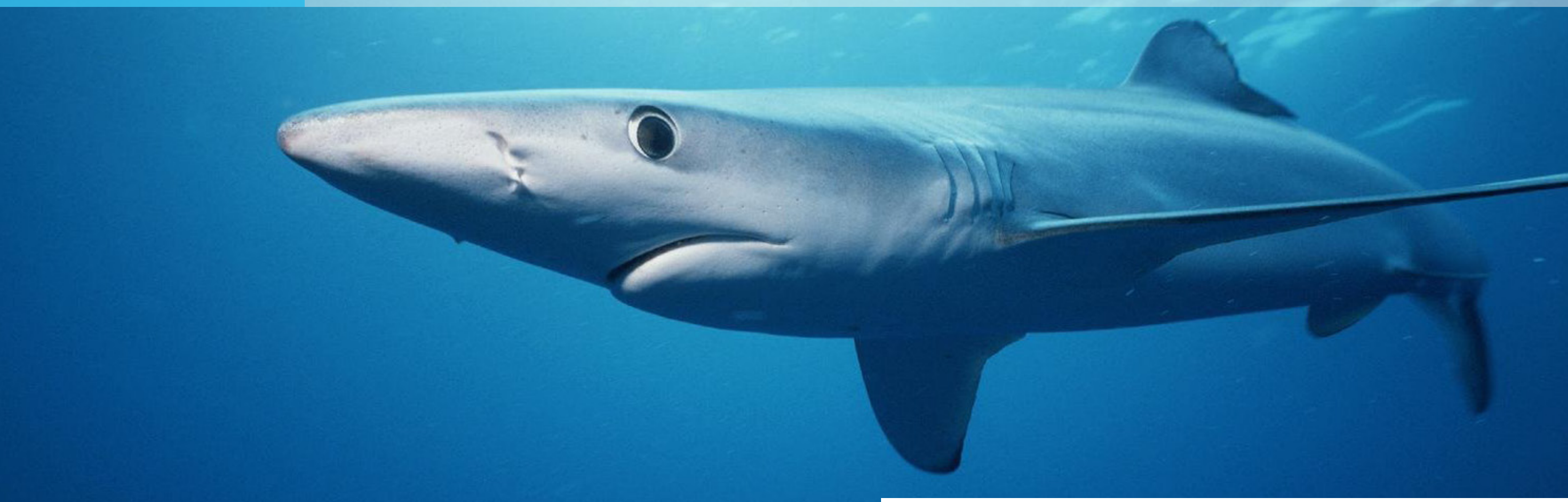
FACT SHEET



# THE CONSEQUENCES OF CLIMATE CHANGE FOR LIFE IN THE Oceans

## Oceans: The rapid pace of change

Oceans have always been ecosystems in a process of change. Again and again lava-spouting volcanoes and plummeting meteorites have fundamentally altered both the climate on the Earth and thus marine habitats as well. Marine dwellers have therefore had to repeatedly adjust to new living conditions – or they became extinct.

Today unicellular organisms, plants and animals again face great challenges. This time, however, they have less time to adapt since the current climate change is progressing rapidly – faster than all changes in the past 65 million years. The Arctic pack ice cover alone has shrunk by half in summer in the past 30 years. At the same time the area of the "dead zones" in coastal waters has grown tenfold. This is what marine areas are called where there is so little oxygen that fish and other animals there cannot survive any more.

These rapid changes are anthropogenically induced, primarily as a result of the constantly rising emission of the greenhouse gas carbon dioxide. This gas causes the temperature in the atmosphere and ocean to rise. Moreover, it dissolves in seawater, turns into carbonic acid there and leads to acidification of the seas. Fertilisers and wastewater carried from fields and cities to the sea are also harmful to the plant and animal world in the ocean. They cause algae to grow, thus resulting in a shortage of oxygen in coastal areas in the long run.

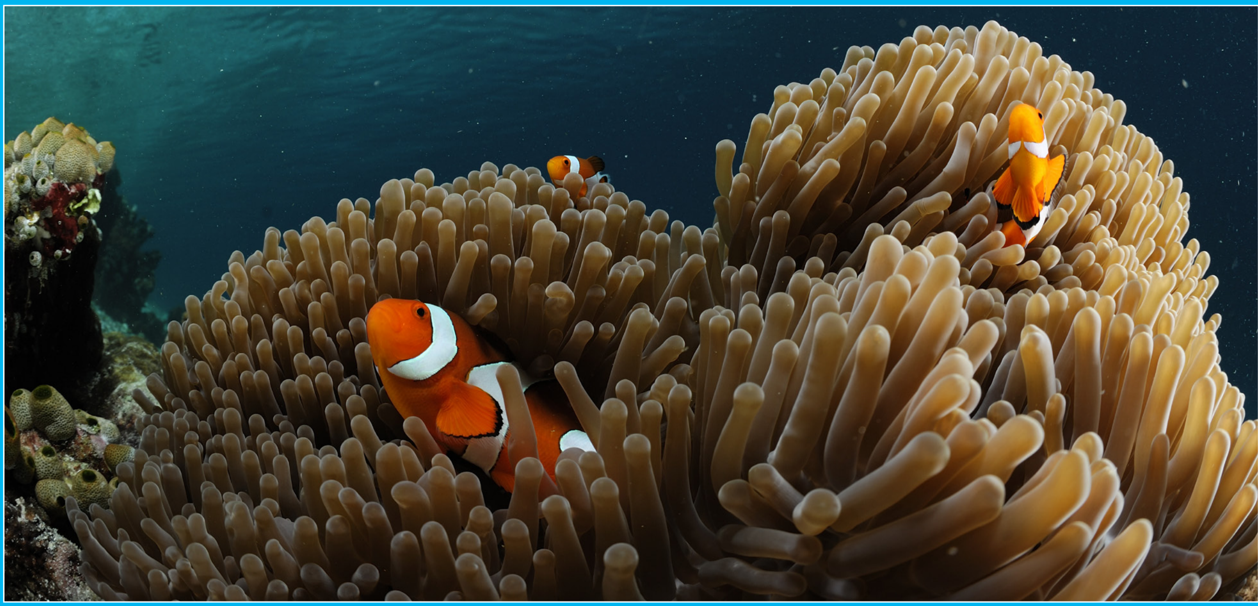
All over the world 200 million people live, like these fishermen, from local fishing. Their existence is at stake when life in the ocean changes. (Photo: Javier Corbo/Flickr, CC BY-NC-ND 2.0)

