Biosciences
at the Alfred Wegener Institute

Polar ecosystems in a changing climate

The Alfred Wegener Institute is the Helmholtz Centre for Polar and Marine Research. It is headquartered in Bremerhaven and has over 900 employees. The Research Centre includes the Potsdam Research Unit, the Biological Institute Helgoland and the Wadden Sea Station Sylt. The Alfred Wegener Institute is a member of the Hermann von Helmholtz Association of German Research Centres. It is funded by the Federal Ministry of Education and Research and the federal states of Bremen, Brandenburg and Schleswig-Holstein.

Photo: AWI

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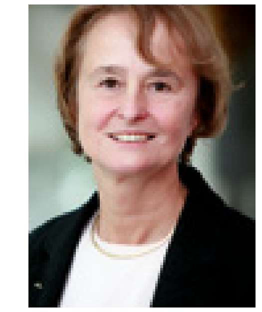
Content

Photo: F. Rödel



Preface

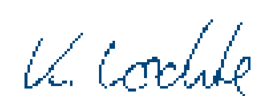
When water is discovered on a distant planet, or perhaps the indication of life - even if it is only the smallest bacteria - we look to the stars with enchantment. Yet life on our planet is equally fascinating, diverse and largely undiscovered, making it all the more important for us to investigate the depths of the oceans and the polar regions in order to better understand the complexity of our world. Viewing the Earth System from the Polar Regions offers us a particularly unique perspective, especially if we wish to understand the functioning of ecosystems under extreme and rapidly changing environmental conditions. The Arctic and parts of the Antarctic are the regions most severely affected by climate change. Here, polar organisms have adapted to extremely cold but stable temperatures over millions of years. Warming, caused by our ever-increasing use of fossil fuels, is already threatening this unique habitat.

The Alfred Wegener Institute for Polar and Marine Research in the Helmholtz Association has been exploring the relationship between global climate and the unique marine and terrestrial ecosystems since 1980. Central foci of research are the icy realms of the Arctic and Antarctic. To facilitate this, the Institute relies on a specialised infrastructure: Research stations at both poles and a deep-sea observatory in the Arctic, the icebreaker 'Polarstern' - a research and supply ship - and two polar aircraft. Scientists from a wide range of disciplines and nations guarantee the necessary know-how by interacting closely when studying the environmental, biological and earth systems of our planet. The goal of our research is to decipher the changes in the global environment and the Earth system, which are partly natural and partly anthropogenic.

Long-term observations, as well as studies and experiments carried out in different research projects, are incorporated into the development of conceptual or coupled mathematical models, with which scenarios of possible future developments are tested. These scientific results are important both, as information for the interested general public, and to provide sound advice for decision makers in politics, business and government.

With this brochure we would like to take you on a journey of discovery to the Arctic and Antarctic. To demonstrate how biologists in our institute do their research in icy regions by cooperating with scientists from other disciplines in order to untangle the riddles of life. For us to understand in detail how life and particularly different ecosystems function, it is essential to expand our research and to especially strengthen fundamental research. Deep thinking to shape the future, is our maxim.

I invite you to read this brochure with anticipation and enthusiasm and to discover new visions of a world that belongs to us all. Every day reveals to us anew the Earth´s awe-inspiring diversity which today more than ever needs be protected, if we and coming generations want a liveable future on this planet.



Prof. Dr. Karin Lochte
Director

Polar ecosystems in a changing climate

During an expedition to Antarctica 20 years ago, the chief scientist posed the following question: „Why do we actually need biologists?“ As a physicist and meteorologist, he was interested primarily in physical processes, such as temperature and salinity changes, currents and heat flux. During this winter expedition in the ice-covered Weddell Sea, we biologists were studying the diversity of life, investigated ice algae, phytoplankton in the underlying water column and the over-wintering strategies of copepods, which belong to the zooplankton.

Together with our Russian colleagues, we found out for example that not all animals "sleep" (hibernate) during the Antarctic winter - an observation that revealed previously unknown relationships between physics and biology. This reinforced our perception that research results should never be considered isolated if we are to better understand the complexities of our Earth system. And it may be that the critical question asked by the expedition leader was meant to incite us young biologists to consider our results in the interplay of physical, chemical and biological processes of this unique habitat. At that time, we investigated how the organisms living in Polar Regions and how the ecosystems function, to enable us in a next step, to see how they react to changes.

The ecosystems and the organisms in the Arctic and Antarctica have over millions of years adapted to the prevailing environmental conditions. The Polar Regions are characterized by half-yearly dark winters and summer periods with 24 hours daylight. Atmospheric temperatures can drop to minus 65 °C - a climate, which for us is extreme. However, the organisms living in the polar oceans encounter relatively benign and constant living conditions. The temperature of seawater does not drop below minus 1.9 °C, after which sea ice will begin to form. It also seldom exceeds 5 °C. This narrow temperature window is ideal for polar animals and plants. Minute changes of these stable living conditions, for many organisms are difficult to compensate if not impossible.

The increasing emission of carbon dioxide and other greenhouse gases due to man's intensive use of fossil fuels is speeding up environmental change, the consequences of which are clearly apparent in the Polar Regions. In the past 50 years, the Arctic has been warming up to such an extent that the annual sea ice cover is dwindling and with it a habitat on which many organisms depend. In Antarctica, warming is thought to have caused the collapse of large ice shelves at the peninsula. Huge icebergs split into hundreds of small tabular bergs. Areas that were once under the ice shelf, have become exposed and habitats on the seabed disturbed and recolonized. The sharp decline in krill and the dominance of salps, which are free floating tunicates or sea squirts that feed on plankton, is particularly striking. The foundations of a balanced food web seem to be changing dramatically.

Moreover, the increasing concentration of the greenhouse gas carbon dioxide in the atmosphere and its interaction with the carbonate system in the ocean is leading to an increase in CO_2 concentrations in the water and thus to acidification of the oceans. Measurements are confirming that calcium-bearing, acid-sensitive organisms, eg. corals, clams and snails, are unable to completely develop their supporting skeleton and protective sheaths. In fish and crustaceans the acidification often impairs the metabolism.

Research and awareness take time. Due to many years of research and process studies in the Polar Regions, we are now able to develop comprehensive future scenarios of climate change for the most severely affected regions of our planet. We have for example identified, during several expeditions, how and in what way the trace element iron regulates the growth of plankton in the central Southern Ocean.

The Intergovernmental Committee on Climate Change (IPCC) has in a recent compilation very clearly shown possible climatic trends in the Polar Regions (www.ipcc.ch). In the next IPCC report, the Alfred Wegener Institute for Polar and Marine Research will show possible consequences of these developments for organisms and ecosystems. This is possible because the scientists of our Institute have over 30 years developed a core competence that is not only internationally well recognised, but is reflected in numerous international collaborations. We are the only institute that maintains a Arctic deep-sea long-term observatory where the rapid changes in the main access area to the Arctic can be monitored. A pulsing warm water inflow from the North Atlantic, is causing shifts in the planktonic food web, to the detriment of cold-loving species. The web is loosing the energy rich polar organisms. At the same time, the export of biologically important elements to the sea floor is reduced and leads to a change in the faunal composition. The consequences of these changes have not yet been assessed.

