the South Atlantic in March 2025. Previously,

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> Experts working on the World Register of Marine Species (WoRMS) keep a record of all newly discovered species. While the number of known marine species has now risen to almost 248,000, we still only know a small proportion of marine biodiversity.



marine biologists had only studied the remains of specimens found in the stomachs of dead seabirds or whales.

The list of fascinating marine organisms could fill many more pages – and some 2300 newly described species are added each year. To identify them, experts are increasingly turning to molecular methods such as barcoding, metabarcoding and metatranscriptomics. Researchers analyze the genetic information of organisms or, more precisely, selected regions of their DNA molecules. This information can be used to uniquely identify species, infer their functions and phylogeny, and identify successful adaptation strategies.

In this way, a large team of scientists recently showed that the Portuguese man o’ war (*Physalia physalis*), a vibrantly coloured siphonophore, is not in fact a

single species, as previously assumed. On the contrary, the populations in the Pacific, the Atlantic and the Indian Ocean differ genetically to such an extent that the researchers were able to identify at least four separate species.

As these and many other examples show, we still don’t fully understand life in the ocean. At the same time, we need much more detailed knowledge in order to draw firm conclusions about biodiversity in any given area of the sea – whether it concerns a single ecosystem, a marine region or the ocean in its entirety.

Biodiversity: A multifaceted concept

The ocean is considered healthy and resilient when its biological communities support a large number of

species that differ in their genetic make-up, appearance, characteristics and functions. If this is the case, experts speak of high biodiversity – a term derived from the words “biological” and “diversity”. Biodiversity is in fact an exceedingly complex concept.

For it is defined as the variability among living organisms of all origins including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part. This includes variation in genetic, morphological, phylogenetic and functional attributes, as well as changes in abundance and distribution over time and space within and among species, biological communities and ecosystems. Terms such as “species diversity” or “species richness” are often used synonymously with biodiversity. However, as the definition shows, the concept of biodiversity is much broader.

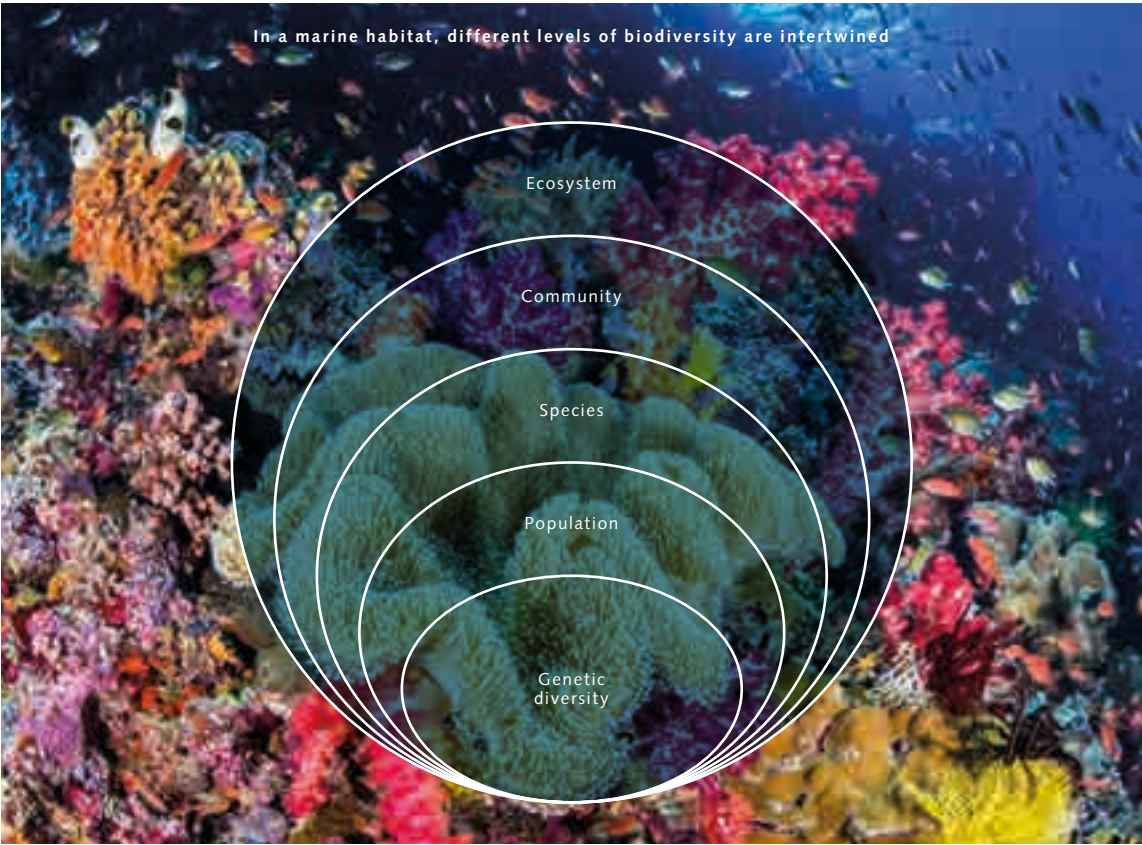
The multidimensionality of the concept of biodiversity makes it hard to grasp. In addition, researchers use

a variety of methods to quantify the biodiversity of a selected area. They may estimate or measure the region’s species richness, calculate the total amount of biomass present and its distribution among species and species groups, or examine the phylogeny of the organisms living in the region and analyse the relationships between the different species.

Species-rich ecosystems are more resilient

Marine habitats displaying high species richness as well as high functional and phylogenetic diversity are generally more resilient than low-diversity ecosystems. When the biodiversity of a marine region declines, the productivity of the biological communities affected tends to decline as well. They are then no longer able to deliver all the services they usually provide.

Experts are currently observing such a decline in performance as a result of drastic losses of biodiversity



> In the ocean, diversity can be found at all levels of biological organization – from genetic diversity to ecosystems. Importantly, all levels are interconnected and facilitate the range of services provided by marine life.

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in many marine regions. In some places, individual populations are in decline, while in others species and habitats are vanishing altogether. The drivers of these trends are man-made. Through climate change and the continued destruction and overexploitation of marine habitats, we are weakening marine ecosystems to the point where their survival and the many services they provide to us humans are no longer guaranteed.

Which organisms live in the sea, where and why?

Science has not yet been able to fully fathom why marine organisms occur in their ancestral habitats and not elsewhere, and which factors and mechanisms determine the distribution of species in the ocean.

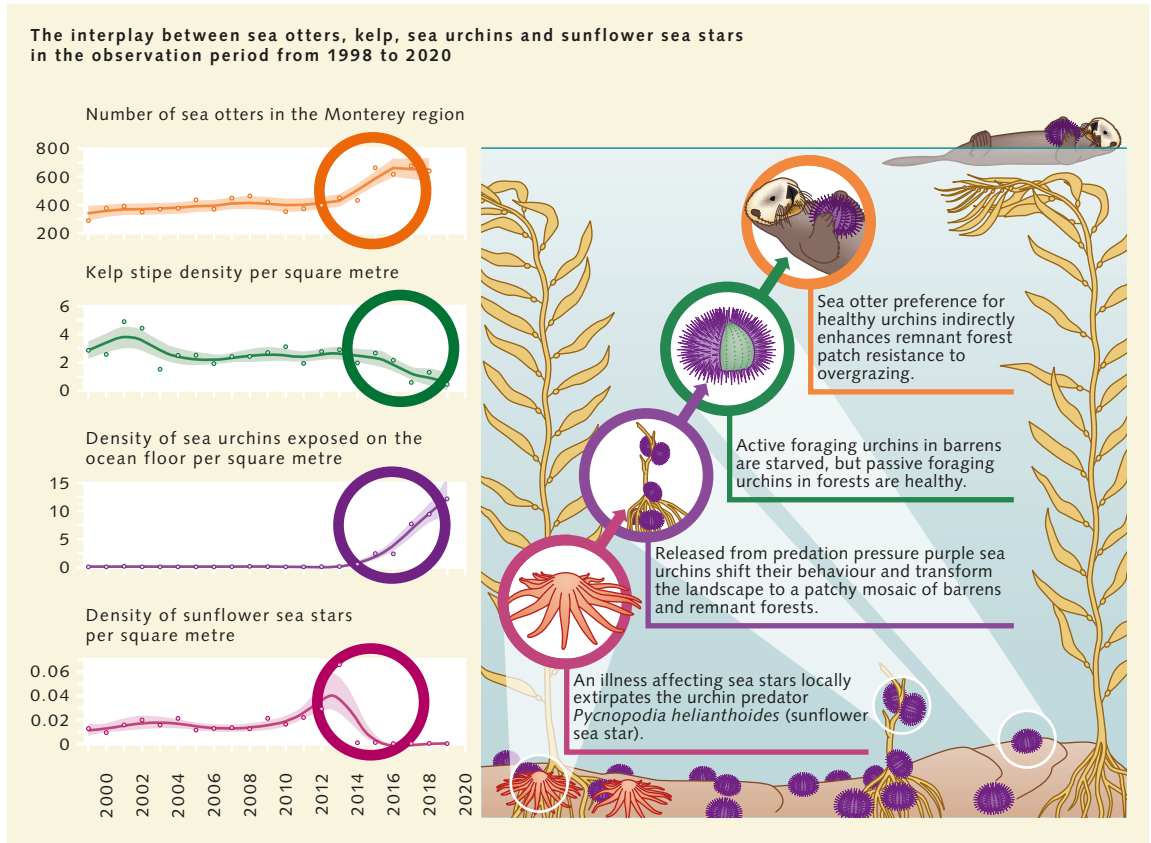
Scientists approach this question from two directions: Firstly, they collect and analyse data on the occurrence of species and habitats. They produce distribution maps and seek to recognize patterns and deci-

pher the local conditions to which these patterns are attributable. At the same time, they look at the principles of how microbial, animal and plant life works and try to derive laws. However, whether or not these conceptual explanations do apply to all marine organisms must then be thoroughly tested.

