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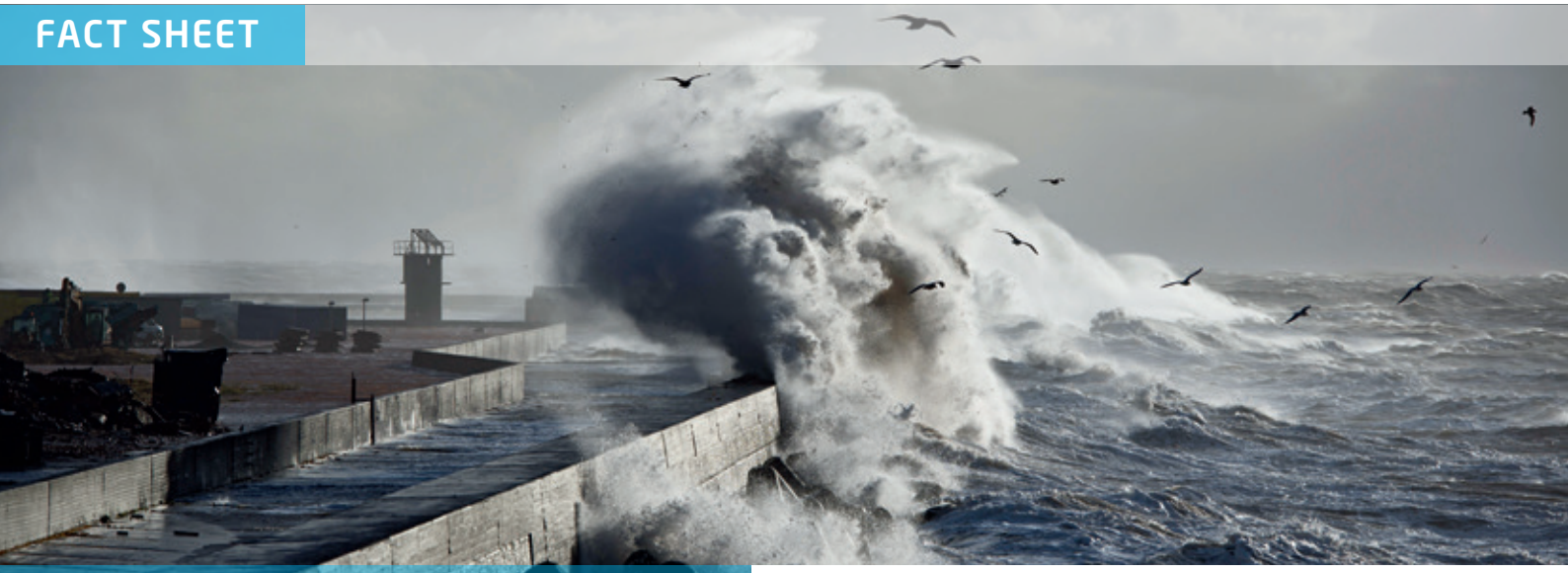
FACT SHEET



THE IMPACTS OF CLIMATE CHANGE ON LIFE IN THE North Sea

The changing face of the sea on our doorstep

Historic drawings of the Hamburg fish market show fishermen preparing man-sized sturgeons and massive cod for sale. The fish had been caught in the North Sea or in the Elbe estuary and was then offered up as poor man's food because supply far outstripped demand.

Scenes like this would be inconceivable today. On the one hand, the fish stocks in the North Sea have been so massively overfished that there are virtually no adult fish measuring more than a metre in length. Popular food fish and other seafood have long become an expensive delicacy. On the other hand, the climate-related warming of the North Sea has forced established native species like cod to migrate north where the water temperature is similar to that measured in the North Sea some five decades ago.

Back then, in the 1960s, marine researchers from the Biological Institute Helgoland commenced a unique research series off the island of Helgoland. Every working day for more than 50 years, they have been measuring the temperature, salt and nutrient content and the turbidity of the North Sea water. The result is a unique series of long-term data, which shows, among other things, that the average annual temperature of the North Sea has risen by around 1.7 degrees Celsius since measurements began.

North Sea islands such as Borkum and Helgoland are perfect for seals. Harbour seals and grey seals rest on the beaches and give birth to their young there. (Photo: Solvin Zankl)

Nowadays researchers from the AWI just need to walk through the Wadden Sea to be able to see the consequences of this change in temperature with their own eyes. Thermophilic species from the south and overseas have moved in and are reproducing and competing with the native species. AWI North Sea experts report on these and other climate-related phenomena in this fact sheet.