Against this background, the Alfred Wegener Institute, over and above its current research activities, is preparing the next generation scientists for the challenges that lie ahead. With a unique and far-reaching educational program, which integrates the high school curricula, our institute's scientists are educating and preparing high school students for university studies in natural sciences. For the students of today, will be the scientists of tomorrow - what kind of world they and their children will inherit, lies in our hands.

Photo: AWI

Central research questions in this context are:

How have past climatic fluctuations affected polar ecosystems and their organisms and which future developments we can deduce from these?

How do biological processes affect the global climate and in which directions will these processes change in the light of global developments?

What are the consequences of the decline in sea ice cover for organisms and the biogeochemical processes driven by them?

Which organisms are particularly important for the maintenance of polar food webs and what would a loss or exchange of such organisms mean for the systems and their role in global processes?

The 21 Century is often described as the age of biology. The science of life has come to dominate many areas of our scientific view of the world, similar to physics in the 20th Century. The biology, being alive, adapts to environmental changes and scientists have to continuously re-detect altered ecosystems. Our idea of how ecosystems function is far from being mature and the question of whether there is an overriding principle that drives evolution and, which we can learn from for humans to act on, is still being hotly debated. However, it is essential that we now more than ever pick up again on Humboldt's pioneering spirit. For the era of the great polymath who looked at the system in its entirety and with no boundaries, was followed by a period of reductionist research in which systems were viewed with respect to their individual components in a purely deterministic manner. In the marine life sciences, we recognized early on how important it is for all scientific disciplines to collaborate closely. The Alfred Wegener Institute has, with its many years of research in the Polar Regions and the related international networking, thus paved the way for us to successfully meet the challenges of this young century.

Prof. Dr. Ulrich Bathmann
Head of Scientific division Bioscience

Research icebreaker 'Polarstern' forces its way through the sea ice.
Photo: L. Tadday, AWI

Ice edge blooms – Migrating oases in polar seas

Ice edge blooms have been studied for decades and are theoretically explainable phenomena. However, phytoplankton in the ocean does not always behave according to the textbook, and sometimes a strong bloom may not develop, even under favourable conditions. By using ship-borne measurements, remote sensing and numerical models, AWI scientists are studying the various influences on the development of ice edge blooms as well as their impact on the carbon fluxes between atmosphere and ocean.

As is the case on land, photosynthesis of plants creates the basis of the food web also at sea, where consumers range from millimetre small copepods to the over 30 meters long blue whale. Far off the coast, the plants of the ocean are microscopic free-floating algae. Although tiny, together they produce as much biomass annually as all land plants combined. Light and nutrients in particular determine how phytoplankton is distributed over space and time, how high the primary production is, and how much carbon dioxide is removed from the atmosphere and sequestered when the biomass sinks to the depths of the ocean. The availability of light and nutrients on the other hand is controlled by physical processes.

In the Polar Regions, the annual variations in solar radiation are extreme and the changing sea ice cover exacerbates the variation. For the phytoplankton sea ice represents an almost opaque lid. With the disappearance of the ice during the spring or early summer more sunlight penetrates the water. With the onset of warming and the melting of sea ice, which has a lower salinity than the surrounding water, lenses of less saline and consequently less dense sea water form near the ocean surface, in which phytoplankton is retained close to the sun-lit surface enabling its rapid growth. However, nutrients are available for a limited time of growth only. In the Arctic, it takes just a few weeks for nitrate to become consumed, causing local phytoplankton blooms to come to a halt. In Antarctica it is availability of the trace nutrient iron, which limits growth. Closer to the pole however, where the sea ice melts later in the year, growth conditions are improving and thus phytoplankton blooms shift poleward during early summer.

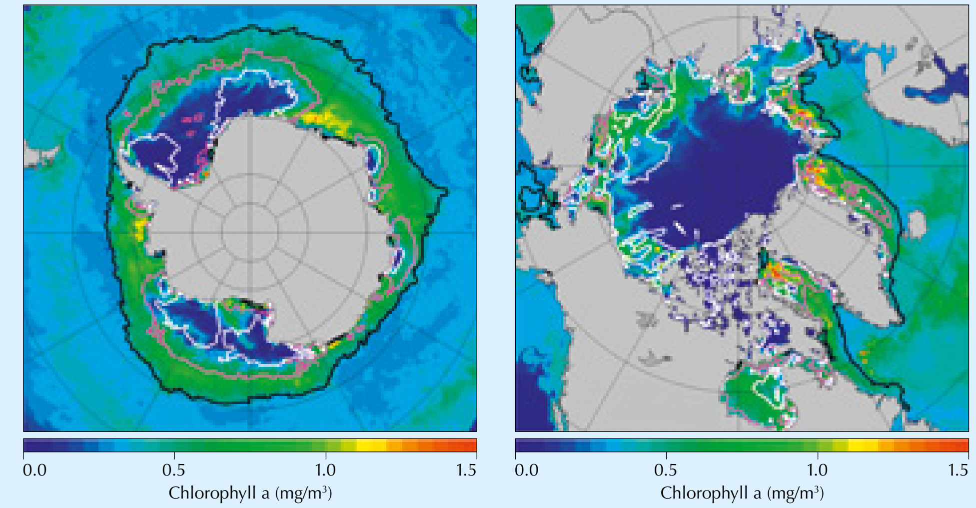
In the Arctic, sea ice at its average maximum extent in winter covers an area of 16 million km². At its minimum extent in summer, it only covers 7.5 million km². The ice edge thus retreats by more than 1000 kilometres. Antarctic sea ice in winter covers an area of about 19 million km² and in the summer only 3 million km² remain. Thus, the seasonal advance and retreat of the sea ice cover controls the annual cycle of biological production in an area that is equivalent to 2.5 times that of Europe,.

Why, however, does it sometimes happen that even under favourable physical conditions a strong phytoplankton bloom may not develop? Is limited nutrient availability or lack of trace elements the cause? Are there not enough algae to seed the bloom, or is there too much zooplankton, which consumes the phytoplankton? And how will climate change affect the polar ecosystems and carbon dioxide exchange between ocean and atmosphere?

In the Arctic, the minimum summer ice cover in the past 20 years decreased from 7.5 to almost 4.5 million km². Arctic ice edge blooms are so short lived that the algae-eating zooplankton, due to their relatively long generation cycles and slow growth rates, are unable to make full use of them. Therefore, much of the phytoplankton bloom in the end sinks to the sea floor uneaten. Thus, a large amount of organic carbon is removed from contact with the atmosphere. Longer periods of open water in course of climate change could weaken this biological carbon pump, but enhance the channelling of biomass into the food web and hence improve fishing yields.