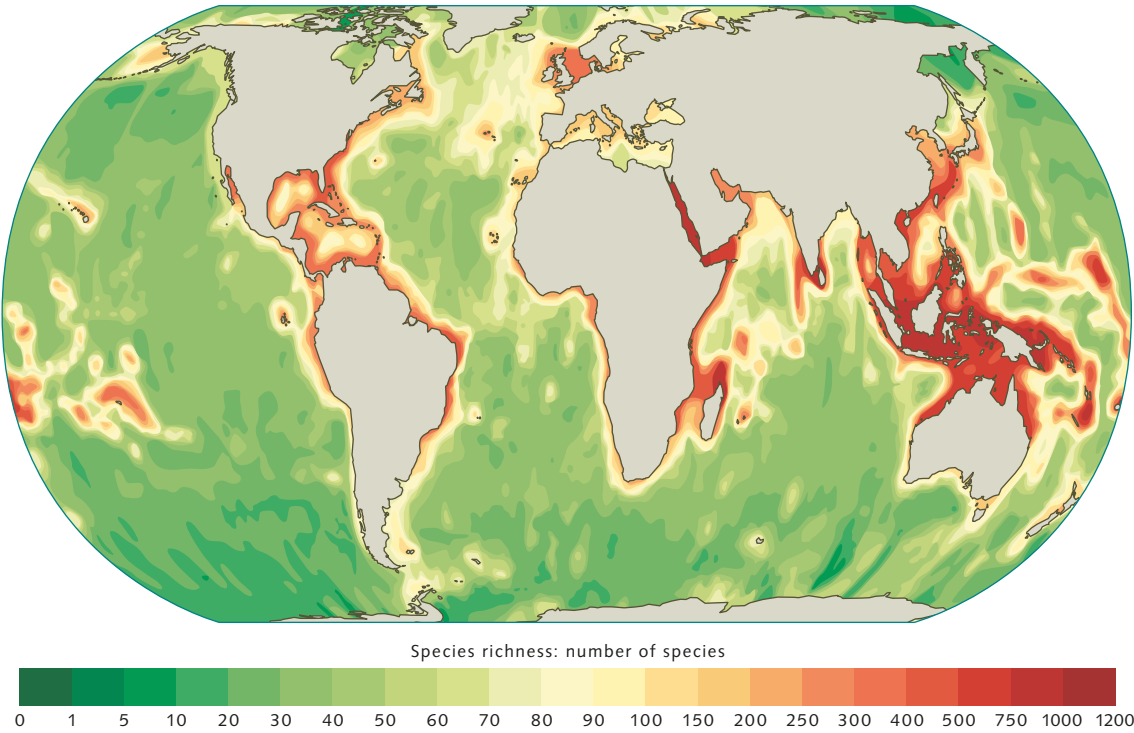
The geographical distribution of animals in the ocean is best understood. Which species can settle where in the sea and find sufficient food is determined by the ambient temperature and availability of oxygen, the overall food supply in the habitat and its complexity. The latter refers in particular to parameters such as habitat structure and interactions between its inhabitants.

The interplay of these key factors explains why a much higher number of species live in the light-filled coral reefs of the marginal tropics than in the surface waters of temperate latitudes or the polar seas. Many of the hotspots of marine biodiversity are therefore found

> The subtle interplay between sea otters, sea urchins, brown algae (kelp) and sunflower sea stars (starfish) off the coast of California shows how species in a habitat influence each other and thus stabilize their ecosystem.



Global distribution of marine biodiversity



> Species richness is generally higher in coastal areas than in the open ocean. Researchers have documented the highest levels of biodiversity in the Indo-Pacific Coral Triangle, the central and western Indian Ocean, the Red Sea and around the islands of the Southwest Pacific.

in marine regions in which warm-water corals grow. At the same time, it is clear that there are exceptions to this rule – such as marine mammals, whose bodies are not dependent on the ocean temperature.

Other factors apply to deep-sea organisms, because they mainly live in marine regions with comparatively stable water temperatures. However, food is generally in short supply in very deep waters. The food factor therefore plays a much more existential role in the geographical distribution of deep-sea organisms than for organisms that inhabit productive, densely populated and generally shallow coastal waters.

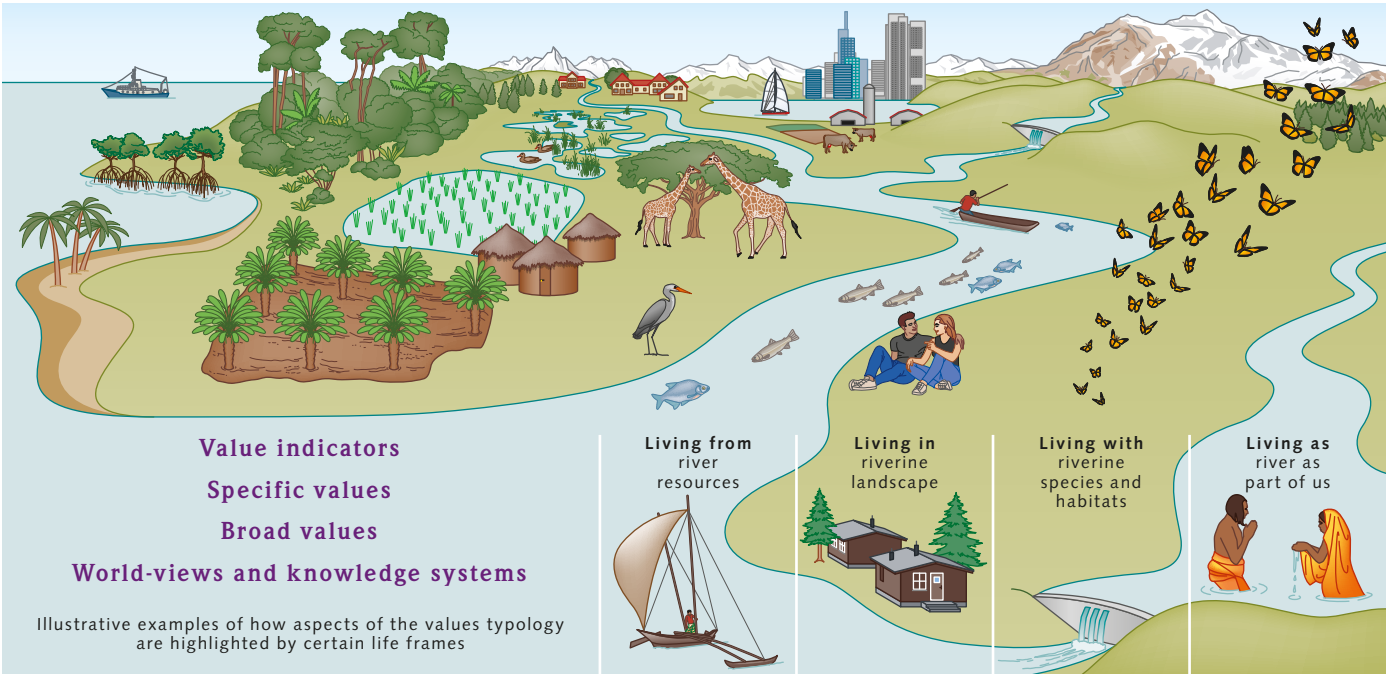
Gaining insights such as these, and others, into the geographical distribution of marine species, communities and ecosystems is essential for effective marine conservation. Knowing which organisms live where and what they need to survive enables us to identify climate-related changes in marine species abundance, among other things, and initiate adaptation measures wherever possible.

The value of the sea and its communities

Preserving life in the ocean means safeguarding our own natural resource base. More people are coming round to this view these days, but it is not yet shared by everyone. The reason is that people's attitudes towards nature – and that includes the ocean – differ considerably. Our experiences of natural spaces, flora and fauna – and hence how we interact with them – also vary. For example, while some people see tiger sharks as monsters of the deep, others are working to protect these magnificent predators, recognizing that their predation of sea turtles and other marine herbivores allows seagrass beds to flourish in tropical and subtropical coastal regions and that the sharks thus play a key role in species interaction in the ocean.

The different perceptions of and interactions with nature give rise to disparate views of nature's role as the foundation of people's lives. This, in turn, results in a multitude of types of value attributed by people to nature.