This fact sheet provides an overview of how climate change impacts life in the ocean, how the changes reinforce one another and what changes we humans have to prepare for.

"Blue Marble" is what this true-colour picture of our planet is called, put together by US specialists from a wide variety of satellite data. It illustrates how much of the Earth's surface is taken up by the oceans. (Photo: NASA Goddard Space Flight Center)

## The blue planet

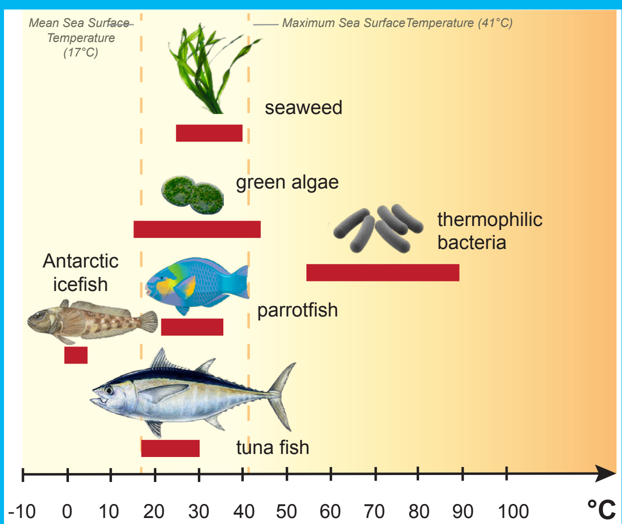
„The "blue marble" – this is what the astronauts of the Apollo 17 mission once called their photograph of the Earth. A picture that went around the world and with it the awareness that we live on a blue planet. The oceans cover nearly three fourths of the Earth's surface. That makes them the biggest habitat in the world and home to over half of all unicellular organisms, animal and plant species of the planet – from microscopically tiny algae to the largest animal on the Earth, the blue whale. The life of all marine dwellers is closely linked to the water bodies they inhabit: it depends on the water temperature, the amount of incoming light from solar radiation, the available nutrients and prey organisms and also on how much salt, oxygen and carbon dioxide the seawater contains. These factors form the basis of their life. They determine in which water bodies a species can live or where it migrates to reproduce. And these are also the factors that alter fundamentally in the course of climate change – and along with them life in the ocean.



As dwellers of tropical coral reefs, clownfish react very sensitively to a temperature increase. For example, if the water is too warm, the fish no longer mate – and if they do, their offspring die in the egg. (Photo: Solvin Zankl)

## Living at the limit

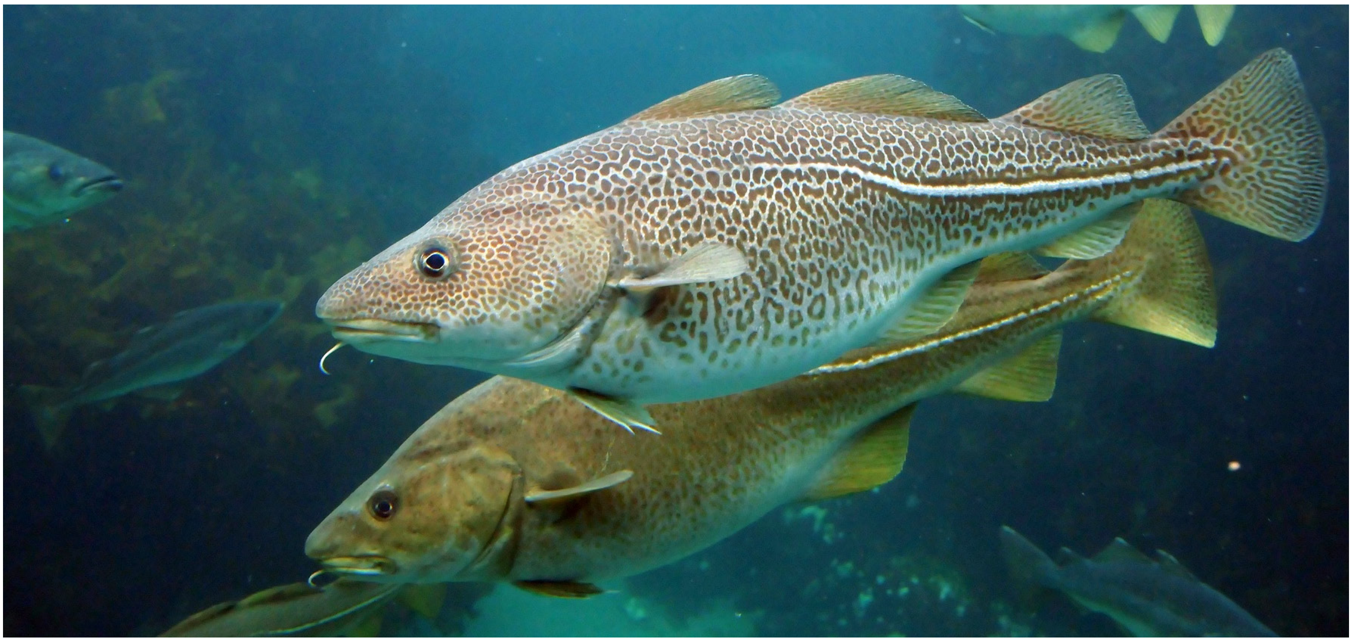
For generations ocean dwellers have adapted to the conditions in their home waters: to the prevailing temperature, the oxygen concentration and the degree of water acidity. They grow best and live longest under these living conditions. However, not all creatures that live together in an ecosystem have the same preferences. The Antarctic eelpout, for instance, lives at its lower temperature limit and has to remain in warmer water layers of the Southern Ocean.