In the Antarctic decadal trends in sea ice coverage are not clearly recognisable because of the strong inter-annual variability. The combination of winter ice cover and subsequent ice edge blooms, however, seem to be an effective mechanism preventing outgassing of the CO_2-rich deep water. A key position in the Antarctic food web is occupied by krill. They are bound to regions with winter ice cover and are the reason for the presence of whales near ice edge blooms. Relatively little biogenic carbon sinks to great depths in the ice edge regions of Antarctica. A decline in ice cover would certainly have negative effects on the krill resources and thus on the entire ecosystem. But in what direction would the biological carbon pump change?

To clarify all these issues different research methods are combined. Measurements from the ship are important to determine the interaction of physical, chemical and biological variables to the depths of the ocean. Since only limited measurements are possible from ships, large-scale and continuous coverage by satellite remote sensing techniques is also required. Finally numerical models are indispensable to analyse and understand the data obtained more effectively, and to venture predictions of future developments.

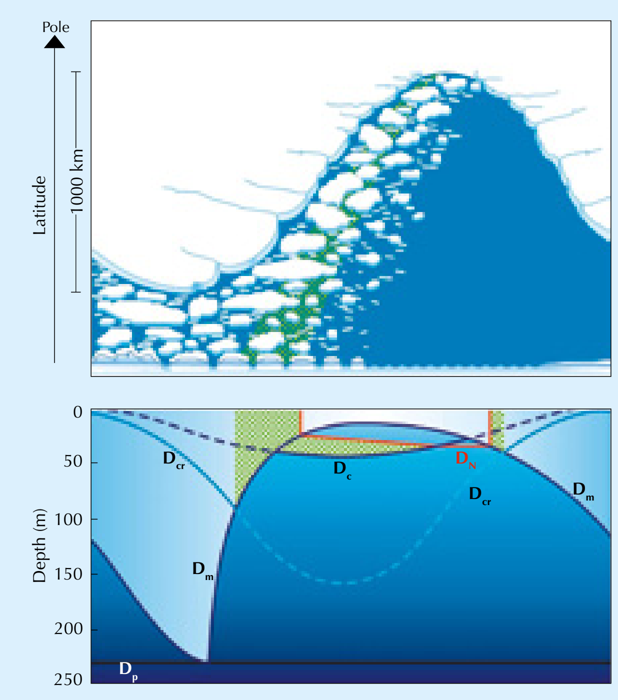


10% Ice Coverage · 95% Ice Coverage · 90% Ice Coverage

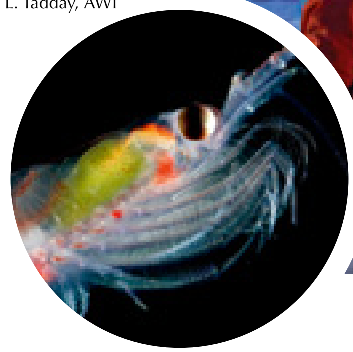
10% Ice Coverage · 95% Ice Coverage · 90% Ice Coverage

Ice edge blooms at the onset of meteorological summer (01.06.2007) in the Arctic and (01.12.2007) in Antarctica, simulated using a numerical model. The colour levels show the concentration of chlorophyll-a as a measure of phytoplankton concentration. The lines - as seen from the Poles – denote the limits of 95%, 90% and 10% ice cover. The ocean circulation model developed by AWI scientists calculates the temporal changes of physical conditions and the bio-geochemical components in three dimensions. The close spacing of the model grid enables the simulation of many details.
Graphics: M. Losch, AWI

Schematic representation of the seasonal migration of ice edge blooms (top) and the mechanism of their generation (bottom). Water absorbs and scatters light, so that its intensity decreases exponentially with depth. If the light requirements of phytoplankton are known, it is possible to determine the depth D_c, above which growth is possible. However, between the sea surface and depth D_m there is a mixed layer where turbulence causes the phytoplankton to swirl up and down. Since the light intensity above the depth D_c, is higher than required for growth, cells in the surface layer can be mixed to a depth D_{cr} below D_c, but will still obtain enough light. However, if the mixed layer D_m is deeper than D_{cr}, no growth is possible. The spring bloom begins when incident light increases and at the same time the ocean surface warms up while vertical mixing is suppressed by the addition ice meltwater. (The lines D_m and D_{cr} intercept then). Eventually, however, the nutrients are exhausted up to the depth D_n; the bloom comes to a halt. The green shading indicates the depth range in which growth is possible.
Graphics: based on Strass & Nöthig, Polar Biol., 1996



Winter diving camp at midday in the Antarctic. The divers are about to collect larval krill under the ice. Inspection of the dive hole, and communication with the diver in the water at minus 30 degrees air temperature.
Photos: L. Tadday, AWI



Antarctic: Krill has evolved adaptation strategies to its extreme environment

Krill plays a key role in the Southern Ocean marine ecosystem. Whales, seals, penguins and many fish species feed primarily on these small crustaceans. The Antarctic Peninsula, an area with highest krill density, is one of the most rapidly warming regions of our planet and the decreasing winter sea ice cover has already affected the krill stock extensively.

An extreme decline in krill would permanently alter fundamental ecosystem processes in the Antarctic marine habitat. The total biomass of krill in the Southern Ocean is estimated to be 300 million tons. The West Atlantic sector of the Southern Ocean, which includes the Antarctic Peninsula, is home to between 50 and 70 percent of the entire Antarctic krill stock. Long-term studies show that the stock has declined significantly over the last 30 years. One reason is the decline in winter sea ice cover.

This trend is accompanied by an increase in salps (Salpa thompsoni), which normally avoid the sea ice cover and are characterized by high feeding rates and rapid growth. In the spring, due to the competition for food by both organisms, phytoplankton may become limiting especially for krill making it unable to meet its energy needs for optimal sexual development and spawning activity. In addition, in summer the stock of krill larvae may be decimated by the high feeding activity of the salps. It is still unclear to what extent these population shifts affect the energy and nutrient flow as well as the biogeochemistry in the Southern Ocean pelagic food web.

The Antarctic marine habitat is characterized by strong seasonal fluctuations in environmental factors. Intense phytoplankton blooms are observed in the open ocean from October to April. During winter, much of the Southern Ocean is covered with sea ice and the food concentration in the water column is extremely low. The daylight hours in the Southern Ocean vary drastically, depending on latitude. Between seasons at 70° S, they range from 24 hours of sun light in summer to total darkness in the middle of winter. "Krill, during the course of its evolution, has adapted to this complex ecosystem. Our goal is to understand these evolutionary adaptations at the organismic, cellular and molecular level," says marine biologist Dr. Bettina Meyer. These are the prerequisites to understand the adaptability of krill to its changing environment, which include an increase in seawater temperature, acidification, changes in the food spectrum, so as to ultimately assess trends in the stock development of krill.

