AN INTRODUCTION TO THE OCEAN

THE OCTOPUS PLATFORM

AN INTRODUCTION TO THE OCEAN

Let's first understand blue science!

It is not a secret but not enough people are aware of it. It is in front of us, around us, below us. It is blue, green and sometimes yellow.

We live and thrive because of it, not really knowing what's at stake. Yet, we must act now.

"It" is the Ocean, the Earth's largest carbon sink by absorbing 9.2 gigatons of CO_2 annually and producing circa 50% of our oxygen. It remains less explored than the moon but we keep investigating more in the sky than in the depth of the blue.

Yet, rising temperatures, largely driven by human activity, are accelerating acidification and threatening marine biodiversity. As the ocean destabilizes, so does life on Earth. Three billion people live from it, but overfishing has depleted 34% of fish stocks, and marine predator populations have plunged 70% in fifty years.

The upcoming Blue Economy and Finance Forum in Monaco (7–8 June 2025) seeks strong commitments, but any action underlining sustainable fisheries, marine renewables, and responsible ocean management must come from knowledge to ensure the investments are done solving keystone problems without creating others.

This is why the worldwide leading ocean and environmental scientists have come together to co-write this scientific introduction to the Ocean system, ensuring it is thorough and accessible to the many with a Creative Commons licence, a world premiere. A warm-hearted thank you to those who will be enlightening us in the coming chapters: Ivar Ekeland from University Paris Dauphine, Daniel Pauly and Rashid Sumaila from the University of British Columbia and Robert Blasiak and Andrew Sean Merrie from the Stockholm Resilience Centre.

With SDG 14 being the least funded UN goal, and 8.5 trillion dollars of value at risk within our economy in the next 15 years, investing in ocean health is not just urgent—it's also an economic imperative.

But let's first understand the science all together!

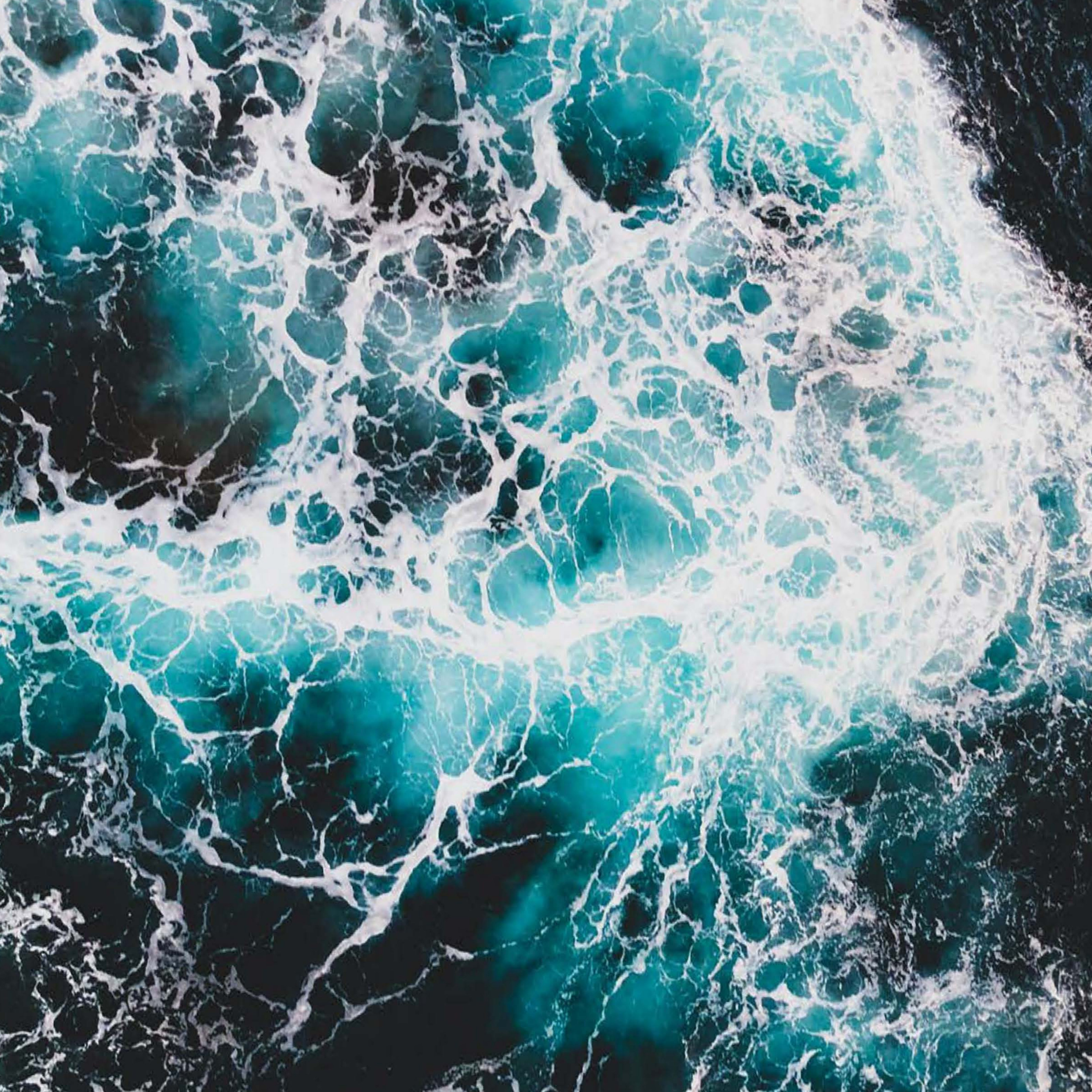
Marie Ekeland, Founder & CEO at 2050

Guillaume Bregeras, Chief Knowledge Officer at 2050

Minh Trinh, Co-founder of Waves of Change

AN INTRODUCTION TO THE OCEAN

 The coauthors at this time are Robert Blasiak, Ivar Ekeland, Andrew Merrie, Daniel Pauly, Rashid Sumaila.



Planet Ocean

The Ocean covers over 70 % of the surface of the Earth. It is far more than a body of salt water. It is the birthplace of life on Earth.

Today it harbours 78 % of the animal biomass, and produces half of the oxygen supply on earth. It is a web of physico-chemical and biological interactions which, combined with human activity,create a complex system, one that is quite different from the land-based system we are used to. In fact, until recently, humans had been content with skimming the surface of the Ocean, but technological progress has opened it deep and wide to exploration and exploitation. It is now seen as a new frontier, a gateway to a "blue economy".

The basic rule about the Ocean is that everything is connected. The pristine beaches of Henderson Island, an uninhabited island in the middle of the Pacific, are littered with plastic trash dumped from lands which border the Atlantic, on the other side of the planet, brought there by marine currents.

Figure 1: the beach on Henderson Island. Source: Jennifer Lavers

The kelp forests of the North Pacific harbour a rich ecological system and function as major carbon sinks. They were nearly brought to extinction in the twentieth century by...the fur trade!

European expansion into the American Northwest was dictated by the fur trade, and sea otters were a prominent target.

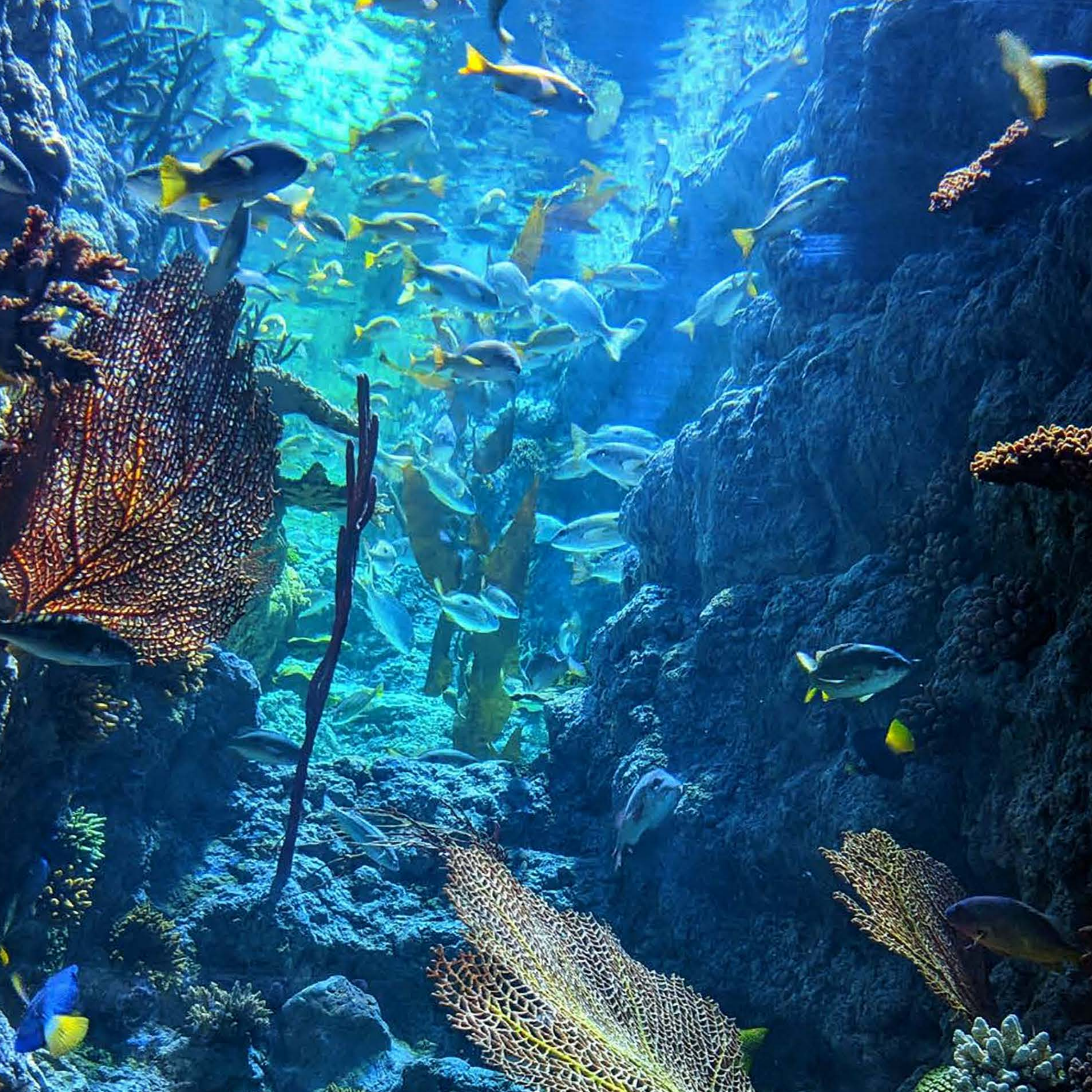
By the beginning of the 20th century, the sea- otter population was reduced to a few thousand individuals living in a fraction of their historic range. What does that have to do with kelp? Sea otters feed on sea urchins, and sea urchins feed on kelp.

The near extermination of sea otters led to a proliferation of sea urchins, which proceeded to wipe out the kelp forests. As the fur trade disappeared, the sea otter population recovered and the kelp forests with them.

However, they are now under threat again for another surprising reason, namely the disappearance of whales. The abundant whales of the North Pacific were exterminated in the 1960s by Japanese and Soviet whaling. The killer whales which fed on them now target sea otters.

The Ocean requires systemic thinking

Since everything is connected, one can no longer speak of "unintended consequences", "collateral damage" or "externalities". Every action undertaken within the Ocean will have consequences far and wide, and they have to be considered and included in the decision process from the beginning.



The Ocean as a System

The Ocean as a physical system:

Water

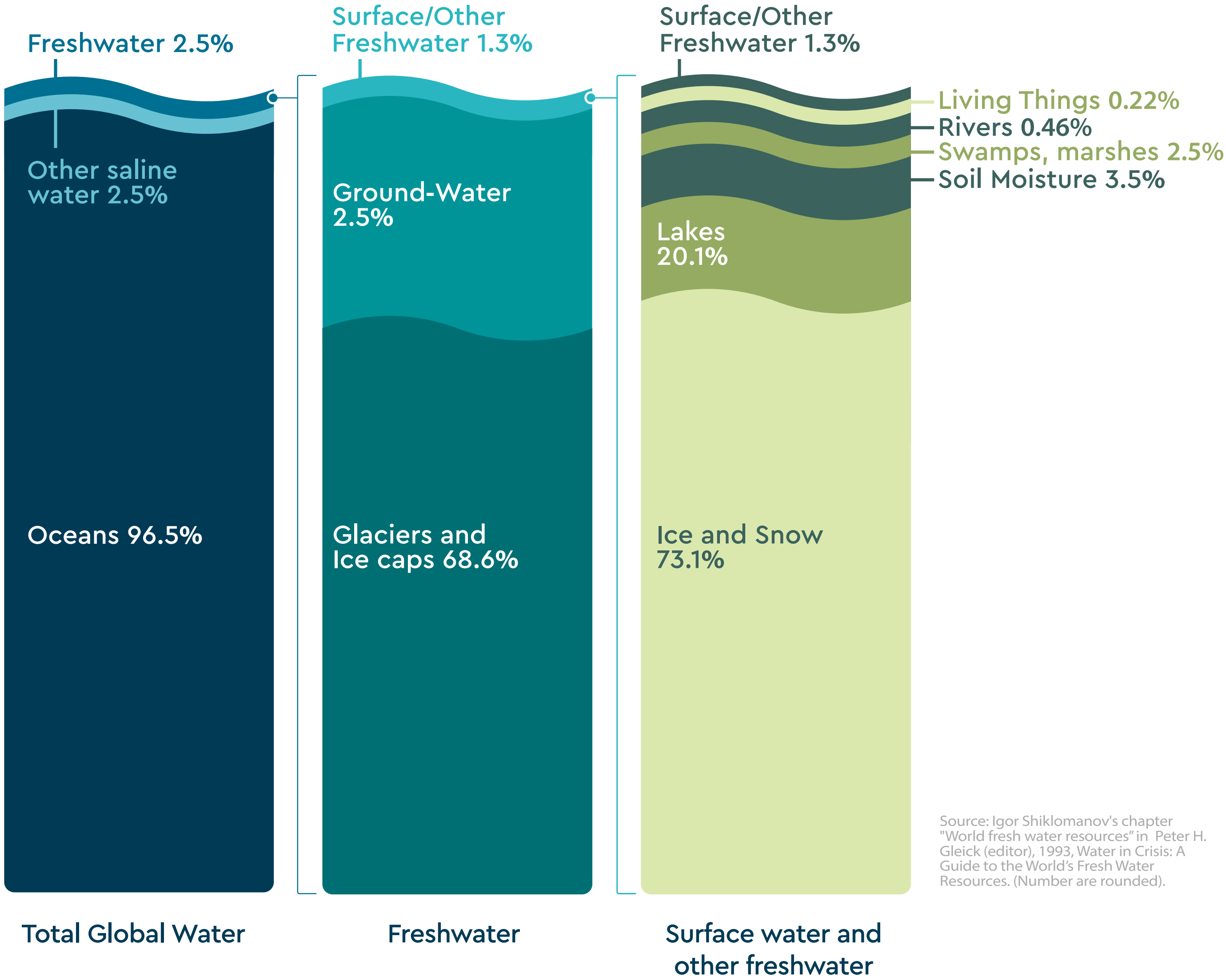
Earth is the only planet in the solar system with an atmosphere which can sustain life. No less significant is the fact that it is the only planet with flowing water. In fact, water is present on Earth in all its physical forms: solid (ice), liquid, and gaseous (vapour). As Figure 2. shows, about 97.5% is stored as saltwater in the Ocean.

The remaining 2.5% can be found as freshwater on the continents, primarily as ice sheets lying on land or floating on the artic seas. A tiny proportion, one-thousandth of 1%, is found as vapour in the atmosphere. There is a constant exchange between these different forms: this is the water cycle. Liquid water evaporates, and when the humidity of the atmosphere reaches certain levels, water vapour in the atmosphere condensates and falls back as rain or snow.

Liquid water freezes into ice when the temperature is low, and ice melts back into freshwater when the temperature rises. This water cycle commands the Earth climate, both in the short term (precipitation) and in the long term (the expansion, or retraction, of glaciers and ice sheets).

Where is the Earth's Water?

Figure 2: Water Distribution on Earth



Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources. (Number are rounded).

The Ocean plays a crucial role in determining and maintaining the climate on Earth. It occupies most of its surface, over 70 %, and contains almost all its water. o It controls the water cycle. In addition, it also functions as a carbon sink. Atmospheric CO2 is absorbed by seawater at the surface, where carbon is stored as bicarbonate ions, which are then carried by currents into the depths of the Ocean. This physical pump is complemented by a biological one.

The result is that the Ocean contains 50 times more carbon than the atmosphere, and absorbs 1/3 of all anthropogenic emissions, thereby considerably slowing down global warming. This is an important example of mixing: the carbon captured at the surface is brought down into the depths. The Ocean is not still. Its surface is moved by the winds, and its depths are moved by currents, which continuously mix the waters.