The temperature windows of some ocean dwellers as a comparison: the figures for green algae, seaweed and thermophilic bacteria were determined in the laboratory. The fish data stem from investigations in the ocean. (Graphics: AWI)

If it enters cold water, the temperature quickly becomes too cold for it. The Atlantic cod in the North Sea, by contrast, would enjoy colder water as large specimens do not feel comfortable in temperatures over ten degrees Celsius. At such threshold values scientists refer to a temperature window: every poikilothermic ocean dweller has an upper and lower temperature limit at which it can live and grow. These "windows" vary in scope. Species in temperate zones like the North Sea generally have a broader temperature window. This is due to the extensively pronounced seasons in these regions. That means the animals have to withstand both warm summers and cold winters.

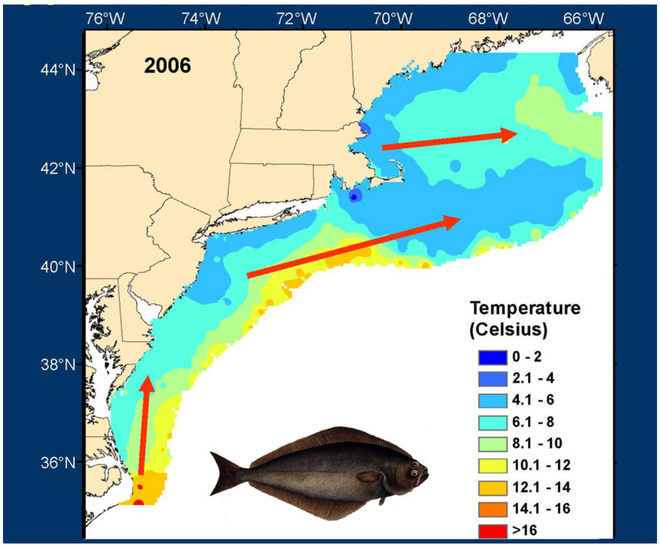
The temperature window of living creatures in the tropics or polar regions, in comparison, is two to four times smaller than that of North Sea dwellers. On the other hand, they have adjusted to extreme living conditions. Antarctic icefish species, for example, can live in water as cold as minus 1.8 degrees Celsius. Their blood contains antifreeze proteins. In addition, they can do without haemoglobin because their metabolism is low and a surplus of oxygen is available. For this reason their blood is thinner and the fish need less energy to pump it through the body – a perfect survival strategy. But: icefish live at the limit. If the temperature rises by a few degrees Celsius, the animals quickly reach their limits.



Meanwhile in the North Sea it is getting too warm for the Atlantic cod. Like many other North Sea fish, this popular food fish is migrating towards the Arctic and shifting its habitat further to the north every warm year. (Photo: Joachim S. Müller/Flickr, CC BY-NC-SA 2.0)

## Global warming: On the way to the pole position

For a long time the North Sea offered Atlantic cod *Gadus morhua* an optimal habitat. At low water temperatures it felt on top of the world, found enough to feed and its offspring also developed marvellously. That was once upon a time. Since the 1960s the water in the North Sea has become 1.7 degrees Celsius warmer. Hot summers with water temperatures around 20 degrees Celsius are not unusual nowadays so it is getting too warm for cod. Only some of its fish larvae develop into sexually mature males and females. In addition, the favourite food of its juvenile fish, the copepod Calanus finmarchicus, is disappearing. As a result of the increasing water temperature, the prey has to make room for the smaller member of the same species Calanus helgolandicus. The food supply for young cod is consequently becoming scarcer and has left the species with no choice for some time now.




Off the US East Coast 17 of the 36 most important food fish species have migrated either to the north or to deeper waters in the past four decades (see arrows) – including the Atlantic halibut. (Map: Janet Nye/ NOAA; drawing: in the public domain)

The fish began turning their back on their old home and swimming northward more than 30 years ago. Since then the habitat of the cod has extended by seven kilometres towards the Arctic every warm year. A fate that the North Sea dweller shares with many other fish species: scientists assume that nearly two thirds of all marine fish species migrate to cooler waters.