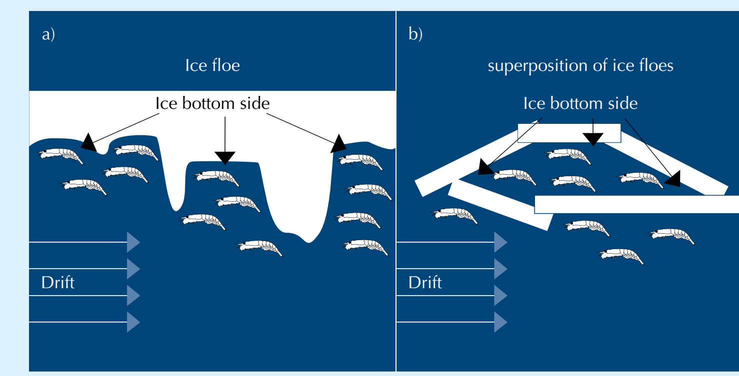
Krill larvae are dependant on sea ice

Krill larvae hatch in the summer and develop into the juvenile stage during the period from winter to spring. In contrast to the adults, the larvae are not in a position to survive long periods of starvation. The first winter after hatching is a critical phase in their life. The larvae cannot find enough food in the water column and thus need to forage almost exclusively under the sea ice where they find a rich microbial community on the underside of pack ice."Our research shows that large numbers of krill larvae are found in areas with overlapping or rafted ice floes. These cave-like retreats offer the larvae and other planktonic organisms excellent feeding conditions and a protected habitat. A change in the seasonal sea ice dynamics, caused by global warming, may affect the winter under ice topography and consequently significantly alter the food availability of the larvae," reports Krill expert Meyer. Expeditions with the research vessel 'Polarstern' during the Antarctic winter should provide the krill researchers with more precise information, such as what an optimal habitat for the successful development of larvae in winter would look like and whether climate-induced environmental changes have a positive or negative effect on the development of the larvae.

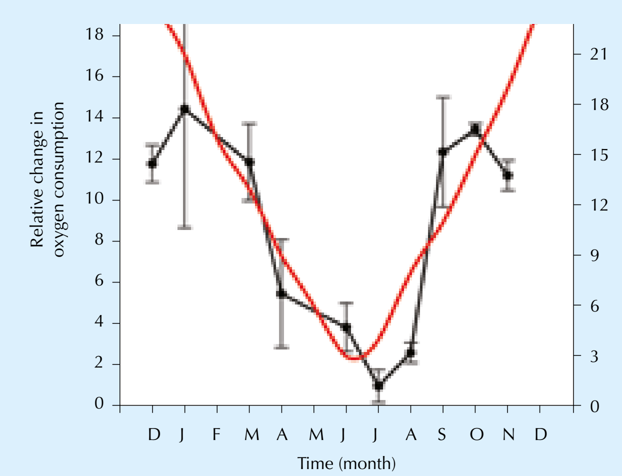
The Antarctic light regime controls physiological functions of adult krill

During the winter months adult krill undergo a characteristic reduction in metabolism and an associated reduction in feeding and growth activity. "This adaptation to the extreme winter conditions is likely to be controlled by the seasonally changing duration of daylight, the so called photoperiod, as we observed in krill caught in the field during 'Polarstern' expeditions at different seasons. Recent long-term laboratory studies in which the influence of different photoperiods was examined, confirmed this observation" says marine biologist Dr. Mathias Teschke. The experiments showed that Krill obviously have an "endogenous clock" that can perceive seasonal variations in light conditions, and thereby, anticipate the succession of the season. Accordingly, the clock controls specific physiological functions and synchronizes them to the changing seasons. The molecular basis of this endogenous timing mechanism in krill and its interaction with the changing environment, is still poorly understood and in future will comprise an important research area in the krill-group at the AWI.

Protection from the cold. Scientists to store their equipment and to warm up use the red plastic igloos. A generator provides light and heat.
Photo: L.Tadday, C. Pape, AWI



a) Krill finds resting areas with low water motion under rough ice flows. b) Rafted ice flows create caverns, ideal as feeding grounds and to protect krill from beeing eaten or swept away.
Graphics: B. Meyer, AWI



Krill are caught with „rectangular Midwater Trawl" (RMT-net) from the research icebreaker 'Polarstern'. The effects of different light conditions on the physiology of krill are examined in the laboratory. The results show the synchronization between the progression of metabolic activity (shown as relative change in oxygen consumption) and the annual cycle of daylight (photoperiod).
Graphic: M. Teschke, AWI

Amber coloured sea ice: The layer of ice algae (diatoms) at the underside of a floe is so dense as to colour the ice a typical brown.
Photo: G. Dieckmann, AWI

Work on the floe, scientists drilling ice cores to investigate the composition of sea ice algal communities.
Photo: G. Dieckmann, AWI

Living at -20 degrees; why sea ice algae don't freeze up

Cold, very salty and very little light: The living conditions in the sea ice would certainly put many organisms to the test. This is not the case for microscopic sea ice algae. They have adapted exceptionally well to this habitat. Why this is so and how they accomplish this is the focus of a group of scientists at the AWI who use modern molecular methods to unravel these questions.

As in the warmer oceans, microscopic algae termed phytoplankton also play a key role in the polar oceans. They represent the beginning of the food chain and ultimately the food for all larger organisms including the whales. In the Polar Regions, algae do not only live in open water, but also in the sea ice - without freezing.

The ice algae colonize small channels that are formed when seawater freezes. Temperatures in these channels drop to -20 °C and lower, while the salinity increases up to 20 percent, in contrast to the 3.5 percent of sea water. Despite the fact that sea ice appears to be white and clear, very little light actually penetrates it, often only 1 percent of the sunlight reaching the surface. The nutrient supply in the ice is also restricted, yet the algae, over millions of years, have succeeded in occupying this habitat, where they are safe from predators, because few other species have adapted to the icy conditions.

The dense mass of algae serve as food, especially during the winter and spring, for instance for krill, which forms large swarms to graze on the algae. When the sea ice melts in late spring and summer, the ice algae are released and contribute to the phytoplankton bloom in the open ocean, constituting the foundation of the food web on which fish, birds, seals and whales depend.

Biologists of the AWI have for many years studied how the phytoplankton has adapted to the extreme conditions in the sea ice. The main object of investigation is the diatom *Fragilariopsis cylindrus*, which was chosen as "alga of the year 2011"by the German Botanical Society.

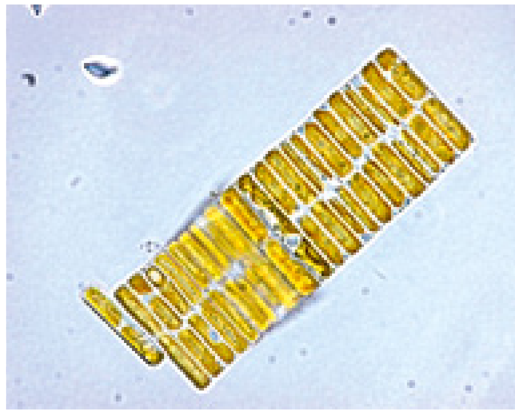
The high salt concentrations in the ice channels would actually remove the water from the algal cells, however, they produce so-called osmolytes, which bind and retain water in the cell. The formation of these osmolytes is based on a pathway that is otherwise only known as the urea cycle in animals.