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Values typology					
World-views	Ways through which people conceive and interact with the world	Anthropocentric	Anthropocentric	Bio/ecocentric	Pluricentric
Knowledge systems	Bodies of knowledge, practices and beliefs Academic, indigenous, local			Cosmocentric	Cosmocentric
Broad values	Guiding principles and life goals	Prosperity, livelihood	Belonging, health	Stewardship, responsibility	Oneness, harmony with nature
Specific values	Judgements regarding the importance of nature in particular situations Instrumental Means to an end, nature as a resource and asset, satisfaction of needs and preferences, usefulness for people Intrinsic Agency of other-than-humans, inherent worth of biodiversity as ends in and of themselves Relational Importance of desirable, meaningful, and often reciprocal human relationships	Commercial fishery stock	Health benefits of recreation on the river	River as fish habitat	
		Cultural meanings of fishing	Intrinsic value of heritage fish Sense of place of a fishing community	The right of fish to exist Respect for fish life cycles	Fish as co-inhabitants Fish as part of kinship or clan relationships
Value indicators	Quantitative measures and qualitative descriptors				
	Biophysical	Tonnes of fish	Physiological effects of being in nature	Number of fish species	Nutrition of fish
	Monetary	Market price of fish harvest	Willingness to pay for recreation	Existence value	
	Socio-cultural	Gender-specific participation in fishing	Ratings of special places	Legal standing of bio-diversity	References to personhood of fish

> People define their relationship with nature in terms of world-views, broad values, specific values and value indicators. This overview illustrates how these can differ between people, depending on their individual life frames.

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has found that people often have one of four types of relationship to nature. They either live from nature, with nature or in nature, or see themselves as an intrinsic part of nature. To which of these types an individual belongs depends on that person's world-view and on the knowledge systems used and the values and value indicators applied by that person. While all this sounds highly abstract on paper, it exerts huge practical relevance. After all, it is people's very own relationship to nature and the oceans that determines their decisions on how to treat nature – at all levels, individual, political and economic.

IPBES concludes in its *Methodological Assessment Report on the Diverse Values and Valuation of Nature* that both political and economic decision-makers up to now only take account of a narrow set of largely market-based values of nature. This is why their decisions are frequently at the expense of nature and thus also at the cost of society and future generations. This is amplified by the circumstance that, in the course of advancing industrialization and urbanization, people are losing direct contact to the natural environment. The result is a disconnection from nature, in tandem with a severe loss of knowledge about the species diversity, the roles and the needs of natural biotic communities on land and in the oceans.

To halt species extinction and bolster the integrity of the natural environment, it will be essential that decision-makers at all levels, in the private sector and in public policy alike, shed past convictions and develop a new awareness of nature. Neglected values and local and indigenous knowledge need to be given consideration in decisions, and the vital role of healthy natural spaces needs to be communicated across all sectors of society. For the fact is: people will only protect and preserve what they know and understand.

Pressure from all sides

Just like us humans, marine organisms need a safe natural resource base on which they can draw for their healthy growth and reproduction. This primarily includes an

intact, unpolluted habitat, ambient temperatures within their specific comfort zone, and sufficient food. However, none of these cornerstones of marine life are considered to be secure today. The direct and indirect interventions of human societies in the global ocean are too far-reaching and severe.

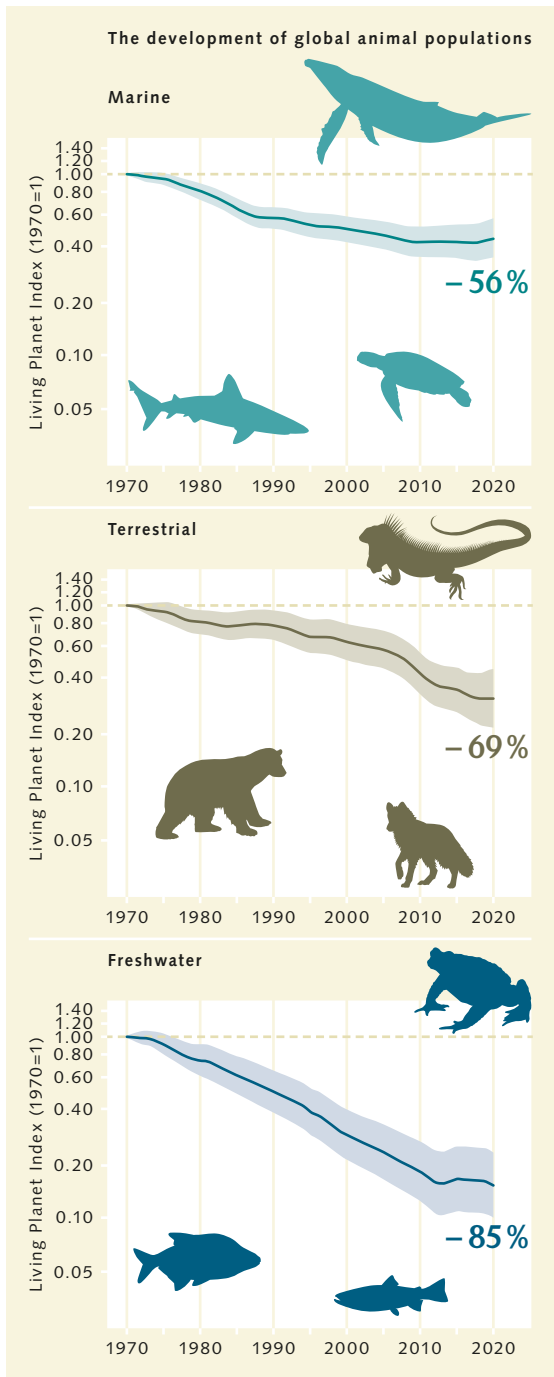
The principal direct drivers of the decline in marine biodiversity are the extraction of raw materials and organisms, changes in the use of coastal areas and oceans, climate change and its consequences for marine life, coastal and marine pollution, and the migration or introduction of invasive species. Indirect impacts are caused by factors such as human population growth, demographic shifts (e.g. urbanization and migration) and socio-cultural, economic, technological and political developments. These factors influence the decisions we make as societies, which ultimately affect nature and marine life.

The overexploitation of marine ecosystems in European waters began as early as the Middle Ages, driven by the growing commercialization of goods, raw materials and marine ecosystem services. This continued in other marine regions of the world in colonial times. The present development trajectory can be termed as the industrialization of marine resource use and exploitation.

Its extent has increased rapidly since the 1950s, resulting in the damage, destruction or disappearance of many original marine ecosystems and a decline in the population numbers of particular animal populations by more than half since 1970. The loss of marine species diversity is now so severe that a global mass extinction can no longer be categorically ruled out.

It is also a fact that our demands on the sea and its biological communities continue to increase, despite all the species and habitat losses in the ocean. New or drastically intensifying forms of utilization include energy generation at sea, shipping traffic, and fish farming and algae cultivation in aquaculture installations. Those pressures are compounded by mounting marine pollution by waste, microplastics and other pollutants, the impacts making themselves felt in the very last nooks and crannies of the oceans.

OVERALL-CONCLUSION



> The three ecosystem categories of the Living Planet Index reveal a dramatic decrease in the number of wild animal populations. The index covers 1816 marine species, 2519 terrestrial species and 1472 freshwater species inhabiting lakes, streams, rivers and ponds.