While species in the northern hemisphere move to the north, fish from the southern hemisphere flee further south. The striped marlin, for instance, actually has its home in tropical and subtropical waters. Now it has also been sighted off the coast of Tasmania. Other species, such as the poor cod *Trisopterus minutus* in the North Sea, do not seek their new habitat in higher latitudes, but in deeper and thus colder water layers.

By virtue of this species migration, ecosystems are mixing and changing. Researchers forecast that the tropics will lose species in this way while the oceans in higher latitudes will increase in species diversity.

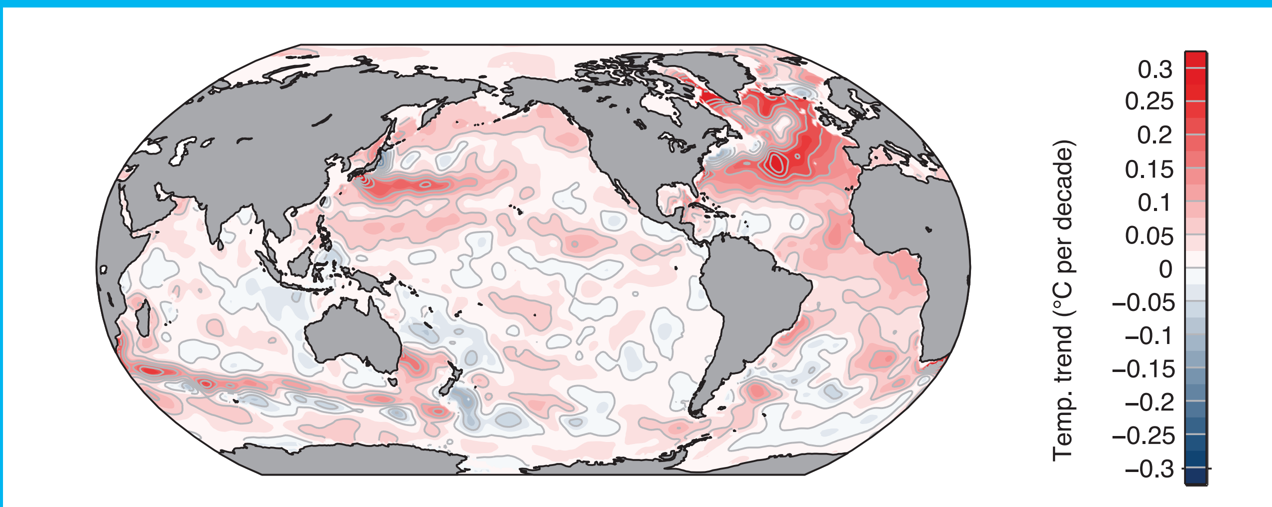
On their way towards the pole the invasive species from warmer waters meet native species. The habitats of both groups are starting to overlap – possibly with far-reaching consequences. After all, the native species play a major role in the local food webs as a rule. As, for example, the polar cod in the Arctic: it is at the very top of the menu of seals. However, the Atlantic cod is already vying with it. AWI scientists have repeatedly observed on expeditions to Spitsbergen that the Atlantic cod now dominates the waters of the island group to a great extent. The researchers found the native polar cod only in the coldest and deepest water layers. They still do not know what impacts these changes have on the food web in the Arctic.

The increasingly warm Pacific water disrupts the mating schedule of salmon. Pink salmon, relatives of these sockeye salmon, now arrive at their spawning grounds two weeks earlier than 40 years ago. As a consequence, bears that prey on the fish in rivers miss part of the migration and thus cannot fatten up as much for the winter. (Photo: Roger Tabor, USFWS, CC BY 2.0)

### The oceans are getting warmer

The oceans are constantly getting warmer. Since the 1970s the global mean surface temperature of the oceans has risen on average by 0.1 degree Celsius. This figure may sound trivial, but when entered into relevant calculations, it means the oceans have absorbed so much thermal energy in the last 30 years alone that this amount would suffice to cause an atom bomb to explode every second or even more frequently for 30 years.

And the warming of the oceans continues. Whereas researchers have observed a temperature rise primarily in the upper water layers (down to a depth of 700 metres) up to now, according to the first part of the 5th World Climate Report they assume that the deeper water layers will also undergo a rise in temperature in this century – a development that has already started.




This temperature map from the 5th World Climate Report shows how much warmer in degrees Celsius the oceans have become at a depth of 0 to 700 metres in the period from 1971 to 2010. Accordingly the highest increases (red areas) took place in the North Atlantic, in the Pacific Ocean off the southern coast of Japan as well as in the Indian Ocean off the southeast coast of Africa. (Map: Rhein, M., et al 2013: Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I, 5th IPCC Report)

It doesn't get any more colourful: an example of the diversity of life in intact tropical coral reefs. This picture is of a reef off the Philippine coast. It shows a shoal of anthias making their way across various corals. (Photo: Klaus Stiefel / Flickr, CC BY-NC 2.0)

## Ocean acidification: When engineers run out of building material

Tropical coral reefs cover less than 0.1 percent of the seafloor. However, these 600,000 square kilometres have a considerable significance. Scientists estimate that over a million animal species have their home in the reefs, including a third of all known marine fish species – beginning with the colourful clownfish and reef sharks all the way to major food fish like cichlids. The tropical reefs thus undoubtedly number among the most species-rich ecosystems in the world.