The most important one is the Meridional Overturning Circulation (MOC), depicted in the figure below. It is a gigantic conveyor belt, driven by differences in salinity and temperature, which circles the globe in about a thousand years, and brings the oxygen and the carbon dioxide from the surface into the depths of the Pacific and Indian Oceans. Note that it has two main branches, the AMOC (Atlantic MOC) which spans the Atlantic Ocean, and the SMOC (Southern MOC) which circles the Antarctic continent.

Thermohaline Circulation

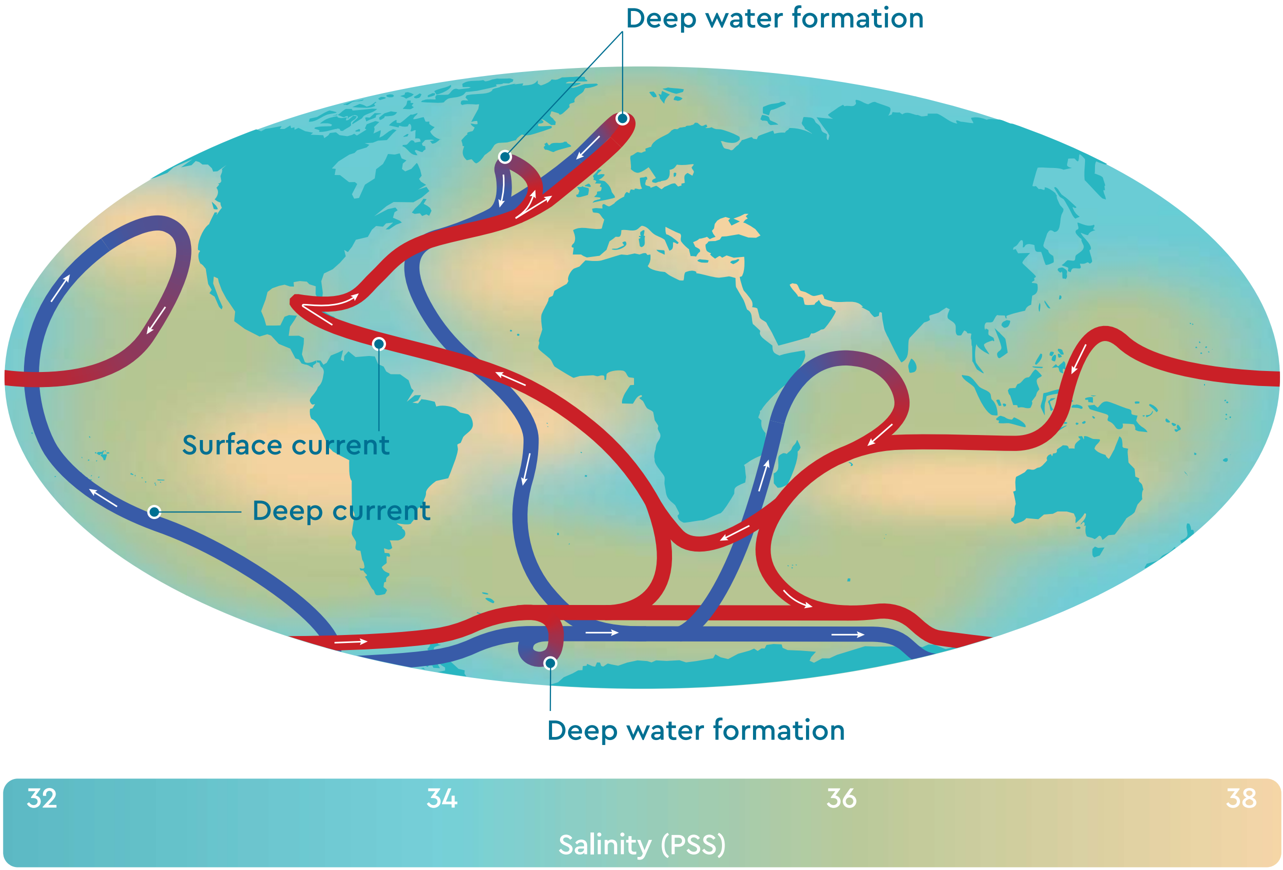


Figure 3: the AMOC. Source: NASA / Wikipedia

There are two levels to the conveyor belt: the upper one, near the surface, and the lower one, in the depths, each level bringing back the water carried along by the other.

The belt is driven by the winds on the surface, and by the rotation of the Earth; a full cycle takes about 1,000 years. The upper and lower levels are connected at certain points (deep water formation) where differences in temperature and salinity causes surface water to sink or deep water to rise; the process is called thermohaline circulation.

Its effect is to mix surface water and deep water (thereby oxygenating the latter), and waters from the Pacific, Indian and Atlantic Oceans: The Ocean is a single physical system.

The Ocean as a physical system:

Marine Life

The various chemical elements which constitute planet Earth move continuously from one form to another and back. Water moves from liquid to ice and vapour and back, but it is still the same water. Similarly, carbon, oxygen, nitrogen, and phosphorus move in cycles from the atmosphere to the soil or the ocean and back.

With the exception of the water cycle, all these cycles are driven by life. Oxygen, for instance, is taken from the atmosphere by breathing organisms and emitted into the atmosphere by photosynthesis, conducted mainly by plants.

This continuous motion is akin to the circulation of blood in a living body, and Lovelock (1919–2022) has formulated the so-called Gaia hypothesis, according to which planet Earth functions as a self-regulating system, trying to preserve the conditions for life, as a living organism tries to preserve the conditions for its own existence.

Marine life is quite different than life on land, because it responds to different constraints. On one hand, marine creatures are carried by water, so they are not constrained by weight (the largest animals on the planet are found in the Ocean), and they can move vertically as well as horizontally.

On the other hand, they live in an oxygen-poor (and, in the depths, in a sunlight-poor) environment, so they are extremely sensitive to slight variations of oxygen content in the water, as well as temperature variations because fish and other water breathers require more oxygen in warmer water.

About 95% of the biomass in the ocean is plankton, small organisms which drift with the currents

At the bottom of the food chain lies phytoplankton, microscopic organisms, mostly unicellular, which perform photosynthesis and account for half of the production of organic matter and oxygen on the planet. These are in turn consumed by zooplankton, which are prey to larger creatures, such as krill, which become prey to still larger animals.

Some, such as baleen whales or filter feeding sharks, feed directly on zooplankton, but there is mostly a graded chain connecting forage fish (herring, sardines, anchovies, menhaden) to top predators (tuna, swordfish, cod).

Food webs are highly structured. Removing a book from a library shelf does not affect the others, but removing one species from the Ocean, by overfishing for example, affects other species: the prey which tend to proliferate as the predators tend to decline.

These effects are quite complex, more so than on land. Gazelles never prey on lions, but large fish which are predators when they are adult, are prey to smaller ones when they are larvae or juveniles. The cod off of Newfoundland, for instance, used to feed on capelin, a smaller fish.

After the collapse of the cod fishery thirty years ago, the cod have not returned, partly because the roles have been reversed. Adult capelins feed on juvenile cods and the ecosystem is now dominated by crabs and shrimps. Mathematical models have been developed to reach a better understanding of such complex systems.

A schematic view of a marine ecosystem

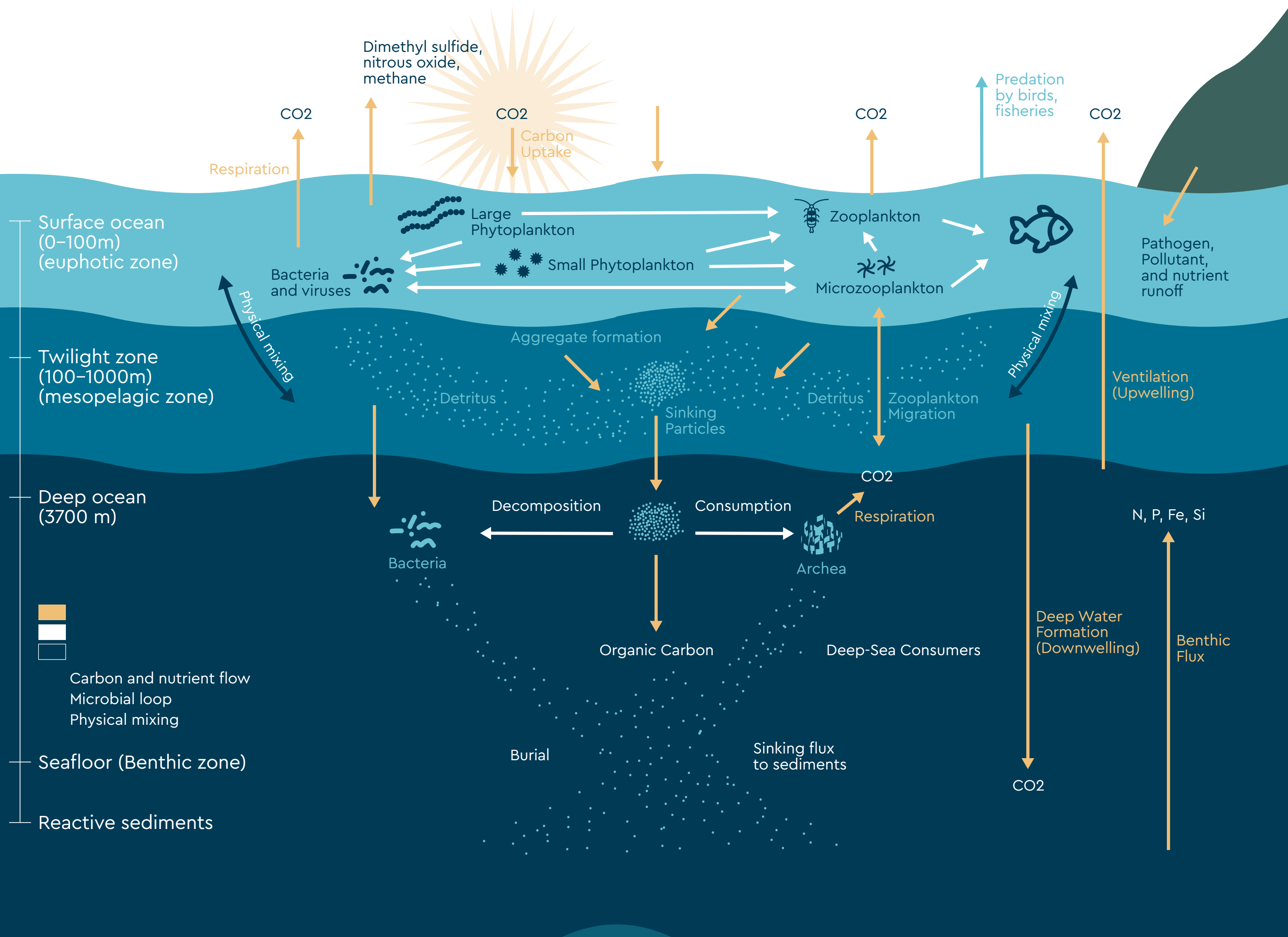


Figure 4: a schematic view of a marine ecosystem

Continents extend under the sea surface by a plateau, called the continental shelf, with depth up to 200 meters, beyond which it increases steeply to several thousand meters. The oceanic zone and the continental shelf support different ecosystems

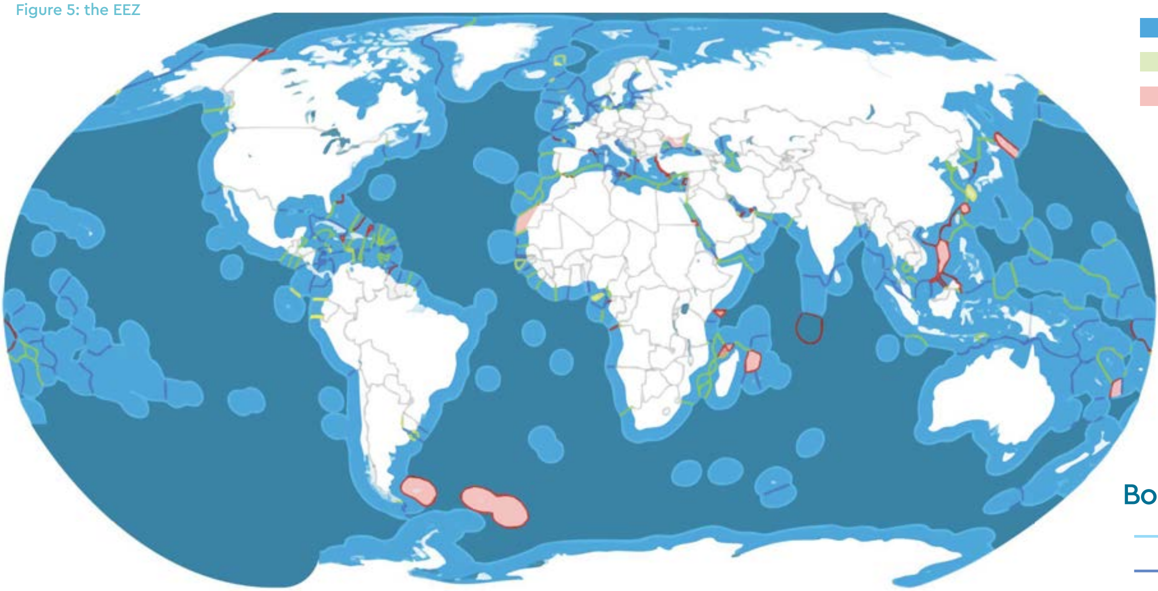
The oceanic zone is structured vertically. The upper zone, down to about 200m from the surface, the photic zone, where sunlight penetrates, concentrates most of the primary production and marine life (plankton, floating seaweed, jellyfish, tuna, many sharks and dolphins). The one directly below, the mesopelagic (twilight) zone, contains fish species which migrate towards the photic zone at night, and various large species (swordfish, squid, and immense numbers of small lanternfish).

The continental shelf is structured horizontally: bays and estuaries create local conditions where separate ecosystems thrive, such as the (now defunct) cod fishery around Newfoundland. This is the zone where most fishing occurs. For millennia, coastal communities have depended on local fisheries for sustenance and have developed valuable knowledge for maintaining the stock. Even today, with the advent of commercial fishing, the vast majority are caught on the continental shelf.

The United Nations' Convention on the Law of the Sea (UNCLOS) has formalized Exclusive Economic Zones (EEZ) for coastal states, which generally extend up to 200 nautical miles offshore and include most of the world's continental shelves. This is why over 90% of the world's marine catch is now caught within the EEZ of maritime countries, either by the countries themselves, or by foreign fleet operating legally (and paying a small fee for doing so), or illegally. Throughout these ecosystems, and from one ecosystem to another, fish move. Larger fish, such as tuna, quickly move among EEZs, and between EEZs and the high seas, where most of the fleets targeting tuna operate.

Exclusive Economic Zones

Figure 5: the EEZ



Dr. Jean-Paul Rodrigue, Dept. of Global Studies & Geography, Hofstra University
Source: Flanders Marine Institute (2019). Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM), version 11.

The Ocean as a:

Global System

The Ocean functions as a single unified system, where physics, chemistry and biology all contribute to the overall effects. For instance, there are two complementary ways to understand the food chain :

The biological approach: Larger animals eat smaller animals which eat phytoplankton. Eventually they are eaten themselves by larger predators or by scavengers ;

The physical approach: Energy enters the food chain at the bottom, as organic matter created by phytoplankton by photosynthesis, and is transferred to the top, where it eventually falls back, as 'marine snow' to the lower layers

Of course, both approaches are correct and contribute to a fuller understanding of what is going on. Let us bring them together to analyze some major features of the Ocean.

Half of the oxygen and half of the organic matter on the planet are produced in the Ocean. And yet the Ocean is an oxygen-poor environment, because oxygen has to dissolve in seawater to reach marine creatures, and the solubility, the maximum amount of oxygen seawater can carry, is limited to a level below that of the air on top of Mount Everest.

This is the major constraint on marine life.

The oxygen content of the water can be affected in several ways, both physically and/or biologically:

The solubility of oxygen in seawater depends on temperature: roughly speaking, it is cut in half when the temperature increases from 0°C to 50°C. This means that it is lower near the equator than in higher latitudes, which is affected by global warming.

In effect, all marine species are competing for a limited amount of oxygen. It may happen that the lower levels of the food chain shut out the upper ones. This happens for instance when chemical fertilizers leach or flow into the Ocean. They carry nitrogen and phosphorus, which favour aquatic plants, leading to so-called "algal blooms" which kill off the fish.

The Ocean pumps CO_2 from the atmosphere and thereby plays a major role in dampening the effects of human emissions and slowing global warming: it is estimated that the Ocean contains 50 times more CO_2 than the atmosphere. There are in fact two pumps operating together:

A physical pump, which operates by dissolving CO_2 at the surface and carrying it into the depths of the Ocean by the MOC. As in the case of oxygen, the solubility of CO_2 is sensitive to temperature: global warming decreases the efficiency of the physical pump;

A biological pump, which operates by absorbing the carbon from dissolved CO_2 into the body of marine creatures. When the creature dies, the shell sinks to the bottom of the Ocean. This process depends on the acidity of the water, that is, the amount of H^+ protons floating around: the higher the acidity, the less efficient the biological pump is.