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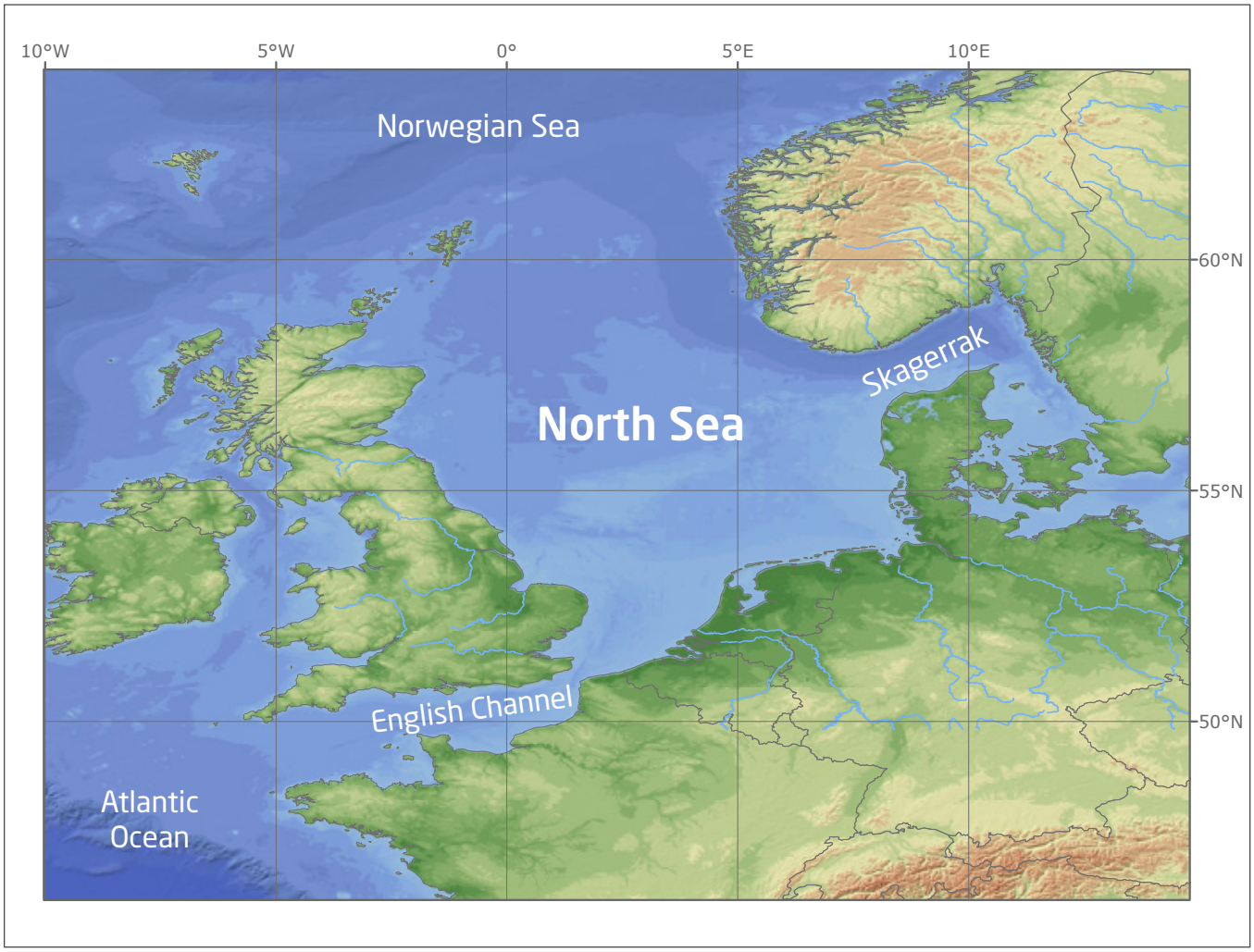


(Map: Antonie Haas/AWI)

The North Sea – a sea of superlatives

The North Sea is a shallow shelf sea (deepest point 700 metres) bordered by Great Britain to the west, Scandinavia to the north-east and the European mainland to the south. The English Channel and the Norwegian Sea connect it to the Atlantic Ocean while the Skagerrak joins it to the Baltic Sea. The area of the North Sea is around 750,000 square kilometres as defined for the region of the ‚Greater North Sea' according to the OSPAR Convention for the protection of the marine environment of the North-East Atlantic (www.ospar.org).