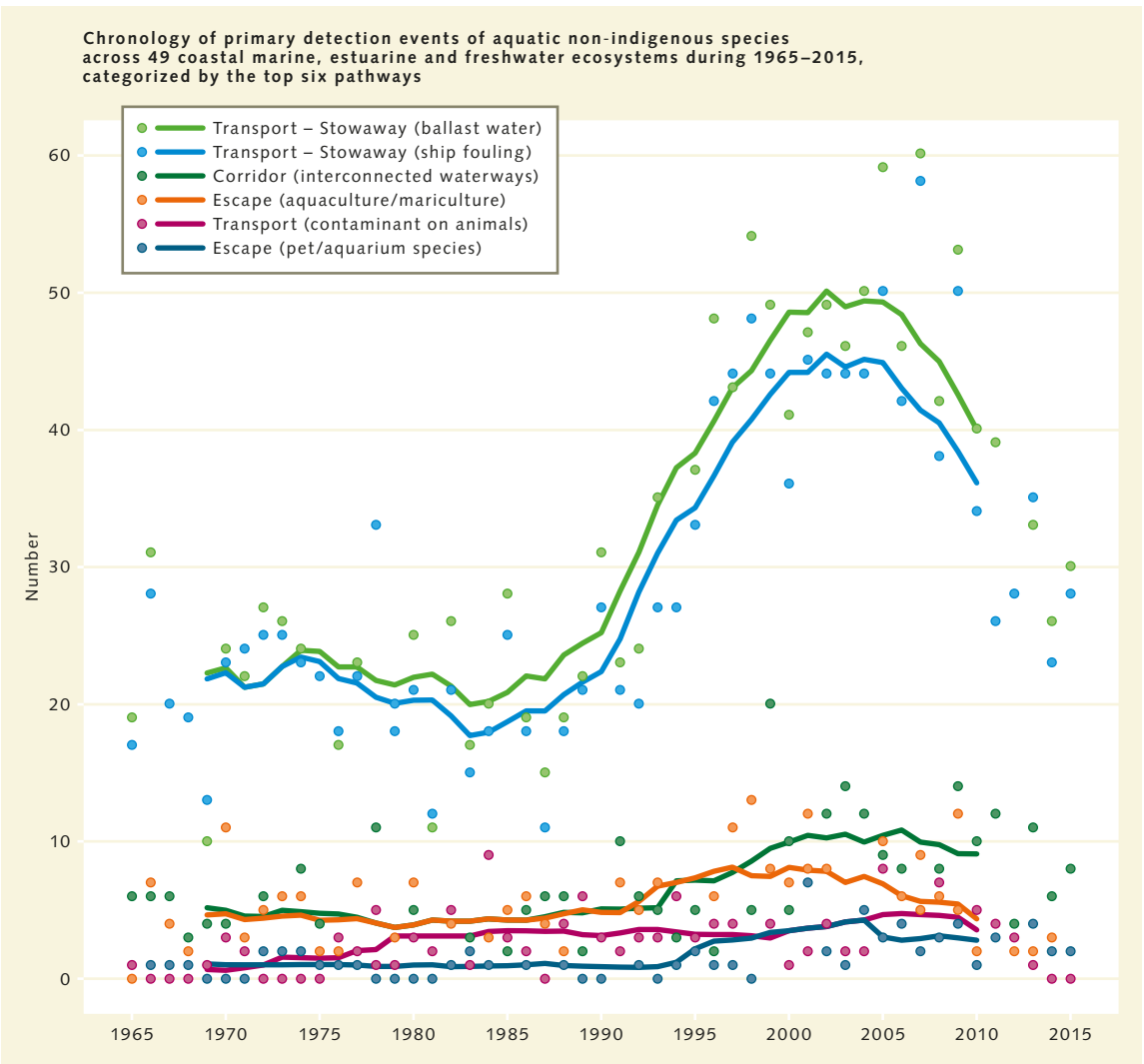
Rising mercury levels in Arctic mammals are a vivid example of the long-term effects of marine pollutants. Despite declining mercury emissions in recent times, polar bears, toothed whales and other Arctic Ocean predators are currently exposed to increasing concentrations of this toxic heavy metal. In the Arctic, mercury concentrations are now 20 to 30 times higher than before industrialization. A study published by Danish scientists in June 2025 explains why: ocean currents are transporting legacy mercury pollution from distant regions like China to the Arctic, where it accumulates in animals and ecosystems. And because ocean currents can take up to 150 years to transport the once carelessly discarded mercury from Asia to Greenland, Arctic mercury levels are still rising instead of falling.

The consequences of climate change for marine life are a significant source of uncertainty. Not only are they driving thousands of species to leave their traditional ranges, tearing apart food webs and bringing biological processes to a standstill, they are also weakening the health and resilience of many marine organisms. Weakened or stressed organisms usually lack the energy to withstand further disturbances, so the consequences of climate change exacerbate the damage caused by other stressors. Experts speak of a cascade effect, which occurs when several disturbance factors impact in the same place at the same time, reinforcing each other's effects.

However, there is one piece of good news: selected marine organisms and biological communities in some marine regions are now being systematically monitored, with their condition being regularly assessed by means of a number of different biodiversity indicators. This enables experts to determine whether or not measures to reduce human-induced pressures are effective and whether or not marine life may slowly be recovering.

Non-indigenous species: Blessing and curse

An important driver of marine species turnover is the immigration and spread of non-indigenous species. These are organisms that have either been introduced into an ecosystem by humans or have been able to migrate on their own after humans removed barriers to their spread.



> Global shipping is a major cause of the immigration and introduction of non-indigenous species. This fact is highlighted in this graph, which shows the pathways through which newly discovered non-indigenous species in marine habitats and onshore waters were found to have arrived.

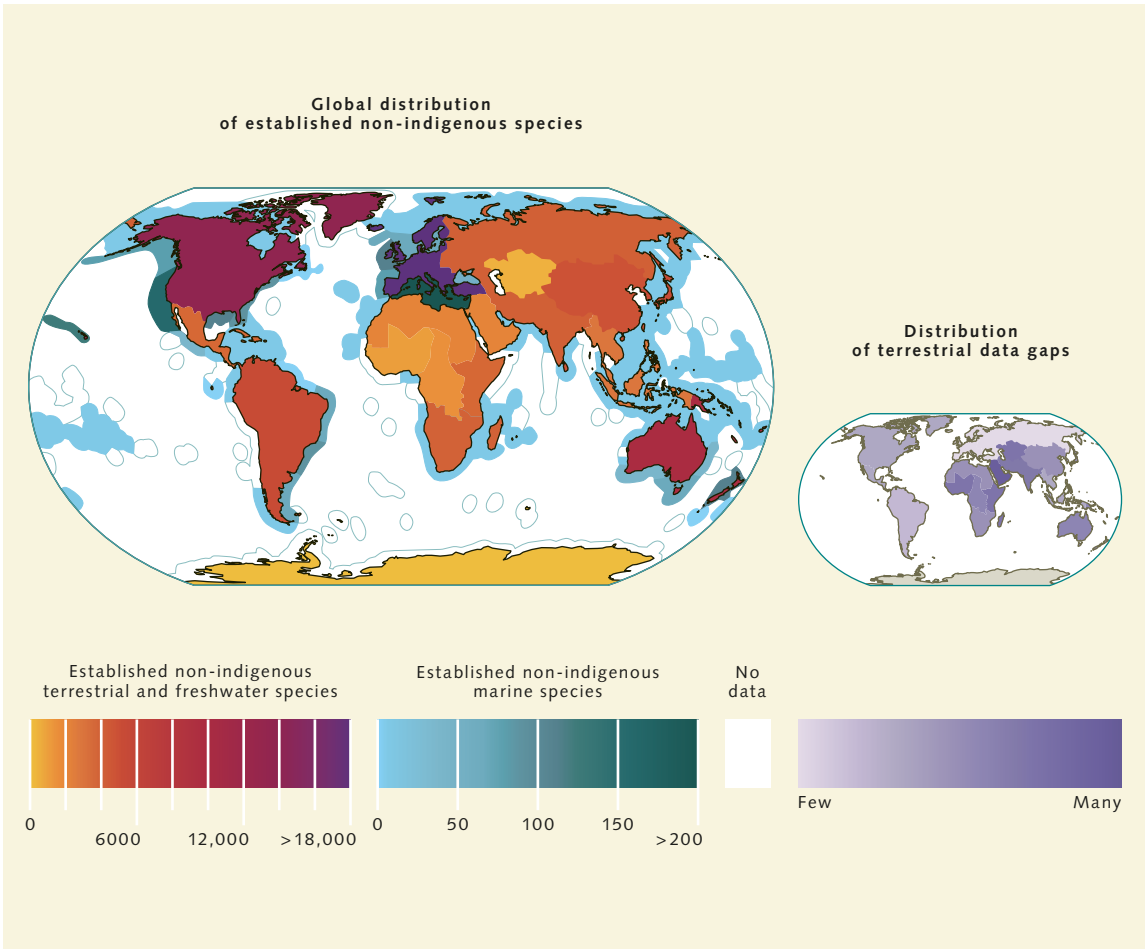
Non-indigenous species can migrate, for example, when the construction of a canal connects two marine areas that were previously separated. Species migrations also occur when climate change warms the ocean and warm-blooded species find suitable conditions in previously cold areas. In contrast, researchers speak of alien species introductions when organisms are brought into new habitats by ships, when they are deliberately released by humans, or when they colonize new areas because they are kept in cages or net bags for food production and manage to escape – whether through accidents, storm damage or the release of larvae.

Non-indigenous species that spread into a habitat and disrupt the normal interactions of native animals, plants and microorganisms are called invasive species. Such adverse effects occur, for example, when newcomers increase predation pressure on keystone species, displace native species or introduce diseases to which local marine life is vulnerable.

There are several examples of marine invasive species. However, their numbers are much smaller than on land because marine habitats are more open at their edges. When newcomers outcompete long-established marine species, the latter are more likely to migrate or

OVERALL-CONCLUSION

> Researchers have been able to detect many more invasive species on land than in the oceans. However, the number of introduced marine organisms has also been increasing. This is due in part to an increased likelihood of new introductions. At the same time, new monitoring programmes mean that new arrivals are more likely to be detected.



retreat into niches than many species inhabiting terrestrial habitats, such as forests or meadows. Nevertheless, scientists fear that globalisation may one day cause marine biological communities to become too similar worldwide, with the overall result that global biodiversity declines. Whether this will actually come to pass is a matter of debate, even among experts.

In species-poor marine areas such as the Wadden Sea in the south-eastern North Sea, the more than 100 known non-indigenous species have so far not displaced any of the native species. In fact, some of the invaders have actually strengthened local ecosystems. For example, the colonization of blue mussel beds in the Wadden Sea by introduced Pacific oysters has made the mixed reefs more resilient. When storms whip across the

North Sea, the oyster-mussel beds tend to suffer less damage than beds formed by blue mussels alone.

Researchers have also been able to document examples in which non-indigenous species have replaced established species in their function. While this has indeed changed the species composition in the ecosystems concerned, the key aspect is that their range of functions has remained the same.