The two pumps store the carbon at different time scales.

The physical pump sends it into the ocean circulationwhere it will reappear after some centuries, while the white cliffs on both sides of the Channel, near Dover and Boulogne, are nothing but the shells of dead plankton, accumulated and stored over millions of years.

Some physical consequences have vast biological effects. Nutrients, as well as oxygen, are in short supply in the Ocean.

Deep waters accumulate such nutrients from organisms living near the surface and sinking after death. In certain regions, currents bring these deep waters up to the surface, cooling surface waters and enriching them with nutrients, which favour the growth of phytoplankton.

This is called upwelling, and the end result is a much richer food chain: approximately 40% of the total global fish catches comes from four upwelling areas, which occupy only 3% of the total ocean area: the Humboldt current, off Peru and Chile, the California current, the Canary current, off Northwest Africa, and the Benguela current, off Southwest Africa.

Figure 6: the upwellings. Source: www.iasgyan.in

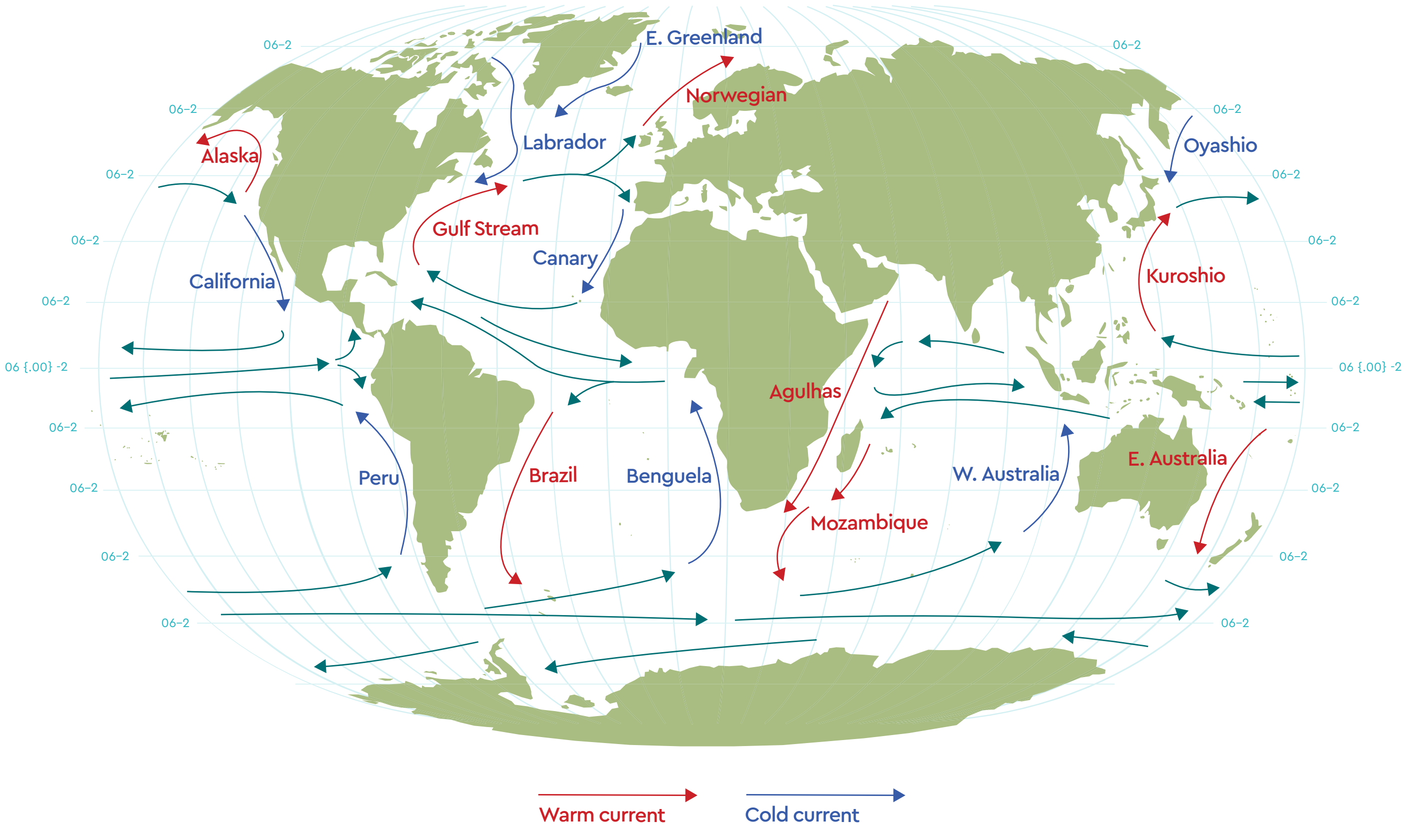


Figure 6: the upwellings. Source: www.iasgyan.inThe driving force of upwellings is wind, which, helped by the rotation of the Earth, drives surface waters away from the coast so that deeper waters are 'pumped' up. This implies that upwellings are very sensitive to wind conditions. During El Niño episodes in the South Pacific, for instance, prevailing winds have weakened, which has in turn weakenedthe Humboldt upwelling and led to the collapse of anchovy fisheries off the coast of Peru.

Tampering with the system

For millennia, humans have used the Ocean in an unsustainable way by taking resources from it and dumping waste into it.

For instance, between 1946 and 1982, low-level radioactive waste was packaged, usually in metal drums lined with a concrete and bitumen matrix and disposed of at more than 50 sites in the Northern Atlantic and Pacific. However, the overall impact of human activity on the Ocean remained limited until 1950. It has now reached a level where it threatens the functioning of the system and could eventually lead to its collapse with poorly understood consequences.

Dumping into the Ocean:

Carbon

Since 1960, humankind has been dumping carbon into the Ocean at the mean rate of 2.7 Gigatons a year, more than 25% of all anthropogenic emissions. This means that the Ocean acts as a buffer.

By absorbing a quarter of all human-generated emissions, it slows down global warming. But these enormous quantities of excess carbon stored in the Ocean have consequences on the Ocean itself.

The most important one is acidification: when CO_2 dissolves into water, it combines with H_2O to produce a free hydrogen ion H^+, and the more CO_2 is absorbed from the atmosphere, the more H^+ ions roam about, which means seawater becomes more acid.

This makes it more difficult for marine organisms, such as mollusks or corals, to capture the carbon into shells or skeletons made of calcium carbonates.

As the acidity of the Ocean increases,
its capacity to absorb carbon decreases

In other words, the biological pump we mentioned earlier slows down.

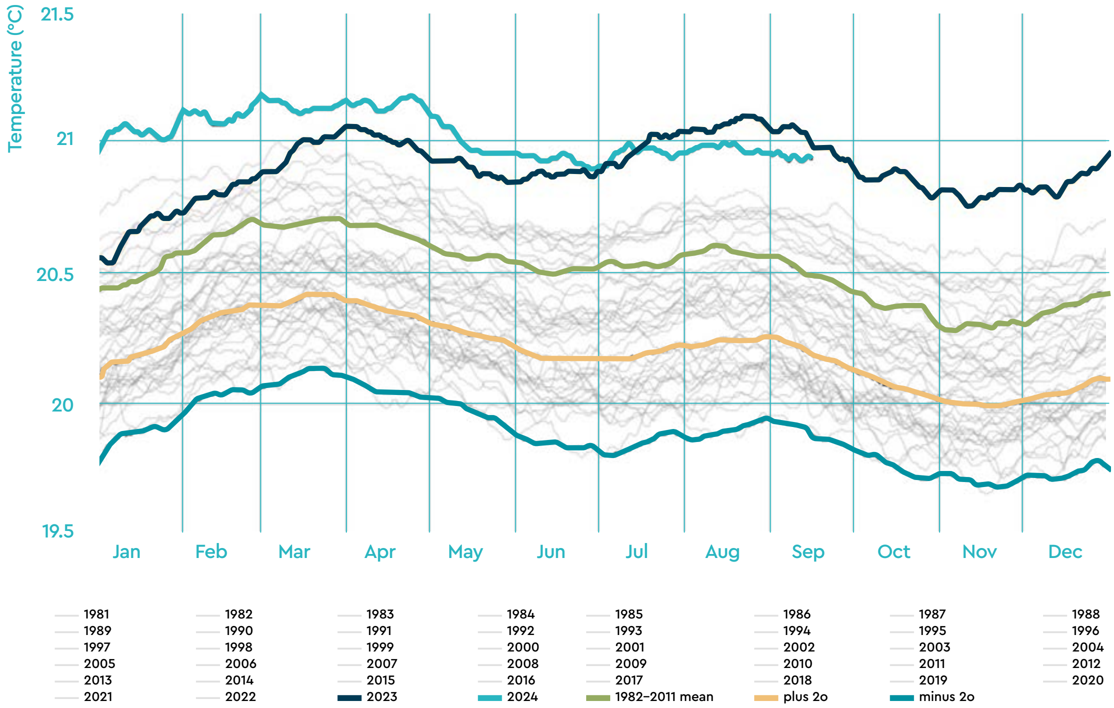


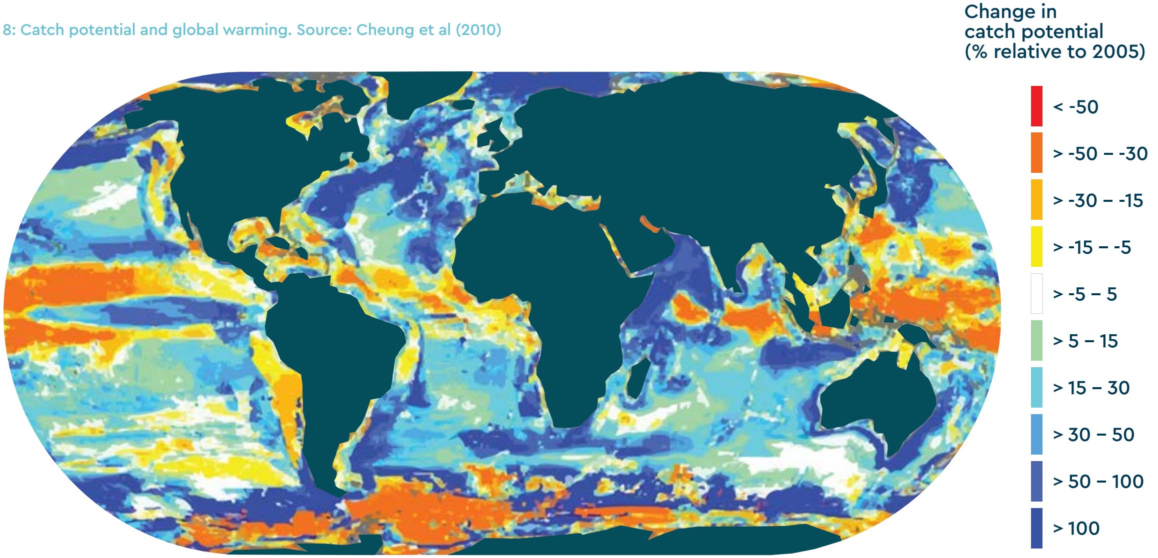
Figure 7: Sea Surface Temperature. Source: climatereanalyzer.org

On top of acidification, the Ocean is affected directly by global warming. As the above figure shows, its mean surface temperature has risen by more than 1°C on average since 1981, and there has been a particularly worrying (largely unexplained and unaccounted for) acceleration in the past two years. As we saw, a rise in temperature, which is a problem in itself, also decreases the oxygen content in the water. Marine life is very sensitive to these changes. Species which can migrate to cooler waters depend on their prey moving with them or infinding substitutes. Species which cannot migrate stay and die.

This is the case for corals. For instance, if temperature increases, corals bleach, that is, they lose their symbiotic algae until conditions get better; if they don't, that is if the temperature permanently increases by more than 2°C, they die. The risk of bleaching due to global warming is estimated to increase about 4% per year, unevenly distributed. The lower latitudes being much more exposed. Note that it is also the case for species that can actually migrate, such as fish.

Global warming may lead to large-scale redistribution of global catch potential, with an average of 30–70% increase in high-latitude regions and a drop of up to 40% in the tropics. This is a global feature of climate change: the global South bears the brunt. The figure on the side describes changes in catch potential between 2005 and 2055 in a business-as-usual scenario:

Figure 8: Catch potential and global warming. Source: Cheung et al (2010)



There are also purely physical consequences to warming the Ocean. Similar to every material, water will dilate when heated. Its volume will increase, and it will take up more space.

This accounts for 50 % of the rise in sea level, the remaining 50 % being due to the melting of ice caps.

This is a slow phenomenon, but its impact is already being felt. As sandy beaches and mangroves disappear, and coastal ecosystems are affected, Indigenous communities, whose livelihood depends on these ecosystems, are under threat, as well as other major coastal cities such as Miami or Jakarta.

Extreme weather events, such as storms or hurricanes, will increase in frequency and strength, shifting away from the tropics towards regions North and South of the equator which were previously unaffected until now.

Figure 9 shows that the Western US and the China Sea are particularly affected with a huge impact on coastal communities and cities. Rising sea levels and increased strength of storms make a deadly combination.

Global

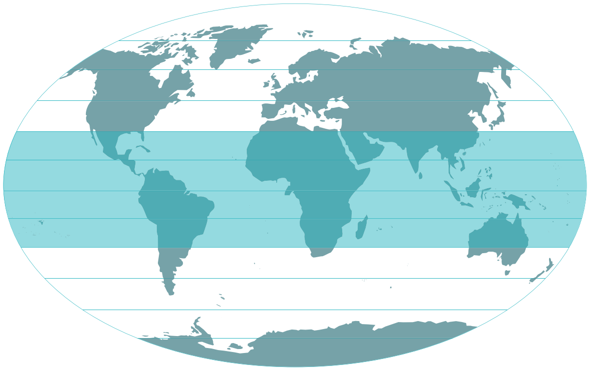
Figure 9: Cyclones and global warming. Source: IPCC

- Tropical cyclones
- Extratropical cyclones
- Atmospheric river

Average and maximum precipitation rates increase with warming

- Tropical cyclones

Increase in strength
Decreased or unchanged genesis frequency

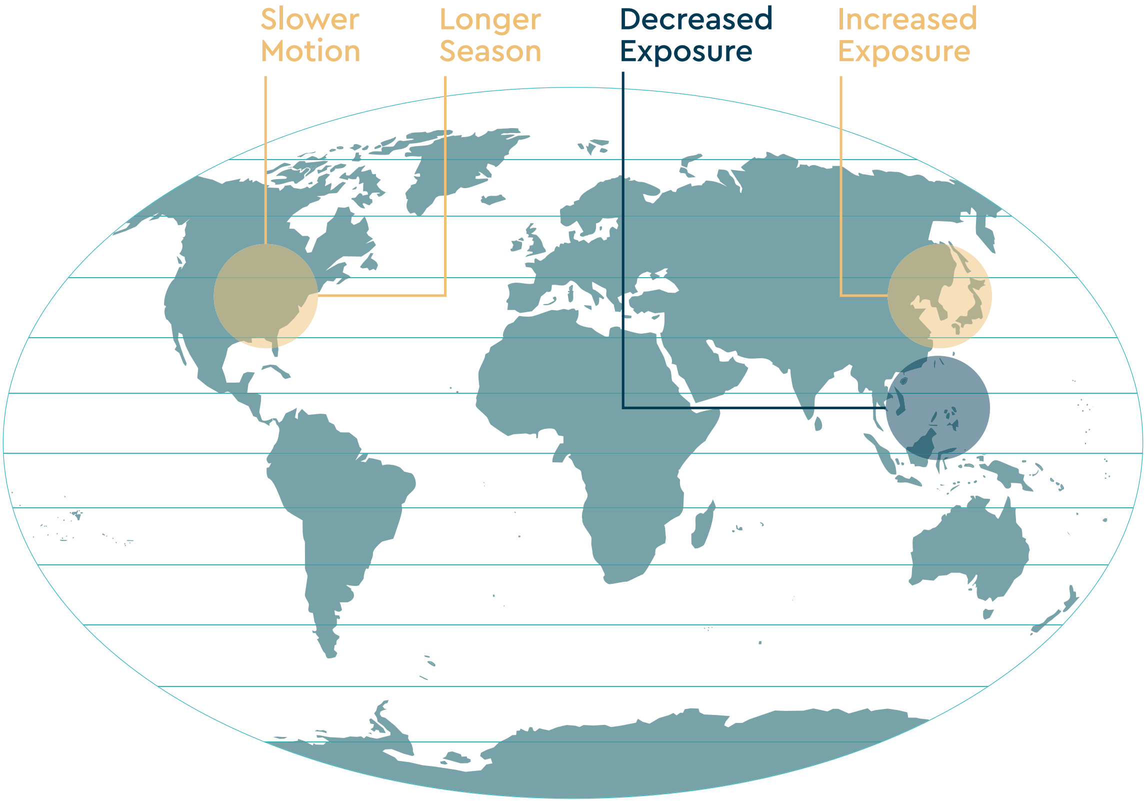


- Atmospheric river

Changes (increase or decrease in wind speed following storm tracks poleward shift in some regions

Regional

Figure 9: Cyclones and global warming. Source: IPCC



All these changes are already being felt. The city of Jakarta, for instance, which is home to over 10 million people (30 in the wider metropolitan area), has been threatened to the point that the government to decide to shift the Indonesian capital to a new city, Nusantara – an island of Borneo built from scratch. But there may be much more in store.