The North Sea coast is among the most densely populated coastal areas in the world. There are around 15 million people living in the region. This kind of superlative also applies to the industrial use of the sea. Whether it is fisheries, oil and natural gas exploration, transport of goods, port services or tourism, the North Sea is among the most intensely used marine regions in the world.

The statistics for the natural habitat are no less impressive. Researchers now know around 230 species of fish and numerous marine mammals, which are native to the North Sea. There are some ten million sea birds that regularly rest or breed in the large mudflats along the coastal region of the south-eastern North Sea, which is now largely protected for this reason.

Environmentalists scored a massive victory in June 2009 when UNESCO designated the Wadden Sea along the German and Dutch coast as a World Natural Heritage Site. The area, which also includes the Wadden Sea National Park, is considered to have the densest population of birds in Europe. Climate-related changes caused have been investigated by AWI scientists at the Wadden Sea station in List on the island of Sylt, for example.

The crew of the AWI research boat Aade head out to the North Sea to take samples from Monday to Friday. The area investigated is between the main island of Helgoland and the adjacent island known as „Düne". (Photo: Solvin Zankl)

How the North Sea is changing: Findings from AWI's „Helgoland Roads" long-term measurements

Since 1962, AWI researchers have been measuring the temperature, visibility, as well as the salt and nutrient content of the North Sea water off Helgoland. They also record biological components of the marine ecosystem. Here is an overview of the most important findings:

Temperature

The average water temperature off Helgoland has increased by 1.67 degrees Celsius since 1962. This increase takes place in all seasons. Nine of the ten warmest years occurred after 1988. The water temperature in the German Bight has risen more than in other regions of the North Sea.

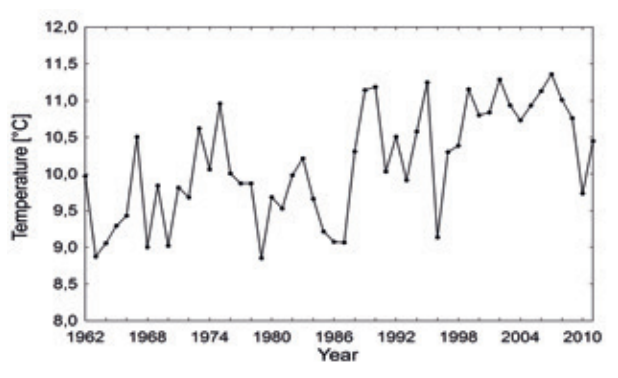
Salt content and visibility

The salt content of the North Sea water off Helgoland has increased slightly since the measurements began - as has the visibility. Both developments are a result of changes in current patterns in the German Bight.

Plankton

Researchers have counted over 300 different species of plankton since the measurements off Helgoland began. Daily monitoring makes it possible to document changes in the seasonal occurrence of individual species and identify new migrant species. For example, the diatom *Guinardia delicatula* often first appeared as late as in May in the mid-seventies, while it now regularly arrives in April. However, the diatom *Mediopyxis helysia* has only recently been caught in the Helgoland researcher's plankton net, likewise the sea walnut *Mnemiopsis leidyi* as a representative of zooplankton.

The species diversity around the island has increased over the last few decades. This development is evident both in phytoplankton and in zooplankton and most especially in the seafloor biocoenoses. Over the last 25 years, AWI North Sea experts have counted around 60 new species on the seafloor around Helgoland. These migrants have probably been able to settle permanently in the North Sea thanks to the warmer water around Helgoland, as documented by research.



The development of the North Sea water temperature (annual averages) in the Helgoland Roads. (Graphics: AWI)

Introduced by humans: In 1986, oyster farmers on Sylt began cultivating the *Crassostrea gigas* oyster, originally from the north-west Pacific, in the Wadden Sea. Five years later, researchers found the first descendants of this species in the wild. (Photo: Martin Stock / LKN-SH)

Warming and species migration: The North Sea, an international habitat

European oysters have long been considered a delicacy. Demand from connoisseurs in Central Europe was so high that fishing nearly exhausted oyster stocks in the North Sea in the 1950s. A replacement needed to be found. So in 1986, oyster farmers on Sylt introduced the Pacific oyster *Crassostrea gigas.* Fishermen at the time never thought it would cause a problem. After all, in order to reproduce, the Pacific oyster needs a water temperature of at least 18 degrees Celsius. At the time, however, these temperatures were rarely reached in the northern Wadden Sea, and then only for a few days. This was a fatal mistake. In the period from 1987 to 2003 alone, Wadden Sea dwellers experienced six years with above-average temperatures. The water temperature then rose above 18 degrees Celsius every summer - giving the introduced oysters a free pass. Their larvae hatched, escaped from the farms and settled on the first available hard surface they found in the Wadden Sea.