Nevertheless, everything possible should be done to prevent the spread of non-indigenous species, as it is also clear that many of the long-term consequences of human-induced species migrations are not yet fully understood. While intensive and, in many places, systematic research is now under way, it is often unclear which species have been present in the area under investigation for what

length of time and whether that time span is long enough for them to be considered “native”. Moreover, it is still too rarely possible to compare the results of observations made in different regions.

A safety net for ocean life

Marine conservation works. This is evident from the trajectory of numerous marine species and habitats that were almost eradicated or suffered extensive human-induced degradation but are now recovering thanks to conservation measures. Indeed, according to experts, the resilience and recovery potential of marine ecosystems are so high that humankind may succeed in largely

restoring the currently severely weakened marine habitats by 2050.

For a successful recovery, a mix of proven marine conservation measures, innovative and participatory approaches to marine management and effective climate policies is required. Other prerequisites are adequate funding, multidisciplinary research expertise, clear policy frameworks and broad support at all levels of our society and across multiple countries.

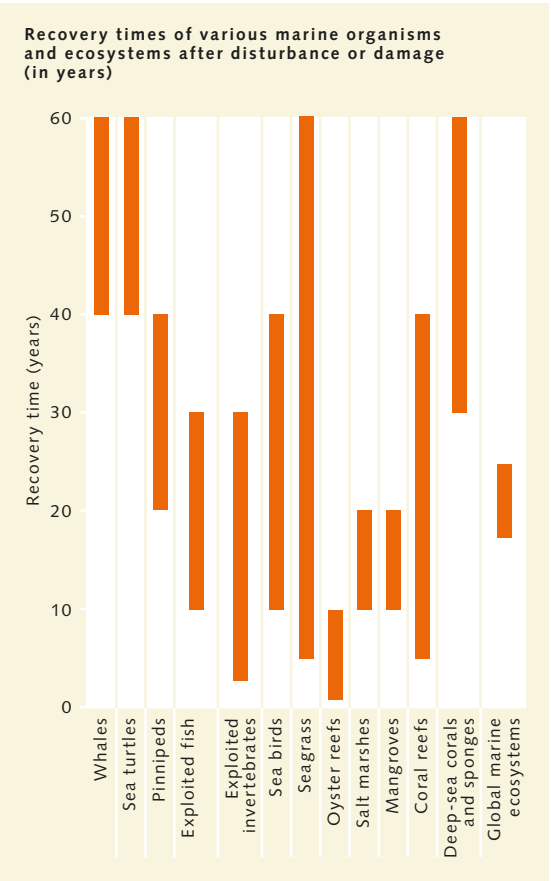
Experts are talking about a global partnership to rebuild marine life. This must be initiated and addressed immediately if the ambitious goal – healthy marine habitats by 2050 – is to be achieved.

Marine conservation measures previously aimed primarily to mitigate or entirely prevent the immediate risks to threatened species and habitats. This was achieved by strictly regulating or prohibiting the hunting of certain species, substituting sustainable for destructive fishing methods, and combating specific sources of marine pollution, for example. Communities also began to restore weakened or degraded coastal and marine ecosystems and protect them more effectively.

The successes that these measures achieved certainly stand up to scrutiny. Overall, however, the outcomes by no means suffice to preserve marine species abundance and biodiversity. At a time of dramatic climate change and species turnover, coordinated and dynamic marine management is needed, with alignment of its individual elements and with all groups impacted by the potential measures involved in its planning.

Indigenous knowledge has a role to play in ensuring the success of this marine management approach, along with a recognition that some sea areas will be intensively used in future. Their total area is likely to be smaller than at present because more protected areas are to be designated in future years. However, it will also be crucial to utilize the ocean outside the protected areas in a way which inflicts minimal or zero damage on the marine environment.

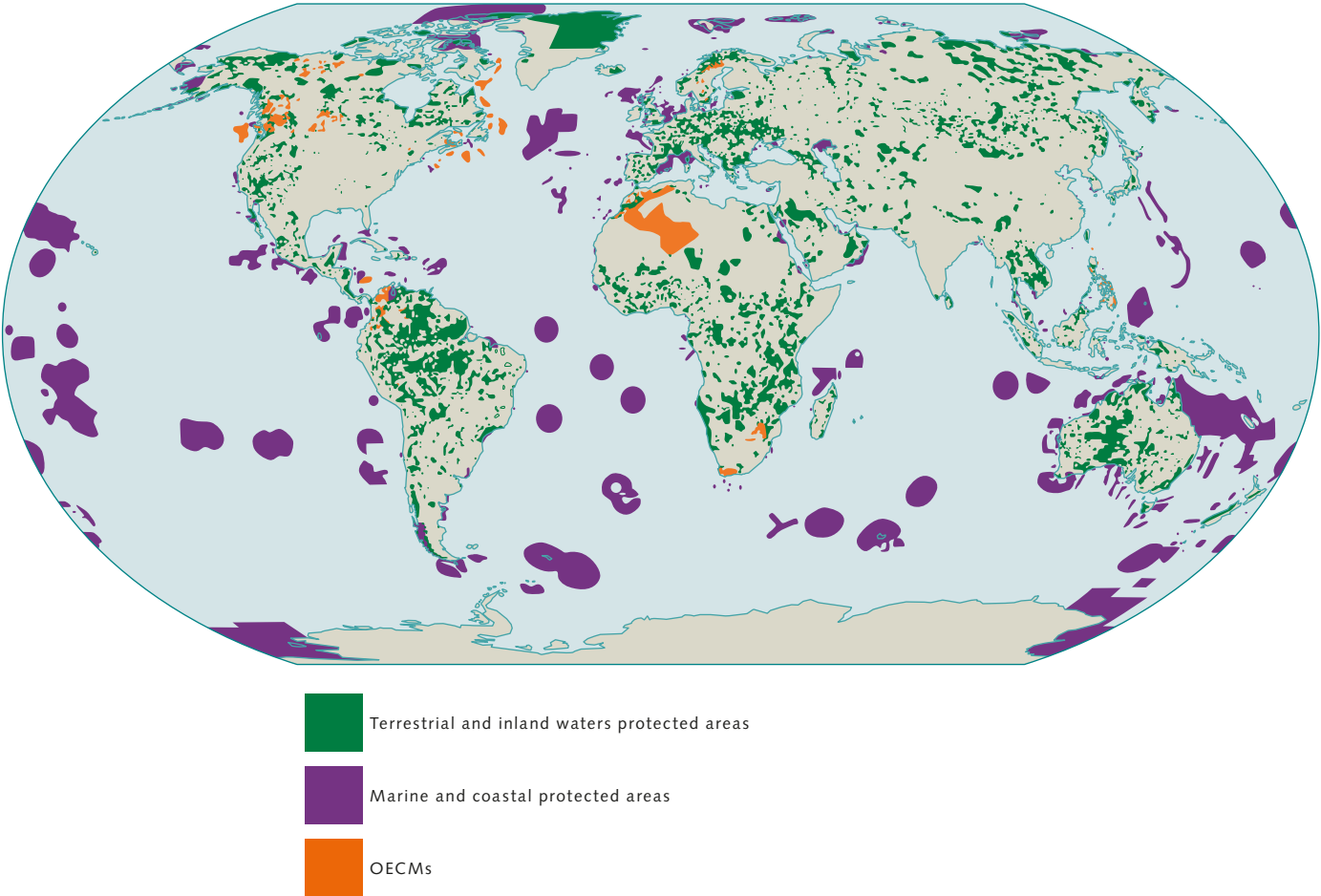
If this transformation is successful, ecosystems – even in intensively used marine regions – can recover and, over the long term, provide the multiple services



> How quickly do marine species recover from harmful impacts or events? That depends on their reproductive cycle. Oysters reproduce rapidly, but it takes 20 to 40 years for a few individual seals (pinnipeds) to develop into a colony.

OVERALL-CONCLUSION

Protected areas and other effective area-based conservation measures (OECMs)
(as of May 2025)



> On the online platform protected planet.net, the IUCN and UNEP publish a regularly updated map showing all the world's protected areas, both terrestrial and marine, as well as areas where nature conservation should be achieved as a secondary outcome (OECMs).

that we have come to expect and rely on. The requisite knowledge is available. Our task now is to set the right priorities and take action.