Particularly fascinating is the fact that at the onset of freezing, the survivalists protect themselves with special antifreeze proteins. Related algal species that grow only in open water do not produce these antifreeze proteins. The algae have also adapted well to the relative darkness: They are capable of growing well under light conditions corresponding to the light of a candle.

Another problem: in sub-zero temperatures, the photosynthetic membranes, in which light is converted into energy, have to remain flexible. Special oils called "PUFAs" (polyunsaturated fatty acids), are synthesized by the algae. Sea ice algae contain much higher concentrations of PUFAs than algae in the water. Via the food chain, these are consumed by crustaceans and fish and thus ultimately end up on our plates. Important, since PUFAs are essential for humans because we cannot synthesise these ourselves.

Recently, the evolution and function of sea ice algae have been studied using modern molecular biological methods. The biologist at the Alfred Wegener Institute, are decrypting the genetic material ("genome") of the algae to compare it with the genetic material of related species not living in the ice. This method is used to determine exactly which algae occur in the ice and what part of the genotype is important. The algae expert and molecular biologist Dr. Klaus Valentin says: "ice algae have actually adapted all their genes to the low temperatures and formed many new features, some of them even taken over from other organisms such as bacteria."

But what does the future of the ice algae look like? Global warming is leading to a long-term decline in sea ice, which is also the habitat of the ice algae. This is becoming smaller and smaller and the coupled ice food web is likely to be affected, because less ice algae means less food for many other organisms. The effects of climate change on the food chain in the polar oceans is finding international resonance and this research area at the AWI is also being driven by sea ice and plankton researchers.



As beautiful as a piece of jewellery, but only recognizable under the microscope in all its glory: a chain of ice algal cells (*Fragilariopsis cylindrus*) approximately 0.4 mm long.
Photo: H. Lange, AWI

RV 'Polarstern' in a coastal polynya in front of the shelf ice in Antarctica.
Photo: AWI

Ocean acidification and iron deficiency affect Antarctic phytoplankton communities

In all oceans, phytoplankton is the basis of the marine food web: The small, single-celled, free-floating algae in the water convert carbon dioxide (CO_2) into organic carbon with the aid of sunlight. Southern Ocean phytoplankton accounts for 20 percent of the total biomass produced by the world's oceans. How will future phytoplankton communities be affected by climate change? What impact will rising temperatures and ocean acidification have?

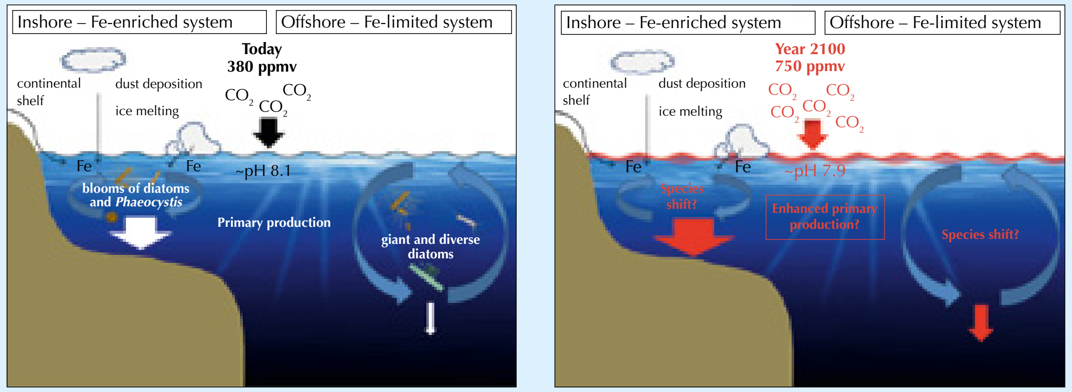
In the Southern Ocean, especially in open waters, macronutrient concentrations, such as nitrate and phosphate are high. Phytoplankton productivity is, however, limited by low concentrations of the important trace element iron. Coastal waters and continental shelf regions of Antarctica are rich in iron, leading to extensive phytoplankton blooms. Strong storms in the Southern Ocean cause a particularly deep mixing of the upper water layer, resulting in low and highly variable light intensities, which also significantly affect phytoplankton productivity.

By 2100, it is expected that atmospheric CO_2 concentrations will increase to levels three times as high as at the beginning of the industrialization. The consequences for the oceans are dramatic: The pH will decrease by up to 0.4 units and consequently increase the acidity of seawater. Moreover, the increasing global temperatures will lead to a warming of the sea surface and a lower mixing depth of the upper water layers, which in turn will increase the mean light intensities and reduce the input of nutrients from deeper water layers. Climate models predict that in comparison with other ocean regions, the environmental changes in the Southern Ocean will be especially severe. All these environmental factors (pH, temperature, light) will affect trace metal solubility and therewith influence bioavailability of iron. The pivotal questions of researchers therefore are: How will these changes influence the composition of future phytoplankton communities in open ocean and coastal regions and possibly alter their productivity?

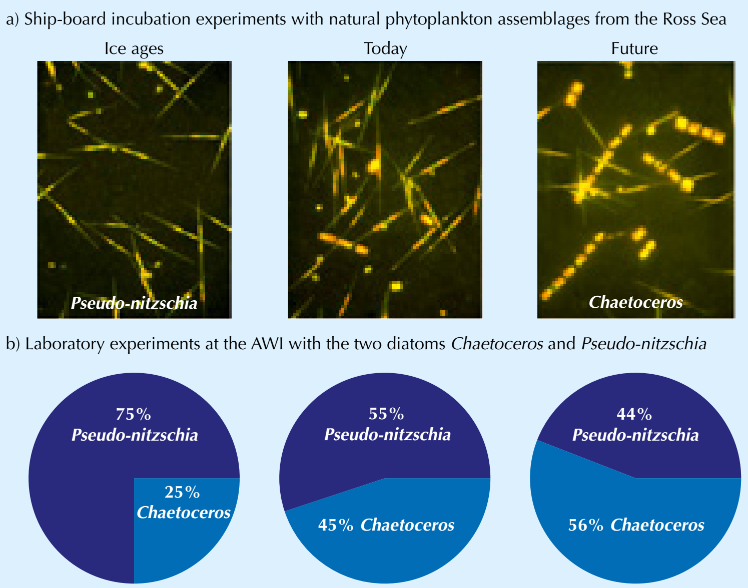
The ecology and biogeochemistry of the Southern Ocean is dominated by diatoms and the flagellate *Phaeocystis*. Diatoms are unique among phytoplankton in that they build stable silica shells. In coastal areas of the Southern Ocean, diatoms and *Phaeocystis* often form blooms. However, in the open ocean blooms are rare due to iron deficiency. Changing environmental conditions are likely to affect Southern Ocean phytoplankton in many ways. So far, relatively little information is available on the potential CO_2 sensitivity of Southern Ocean phytoplankton. The first answers to these questions were found by biologists of the AWI, during an expedition in the Ross Sea. "Joint experiments with our Canadian partners showed significant CO_2-induced changes, both in productivity and phytoplankton species composition. Especially diatoms such as the chain-forming *Chaetoceros* seem to benefit from future higher CO_2 concentrations, while under lower CO_2 concentrations, such as they occurred during ice ages, the needle-shaped diatom *Pseudo-nitzschia* dominated" explains the phytoplankton expert Dr. Scarlett Trimborn.