Then as now, the native blue mussel banks provided a solid foundation. What happened is easy to predict. Within a short timespan, the mussel banks were

What were once blue mussel banks in the Wadden Sea now look like this: Pacific oysters are dominant. However, the mussels not only find space among them, they are also protected from predators. But because they compete for food with the oysters, the blue mussels are on average slightly smaller than before. (Graphics: AWI)

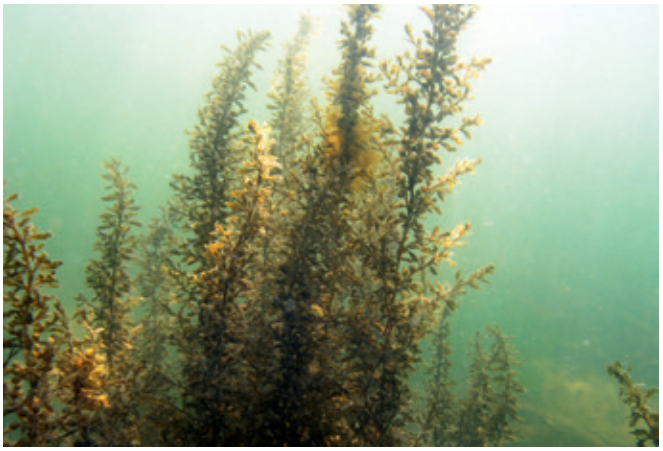
The introduction of the Pacific oyster gave rise to a decline in oystercatchers in the Wadden Sea. Despite what their name suggests, these birds specialise in cracking open blue mussels. They hammer on the shells with their beaks. But this technique does not work for oysters, which have thicker shells. (Photo: Andreas Trepke CC BY-SA 2.5)

Moving in made easy
The North Sea is one of the main international shipping routes. The ports in Hamburg and Rotterdam are two of the biggest cargo handling centres in the region they serve. But the ships not only bring goods from all over the world to Central Europe. Often they also bring ballast water containing foreign plant and animal species or have a variety of those intruders attached to their hulls. How many of these newcomers end up surviving in the North Sea is a matter of guesswork. However, increasing climate change gives the heat-loving migrants at least a chance of survival.
(Photo: Günter Heyde)

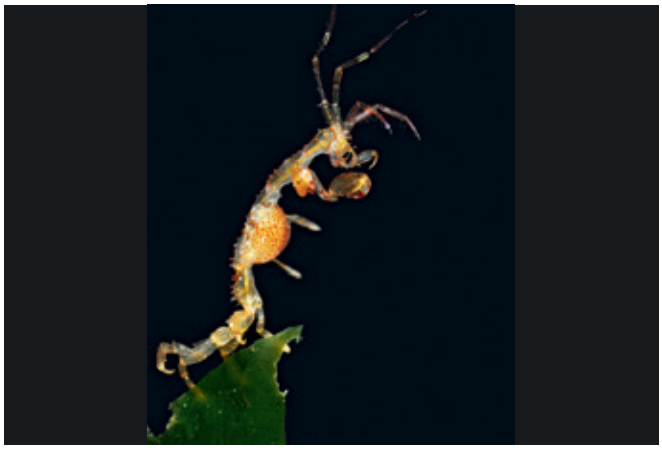
transformed into oyster reefs. This change had the greatest impact on sea birds that fed on blue mussels. Eider ducks, red knots and oystercatchers could not break into the hard shells of the introduced Pacific oysters with their beaks.

With no real predators, the Pacific oyster was able to spread further and further. Today, there are whole hectares containing up to 2,000 animals per square metre. This has also created new habitats, primarily for other Wadden Sea immigrants, such as the Japanese wireweed *Sargassum muticum.* The brown algae attaches itself to the oyster shells, grows up to four metres and thus creates forests of algae in which a third North Sea newcomer, the Asian skeleton shrimp, can also find a home. And the list of immigrants keeps on growing.