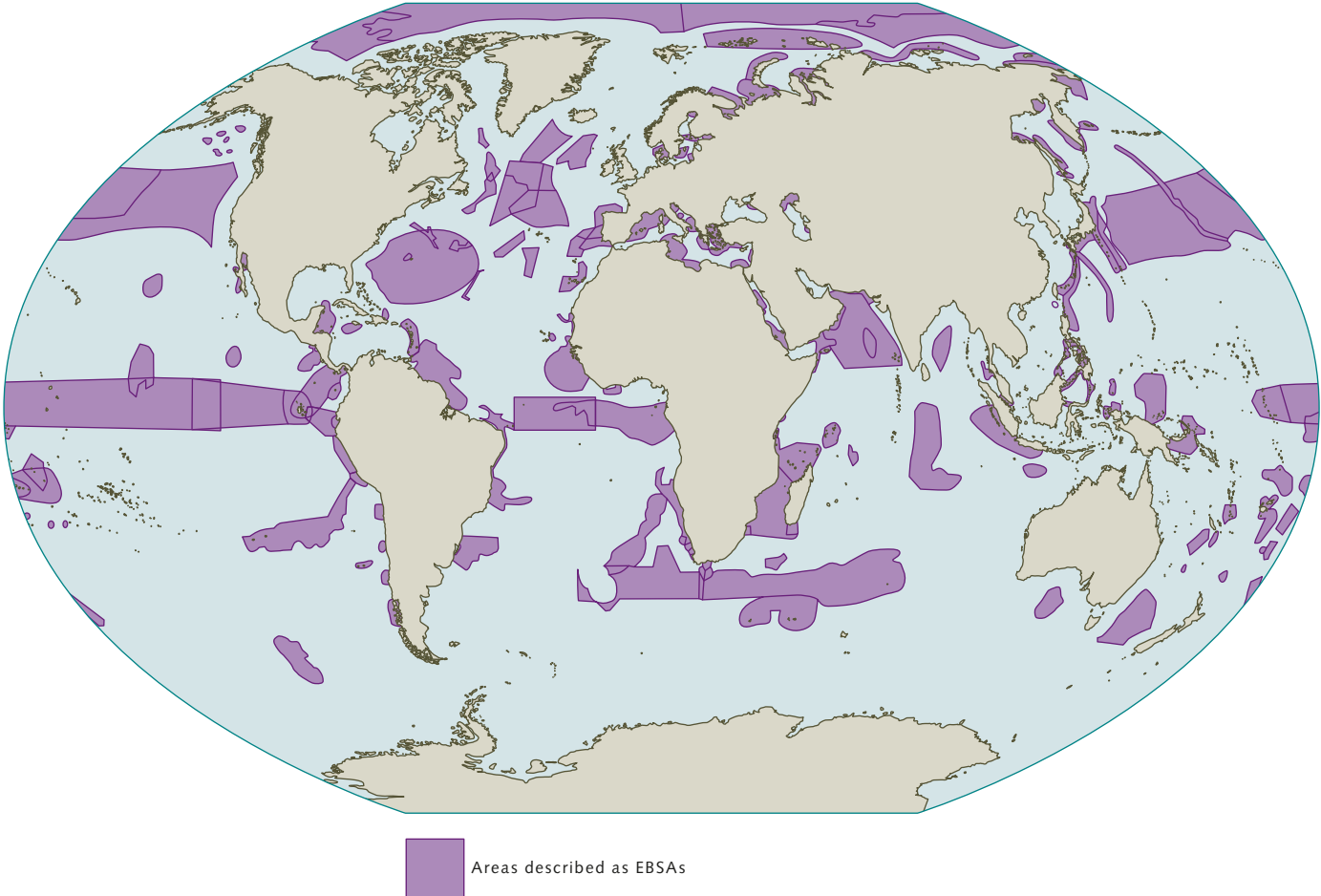
Marine protected areas: All too often ineffective
Marine protected areas (MPAs) are widely regarded as a key instrument in combating overexploitation of the oceans and associated species extinction. They are established in order to protect marine organisms and habitats from human impacts by prohibiting or regulating certain activities. Their number has increased significantly in recent years. However, MPAs' conservation objectives

and management strategies vary considerably. One protected area is not like another. This makes it difficult to say for sure what percentage of the ocean is indeed protected effectively.

Consistently protecting marine regions helps to preserve local species and habitats. Yet the benefits of protected areas beyond their boundaries are not always scientifically proven, often due to a failure to implement planned conservation measures (paper parks).

Migratory species benefit from protected zones mainly when there is large-scale connectivity between these areas and they are located in regions where marine orga-

EBSAs around the world
(as of 2025)



nisms breed or rear their young. Meeting the needs of all the inhabitants of a protected area simultaneously is challenging due to the often diverse behavioural patterns of the various species.

Protected areas address some of the challenges facing the marine environment, such as the risks to and destruction of local biocoenoses by overfishing, overextraction of resources, or mass tourism. However, they do not guard against large-scale pollution (e.g. microplastics) or climate change impacts. They are, therefore, just one of many tools available to combat the climate and biodiversity crisis facing the oceans.

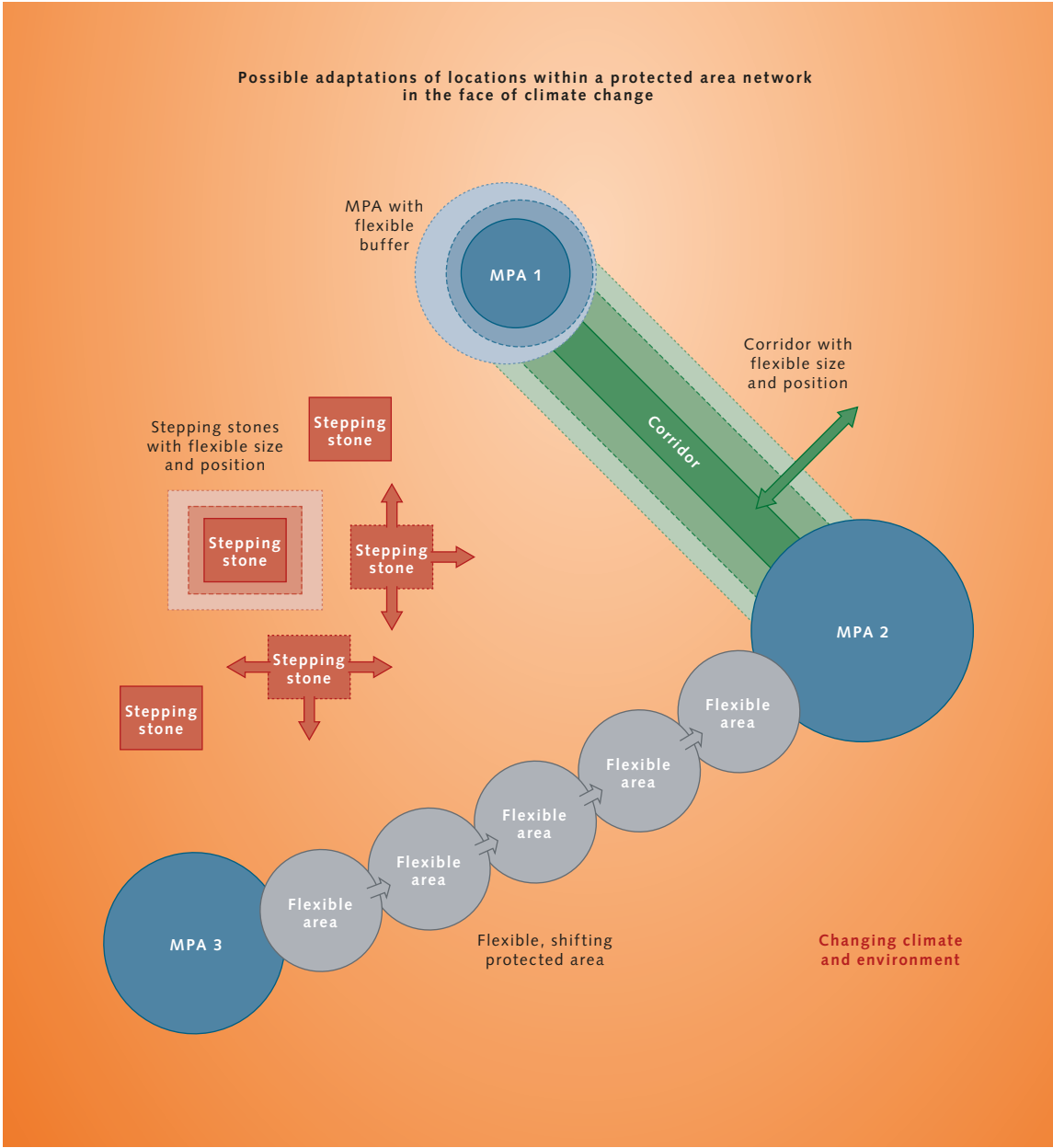
As more protected areas are designated, conflicts of interests increase – especially in areas with previously intensive human use, such as fishing. When planning a protected area, it is therefore absolutely vital that the interests of all user groups are genuinely considered. The prospects of success increase if protected areas are planned, implemented and monitored inclusively and transparently and user groups are offered alternative income sources.

In order to assess a protected area's trajectory and performance, scientific studies are required, which must be conducted regularly over extended periods. This

> Site proposals that are approved by the Conference of the Parties (COP) to the Convention on Biological Diversity are immediately recognized as EBSAs and are added to the official EBSA map. However, this does not confer protected status.

OVERALL-CONCLUSION

> In the face of ocean warming, some marine species are shifting polewards or into deeper waters. To ensure that these species continue to be safeguarded, protected areas must move with them. This can be achieved if dynamic and flexible areas, stepping stones and corridors are factored into planning from the outset.



research should aim to determine whether the original conservation objectives are being achieved, whether the granting of protected status has a positive effect on ecosystems, and which species benefit from the protected area.