To improve our understanding of CO_2 effects on species shifts, laboratory experiments were carried out to test the influence of CO_2 on diatoms in competition with each other. To do so, the diatoms *Chaetoceros* and *Pseudo-nitzschia* were cultivated together under glacial, present and future CO_2 concentrations. In line with the observations at sea, the growth of *Chaetoceros* increased under elevated CO_2 concentrations, while the population of *Pseudo-nitzschia* declined. This enabled the researchers to demonstrate that diatom species react differently to ocean acidification. These responses could partly be explained by the different physiology of the two species.

The potential of species shifts in Southern Ocean phytoplankton assemblages, in particular how ocean acidification effects are modulated under different iron availability, was further assessed during an expedition to the Weddell Sea. The cultivation of natural phytoplankton communities on board of 'Polarstern' under various CO_2 scenarios in combination with different iron concentrations gave new insights into the understanding of the CO_2 sensitivity of Antarctic phytoplankton: Altered availability of iron in combination with ocean acidification potentially leads to a different species composition. Further laboratory and field experiments are planned and will include investigations on the effect of CO_2 under dynamic light conditions as they occur in the water column. Also, the infuence of dust deposition and the iron contained therein will be explored under different ocean acidification scenarios. Further, the role of grazers on iron bioavailability for phytoplankter will be addressed in future 'Polarstern' cruises.

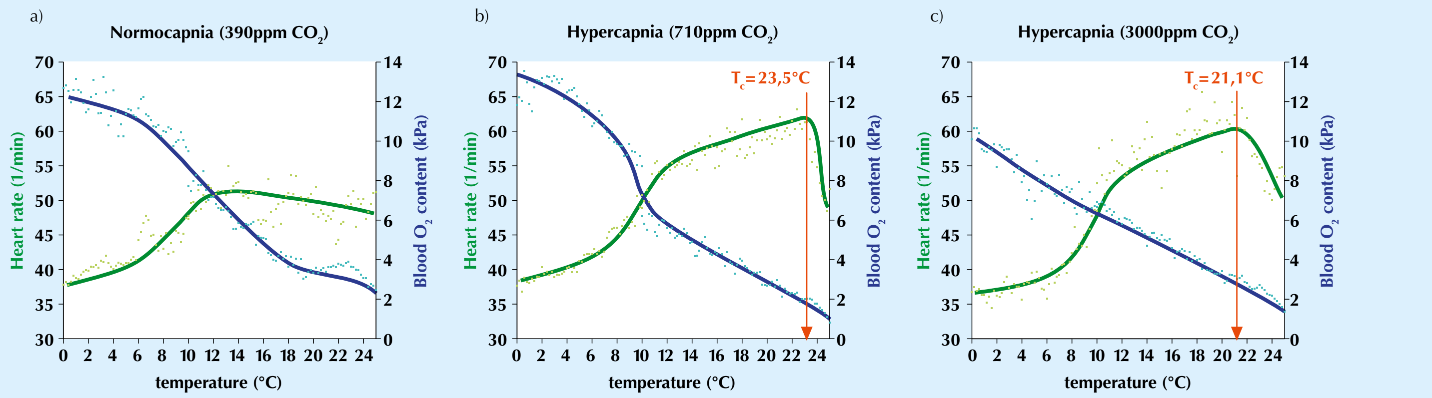


Phytoplankton communities of the Southern Ocean are largely structured by the presence of the trace element iron. The phytoplankton of the coastal and shelf regions benefit greatly from iron input through either dust deposition, melting icebergs or land-run-offs and contact with sediments, often resulting in diatom and *Phaeocystis* blooms. In the oceanic regions, however, iron deficiency precludes phytoplankton growth. Here the species communities are very diverse, and especially large species occur. Models predict that climate change effects in the Southern Ocean are likely to be particularly severe in comparison to other ocean regions. How will coastal and oceanic regions of the Southern Ocean react to this? Today, the CO_2 concentration in air is about 380 ppmv, which in turn relates to a pH of ~ 8.1 in seawater. By the year 2100, it is expected that the CO_2 concentration in the air will increase to 750 ppmv as a result of fossil fuels burning, so that the pH of seawater will drop to 7.9, thus acidifying the sea. So far, little is known about the influence of ocean acidification on the phytoplankton communities in the open ocean and coastal regions. Will higher CO_2 concentrations in the future change the species community structure and lead to enhanced primary productivity?
Graphics: S. Trimborn, AWI



a) Ship-board incubation experiments with natural phytoplankton assemblages from the Ross Sea show CO_2-dependent changes in the species composition of diatoms. Under low CO_2 concentrations, as they occurred during the ice ages, the needle-shaped diatom *Pseudo-nitzschia* dominated, while at higher future CO_2 concentrations the growth of chain-forming *Chaetoceros* increased. b) In the laboratory, similar observations were made during competition experiments, in which the diatoms *Chaetoceros* and *Pseudo-nitzschia* were grown under CO_2 concentrations of the ice ages, today and future. The cell numbers of *Chaetoceros* increased from 25% to 56% under elevated CO_2 concentrations, while those of *Pseudo-nitzschia* decreased from 75% to 44% under these conditions.
Graphics: Photos by Tortell et al. 2008 and 2010, Pie charts nach Trimborn et al., unpublished data

An ice fish, caught during an expedition. These polar fish are unable to compensate the increased oxygen demand at higher temperatures. Adult greater spider crab (*Hyas araneus*) and Greater spider crab larva (*Hyas araneus* Zoea I).
Photos: F. Mark, M. Schiffer, L. Harms, AWI



Curves showing heart rate (green) and oxygen concentration (blue) in the blood of the spider crab from Helgoland under normocapnia (current atmospheric CO_2 concentration; 390ppm) and hypercapnia (elevated atmospheric CO_2 concentrations, b & c). The forecast for 2100 is 710ppm CO_2. When heated above the optimal habitat temperature of 10 °C, hypercapnia increasingly impairs the efficiency of the animals: Rising temperatures increase the metabolic rate and oxygen consumption and the oxygen concentration in the blood begins to decline. To ensure the supply of oxygen under hypercapnia the heart must pump more blood and the heart rate increases. If the heart can no longer meet its own demand of oxygen, the heart's performance is reduced, and the oxygen supply to the body breaks down (red arrows). This capacity limitation marks the critical temperature (T_c, red). Under normocapnia (a) it lies above the experimental temperatures (> 25 °C), but decreases to 21.1 °C with increasing CO_2 concentrations (b, c).
Graphics: after Walther et al., 2009

The oceans are acidifying: spider crabs and ice fish are feeling the repercussions of climate change

Carbon dioxide as a greenhouse gas not only warms the climate and, thereby, the oceans but will also acidify the seawater – with drastic effects on the life and the distribution of fish and crustaceans in the polar latitudes.