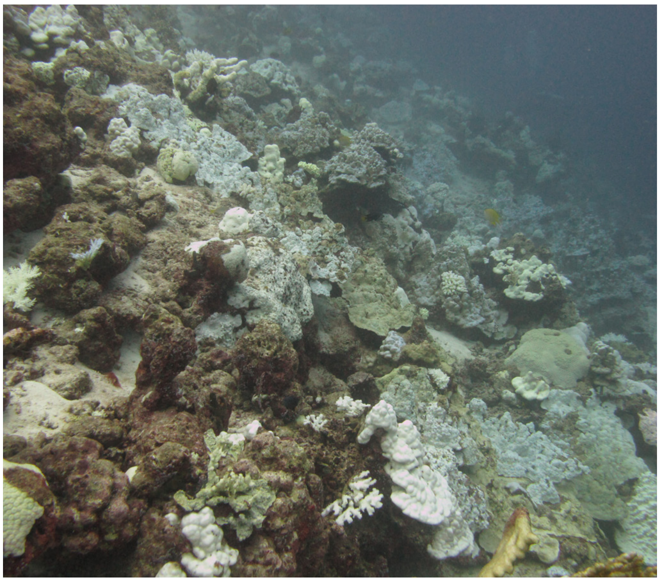
Green sea turtles number among the typical dwellers of tropical coral reefs, like those in the Palmyra Atoll, a group of islands between Hawaii and Samoa. As juvenile animals, they look for seaweed, sponges, starfish and snails here. As adult animals, they then feed solely on plants. (Photo: Kydd Pollock, USFWS, CC BY 2.0)

But it is a habitat in danger. Scientists presume that coral reefs will be one of the first ecosystems to be fundamentally impacted by climate change. Around half of all reefs are currently threatened. A look back at the year 1998 shows what they are threatened by. It was one of the warmest years in the past century, influenced by a pronounced El Niño event. Back then 50 to 90 percent of all corals died in the western and central Indian Ocean alone.

This widespread coral death was a herald of what awaits us in the future since tropical corals react very sensitively even to small temperature rises. One example of this: the most comfortable temperature for them is between 23 and 29 degrees Celsius. If the thermometer rises to 30 degrees Celsius only for four weeks, however, the otherwise so colourful corals suffer from heat stress and turn into a calcareous skeleton as white as chalk – they bleach. That means they expel their small co-dwellers, the so-called zooxanthellae. These tiny algae live in coral tissue and supply their host with up to 90 percent of the food it needs. Without this symbiosis the corals would quickly look pale since their white skeleton shines through the abandoned colourless tissue.

If the heat stress lasts only a short time, the corals can take in their zooxanthellae again and recover from the bleaching. If it lasts a longer time, the algae do not return and the animals starve. Scientists predict that such bleaching events could become the rule as of the second half of this century. They will then be a threat nearly every summer.

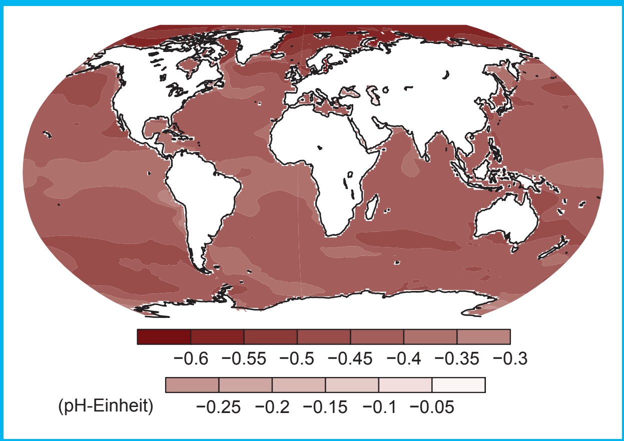
Climate change poses another risk for tropical coral reefs, however: ocean acidification. When the greenhouse gas carbon dioxide dissolves in seawater, it is absorbed by the creatures living there and disrupts the formation of carbonate in their organism – the building material with which corals, mussels and other ocean dwellers form their skeletons and shells. This means as ocean acidification increases, the engineers of the sea stop growing. In greatly acidified water the calcareous skeletons of the corals even disintegrate – and with them the foundation of an ecosystem in which not only hundreds of thousands of species have found a niche, but which feeds a large number of people, especially in the tropics: fishermen and their families as well as diving instructors, hotel employees, restaurant operators, etc. ...



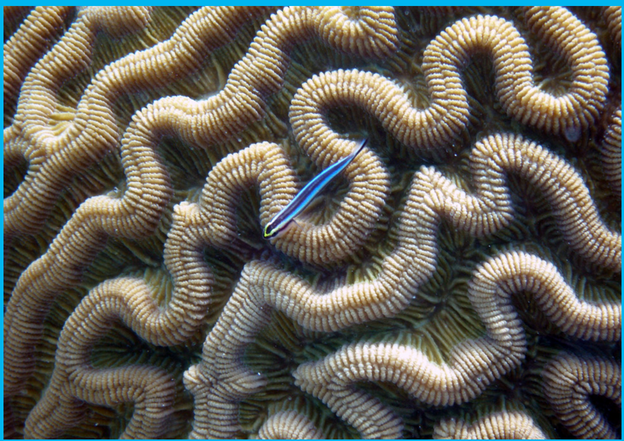
AWI researchers took this photo in Thailand's Andaman Sea in spring 2010. It shows a coral reef that is almost completely bleached and has died to a great extent. (Photo: Gertraud Schmidt/AWI)