Methods that enable early identification and assessment of the benefits and disadvantages of protected

status for people, the ocean and society should also be utilized more frequently. These forecasts can help encourage the diverse user groups to champion the area's protected status.

When planning, implementing and evaluating protected areas, the impacts of climate change on marine life will need to be given more consideration. New,

flexible protected areas that are closely monitored and can be adapted and shifted in tandem with climate-induced species migration are required. Flexible buffers, corridors and protected stepping stones are essential to enable marine organisms to migrate into climatically suitable zones.

Cooperation across all borders and levels

The ocean has no national or institutional boundaries. This presents the international community with at least two major challenges in marine management and biodiversity conservation.

Firstly, stakeholders across all governance levels must collaborate on all topics of relevance to the ocean and coordinate their plans for its sustainable use. Secondly, it is essential to develop solutions that strengthen biocoenoses locally or regionally without causing harm elsewhere in the ocean. Ideally, local measures such as sustainable fisheries or restoration of degraded seagrass beds and salt marshes will promote the health of all or much of the ocean.

Humankind, however, is still a long way from realizing this ideal of integrated ocean governance that is aligned with marine ecosystems' needs. At present, ocean issues at all levels are dealt with by multiple stakeholders and institutions which, in turn, are governed by a diverse array of agreements and legislation, depending on the topic.

This fragmented system of ocean governance causes conflicts of interests and inefficiency. Moreover, it limits our scope and capacities to mitigate the mutually reinforcing effects of four environmental crises: marine over-exploitation, climate change, species extinction and ocean pollution. "We are not facing a crisis of knowledge but a crisis of willingness and implementation," said Razan Al Mubarak, President of the International Union for Conservation of Nature (IUCN), at the Third United Nations Ocean Conference, summing up the weaknesses of ocean governance.

New and, above all, holistic thinking about marine conservation and management is therefore required. It is essential to focus strategically on the preservation, protec-

tion and recovery of ocean life and deprioritize short-term economic interests that harm the ocean's biocoenoses.

Will the new UN High Seas Treaty be a turning point?

Currently, there are high hopes of the new UN High Seas Treaty (BBNJ), which enters into force at 17 January 2026. It regulates the criteria for designating marine protected areas in the high seas and obliges regional fisheries management organizations to cooperate more intensively with other ocean governance stakeholders.

It also states that every project in international waters must undergo a prior environmental impact assessment. It includes provisions on transnational knowledge and technology transfer and establishes fair benefit-sharing and participation for all as a guiding principle, including the notion that all states should share in the monetary and non-monetary benefits from the utilization of marine genetic resources and, accordingly, in any economic gains of such utilization.

To halt the decline of marine biodiversity, a radical transformation of ocean governance is required. Which specific steps can initiate this process? It's difficult to say. However, experts do have a clear idea of the general framework needed for future national and international marine policymaking aimed at preserving and protecting ocean life effectively. It is essential to think holistically about the needs of human communities and ocean life, to share knowledge and data, embrace collective and transparent decision-making, provide adequate funding for innovations and monitoring systems, and act with foresight to optimally mitigate the mutually reinforcing impacts of climate change and other environmental crises on ocean life.

Ocean life is a vital natural resource base for humankind. Investing in its conservation and protection is not an act of charity. Summed up in the words of one of the participants at the Third United Nations Ocean Conference, it is "the smartest and most cost-effective investment that we as a society can make for the sake of our climate, our food supply, our security, our health, and our own and our children's future". Let's make a start!

Contributors

Ben Boteler is a Senior Research Associate in the Research Institute for Sustainability (RIFS) at the GFZ Helmholtz Centre for Geosciences in Potsdam. He is a political scientist. His research focuses on how innovative governance strategies can help to progress transformative action towards overcoming global challenges such as climate change, pollution and biodiversity loss. His current research focuses on the implementation and performance of EU marine policies to reach the goals set out in the EU Green Deal. He explores this issue in various European research projects. In parallel, Ben Boteler – originally from the US – follows the negotiations on the implementation of the UN High Seas Treaty with keen interest: until 2022, he was the co-lead of a project which aimed to facilitate the development of comprehensive, cross-sectoral approaches for the conservation and sustainable use of biodiversity in the high seas.

Dr. Christian Buschbaum is a marine ecologist and conducts research at the Alfred Wegener Institute Wadden Sea Station Sylt, where he heads the Working Group on Community and Evolutionary Ecology and the AWI North Sea Office. His current research interests include the impacts of invasive marine species on native ecosystems, and large-scale ecological comparisons of species interactions in sedimentary coastal ecosystems. This latter topic has taken him to Asia, Australia, South America and the polar regions. He is currently conducting experimental studies to investigate how climate change is altering species interactions on Arctic shores. Christian Buschbaum believes that as a scientist, he also has a responsibility to protect domestic coastlines and is therefore intensively involved in the Trilateral Wadden Sea Cooperation between the Netherlands, Germany and Denmark. He is also the Scientific Lead in the National Neobiota Expert Group, which falls within the scope of the Federal/ State Working Group North Sea and Baltic Sea (BLANO) and contributes to the national implementation of the EU Marine Strategy Framework Directive. An expert in non-native species, Christian Buschbaum contributed to the 2022 report *Neobiota of the German North and Baltic Sea Coasts* (Neobiota der deutschen Nord- und Ostseeküste 2022) – the first publication to provide a complete overview of all non-native marine species in Germany.

Dr. Chhaya Chaudhary is a noted expert on marine biodiversity patterns and species diversity distribution. She is a postdoctoral researcher at the Institute of Marine Ecosystem and Fisheries Science (IMF) at the University of Hamburg, where she is employed as a Research Associate in the Integrative Mapping of Atlantic Protection Areas project. Her research aims to map biodiversity hotspots in the Atlantic Ocean, decode species diversity distribution patterns, and evaluate how climate change

reshapes marine ecosystems of the Atlantic high seas. By applying habitat modelling and biodiversity analysis, she projects how climate change may destabilize species distributions and erode hotspot integrity. These insights allow her to anticipate future ecological “winners and losers” of climate change and prioritize regions where conservation interventions could buffer climate impacts. Her approach merges cutting-edge computational tools with decades of biological data to bridge the gap between theoretical ecology and actionable marine spatial planning.

Dr. Christian von Dorrien heads the Fisheries and Environment Baltic Sea research area at the Thünen Institute of Baltic Sea Fisheries in Rostock. A fisheries biologist, he focuses his research on fisheries management in protected areas and ecosystem-based fisheries management. In the Baltic Sea, for example, he has investigated the impacts of Natura 2000 management measures on commercial fisheries in protected areas. He is also involved in the development of methods for monitoring and mitigation of bycatch of protected species. Christian von Dorrien provides advice to the German Federal Ministry of Agriculture, Food and Regional Identity (BMLEH) on fisheries management in protected areas and mitigation of bycatch of protected species. He also contributes to various expert working groups of the International Council for the Exploration of the Seas (ICES).

Dr. Bianca Haas is an expert in fisheries management and ocean governance at the University of Wollongong in New South Wales, Australia, where she is engaged in research and teaching. She was born in Austria. For her PhD, she studied the potential contribution of regional fisheries management organizations (RFMOs) to the Sustainable Development Goals. Her current research focuses on equity concerns in transboundary fisheries management in the Indo-Pacific. Here, she monitors and analyzes the RFMOs’ work on tuna fisheries in the Indo-Pacific and also studies how the new UN High Seas Treaty (BBNJ Agreement) will affect the work of the RFMOs and to what extent they are involved in its implementation.

Dr. Stefan Hain heads the Environmental Policy Unit at the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) in Bremerhaven; in this capacity, he serves, among other things, as the AWI’s liaison to the German Environment Agency (UBA), Germany’s competent authority for approving activities in the framework of the Antarctic Treaty. A marine biologist, he completed his doctoral studies at the Alfred Wegener Institute and, since then, has worked at the interface between science and policy for more than 25 years – first as

Many experts contributed their specialist knowledge during the compilation of the *World Ocean Review 2026*. They included, in particular, scientists working at the member institutions of the German Marine Research Consortium (KDM).

Deputy Secretary of the OSPAR Commission in London and later heading the United Nations Environment Programme (UNEP) Coral Reef Unit in Cambridge, UK. In 2009, he returned to the Alfred Wegener Institute; since then, as the Institute’s environmental policy spokesperson, he has coordinated the AWI’s contributions to various international processes that are potentially relevant for the scientific research carried out at the AWI. In this role, he provides intensive support for efforts to establish a marine protected area in the Weddell Sea in the Southern Ocean and closely monitors international negotiations on the implementation of the UN High Seas Treaty (BBNJ Agreement).

Dr. Uwe John is a molecular ecologist at the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) in Bremerhaven and is a noted expert on microscopic marine organisms and molecular and genomic analytical techniques. His research often focuses on microalgae, as is the case with his current project in which Uwe John and his team investigate and evaluate the risks associated with more frequent formation of harmful algal blooms in Greenland’s waters as a result of climate change. The purpose of this study is to generate baseline data on biodiversity and species interactions, develop indicators, identify tipping points and determine the potential impacts of harmful algal blooms on local ecosystem functions and services.