In 2012 alone AWI scientists counted a total of 52 introduced species in the German sector of the Wadden Sea - and every year there is a new exotic addition. Only very few species, like the oyster, are deliberately introduced. Some newcomers to the North Sea are merely stowaways. Attached to the outside of large ships or in ballast water tanks, they travel around the seven seas for weeks before finally arriving in the North Sea. This is what happened to the Australian barnacle *Austrominius modestus.* They were discovered on the coast of the island of Sylt by scientists back in the 1950s. They minded their



With lengths of up to four metres, the Japanese wireweed *Sargassum muticum* is currently the longest algae in the Wadden Sea. In shallow water it forms a richly structured habitat used by many species. For example, herrings attach their eggs to its leaves. (Photo: AWI)



The Asian skeleton shrimp *Caprella mutica* is so delicate that you need to look very carefully to see it. In summer 2009, AWI Wadden Sea researchers found it in the wild for the first time, where it had found a new home in the wireweed thickets. (Photo: Uwe Nettelmann/AWI)

War of worms
For some time, the Wadden Sea's most famous inhabitant, the sandworm *Arenicola marina,* has had to deal with a new neighbour. The king ragworm *Nereis virens,* originally from North America, is providing unpleasant competition to the sandworm, especially in the low water line area. Laboratory tests have shown that the immigrants bite the sandworm with their two protruding jaw clamps, thus driving them out of their own homes. The sandworm can only escape to higher-level terrain.
(Photo: Solvin Zankl)

own business there for a half a century. The reason: the winters were too cold for them to spread further in the North Sea. But when the water temperature rose and there were no extended periods of frost, the offspring of the Australian barnacle flourished to such an extent that in 2007 there were more of them than native barnacles in some areas of the North Sea.

The striped red mullet also found its way to warmer waters. The popular food fish from the Mediterranean region has increasingly been caught in the North Sea since the beginning of the nineties. To date, the mullet has only been a summer guest to the German Bight. In autumn, the fish leave the area before returning in early summer with the next influx of warm Atlantic water.

Pacific oysters, wireweed, skeleton shrimps, striped red mullets - none of these newcomers has yet forced out a native North Sea species completely. However, AWI scientists have ascertained that the pace at which new species are currently moving into the North Sea is faster than ever before and has been accelerated by climate change and global trade. It is difficult to evaluate this development. One thing is clear, however: in the long term, the migration of new species will mean that ecosystems around the world will become more similar and the interaction between species, which have been happily cohabiting for centuries, will change.

The American razor clam *Ensis americanus* is another immigrant. The species came to the North Sea in 1978 in the ballast water of a ship and rapidly became the most common mollusc in the North Sea and the Wadden Sea. (Photo: Christian Buschbaum/AWI)

The striped red mullet *Mullus surmuletus* migrated to the North Sea from the Mediterranean. However, their range is closely linked to water temperature. When the North Sea cools down in autumn, the mullet return to the warmth of the Atlantic. (Photo: Sven Gust)

Salt marshes form a natural transition between the land and the sea. They are created when so much sediment has been deposited that the area grows out of the tidal zone and is only occasionally flooded. (Photo: Christian Buschbaum/AWI)

What happens if the sea level rises?

Over the past 7,500 years, the water level of the North Sea has risen by an average of 1.5 millimetres per year. This increase is partly due to the rise in the global water level and also to changing air pressure patterns in the North Sea.

This slow rise will not harm the Wadden Sea, providing it can keep pace, i.e. providing sufficient sediment is deposited during high and low tide. However, if the sea level rises faster, there is a greater risk that those mudflat areas that currently go dry to a large extent at low tide could be transformed into lagoons permanently covered by water. Species such as oystercatchers, which can only find enough food at low tide, would suffer under these circumstances - as would the many dwellers of the mudflats and salt marshes on the outside edges of the Wadden Sea. The salt marshes provide a habitat for numerous plants, some 50 species of birds and nearly 2,000 species of insects. If the North Sea floods them more often in future, the plants face death by drowning and the animals face loss of their nesting and feeding grounds.

The mudflats are part of the Wadden Sea National Park. They are flooded and run dry regularly as the tides change. They are criss-crossed by tidal inlets that draw the North Sea water in and out again. (Photo: Martin Stock / LKN-SH)

The dunlin uses the Wadden Sea as a stopover between its breeding and winter areas. The migratory bird eats enough here in spring and autumn to give it the energy reserves necessary to continue its flight. (Photo: Martin Stock / LKN-SH)