### The oceans acidify

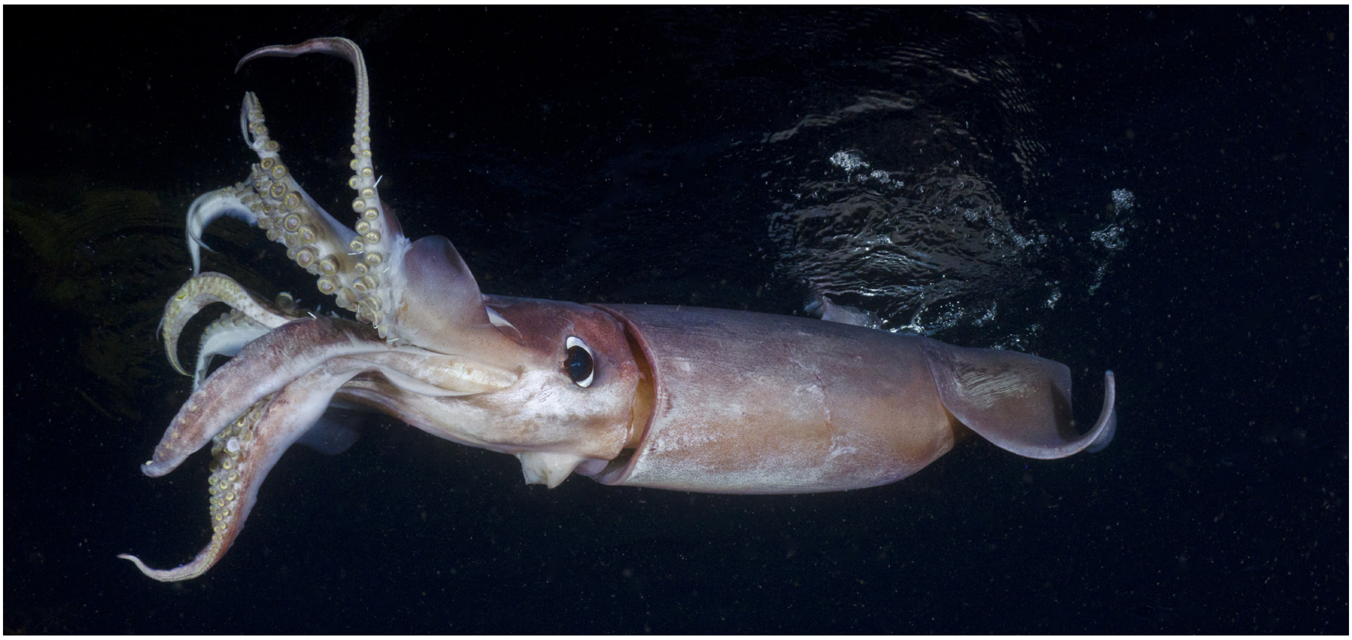
The oceans absorb more than a quarter of the carbon dioxide produced by humankind every year. Without this natural sink the greenhouse gas concentration in the atmosphere would be very much higher today. This buffer capacity has its price, however: when carbon dioxide dissolves in the ocean, the gas reacts with seawater to form carbonic acid and thus lowers the pH value of the water. Seawater is typically slightly basic with an average pH value of around 8.2. But in the past 200 years this figure has dropped to about 8.1. That sounds like very little, but it corresponds to a 30 percent rise in the degree of acidity. Researchers assume that the pH value will fall by another 0.3 to 0.5 units by the year 2100 and thus acidify the seawater several times over. The increase in carbon dioxide already has an impact today, particularly on organisms that form calcareous shells and skeletons. This is because carbonic acid reacts with the building materials they need to grow and maintain their shells. If the pH value drops below 7.5, the calcareous shells even begin to decompose.




This map shows the change in pH value in surface water up to 2100, calculated with the help of computer models. (Map: IPCC, 2013: Summary for Policymakers)



A Sharknose goby swims over a brain coral in whose convolutions the green zooxanthellae are visible which are feeding the corals. (Photo: NOAA CCMA Biogeography Team, CC BY 2.0)



The Humboldt squid is one of the few marine dwellers that appears to benefit from the climate-related changes in the ocean. In the past 20 years it has extended its territory from the western coast of Central America to Alaska. (Photo: Andy Murch)

## Oxygen shortage: Hunting for prey in the "oxygen minimum zones" of the Pacific

The Humboldt squid can be best described in numbers: ten arms, more than two metres long, up to 50 kilograms in weight and a habitat that has extended over 4,500 kilometres to the north in the past 20 years. This is the distance that lies between its original home in the tropical warm waters off the western coast of Central America and Alaska, off the coast of which the squid was sighted for the first time in 2005. It owes this incredible triumphal march to its most important secret of success: virtually no other animal profits as much from the spreading oxygen shortage in the middle water layers of the Pacific Ocean as this squid.