Michael Kriegl is a marine scientist at the Leibniz Centre for Tropical Marine Research (ZMT). Working at the interface between natural and social sciences, he studies the dynamics of social-ecological systems along tropical coasts, combining methods such as network analysis and qualitative system modelling with participatory approaches in order to support knowledge co-production. With a regional focus on Latin America, he collaborates intensively with local stakeholders to investigate social and ecological interactions in small-scale fisheries and aquaculture. His aim is to connect scientific knowledge with local realities in order to develop viable strategies for the conservation and management of marine resources. Alongside his research, Michael Kriegl is a passionate advocate for science communication and promoting ocean literacy.

Prof. Dr. Heike Lotze is a marine biologist and is engaged in research and teaching at Dalhousie University in Halifax, Canada. She has a strong interest in human impacts on marine species and ecosystems and their consequences for the ocean and society today, in the past and into the future. Human activities such as fishing and hunting, habitat transformation and nutrient loading have affected marine resources and shaped their ecosystems for millennia, but have greatly accelerated over time

and expanded from inshore regions to the open ocean. In her research, Heike Lotze aims to reconstruct the long-term history of human-induced changes in marine species and ecosystems, and to analyse the causes and consequences of these changes on the structure and functioning of ecosystems today and into the future. She uses a multi-disciplinary approach, integrating data from palaeontology, archaeology, history, fisheries science, ecology, and climate science, and a combination of field surveys and laboratory experiments, literature studies, ecological modelling and the analysis of large data sets.

Prof. Dr. Hans-Otto Pörtner is a marine biologist at the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) in Bremerhaven. He founded the Department of Integrative Ecophysiology, which he headed until his retirement in 2024. He was also one of the two Co-Chairs of IPCC Working Group II (WGII) during the sixth assessment cycle (2015–2023). Hans-Otto Pörtner has developed groundbreaking theories on how ocean warming, ocean acidification and the increasing lack of oxygen are affecting marine organisms and ecosystems and has produced numerous studies in support of these theories. Two key questions guiding his research concern the molecular, biochemical and physiological mechanisms that affect tolerance, performance and adaptation of marine organisms, and whether and how these mechanisms apply more broadly to all organisms, including humans. His academic papers are now among the most frequently cited publications in climate and marine research. He is an elected member of the European Academy of Sciences (EURASC) and was appointed to the German Advisory Council on Global Change (WBGU) by the German Government in 2020 and 2024. Within the framework of JPI Climate and JPI Ocean, he is co-chairing an assessment of the potential weakening of the Atlantic Meridional Overturning Circulation (AMOC) and its impacts on the climate and habitats of affected regions.

Prof. Dr. Martin Friedrich Quaas is Professor of Economics at the University of Leipzig and Head of the Biodiversity Economics Group at the German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig. He conducts research on the sustainable use of natural resources, often in interdisciplinary collaboration with ecologists. He has published over 100 papers in international journals. He is co-editor of journals such as the *Journal of Environmental Economics and Management* and was a lead author for the methodological assessment of the values of nature for the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). This report, whose original title is *The Assessment Report on the Diverse Values and Valuation of Nature*, was published in 2022.

Dr. Jörn Schmidt is a fisheries ecologist and Director for Sustainable Aquatic Food Systems at WorldFish – an international research organization working to improve food security, nutrition and livelihoods through sustainable, equitable, and inclusive aquatic food systems. He previously led the Research Group on Marine Food Security at Kiel University’s Center for Ocean and Society (CeOS) and served as Chair of the Science Committee of the International Council for the Exploration of the Sea (ICES). His research focuses on social-ecological systems and concepts of sustainability in the ocean, fisheries management, science communication, developing practical management advice and working with fishing communities. Jörn Schmidt was one of the German contributors to the United Nations’ *Second World Ocean Assessment* and is currently involved in producing *WOA III*, which will be released in early 2026.

Abbreviations

ABNJ Areas Beyond National Jurisdiction

BBNJ Biodiversity Beyond National Jurisdiction

BII Biodiversity Intactness Index

CBD Convention on Biological Diversity

CCAMLR Commission for the Conservation of Antarctic Marine Living Resources

CCRF Code of Conduct for Responsible Fisheries

CCS Carbon Capture and Storage

CITES Convention on International Trade in Endangered Species of Wild Fauna and Flora

CM Conservation Measure

CMM Conservation and Management Measure

DNA Deoxyribonucleic Acid

EBSA Ecologically or Biologically Significant Marine Area

eDNA environmental DNA

EGCS Exhaust Gas Cleaning System

EU European Union

FAD Fish Aggregating Devices

FAO Food and Agriculture Organization of the United Nations

FishMIP Fisheries and Marine Ecosystem Model Inter-comparison Project

GHG Greenhouse gas

HELCOM Baltic Marine Environment Protection Commission (Helsinki Commission)

HNS Hazardous and Noxious Substances

ICRW International Convention on the Regulation of Whaling

IHO International Hydrographic Organization

IMO International Maritime Organization

IOC Intergovernmental Oceanographic Commission of UNESCO

IPBES Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services

IPCC Intergovernmental Panel on Climate Change

ISA International Seabed Authority

ITLOS International Tribunal for the Law of the Seas

IUCN International Union for Conservation of Nature

LPI Global Living Planet Index

MARPOL International Convention for the Prevention of Marine Pollution from Ships

MBARI Monterey Bay Aquarium Research Institute

MIT Marine Trophic Index

MMPA Marine Mammal Protection Act

MPA Marine Protected Area

NOAA National Oceanic and Atmospheric Administration

OBIS Ocean Biogeographic Information System

OECM Other Effective Area-Based Conservation Measures

OSPAR Oslo and Paris Convention

PML Plymouth Marine Laboratory

POPs Persistent organic pollutants

PSMA Port State Measures Agreement

RFMO Regional Fisheries Management Organisation

RLI Red List Index

SDGs Sustainable Development Goals

SOFIA The State of World Fisheries and Aquaculture

UN United Nations

UNCLOS United Nations Convention on the Law of the Sea

UNEP United Nations Environment Programme

UNESCO United Nations Educational, Scientific and Cultural Organization

WDPA World Database on Protected Areas

WoRMS World Register of Marine Species

WTO World Trade Organization

WWF World Wide Fund for Nature

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Chapter 4

Pressure from all sides

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IOI: The International Ocean Institute is a non-profit organization founded by Professor Elisabeth Mann Borgese in 1972. It consists of a network of operational centres located all over the world. Its headquarters are in Malta. The IOI advocates the peaceful and sustainable use of the oceans.



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mare

mare: The bimonthly German-language magazine *mare*, which focuses on the topic of the sea, was founded by Nikolaus Gelpke in Hamburg in 1997. *mare's* mission is to raise the public's awareness of the importance of the sea as a living, economic and cultural space. Besides the magazine, which has received numerous awards for its high-quality reporting and photographs, its publisher mareverlag also produces a number of fiction and non-fiction titles twice a year.



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Acknowledgement

Producing a publication like the *World Ocean Review* is an undertaking requiring major commitment and effort. I would therefore like to first express my thanks to all the participating scientists for their contributions to this review. I am also most grateful to the organizational team of the German Marine Research Consortium for ensuring a smooth and uninterrupted communication process and for working so hard behind the scenes.

I further wish to express my particular appreciation to scientific journalist Sina Löschke, who gave structure to the individual texts and ensured that they could be read and enjoyed by scientists and the general public alike. My sincere thanks also go to designers and layouters Anna Boucsein and Andrea Best, photo editors Petra Koßmann and Anastasia Hermann, text editor Dimitri Ladischensky, proofreader Susanne Feyke, and last but not least Jan Lehmköster, the project manager at maribus, who nurtured the *World Ocean Review* from the beginning.

Nikolaus Gelpke

Managing Director of maribus gGmbH

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The cover picture shows an Acropora stony coral releasing thousands of tiny bundles of eggs and sperm into the sea in order to reproduce. This natural spectacle is called a coral spawning event and occurs on one or two specific nights each year. What makes this so special is that all stony corals of one species spawn at the same time, across many reefs and distances spanning hundreds of kilometres. The buoyant egg and sperm bundles then rise to the sea surface where they get broken up by wave action and mixed together. This allows egg and sperm cells from different corals to meet and fuse. Over the course of the next day, these fertilized cells develop into free-floating coral larvae. These larvae then search the seabed for a suitable place to settle. If they succeed, the inconspicuous larvae grow into tiny coral colonies with their own hard calcareous skeleton. However, it takes at least five to six years for them to reach a size at which they, in turn, can spawn.



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Publication details

Project manager: Jan Lehmköster, maribus
Editing and text: Sina Löschke
Copy editing: Dimitri Ladischensky, mare
Design and typesetting: Anna Boucsein and Andrea Best, mare
Proofreading: Susanne Feyke
Photo editing: Anastasia Hermann, mare
Graphics: Walther-Maria Scheid
Production: HS Printproduktion, Holger Schmürgalski
Printing: Druckhaus Sportflieger
Paper: G-Print, FSC®-zertifiziert

ISBN 978-3-86648-776-5

Published by: maribus gGmbH, Pickhuben 2, 20457 Hamburg

www.maribus.com

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