The acidification of seawater and global warming, affect the MOC, which relies on very fine differences in salinity in temperatures to operate.

Recent studies show that it is possible, if not likely, that the Atlantic branch, the AMOC, will stop before this century is over, causing enormous consequences on climate and marine life.

Dumping into the Ocean:

Plastics

The signature of humanity is plastic. It is found everywhere in the Ocean. The beaches of Henderson Island are littered with plastic debris. A plastic bag was once found 10,975 meters deep in the Mariana trench.

Plastic has entered the food chains and has been found in every part of the human body,the consequences of which remain unkown.

Between 1950 and 2017, 9.2 billion tonnes of plastic are estimated to have been made, with more than half having been produced since 2004 and 60% of it is still around today.

The geological strata which we will leave behind us will be easily identified, because of its plastic content.

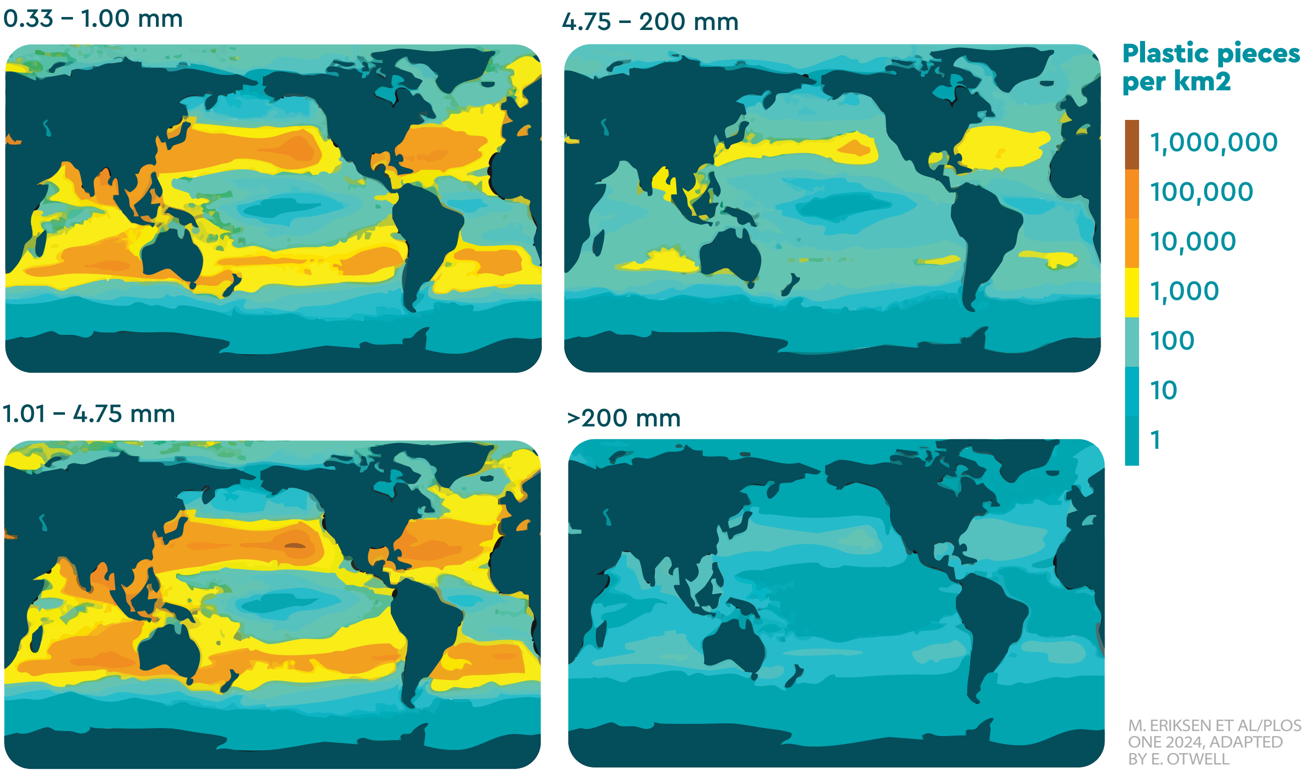


Figure 10: plastics in the Ocean according to size

In 2019, humanity produced 460 million tons of new plastic, and 330 million tons of plastic waste. About 10% were recycled, 20% incinerated, and the rest remains littered across the Earth or in landfills. Some of it finds its way into the Ocean. There are also ocean-based sources of plastic pollution such as discarded fishing gear (including traps and nets), which is estimated to be up to 90% of plastic debris in some areas.

Plastic debris found in the Ocean come in all sizes: from large debris, such as Coca-Cola bottles, to microbeads less than 5 millimeters wide, commonly found in health and beauty products.

The plastic industry also produces large quantities of "nurdles", round pellets ranging from 1 to 5 mm in diameter which are shipped around the world to be molded into whatever shape the final producer sees fit.

They spill into the environment during production and transportation and eventually find their way into the Ocean.

The total amount of plastic entering the Ocean from all sources is estimated to be around 12 million tons in 2029, rising to 30 million tons in 2040. All this plastic accumulates.

The direct input of plastics from both land-based and sea-based sources since the 1950s is estimated to be around 180 million tons. There may even be more plastic than fish in the Ocean by 2050.

For marine life, plastic is a killer. Animals become entangled in large debris, such as discarded nets, and die;marine mammals and turtles by drowning, others by starvation.

They can also mistake plastic for food. Marine turtles mistake floating plastic for jellyfish which clog their stomachs with indigestible matter, while larval fish ingest microplastics instead of nutritious food at crucial stages of their development.

Plastic enters the marine food chain at all levels and is found in all organisms.

A recent study, covering the Tropical Eastern Pacific and the Galápagos archipelago, has found microplastic particles in 100% of the water samples and marine organisms.

They travel up the food chain, and end up in humans, where their long-range effects are unknown.

Plasticized animal species - Ingestion

Number of species with documented records of marine debris ingestion

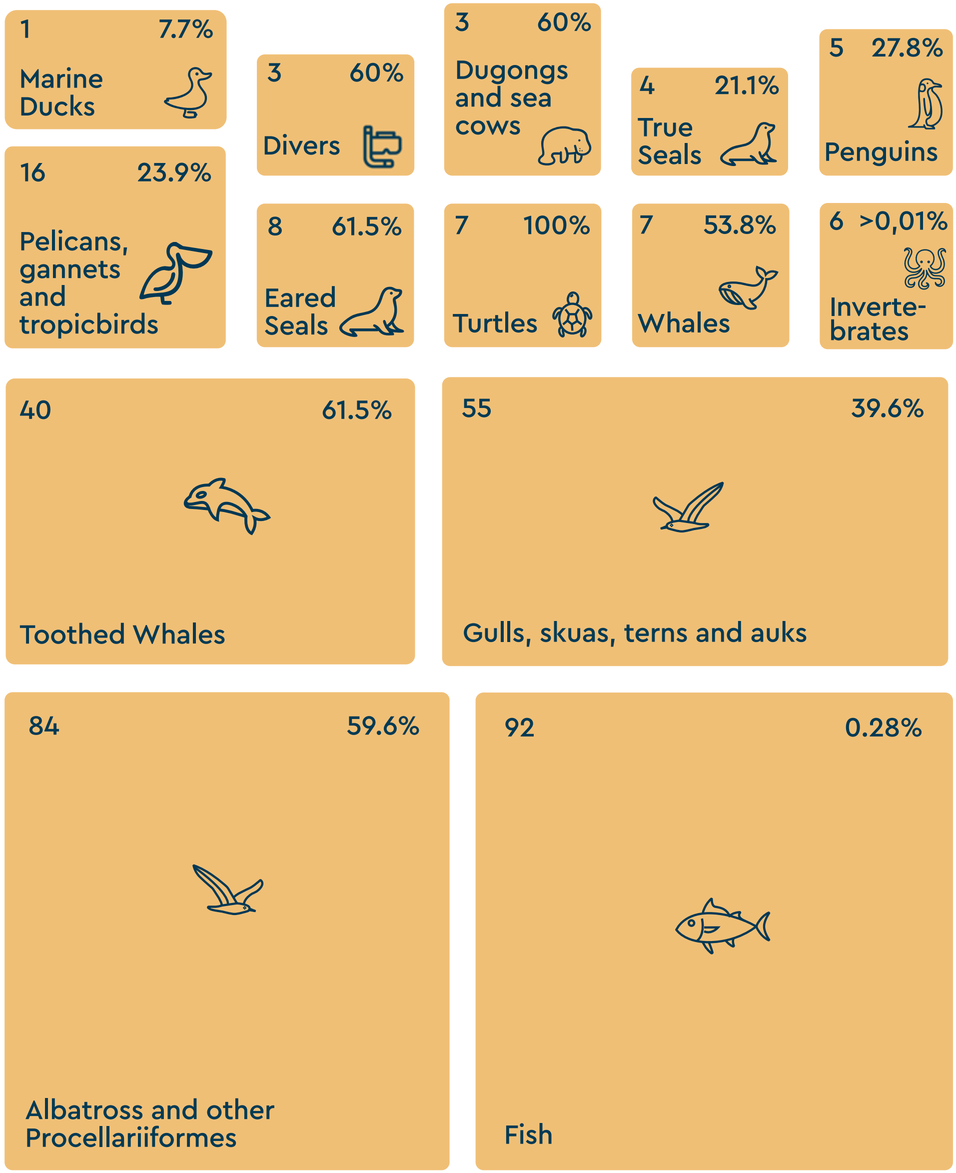


Figure 11: plastics and marine life

Plasticized animal species - Entangled

Number of species with documented records of entanglement in marine debris

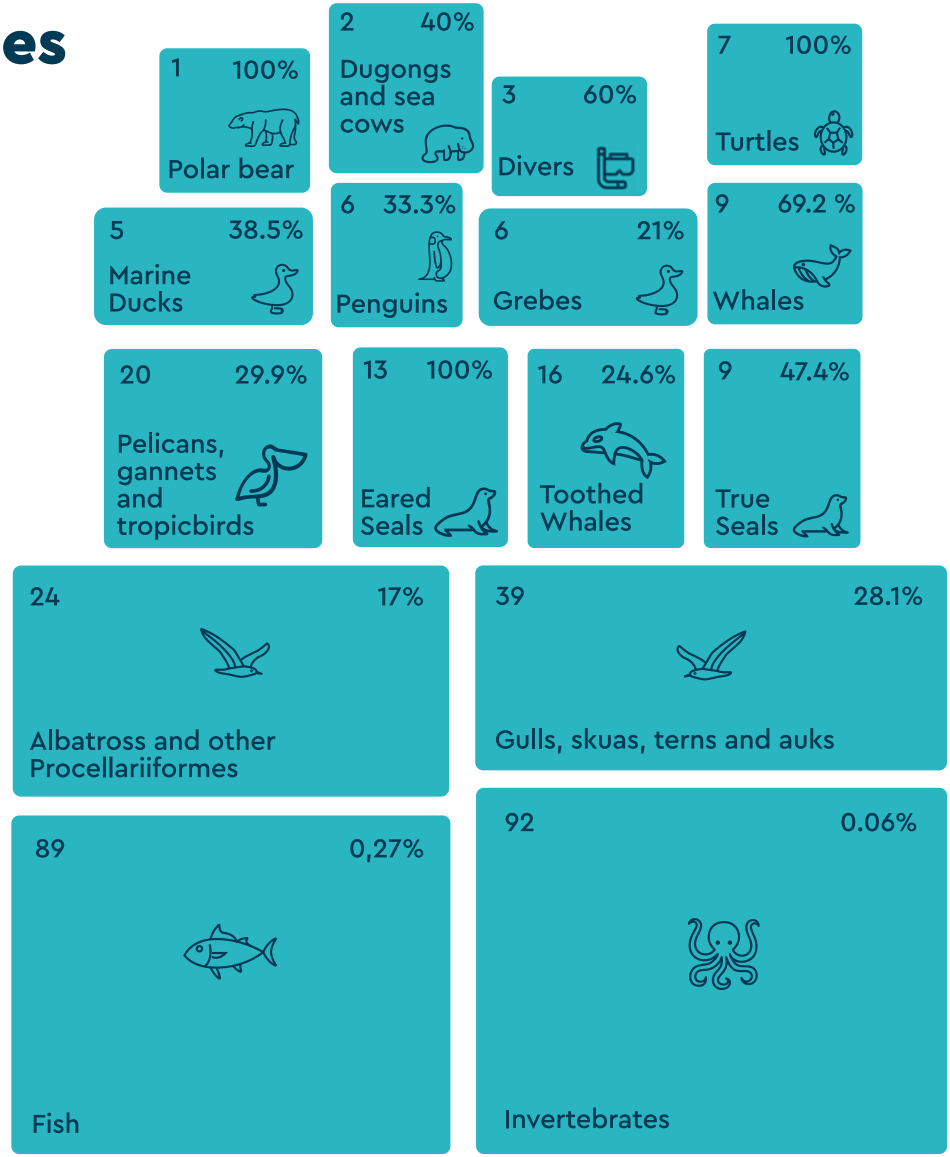


Figure 11: plastics and marine life

Macroplastics (more than 20cm in diameter) show up as floating masses in oceanic gyres, like the Great Garbage Patch of the North Pacific, or as mixed debris on previously pristine beaches, as on Henderson Island.

Discarded or lost fishing gear have been found to comprise the majority of ocean macroplastics. A 2019 study estimated that the North Pacific Garbage Patch contained 42,000 tonnes of macroplastics, of which 86% was abandoned fishing nets.

The Ocean as a physical system:

Aquaculture

Aquaculture, the farming of fish, shellfish, and other aquatic organisms, has seen significant growth over the past few decades, becoming the world's fastest-growing food production sector.

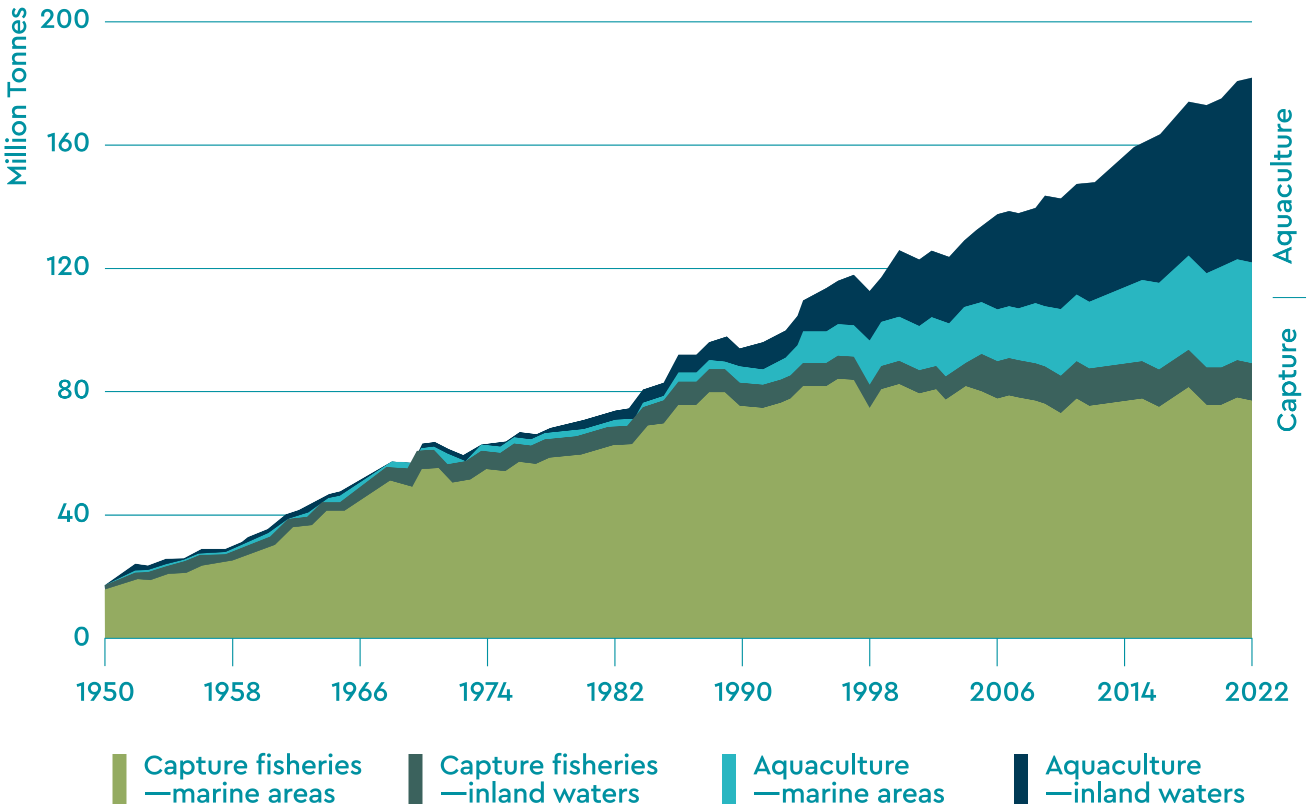
This expansion has been driven by increasing global demand for seafood as a protein source, declining wild fish stocks, and advances in aquaculture technology and practices.