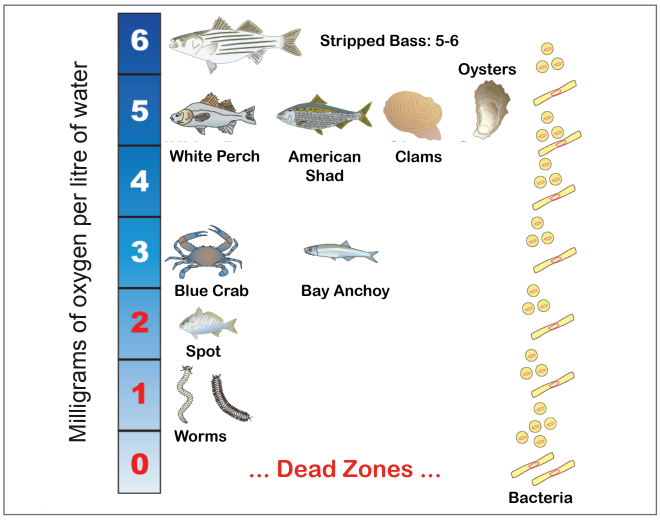
"Red tide" is what Americans call algal bloom in summer, like this one off the coast of Oregon. It is caused by wastewater and fertilisers and leads directly to oxygen depletion in the water beneath it. (Photo: Alex Derr/Flickr, CC BY-NC-SA 2.0)

Scientists refer to regions in the ocean in which the oxygen concentration of the cold deep water drops to a threshold value of 60 micromoles per litre of water as "oxygen-deficient" or as "oxygen minimum zones". In comparison, most sharks, rays and other fish require a significantly higher oxygen concentration, especially in warmer waters.

Researchers have found out that the Humboldt squid can spend an entire day in the oxygen minimum zone without suffering any harm. Humboldt squids frequently take advantage of this option for two reasons. Firstly, few enemies, such as sperm whales and Risso's dolphins, follow them into oxygen-deficient depths. Secondly, all fish and crustacean species capable of living in these oxygen-deficient zones move so slowly that they are easy prey for these omnivores.

Nevertheless, even the Humboldt squid avoids marine regions with an extreme oxygen shortage, such as those that primarily occur in coastal areas. These so-called dead zones arise where rivers carry large volumes of wastewater and nutrients into the sea. They lead to extensive blooms of unicellular algae whose remains subsequently sink to the depths and are decomposed there by oxygen-consuming bacteria. As a result, the oxygen concentration of this water declines so rapidly that only organisms requiring no or only very little oxygen exist there.

The number of these dead zones in coastal regions will continue to increase in future and endanger, in particular, animal life there. In addition, the more climate change progresses, the more oxygen-deficient zones will exist in the open seas and the more often there will be literally a lack of "air to breathe" there for fish, crabs, snails and all other marine dwellers dependent on oxygen.




Ocean dwellers have different demands in terms of the oxygen concentration of the water. The lower it drops, the fewer species survive. (Graphics from www.teachoceanscience.net)

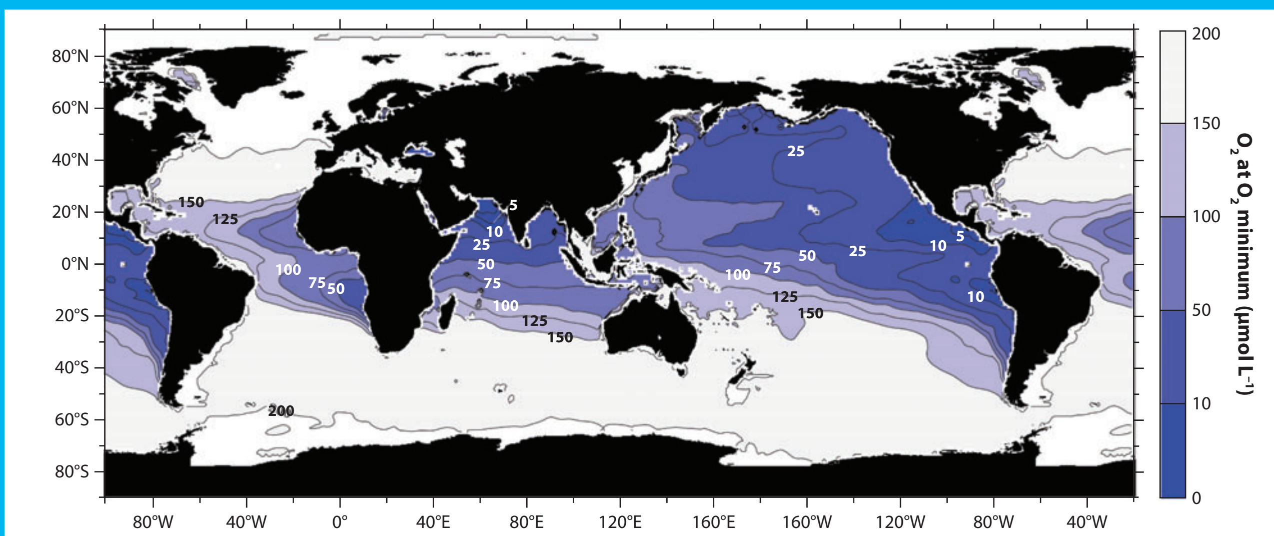
**The oceans are running out of air**

The oceans have lost between one and seven percent of their oxygen concentration in the past 50 years. The reasons for this are:

(1) The rising water temperature – warm water contains less oxygen than cold water

(2) The increasing stratification of the water due to warming. As a result, the water masses mix less and consequently less oxygen-rich surface water reaches the midwater layers below.