Polar organisms have very specifically adapted to the stable, cold temperatures in the high Arctic and Antarctic. Many metabolic processes in crustaceans and fish have been optimized for life in icy conditions. A temperature increase and elevated CO_2 concentrations will be difficult if not impossible to compensate. To estimate the interaction of temperature and carbon dioxide concentrations in the sea and their consequences, scientists from the AWI are studying various cold-blooded polar organisms, and comparing them to species from temperate latitudes. They want to evaluate the effects of temperature increase and ocean acidification on life and the distribution of marine animals.

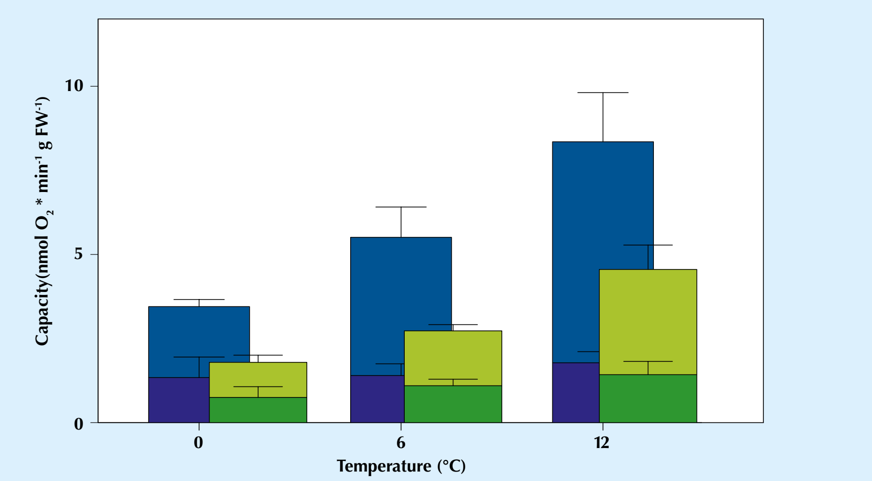
The great spider crab *Hyas araneus*, whose distribution ranges from the arctic waters around Spitsbergen to Helgoland in the German Bight, in its southern distribution limit, is very sensitive to rising temperatures. Poikilothermic (cold-blooded) organisms increase their metabolic rates at higher temperatures, so that the animals need more energy. Crustaceans have to increase their heart rate, among other things, so that more oxygen is transported to the organs. Above a certain temperature, this increased oxygen demand cannot be met anymore. Scientists call this the "critical temperature", since it marks the upper end of the temperature tolerance of an organism. Acidification of seawater due to increased carbon dioxide levels lowers the critical temperature and severely constrains the temperature tolerance of the crab. At their northern distribution limit, the spider crabs have acclimatised to lower temperatures in contrast to their southern cousins, and therefore have a higher thermal sensitivity.

The spider crab already reacts to changes at an early larval stage. It consumes less food, growth and development slows down, with one of the consequences being a higher mortality rate. Thus, the entire developmental cycle of this species is negatively and enduringly disturbed by CO_2 changes. "In the long term, this could lead to a shift of its range to colder, northern areas, at least to avoid the problem of temperature. However, this will only succeed if the resulting changes in species composition in the new ecosystem remain balanced and the animals are able to permanently find enough food and encounter few predators", says the marine animal physiologist Dr. Felix Mark.

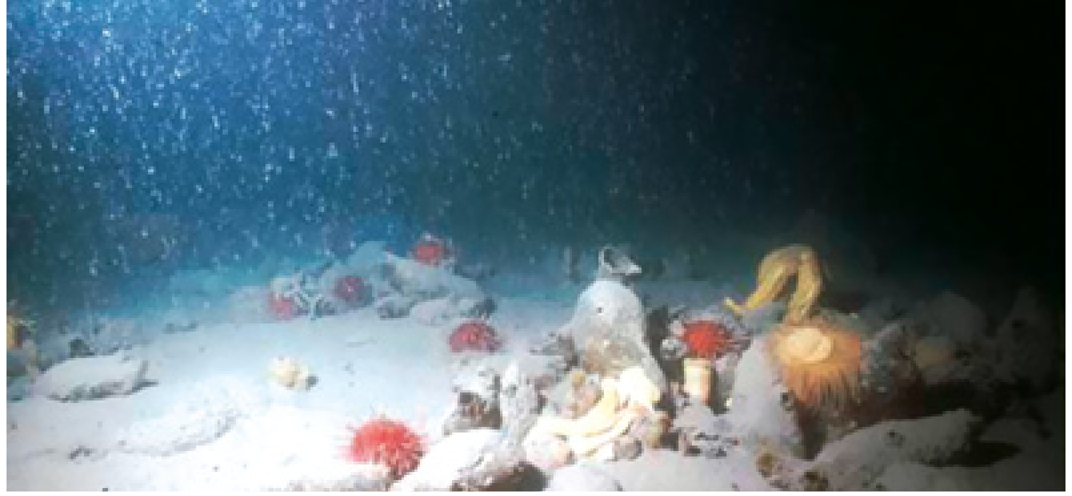
Residents of Polar Regions, which are adapted to the permanent cold react sensitively to warming and acidification. For instance, polar fish are exceptionally well adapted to the constant cold temperatures. In some fish species of the Antarctic, for example the ice fish, this has even led to loss of the oxygen-carrying molecules haemoglobin and myoglobin. Because of their low metabolic rates, the fish are able to rely solely on the dissolved oxygen in the blood. This considerably limits the oxygen-carrying capacity of blood and can only function to this extent in the cold and stable living conditions of Antarctica because oxygen dissolves more readily in cold sea-water. In a warming ocean, the increased oxygen demand thus soon cannot be met anymore.

To better understand these processes, AWI researchers have for the first time tested the effect of CO_2 on mitochondria. These are small organelles that provide the body with the vital energy. They produce a general energy carrier, ATP, from energy-rich molecules (glucose, fatty acids) and oxygen. In order to most effectively utilize the available oxygen and to compensate metabolic peak loads, mitochondrial capacities are often enlarged in polar species. Recent studies in the Biosciences Faculty of the AWI have shown that an increase in seawater carbon dioxide concentrations appears to reduce both mitochondrial capacities and their ability to adapt to higher temperatures. At the upper end of the temperature range, the mitochondria are no longer able to meet the energy requirements of the organism. The consequences of hypercapnic exposure can thus induce a decrease of the animal's "critical temperature", reducing its temperature tolerance.

Unlike the spider crab, the cold adapted fish species are not able to compensate the consequences of global warming by migrating to colder regions. They are therefore at a kind of „evolutionary dead end" and run the risk of being unable to keep up with rapid climate change.