Global aquaculture production has risen from 22 million tons annually in 1990 to 94 mt in 2022 while wild fisheries catches have plateaued since 1990 at around 90 mt, due to overfishing, habitat degradation, and other environmental pressures.

Aquaculture now accounts for over half of all seafood consumed worldwide

World fisheries and aquaculture production of aquatic animals

Figure 12: fisheries and aquaculture



NOTES: Aquatic animals excluding aquatic mammals, crocodiles, alligators, caimans, aquatic products (corals, pearls, shells and sponges) and algae. Data expressed in live weight equivalent. SOURCE: FAO. 2024. FishStat: Global production by production source 1950–2022. [Accessed on 29 March 2024]. In: FishStatJ. Available at www.fao.org/fishery/statistics/software/fishstatj. Licence: CC-BY-4.0.

In 2022, for a total of 94.4 mt, marine aquaculture accounted for 35.5 mt and continental for 59.1mt. This corresponds to two different types of aquaculture:

A: the farming, mainly in Asia, of algae and herbivorous animals, predominantly bivalves such as clams, mussels, and oysters, and a few fish species such as carps. This form of aquaculture contributes to easing pressure on wild fish populations, notably in China, by far the world largest aquaculture producer.

B: the farming, mainly in the West, of carnivorous fish, notably Atlantic salmon. This form of aquaculture actually consumes fish. Thus, for every kilogram of salmon that is 'produced' between 3 and 5 kg of perfectly edible fish – such as sardine, mackerel and anchovy is consumed in the form of fishmeal and fish oil.

Aquaculture B, while a huge source of revenue for the fortunate owners of salmon farms, does not contribute to easing the pressure on wild fish population. To the contrary, it endangers the food security of many countries that now export fishmeal and oil rather than consuming the fish from which these export products are derived.

Other concerns related to aquaculture B include environmental impacts such as habitat degradation from intensive farming operations and destruction of wild populations through diseases and parasites carried by farmed individuals which escape from the open sea pens.

In addition, these escapees contaminate the genetic pool of wild populations and compromise their ability to survive in natural conditions: the population of wild North Atlantic salmon today is just 25 percent of its level in 1970.

On the other hand, the farmed population in Iceland only was about 500 times larger than the wild one and is projected to double.

However, innovations in sustainable practices, such as integrated multi-trophic aquaculture, alternative feeds, and improved management, could be helping toward minimizing these issues while meeting the growing global demand for seafood.

This duality makes aquaculture both a promising solution for food security and a sector requiring careful regulation and continued improvement.

Having said this, there is increasing evidence that the aquaculture growth rate is also decreasing, calling for a tempering of the prevalent over-optimism.

Transportation

Dumping into the Ocean is done from ships as well as from the land or the atmosphere. There are thousands of fishing vessels out there, but they are dwarfed, in number and in size, by the cargo ships, tankers and container carriers that ply the Ocean.

Over 80 % of goods traded across the world travel as ship cargo, and the volume loaded has doubled in ten years. Ships dump their carbon into the atmosphere (they account for 3% of GHG emissions), and their waste into the sea, from fishing gear to oily bilgewater. They also carry invasive species from one continent to the other, for instance, by pumping up ballast water when they are unloaded and dumping it back when no longer needed, generally in another harbour.

There is some good news coming from that side. In 2024, an international treaty has come into force establishing standards and procedures for ships to manage ballast water. In April 2025, in the absence of the US, the International Maritime Organization (IMO), a UN body that regulates global shipping, approved new regulations to cut greenhouse gas emissions across the maritime sector. The deal mandates a trajectory to net-zero emissions by 2050, backed by financial penalties and a structured compliance framework.

However, there are other ways marine transportation propagates invasive species. Approximately 19,000 ships passed through the Suez Canal in 2020, 12% of world trade and 30% of world container traffic. But this has an environmental price: native fishes of the Mediterranean are being replaced by species from the Red Sea, including some toxic ones.

Figure 13: Sea Lanes around the planet. Source: static.cambridge.org

Note that ships are creating new risks because of their sheer size. In March 2021, a 400 meters long container ship obstructed the Suez canal for one week.

Tankers now can carry 2 million barrels (320,000 m3) of oil, which is about eight times the amount spilled in the widely known Exxon Valdez incident.

Cruise ships can carry 10,000 passengers (7600 passengers, 2400 crew) on 20 decks, and are banned from a growing number of harbours.

The sea lanes which carry goods are duplicated on the sea floor by cables which carry information. Comparing the two maps, of the sea lanes and submarine cables, we see that the Ocean is a very busy and crowded place

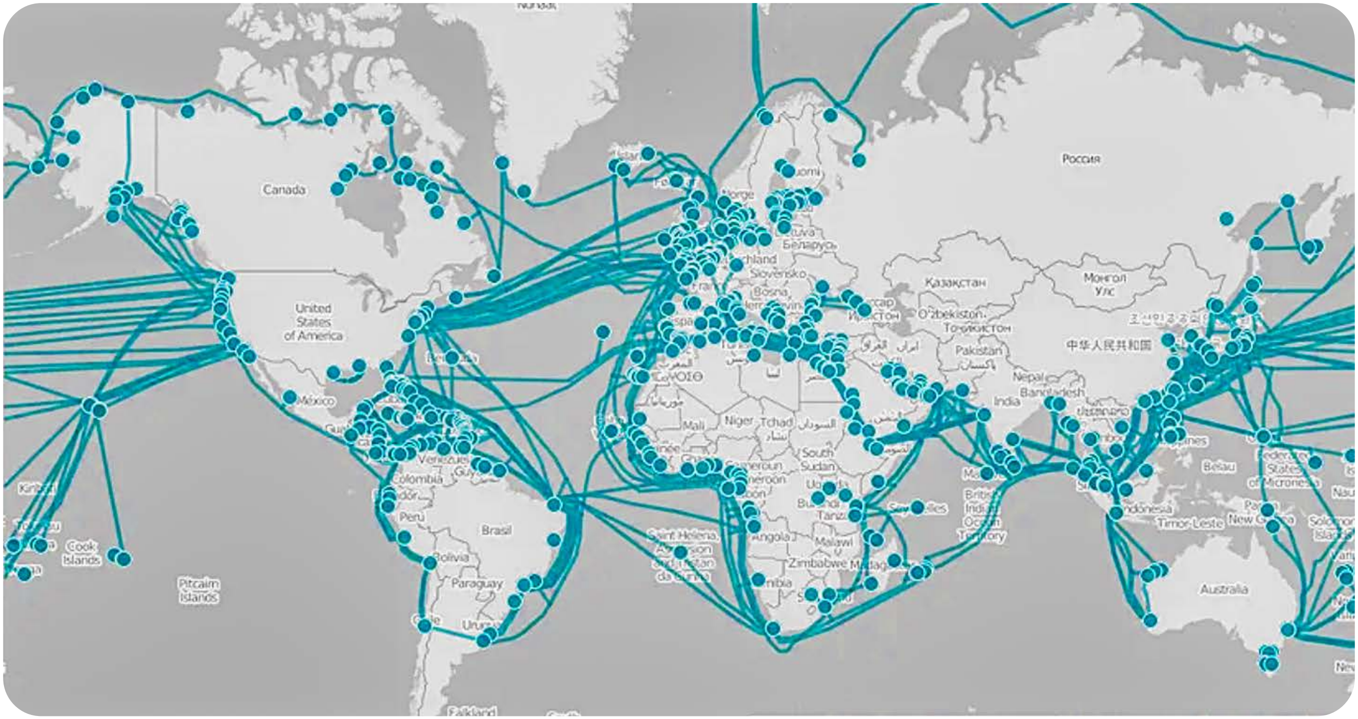


Figure 14: Submarine cables. Source: Wikipedia

Taking from the Ocean:

Fishing

Historical evidence shows that the biomass of high trophic level fishes, such as cod, halibut, hake, haddock, redfish, saithe, and whiting, the ones that sit on top of the food chain and are the most targeted for human consumption, has been divided by nine during the twentieth century.

The following picture gives the state of the stock from 1900 to 2000:

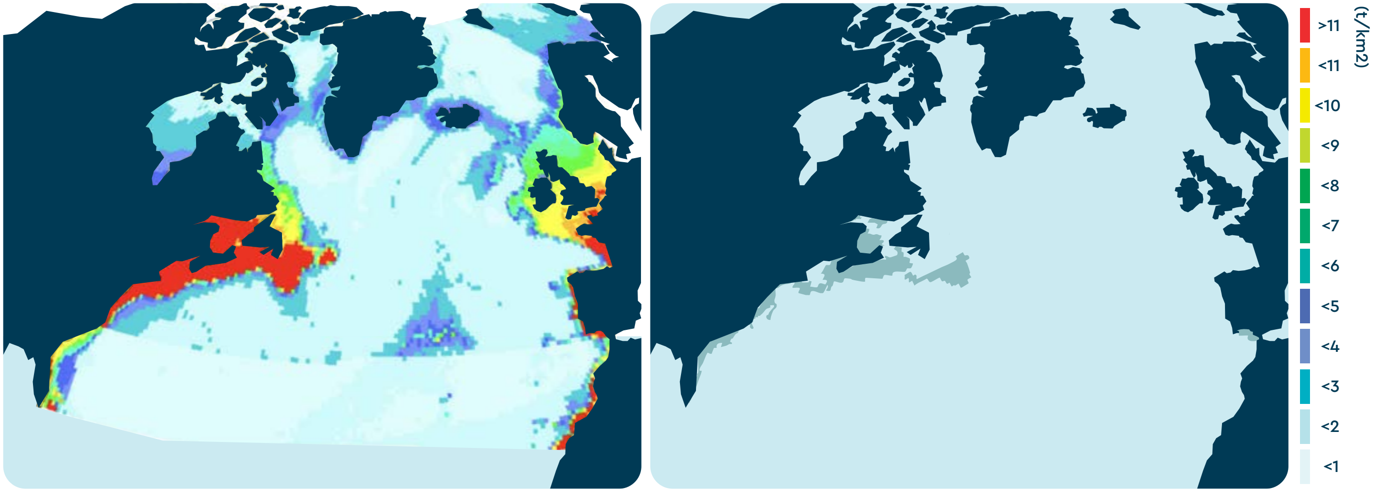


Figure 12 : One century of catches in the North Atlantic. Biomass distribution for high-trophic level fishes in the North Atlantic in (a)1900 (b) 1950 (c)1975 and (d) 1999. Units for the legend are tonnes km −2 Source : Christensen et al. (2023)

This is a major collapse, and the fact that it has occurred under the radar, without raising attention outside of the scientific community, is a testimony to the "shifting baselines" phenomenon: for each generation, the "natural" state of an ecosystem is the one they experienced when they were young, and all further degradations or improvements will be measured against it.

As the ecosystem degrades, and new generations arrive, the baseline shifts downwards and previous memories of a healthy ecosystem disappear.

Let us take a specific example. Figure 13 describes five centuries of commercial cod catches in Eastern Canada and its eventual collapse.

It peaked in 1970 with 520,000 tons, and it fell to 11,400 tons in 1992, at which a moratorium was proclaimed in hope of a recovery which has not yet occurred.

Nor is it likely to occur, for the disappearance of cod, a top predator when adult, has fundamentally changed the ecosystem, where snow crab and northern shrimp now proliferate.

These new species have given rise to a thriving shellfish industry, so there is no economic interest in restoring the cod population.

These new species have given rise to a thriving industry, so there is no economic interest in restoring the cod population.

Five centuries of cod catches in Eastern Canada

Estimates of North Atlantic cod (Gadus morhua) catch off Newfoundlandand Labrador, Eastern Canada

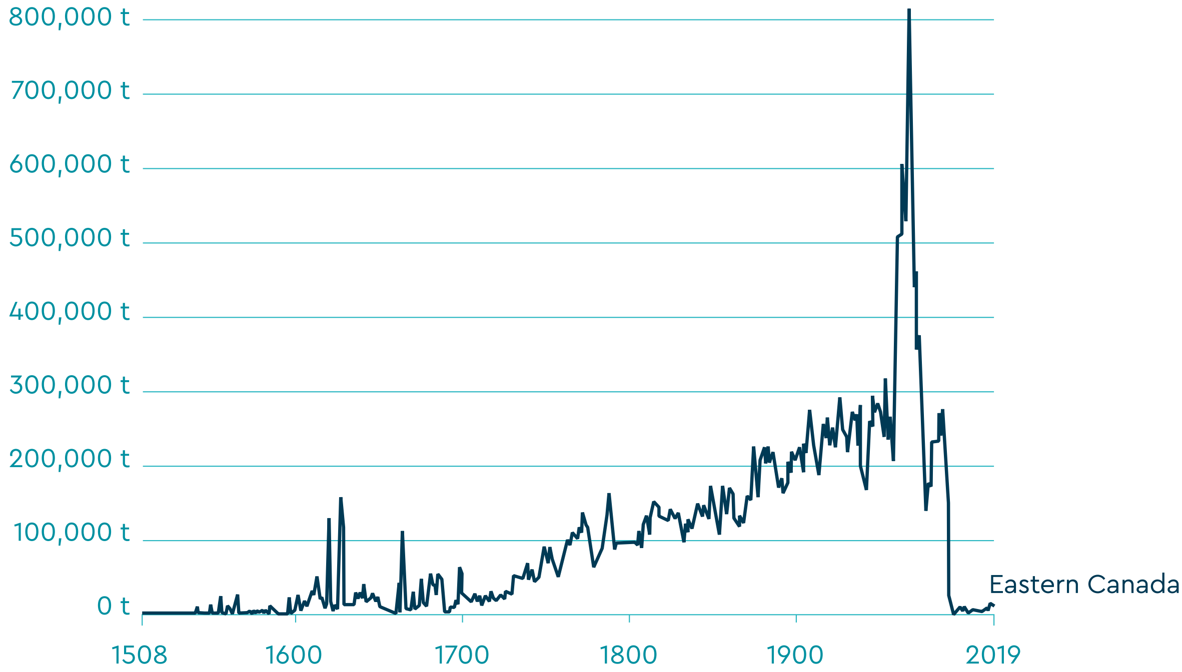


Figure 13: Collapse of the Newfoundland cod fishery

Data source: Schjins et al. (2021). Five centuries of cod catches in Eastern Canada. OurWoldinData.org/fish-and-overfishing | CC BY

This is a typical example of "fishing down the food chain": fisheries in a given ecosystem, having depleted the large predatory fish on top of the food web, turn to increasingly smaller species, finally ending up with previously spurned small fish and invertebrates.

Another example is provided by the sardines and anchovies fishery off the coast of Namibia. These species used to benefit from the upwelling in the Benguela current, and proliferated until the industrial fisheries took over from the local ones and skimmed off the commercial fish.

The local ecosystem is now dominated by jellyfish, which outnumber (masswise) fish in the ecosystem by a factor 2.5, and by bearded goby, a bottom-feeding, mud-eating small fish. Larger fish cannot recover, for they are eaten by jellyfish at the larval stage. The social and economic consequences of the fishery collapse for human populations living along the coast are devastating.

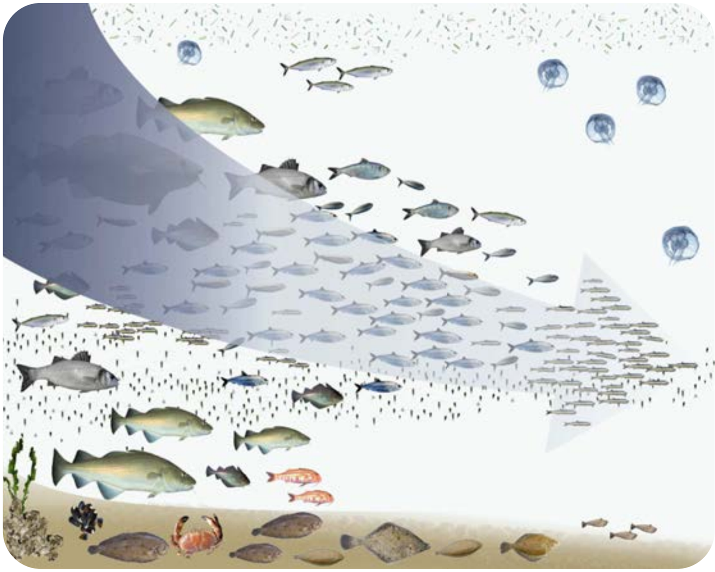


Figure 14 : Fishing down the food web. Source : Hans Hillewaert

The observed trend at the world level is less alarming: wild fish catches have hovered around 90 million tons since the nineties.