In coastal waters intensive land use by people causes a rising input of fertilisers and wastewater in the seas. These nutrients bring about large-scale growth of algae in coastal waters. The remains of the latter are decomposed by oxygen-consuming bacteria. As a consequence, the oxygen concentration of the water declines; most creatures leave the area or die. Today researchers know of more than 400 coastal regions in which the water layers contain so little oxygen that they are designated as "dead zones". Virtually no animals live there anymore.




This map shows how little oxygen the most oxygen-deficient water layer in the respective marine region contains. Wherever the figure is less than 60 micromoles per litre, fish are virtually unable to live any longer. (Map: Keeling et al, Annu. Rev. Sci. 2010 2:199-229)

Particularly people in the developing and newly industrialised countries will be the victims of climate-induced changes in the oceans. In future there will be fewer, more irregular and significantly smaller fish in their fishing grounds. (Photo: WWF-US/James Morgan)

## Future fishing prospects: top in the north, flop in the tropics

The statistics do not hold good news for fishermen in Indonesia. If the calculations of the climate and ecosystem models are accurate, fishermen there will catch 40 percent fewer fish as of 2050 than today. These losses will be a direct economic consequence of climate change because one thing is certain: if seawater continues to get warmer, the once so species-rich tropical waters will become deserted. Some of the fish will attempt to escape the heat by swimming towards the pole. Others will move to greater depths if possible. In any case, however, a large-scale shift in species composition is in the offing in the course of climate change.

Fishermen in northern and thus cooler regions, such as Nova Scotia in Canada, will presumably profit from the climate-induced shift in species composition to the north. In all likelihood they will have more fish in their nets in the future. (Photo: Sina Löschke, AWI)

Fishermen in Nordic countries like Greenland, Iceland and Norway already profit from it today. They now net southern species like cod much more frequently than 20 years ago. And in all likelihood their catches will improve even more soon. According to model calculations, they will land up to 70 percent more fish in 2055 than in 2005.

However, fishermen in both the polar regions and the tropics will have to adjust to a second phenomenon. The size of the fish caught will decline by 14 to 24 percent worldwide in the coming decades. According to forecasts, this development in the higher latitudes will be brought about primarily by the immigration of smaller species. In regions near the equator heat stress will impede the growth of fish. This is due to the fact that the warmer the water is, the higher the rate of metabolism of the fish. That means more oxygen and thus energy that the animals previously invested in their growth will be required in future to compensate for thermal stress.

Fishing will thus be the first industrial sector to feel the impacts of climate change. The annual costs for adjustment to this change will come to around 7 to 30 billion US dollars up to 2050. The majority of that will be accounted for by fishermen in the tropics.




**How does humankind benefit from the ocean?**

For some the ocean is a workplace, the basis of their livelihood and a major food supplier. For others it is a place for recreation and leisure activities as well as a vacation spot. However, the oceans are much more than that and one thing above all else – they are indispensable for life on Earth. Here is a brief outline:

- Oxygen

We owe every second breath of air to the oceans. Phytoplankton, microscopically tiny algae, produce nearly half of the oxygen in the air – more than all forests and meadows together.

- Heat store

The ocean can store a thousand times more heat than the atmosphere. Oceans have absorbed around 90 percent of the heat that has accumulated over the past 40 years.

- Source of food

Fishing supplies a third of the entire population on the Earth with nearly a fifth of its protein needs. About 400 million people rely on fish as their daily source of food. Altogether humankind takes approx. 90 million tons of fish out of the sea every year.

- Source of income

Worldwide 43.5 million people work in the fishing sector, which earns about 85 billion US dollars a year. In addition, there are the earnings derived from tourism: every year holidaymakers spend 9.6 billion US dollars on visits to coral reefs.

- Transport route

The ocean is the number one transport route worldwide. Nearly 90 percent of all goods are sent via ship.

- Protection

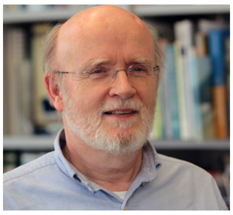
Coral reefs protect a total coastline of over 150,000 kilometres in length. It extends across 100 countries. For the people who live on these coasts coral reefs as natural breakwaters provide protection against storm surges and tsunamis.

A scientist examines water samples taken on an Antarctic expedition of the research icebreaker Polarstern. Such laboratory analyses lay the foundation for our knowledge about climate-induced changes in the oceans. (Photo: Thomas Steuer/AWI)

## From the DNA strand to the big predators

At the beginning of the 1990s researchers of the Alfred Wegener Institute were among the first scientists who investigated the impacts of the increasing carbon dioxide content in the air on the oceans. They quickly perceived how far-reaching the consequences of ocean warming and acidification can be and started to research in a more detailed manner how poikilothermic marine dwellers react to the warmer, acidifying water – beginning with behaviour and performance tests right through to changes in genotype. Simple organisms, they found out, would be able to adapt better than more highly developed species. However, the scientists also knew that an ecosystem with its many species is like a gigantic clockwork mechanism with many cogwheels. If only one of the small parts changes or breaks down completely, the entire system no longer functions in the customary way. That is why biologists, chemists, physicists, geologists and modellers are working together at AWI today to gain a comprehensive understanding of what consequences the current changes in the seas have for their ecosystems. They carefully examine unicellular organisms and top predators alike, look from the atmosphere all the way to the deep sea and attempt to learn from these changes as much as they can in order to enable precise forecasts for the future.

## Contact to the AWI experts

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