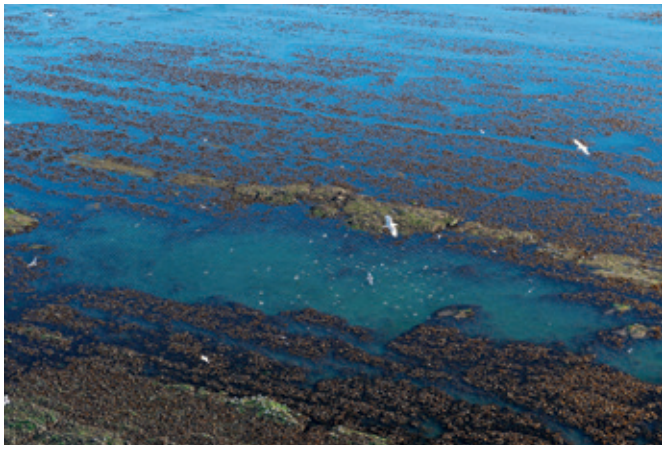
A great hiding place for the little ones: this underwater shot of the Helgoland kelp forest reveals why young fish in particular need the dense kelp undergrowth to survive. The thicket of algae not only provides sufficient food, it also protects them from predators. (Photo: Uwe Nettelmann/AWI)

Kelp off Helgoland: An underwater forest submerges

An underwater forest is growing on the rocky seabed around Helgoland. A thicket approximately two metres high, with finger, sugar and palm kelp forming different layers, provides a habitat, protection and food to more than 200 species of animal and algae, including polychaetes, amphipods and many juvenile fish which feed off smaller animals.

It is an oasis of diversity that is fundamentally different from better known ecosystems such as coral reefs in one way: kelp prefers cool temperatures between five and 15 degrees Celsius.

But this preference for cool water means that climate change in the North Sea could spell disaster for these underwater forests. AWI researchers have not observed any major dying out of kelp off Helgoland, as has been reported by scientists off the north coast of Spain and in southern Norway. However, investigations by AWI scientists suggest that the very crucial finger, palm and sugar kelp stocks of the island react sensitively to heat.



Seagulls circle over the kelp on the Helgoland bedrock and look out for prey. The underwater forest below their feet has been growing here for about four hundred years. Before that, a thick layer of sand covered the rock. (Photo: Uwe Nettelmann/AWI)

This special aerial photo gives us a glimpse under water. The shades of red show where kelp is growing around Helgoland and its neighbouring island of Düne. The photo was visualised based on data from the AISA Eagle+ sensor carried on an airplane. (Source: Florian Uhl)

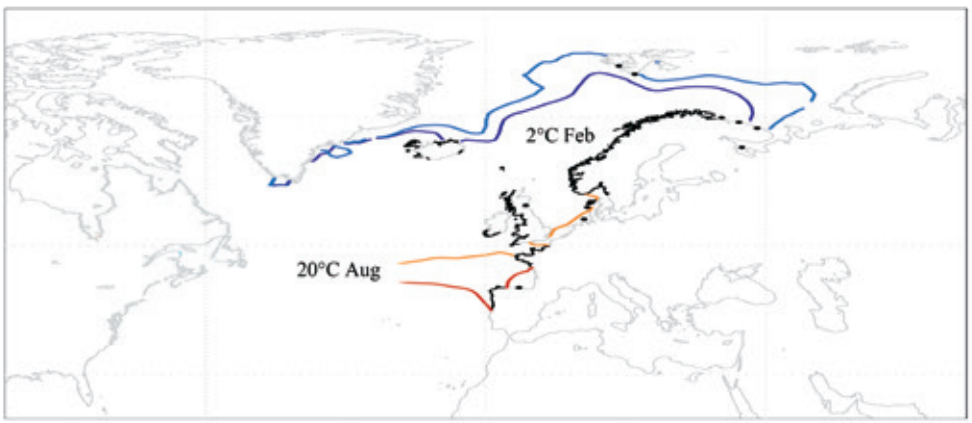
For example, if the water temperature surpasses the 18-degree mark in summer, as it did on an average of eight days per summer in the period between 2007 and 2013, the reproduction cells that the finger kelp *Laminaria digitata* forms in its palm-like leaves are damaged. This impairs germination. As a result, the reproductive capacity of the kelp is considerably reduced. If the water temperature increases to 20 degrees Celsius due to a heat wave, the kelp stops reproducing entirely for a time. At the same time, the higher-level kelp plants, which are visible at low water, die off. If these warm periods do not recur every year, the kelp forests on the Helgoland bedrock can always recover. However, if these heat waves become the norm - as predicted by climate experts – their chances of survival are diminished.