This is because we are not fishing the same fish. As certain fish populations collapse, ships go farther out and farther down to discover new ones.

By the end of the 20th century, fishmongers' stalls in Europe were featuring fish which were totally unknown to consumers before, such as Greenland halibut, black scabbardfish, orange roughy, or grenadiers.

What these new species have in common is that they live at great depths, so fishing for them requires special gear and lots of energy, and they have very long life spans and very slow reproductive rates.

The orange roughy, for instance, is fished at over 900 m depth. It lives over 150 years and needs at least 20 years to reach sexual maturity. Cod, on the other hand, reaches sexual maturity at 3, meaning that it reproduces seven times faster.

This means that deep-sea fish stocks will be depleted much faster. Deep-sea fisheries are very close to mining a non-renewable resource.

The following picture, figure 15 shows the evolution of fish stocks according to the FAO. Note that the proportion of stocks fished at unsustainable levels (meaning that they are being driven to extinction) has been increasing since the mid-1970s, from 10% in 1974 to 38% percent in 2021.

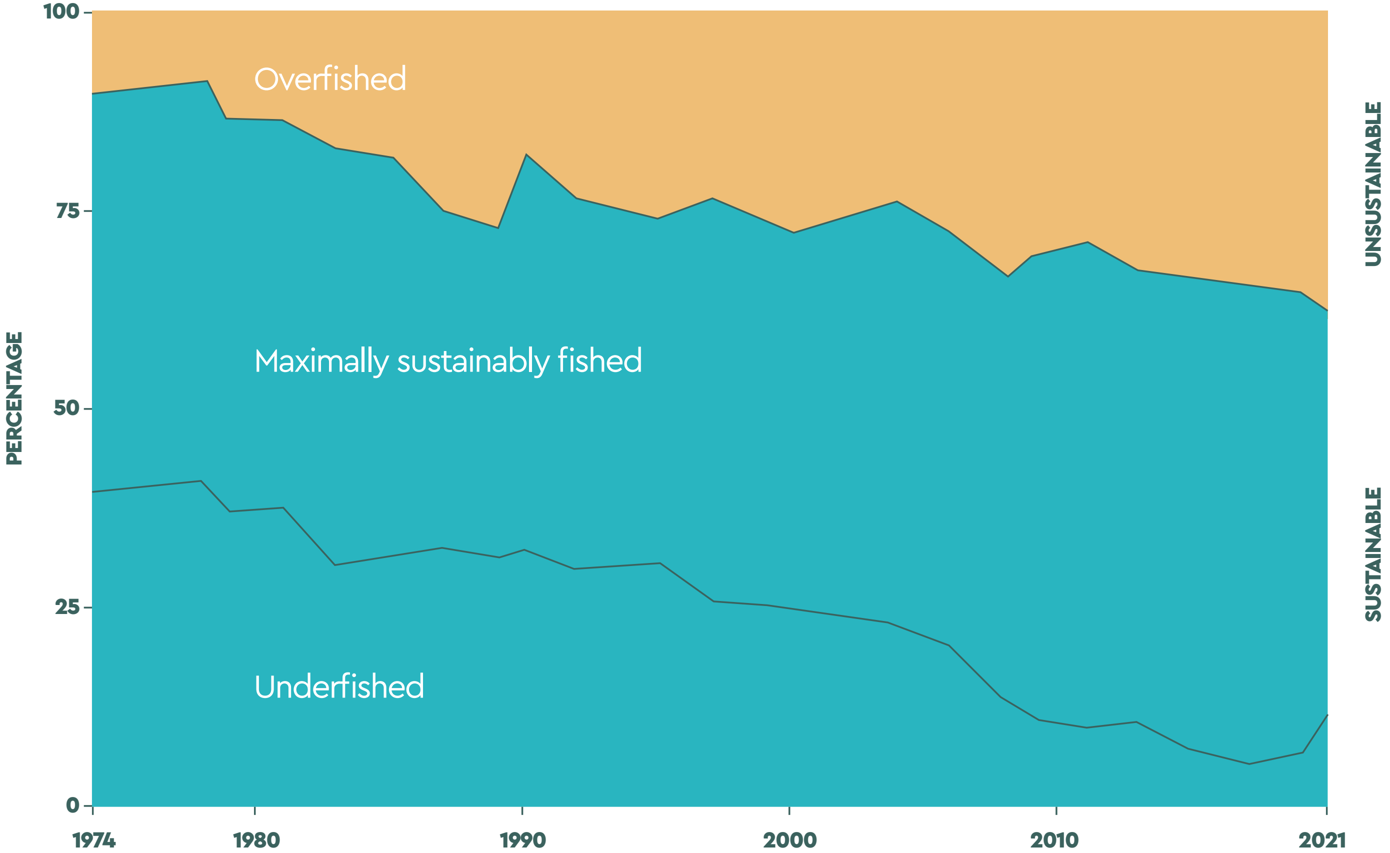
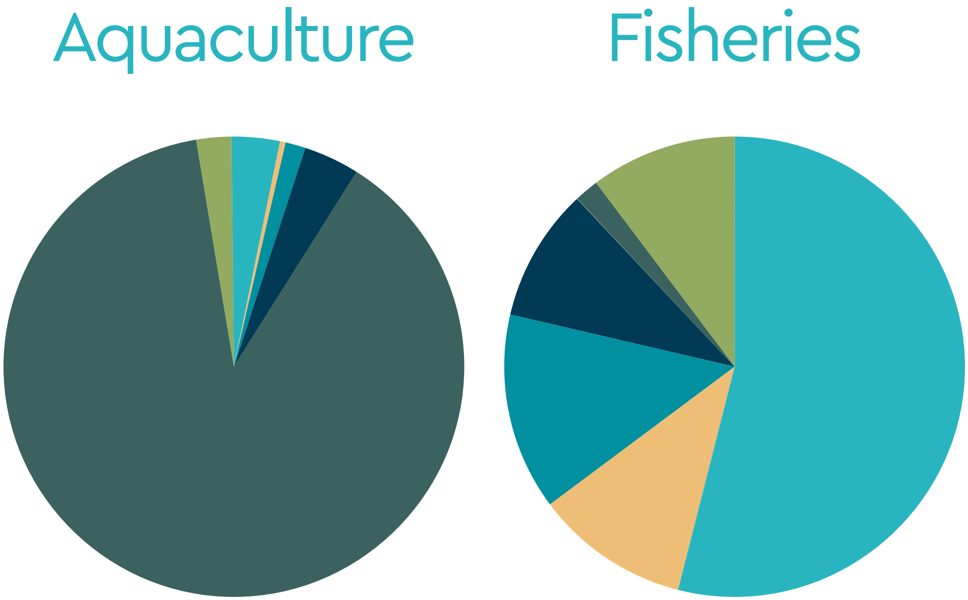


Figure 15 : the state of world fisheries. Source : FAO

Global fish consumption has been increasing steadily, driven by rising demand for seafood due to population growth, rising incomes, and greater awareness of fish as a nutritious food source. As we have seen, aquaculture now accounts for half the fish consumed worldwide. However, significant disparities exist between the Global North and Global South as the following picture, figure 16, shows.



	Aquaculture	Fisheries
Countries yield < 100 (ty^{1})	58	27
Common prod/catch < 60%	1	201
SID's prod/catch (Mt)	0.05	1.28
Africa prod/catch (Mt)	1.98	9.59
South America prod/catch (Mt)	2.33	8.43

North America South America Africa Asia Europe Oceania

Figure 16: The continental percentage contribution of global food fish production from aquaculture and fisheries catch

The Global North, characterized by higher-income nations, consumes a significant portion of wild fish caught from both domestic and imported sources, often in the Global South.

In contrast, the Global South, with many lower- and middle-income countries, tends to rely heavily on fish caught locally for nutrition and livelihoods, particularly within coastal communities. Fish trade from the Global South to wealthier markets in the Global North can exacerbate local overfishing and resource depletion.

This has serious social and economic consequences for coastal communities in the Global South, where fishing is often a cornerstone of local economies and a vital source of protein.

Aquaculture is not a solution because farmed fish produced elsewhere, mostly in China, accounts for 60% of the world production, and must be bought on global markets.

Efforts to address these imbalances include promoting sustainable fishing practices, strengthening local management, and encouraging equitable trade policies to ensure that coastal communities are not deprived of their resources in wild fish.

However, achieving these goals remains a huge challenge that demands international collaboration and effective governance to balance local needs and global demand for seafood.

Taking from the Ocean:

Oil and Gas

For the past twenty years, around 30% of crude oil production has come from the Ocean, and there is no sign of that trend abating. As the following picture shows, firugre 17, offshore drilling has gone deeper and deeper.

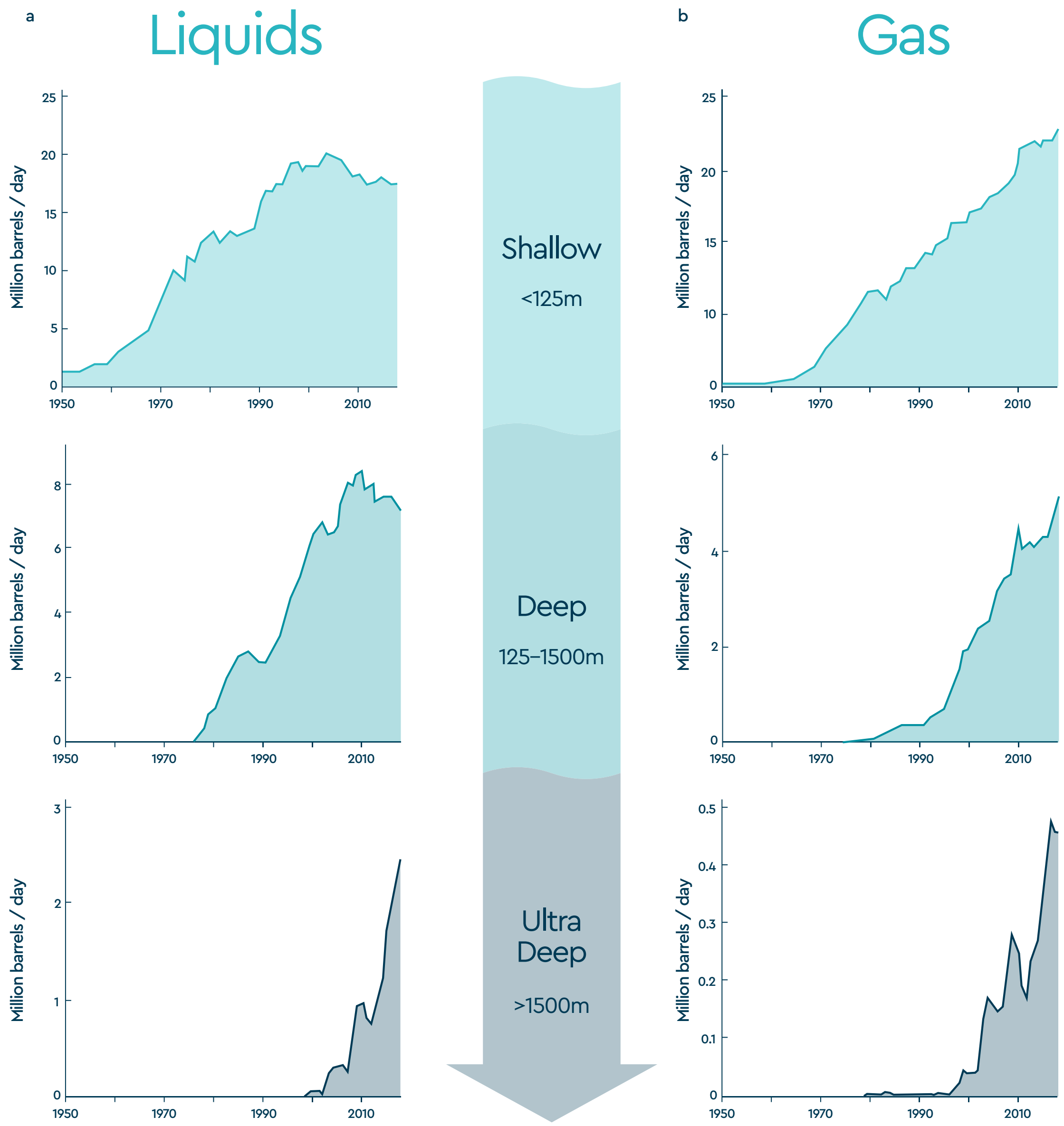


Figure 17: Global offshore (a) liquids and (b) gas production across depths from 1950 to2018. Liquids include both crude oil and natural gas liquids. Water depth categories include shallow (<125m), deepwater (125–1500m), and ultra-deepwater (>1500m). Source : Jouffray et al. (2020)

This trend carries risk. In the Gulf of Mexico, the platform DeepWater Horizon was sitting over 1,300 meters of water and seeking oil at over 10,000 meters. It blew up in 2010, spilling over 780,000 m3 of oil over five months, causing a major ecological disaster.

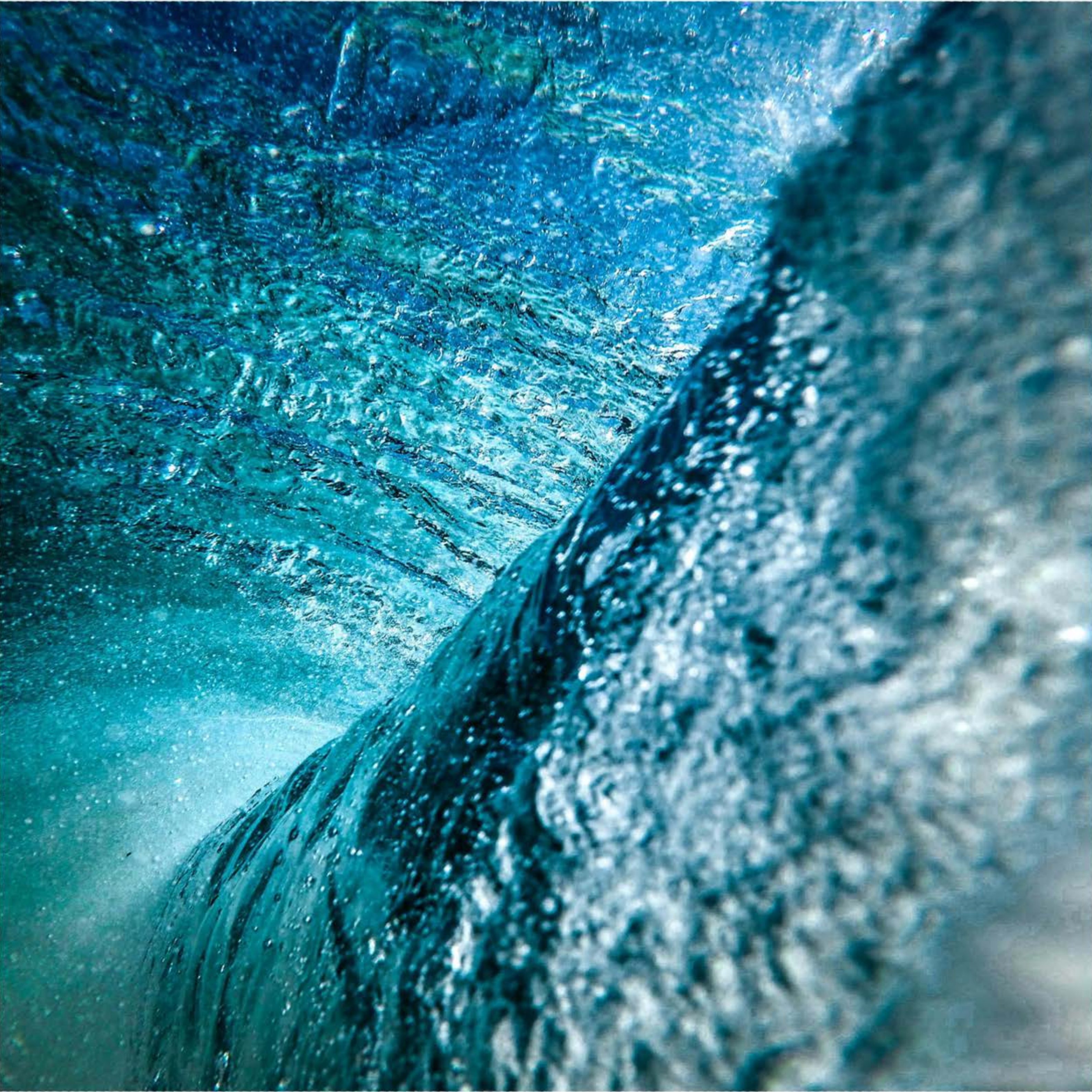
Taking from the Ocean:

Space

Offshore drilling requires space on the surface of the Ocean. There are at present 184 oil platforms in the North Sea alone.Marine aquaculture also requires space, with its huge pens for farmed fish.