But there are also positive changes to report. The increasing influx of Atlantic water into the North Sea is probably responsible for the decrease in turbidity of the surface water off Helgoland. Today, you can see a whole metre deeper into the water than you could in 1969. At the same time, more light is penetrating into the depths. These changes have led to the Helgoland kelp forest extending into deeper waters. While the palm kelp *Laminaria hyperborea* only grew to a depth of eight metres in the late 1960s, AWI biologists found it at a depth of up to 10.5 metres in 2005. Parallel to this development, the maximum depth for finger kelp and some types of red algae have also shifted downwards.

Aside from the shift downwards, biologists have also observed increased leaf growth on the kelp. The total biomass of the kelp forest has increased, as has the production capacity of the bedrock.

Shade lovers: palm kelp *Laminaria hyperborea* prefers subdued light and a water temperature of two to 15 degrees Celsius. Off Helgoland, it grows at a depth of two to ten metres. (Photo: Uwe Nettelmann/AWI)

During the extensive investigation of the forest, AWI biologists also made another surprising discovery. Contrary to their assumptions, the Japanese wireweed, which had been recorded as early as 1988, has not penetrated the forest of palm, but is only growing in selected areas in the shallow section of the bedrock just below the low water line. However, this could change in part if increasing temperatures drive the palm kelp out of the North Sea, leaving plenty of free space on the Helgoland bedrock.



Future prospects

Palm kelp cannot tolerate temperatures above 20 degrees or below two degrees Celsius. This means its current range is limited to those areas marked by the red (20°C August maximum) and purple lines (2°C February minimum). If the sea warms up as fast as the climate models predict, this habitat will shift north by the year 2100 to the area marked by the yellow and blue lines. This means palm kelp will presumably disappear from the shores of Helgoland, just like finger and sugar kelp.
(Map: Müller et al. 2009. Botanica Marina 32: 617-638)

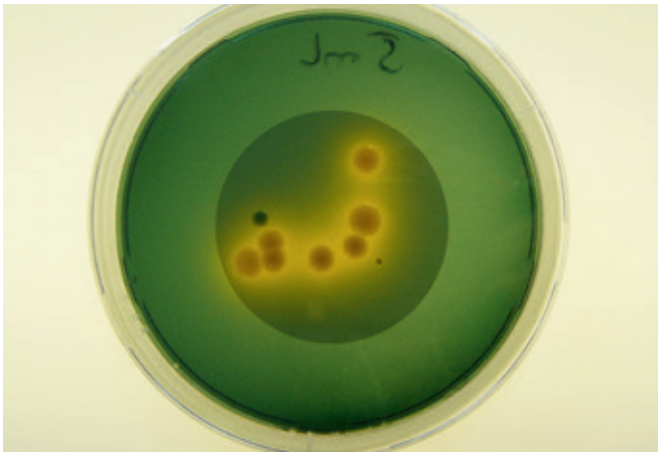
Walking barefoot along a North Sea beach may have a serious disadvantage in summer - especially if you have a wound on your foot and pathogens like Vibrio bacteria get into it. The number of Vibrio wound infections has been constantly on the rise since the 1990s, reaching particularly high levels during long periods of hot weather when the water temperature exceeds 25 degrees Celsius. (Photo: Sina Löschke/AWI)

Pathogens: The North Sea as a paradise for bacteria

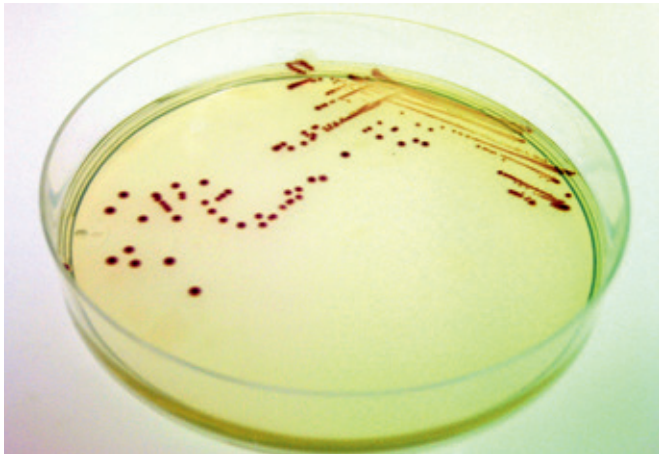
When the surface temperature of the North Sea reaches the 20-degree Celsius mark in July and August, it is not just the holidaymakers who feel good. Primarily bacteria like the pathogen *Vibrio vulnificus* are most likely to benefit from the increase in temperature. They multiply phenomenally in water warmer than 20 degrees Celsius, with a result that more and more people on the northern coast of Europe have been getting ill since the mid-nineties. But how do people come into contact with these pathogens?

The bacteria are concealed in oysters, which are eaten raw, or can get into the human body through open wounds during a swim or barefoot walk along the beach. These incidents result in either food or blood poisoning, the latter being fatal in 30 percent of the cases.

However, the risk of being infected with *Vibrio vulnificus* in the summer does not depend on water quality. The bacteria are a natural part of the plankton community. They also occur in otherwise perfectly clean North Sea waters.



Vibrio bacteria are only visible to the human eye when they grow tightly packed in a nutrient solution (TCBS agar) as in this picture. This photo is taken from a research project in which AWI scientists investigated the distribution of Vibrio on selected North Sea beaches. (Photo: Sonja Oberbeckmann)



There are also Vibrio bacteria growing in this Petri dish. These unicellular organisms occur naturally in the sea. But if the water temperature exceeds a species-specific level, they reproduce so quickly that they can be hazardous to humans and animals. Twelve of the known Vibrio species have a pathogenic effect. (Photo: René Erler/AWI)

Anyone who enjoys eating seafood should be careful on warm summer days. If the temperature exceeds 20 degrees Celsius, the toxic Vibrio bacteria in oysters, for example, multiply. Eating them could cause food poisoning. (Photo: Michael Pfeiffer)

AWI scientists have worked out that the water temperature affects whether the pathogens reproduce across a large area of water. If the water temperature increases by just one degree within the 15 to 20 degree range, the probability of *Vibrio vulnificus* spreading across a body of water rises by four percent. If the water temperature goes above 20 degrees Celsius, every additional degree makes the probability of the bacteria occurring in relevant concentrations in the water ten times greater. However, *Vibrio vulnificus* only needs warmth for the first phase of its life. Once developed, the bacteria can survive for months in temperatures as low as 15 degrees Celsius, before suddenly disappearing again.

The Vibrio genus of bacteria poses a threat not only to humans. Where the water temperature exceeds 19 degrees Celsius, the bacteria can also do serious damage to the reefs of Pacific oysters - especially if the bacteria meet mussels on the verge of spawning and already weakened. If the water temperature then exceeds the critical level, the oysters' immune system fails.

AWI biologists carried out laboratory tests revealing that greater numbers of Pacific oysters ready to spawn die of Vibrio infections at high temperatures than those subjected to the pathogens in warm water, but not in reproduction mode. This finding also explains why, for example, the number of dead molluscs on the natural oyster reefs of the southern Wadden Sea is particularly high in warm summers.

Ocean acidification: How the great Atlantic scallop loses the strength to swim

The great Atlantic scallop has a special talent. Unlike oysters and blue mussels, it can swim away from potential predators such as starfish or crabs. To do so, the North Sea dweller quickly snaps its shell together again and again, creating a jet of water that catapults it forward as if jet-propelled.

This escape method has worked very well until now. However, AWI biologists have discovered that as a result of on-going climate change the great Atlantic scallop will find it increasingly difficult to escape its predators. This is due to the increasing acidification of seawater.

Every year, the oceans of the world absorb one quarter of the carbon dioxide that we humans produce. When this greenhouse gas dissolves in water, it produces carbonic acid, which lowers the pH value of the water. The oceans are becoming more acidic.

The great Atlantic scallop is coping badly with these new living conditions. Laboratory tests at the AWI have shown that the animals have metabolism problems in more acidic water and need to invest so much energy into preserving their important bodily functions that they do not have the strength to snap their shells together and therefore to swim away in an emergency. This should make life easier for scallop predators like crabs and starfish in future.

Up to now, the great Atlantic scallop *Pecten maximus* has been able to swim away from its predators. However, with the North Sea becoming increasingly acidic, it is becoming more and more difficult for the scallop to execute swimming movements. (Photo: David Borg)

With modern technology: in summer 2013, the AWI commissioned its new Wadden Sea research ship, Mya II. (Photo: Florian Lange/AWI)

Research questions: Where is the North Sea heading?

Global climate change leads to fundamental changes in the North Sea, especially along its coastal regions. It increases the water temperature and the sea level, reduces the pH value of the water and allows non-native species to feel more at home in North European waters. Scientists at the Alfred Wegener Institute are working jointly at three different sites on an interdisciplinary basis in order to understand how these changes will impact North Sea and Wadden Sea dwellers. This involves producing long-term data series, carrying out experiments in the laboratory and investigating in the field how selected species are reacting to the new living conditions and which migrants are settling where. These data help the researchers to draw conclusions on how the biocoenoses of the North Sea and, at the same time, the whole ecosystem will continue to change.

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