The needs of marine transportation go beyond sea lanes, since they require transforming the coastline for harbours to accommodate larger and larger ships or building canals to shorten communications.

Marine renewable energies, from wind or waves, also require space. Offshore wind farms are blossoming along the coasts of Europe and China. There is also direct pressure on the Ocean from coastal communities wanting to expand or develop. More than 40% of the global population lives in areas within 200 km



of the ocean. Countries like the Netherlands, cities like Mumbai, and parts of China's coastal region are largely built on low-lying land reclaimed over centuries. More recently, cities like Monaco, Singapore and Dubai have built into the coastal waters by pouring sand, earth and rock into the sea.

The scale of land reclamation and the crowding out of natural processes and human activities are particularly apparent in the South China Sea.

More than half of the world's fishing vessels operate in the region, an estimated one-third of global maritime traffic passes through it, and it is a major node in the network of undersea telecommunication cables.

One single archipelago, referred to as the Paracel, Hoàng Sa, and Xisha Islands, has tripled its land area, from 7.75 to 20.75 km^2, hosting 20 habitable outposts with infrastructure such as wind turbines, helipads, and harbors.

As a result, there has been destruction of coral reefs, fish stocks are down by 70%–95% and seabirds have disappeared from the archipelago, although it sits in the middle of the East Asian-Australasian flyway, which includes the most threatened or near-threatened species of any of the world's migratory routes.

Taking from the Ocean:

Water and Sand

Sand is the key raw material in the concrete, asphalt and glass that build our infrastructure. It is also used for land reclamation as well as flood protection in coastal areas, as efforts are ramping up to protect eroding coasts and address climate change impacts such as sea-level rise and increasingly severe storms. It is estimated that between 4 and 8 billion tons of sand and other sediments are dredged every year in the marine and coastal environment. Furthermore, data analysed for the years 2012–19 shows the scale of dredging is growing.

The world is approaching the natural replenishment rate of 10 to 16 billion tons per year which is needed by rivers to maintain coastal and marine ecosystem structure and function.

Freshwater demand for all uses has been increasing by 1% per year since 1980, and half of the world's population experiences severe water scarcity for at least part of the year.

In that context, desalinisation of seawater appears to be an interesting solution, especially since major cities lie on the coast.

However, desalination is currently an expensive process, requiring considerable amount of energy, and is reserved for high-end uses in high-income coastal countries, especially in the Middle East.

Both sand dredging and water desalination have an environmental impact.

Dredging kills the bottom-living creatures and destroys their habitat, and desalination produces brine, water with high concentrations of salt, which is ejected into the Ocean with whatever chemicals were used during the process and negatively affects marine life.

Taking from the Ocean:

Mining

Deep sea mining (DSM) refers to the process of retrieving mineral resources from the ocean floor, typically at depths of 200 meters or more. This involves extracting valuable materials such as polymetallic nodules, cobalt-rich crusts, and seafloor massive sulfides that contain essential metals like copper, cobalt, nickel, manganese, and rare earth elements. These minerals are crucial for modern technologies, including renewable energy systems, electric vehicle batteries, and electronic devices.

Mining is conducted using remotely controlled equipment designed to operate in high-pressure, low-light, and highly variable deep-sea environments.

While DSM remains in its infancy as a commercial industry, significant interest and exploration activities are ongoing.

As of March 2025, the International Seabed Authority (ISA), which regulates mining activities in international waters, has granted thirty-one 15-year contracts for exploration to 22 contractors.

Most of these exploration efforts are focused on the Clarion-Clipperton Zone (CCZ) in the Pacific Ocean, an area of several million km2 between Hawaii and Mexico, which turns out to be rich in polymetallic nodules.

Despite this interest, no large-scale commercial mining has commenced, as the sector faces regulatory, environmental, and technological challenges.

Proponents of DSM argue that it could offer a critical solution to meeting the growing global demand for minerals essential to green energy technologies.

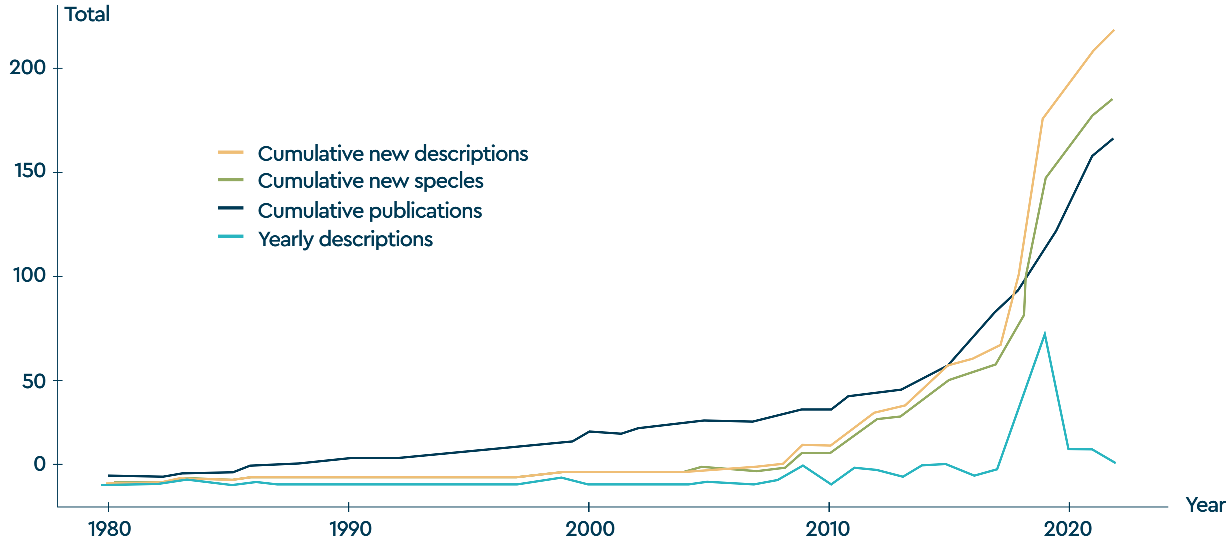
Compared to terrestrial mining, which often leads to deforestation, soil degradation, and displacement of communities, DSM is seen as having the potential to reduce some environmental and social impacts on land.

Additionally, accessing the vast, untapped resources of the seabed could diversify mineral supply chains and reduce dependence on a few major terrestrial sources, which are often concentrated in politically or economically unstable regions.

Opponents of DSM emphasize its significant environmental risks, as mining the ocean floor can cause severe, potentially irreversible harm to fragile marine ecosystems. The Clarion–Clipperton zone (CCZ) for instance, is home to more than 20 species of dolphins and whales, which are severely affected by the noise from the mining machines that run 24 hours a day.

This is only the tip of the iceberg, since many of the species in that habitat, especially those who dwell near the bottom, remain unknown. Since the CCZ has been identified as of economic interest, a systematic inventory of the fauna on the seabed has begun and is still underway.

It turns out that 90% of the species identified since 2000 are new to science. The following figure, figure 18, shows the stream of discoveries by year and the types of species identified.



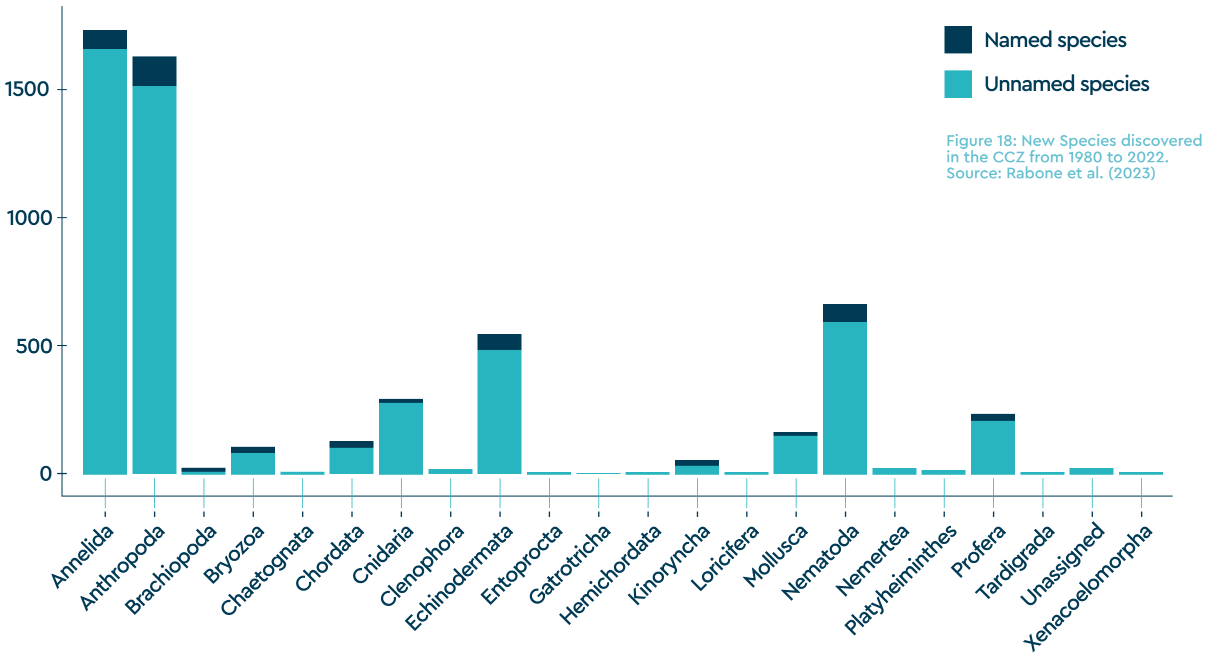


Figure 18: New Species discovered in the CCZ from 1980 to 2022. Source: Rabone et al. (2023)

The removal of seabed resources can destroy habitats for unique deep-sea species, some of which may be endemic to specific regions and poorly understood by science. Mining activities may also generate sediment plumes, causing turbidity that can smother marine life and disrupt ecological functions over vast distances. The impacts on deep-sea carbon sequestration processes, biodiversity, and food webs are not fully understood, raising concerns about unintended consequences that will not be considered by mining companies, potentially generating massive externalities.

The Ocean seabed is a new frontier, so vast as to defy imagination, which technology has opened to human activity. DSM is just one instance of this, and we will see more. Given the difficulty of operating heavy machinery at 4 to 6 km depths, and raising the minerals to the surface, DSM is restricted to very few powerful companies operating in major countries, while the rest of the world bears the externalities.

Coastal and small island communities will face losses in fisheries and traditional ocean uses if ecosystems are degraded. Land mining nations such as South African and Chile may suffer the consequences of increased supply from the seabed. Balancing short-term private profits with long-term social and environmental externalities is a global governance issue which is hotly debated, and a growing collection of governments, companies and other actors have called for a moratorium until robust scientific knowledge and governance mechanisms are in place to ensure responsible, sustainable management of seabed resources.

Taking from the Ocean:

Genes

Extreme temperatures, pressure, and the chemical composition of waters surrounding deep-sea hydrothermal vents result in unique biochemical conditions, well suited for a host of industrial uses that require thermo- and barostable (pressure) compounds or enzymes.

These compounds can be used in diverse areas, from the food industry to biofuel and biopharmaceutical production.

There is a lot to exploit: an estimated total of more than 2.2 million marine species.

The open ocean, the depths, and the twilight zone are all critically important areas to discover the ocean's potential while maintaining its capacity to provide a diverse array of benefits to the food system and humanity at large.

The following picture, figure 19, illustrates the growing interest in patenting maritime genetic resources.

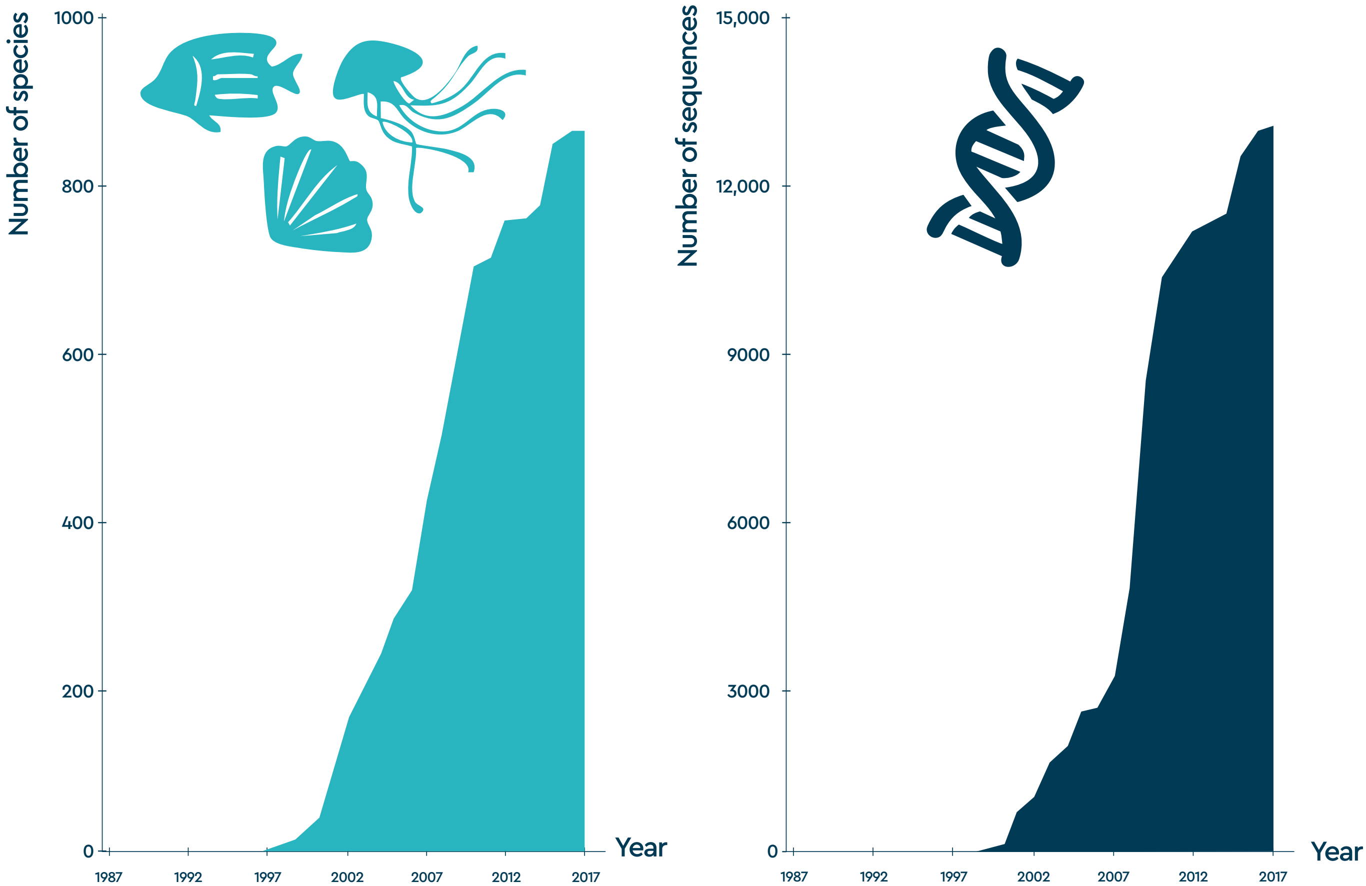


Figure 19 : Patenting marine genetic resources. These graphs show the cumulative number over time (1988–2017) of (a) marine species with patent sequences and (b) patent sequences from marine species. Source : Blasiak et al. (2018)

Although it is challenging to identify gene patents from organisms located solely in areas beyond national jurisdiction, examination of all marine gene patent claims reveals that ten countries account for the vast majority (>90%) of claims, with three countries (USA, Germany, Japan) submitting 70% of them. Subsequent research indicates that nearly half of all patents on marine gene sequences (from a total of around 13,000 marine genetic sequences targeted by patents) were registered by just one corporation, namely BASF : it registered 47% of all marine sequences included in gene patents, exceeding the combined share of 220 other private companies (37%). Universities and their commercialization partners registered 12%.

Only nations with well-developed research infrastructure will fully realize potential gains from marine genetic resources in areas beyond national jurisdiction, as they possess the technical capabilities to access these potentially deep and distant resources. Developing countries consider the existing regime of an unregulated high seas as highly unequal. They have advocated for equitable access and benefit-sharing of marine genetic resources, referring to the common heritage concept already applicable to mining in areas beyond national jurisdiction.

Until an agreement is in place, biotechnology corporations, state or privately owned, will continue to operate in this unclear governance context – profiting in some cases from the lack of benefit-sharing obligations, but perhaps also limiting their investments and research efforts due to regulatory uncertainty. Neither instance is aligned with aspirations of a sustainable and equitable ocean economy.

Towards a blue economy

As figure 20 shows, the last fifty years are characterized by a "blue acceleration", namely the overall expansion of ocean activities. It is ongoing, and the ocean economy is projected to grow faster than the global economy in the coming decades, reaching **$3 trillion by 2030.**

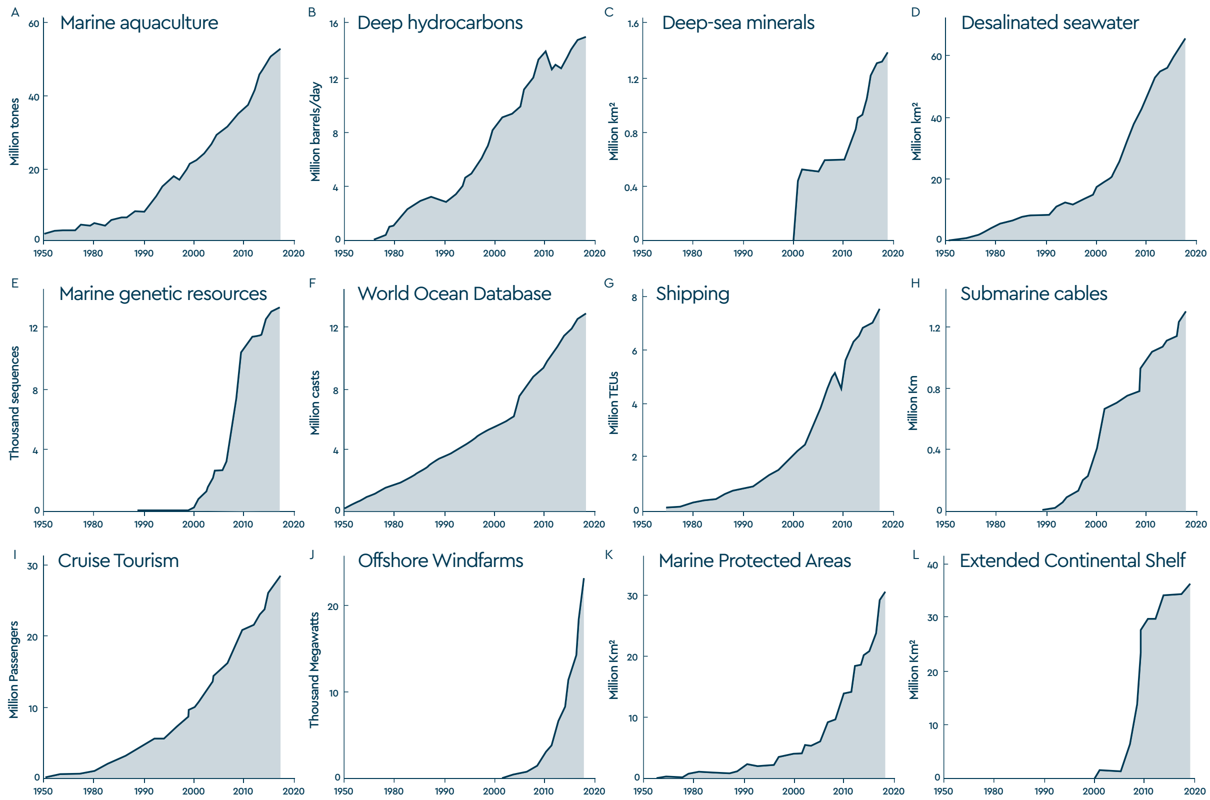


Figure 20: The blue acceleration. Source: Jouffray et al. (2020)

A remarkable feature of the blue acceleration is that it is controlled by a small number of large transnational corporations (TNC).

As of 2018, as the following picture, figure 21 shows, the 10 largest TNCs in each of the eight core ocean economy industries generated, on average, 45% of the respective total industry revenues.

Aggregating across all eight industries, the 100 largest corporations account for 60% of total revenues.

This level of concentration in the ocean economy presents both risks and opportunities.

Opportunities because the full power of science and industry can be harnessed to live with the Ocean in a beneficial and sustainable way.

Risks because these opportunities are not shared by the vast majority of humans, whose societies do not have the technical ability and the industrial power to reach this new frontier, even though the Ocean is the common inheritance of mankind.

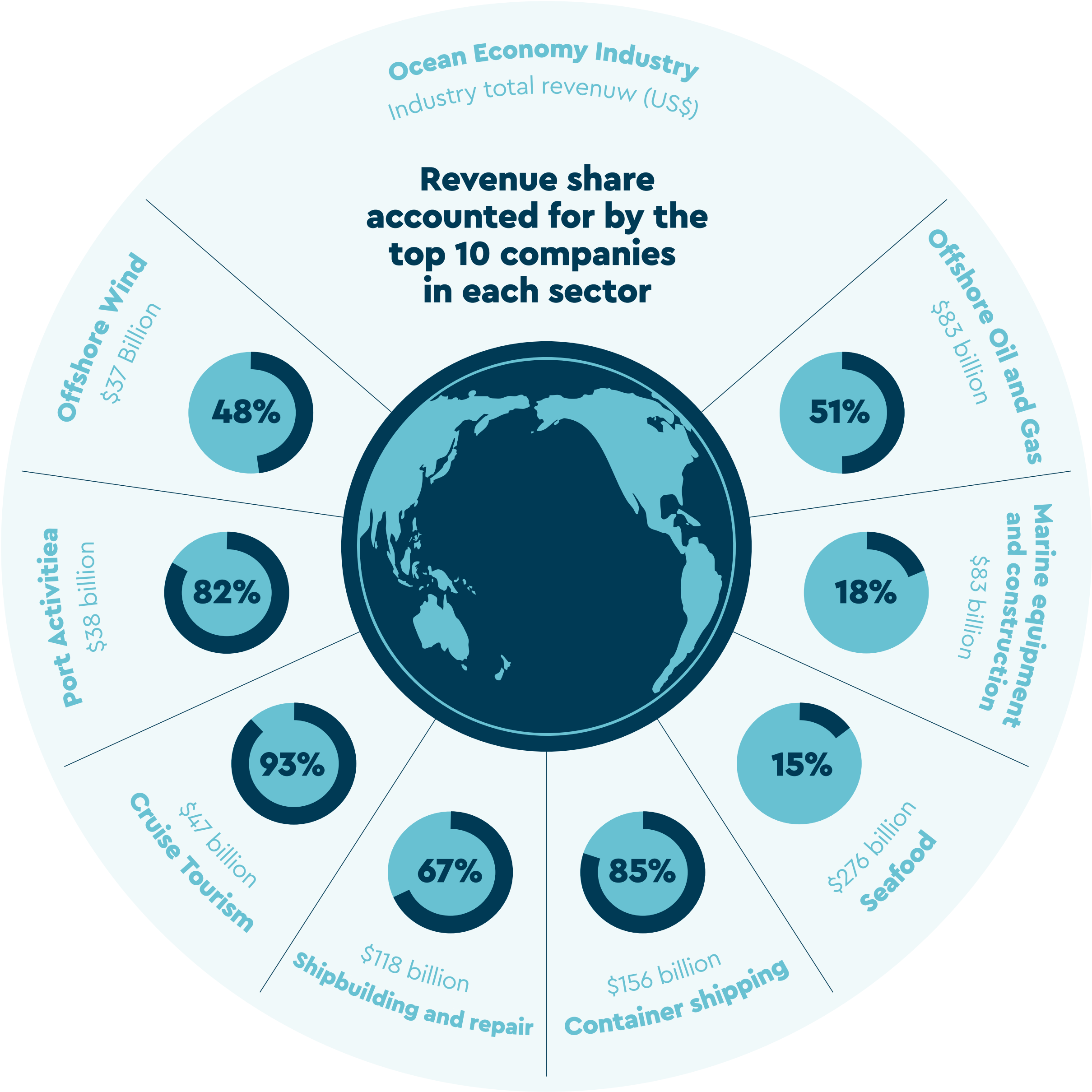


Figure 21: Concentration in the blue economy. Source: Virdin et al. 2021

Economic activity is transforming the Ocean, as it did in North America during the nineteenth century, but the conditions are very different.

The marine ecosystem has nothing in common with the vast and flat agricultural plains of the American Midwest.

The Ocean is a complex system, everything is connected to everything else, and the effects of human activity are difficult to predict and contain. In economic terms, externalities are much more important in the Ocean than on land.

An economic externality occurs when an industrial activity, resulting in the production of a certain good or service, has side effects which are costly to someone else, but are not reflected in the price of the good or service.

Economic activities in the Ocean usually negatively impact each other, if they are not downright incompatible.

Figure 22 highlights the conflicts between marine economic sectors, and the major externalities between them.

The blue economy

Figure 22: Conflicts between blue economy sectors. Source: Sumaila and Villasante (2025)

However, the Ocean should not be considered purely as an economic proposition. It sustains the livelihood of billions of people;it is deeply ingrained in our social structures and representations; and, at a deeper level, its health has profound implications for life on Earth.

The effect of economic activities on life, not only of individuals, but also of societies and ecosystems, should be taken into account. In other words, externalities spill over from economics to fairness and ethics, and even to a sheer desire for survival. Figure 23 attempts to list some of these concerns for the eight main Ocean industries.

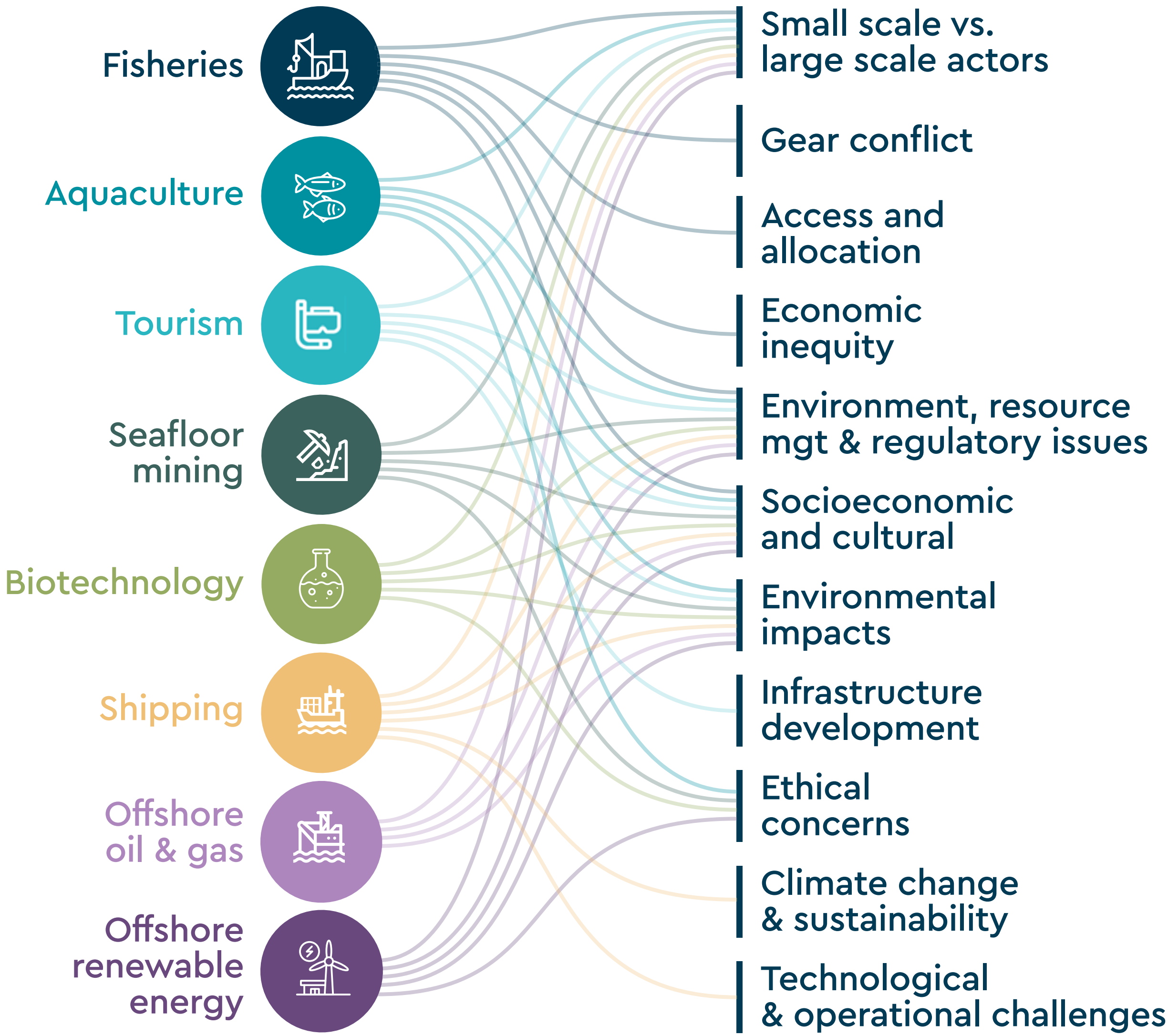


Figure 23: The checklist in the blue economy
Source: Sumaila and Villasante (2025)

The blue acceleration comes with a challenge. Can we find a legal and regulatory framework whereby the Ocean, the common inheritance of mankind, can be opened to human endeavour in such a way that (a) the future is not compromised, i.e. the Ocean does not drift into a different, less favourable state, and future generations can still benefit from its bounty, and (b) the future promises of the blue economy, and its present costs, when realized, are shared fairly?

As opposed to a situation where the benefits would go to the few who have the industrial power to exploit the Ocean and the costs would go to the many who depend on the sea on more traditional ways, and who would see their way of life, and sometimes even their habitat, wiped out by externalities from developing industries, or simply becoming obsolete.

As we saw, the Ocean is divided into two regions: the Exclusive Economic Zones (EEZ), which extend 200 nautical miles from the coastline, beyond which begins the High Seas. On the EEZs, states exert full sovereignty. The High Seas, on the other end, are defined by the UN Convention on the Law of the Sea (UNCLOS) to be the common heritage of humankind. Specifically, article 136 states that:

> **"at the present time, the area of the seabed and ocean floor and the subsoil thereof, beyond the limits of national jurisdiction, as well as its resources, are the common heritage of mankind, the exploration and exploitation of which shall be carried out for the benefit of mankind as a whole, irrespective of the geographical location of States"**

In 2023, after twenty years of negotiations, UNCLOS was complemented with an agreement under on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (colloquially, the "High Seas Treaty").

While the High Seas Treaty is poised to fill multiple governance gaps, to date it has only been ratified by 21 countries (April 2025) and will only enter into force one year after the 60th ratification is achieved.

The High Seas now cover about 64% of the Ocean. Article 76 of UNCOS allows coastal states to claim an EEZ beyond 200 nautical miles if their continental shelf extends that far. Under current claims, this will eventually leave only 48% of the seabed as humanity's common inheritance. So, the area considered the common inheritance of mankind is shrinking.

On the other hand, the legal structure of this common inheritance is consolidating. Torn between economic and geopolitical considerations, and ethical and survival imperatives, humanity is slowly groping its way forward.

Bibliography

Jean-Baptiste Jouffray, Robert Blasiak, Albert V. Norström, Henrik Österblom, and Magnus Nyström, "The Blue Acceleration: The Trajectory of Human Expansion into the Ocean", One Earth 2, January 24, 2020, https://doi.org/10.1016/j.oneear.2019.12.016

Robert Blasiak and Joachim Claudet, "Governance of the High Seas", Annu. Rev. Environ. Resour. 2024. 49:549–72, https://doi.org/10.1146/annurev-environ-011023–022521

Robert Blasiak, Jean-Baptiste Jouffray, Colette C. C. Wabnitz, Emma Sundström, Henrik Österblom, "Corporate control and global governance of marine genetic resources", ci. Adv. 4, eaar5237 (2018).

U. R. Sumaila, L. Alam, K. Pradhoshini, Temitope T. Onifade, Selma T. Karuaihe, P. Singh, Lisa A. Levin and R. Flint, "To engage in deep-sea mining or not to engage: what do full net cost analyses tell us?", npj Ocean Sustainability (2023) 2:19 – https://doi.org/10.1038/s44183–023–00030-w

U. Rashid Sumaila, Andrea Pierruci, Muhammed A. Oyinlola, Rita Cannas, Rainer Froese, Sarah Glaser, Jennifer Jacquet, Brooks A. Kaiser, Ibrahim Issifu, Fiorenza Micheli, Rosamond Naylor and Daniel Pauly, "Aquaculture over-optimism?" Front. Mar. Sci. 9:984354. doi: 10.3389/fmars.2022.984354

U. Rashid Sumaila and Sebastian Villasante S (2025). Surging blue economy, increasing conflict risks and mitigation strategies. Front. Mar. Sci. 12:1499386.
doi: 10.3389/fmars.2025.1499386.

J. Virdin, T. Vegh, J.-B. Jouffray, R. Blasiak, S. Mason, H. Österblom, D. Vermeer, H.Wachtmeister, N. Werner, « The Ocean 100: Transnational corporations in the ocean economy » Sci. Adv. 7, eabc8041 (2021).


We should work with the Ocean, not wage war against it!

AN INTRODUCTION TO THE OCEAN

guillaume@2050.do | minh@wavesofchange.earth