The mitochondrial capacity of a cold-adapted Antarctic fish (*Notothenia rossii*) before (blue) and after two months of adaptation to 2000ppm CO_2 (green). Shown are the capacities of the mitochondrial complex 1 (dark) and 2 (light) at ambient temperature (0 °C) and two elevated temperatures (6 and 12 °C). In all cases the capacity is greatly reduced under hypercapnia.
Graphic: Strobel et al., in prep



Many benthic organisms in the Antarctic are filter feeders. During times of intensive glacier melting, clouds of silt from glacial run-off cover the animals. Sensitive species leave these coastal areas, while other species spread.
Photo: R. Sahade, University of Cordoba, Argentina

Melting glaciers – Changing coastal ecosystems in the West Antarctic

On King George Island of the South Shetland archipelago near the West Antarctic Peninsula, scientists from Germany, Argentina and The Netherlands, together with partners from other countries are exploring how fast the glaciers are melting, and how coastal ecosystems respond to climate change.

The 1300 km long mountain ridge of the Antarctic Peninsula, the area of research, extends in a north-west direction towards Tierra del Fuego, and is only about 1000 kilometres away from the tip of South America. Unlike central Antarctica, the polar climate here is maritime. The mean annual air temperature at the Peninsula has increased by almost 3 °C since 1950, five times as fast as the global average. This warming causes a rapid decline of ice shelves and coastal glaciers.

Scientists want to know whether the current warming phase is really an exceptional event and a direct consequence of anthropogenic CO_2 emissions? Or are we experiencing a cyclically recurring period of natural warming of our planet?

To answer these questions, scientists study sediment cores, in which they track the earth's historical climate. The dating of geomorphologically old features on land also provides important insights, because fossil beaches that are now 10 feet above sea level, once represented the ocean floor. Remains of shells are the proof and enable us to draw conclusions on geochemical conditions in marine sediments during the lifetime of the animals, about 5000-7000 years ago.

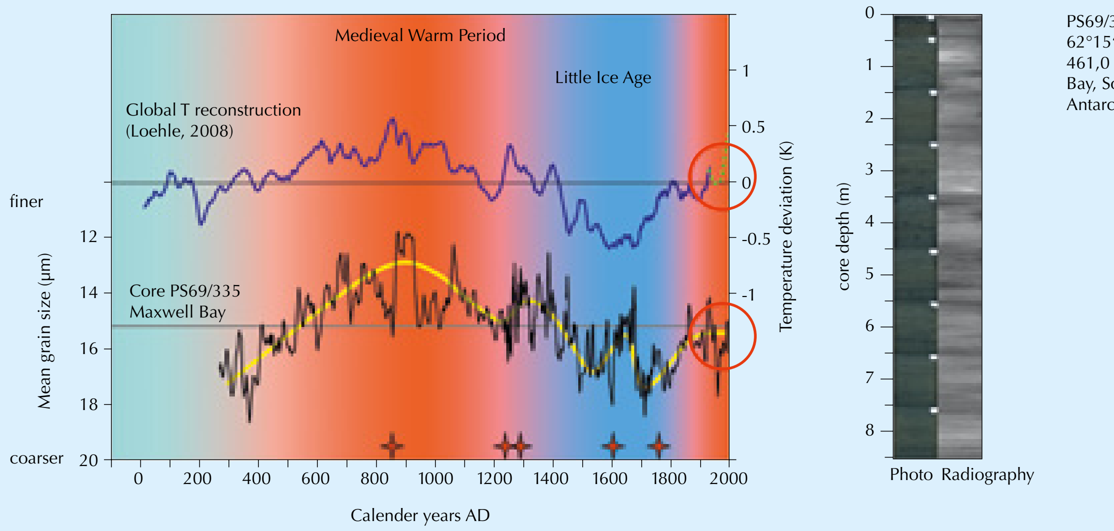
Satellite images provide information on the current effects of climate change, since they continuously document the stages of ice retreat. Differential GPS altitude measurements of the glaciers over the past 15 years show a marked decrease of the ice especially within the first 250m of glacier altitude above sea level. Modelling of the glaciers' mass balance, supported by extensive meteorological measurements and direct recordings of coastal run-off volume enable us to estimate the melt-water input into the bays. These melt-water streams carry very fine sediments, known as particulate matter, which are transported out of the fjords of the island and deposited in deeper areas. The fine-grained sediments represent a climate archive of high temporal resolution, which is analysed using sediment cores of several meters length.

According to the varying contribution of melt-water sediments, researchers are able to reconstruct global climate signals around the peninsula during cooler phases, such as the Little Ice Age (ca.1350-1900 AD) and warmer phases such as the Medieval Warm Period (about 700-1350 AD). "Our data show that the current warming trend is different from similar climate phases during the past 2000 years," explains Dr. Christian Hass, sedimentologist from the AWI.

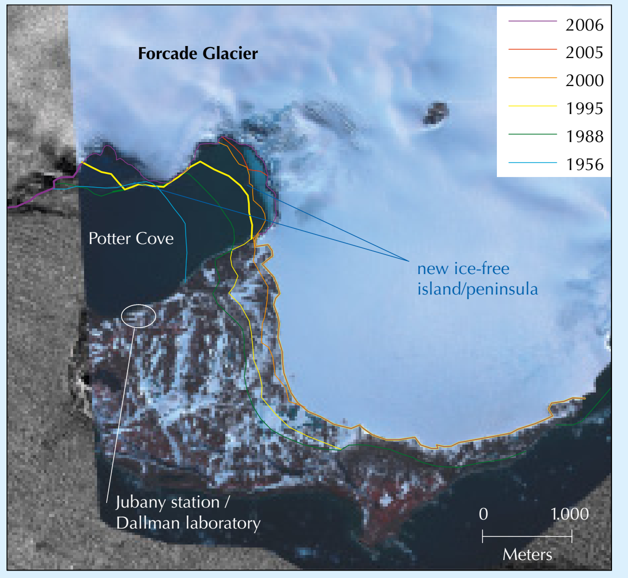
To achieve the recent climate reconstruction, the geochemical composition of the particle load is examined more closely, with the focus being on the past 100 years i.e. the period in which the massive glacial retreat occurred. Measurements of naturally occurring lead isotopes in the sediment show that the amount of deposited sediment has tripled since the middle of the last century, due climate change.

Glacial retreat and sediment runoff have a massive impact on the coastal marine habitat, and thus on ecosystems. Fjords such as Potter Cove are densely colonized by benthic algae and animals. Decreasing salinity and sediment runoff from the melting ice reduce phytoplankton primary productivity in spring. Important Antarctic organisms such as krill are no longer encountered in the cove. An increasing silt deposition on the sea floor and changes in the pelagic food web, in large parts of the fjord, are leading to the impoverishment of the benthic communities. Sediment-tolerant species such as the Antarctic soft-shell clam *Laternula elliptica* (Pennatulidae) are propagating. Interestingly, this species is also documenting the change. *Laternula* has slower growth rates in areas with high sedimentation rates, which is probably due to the dilution of their planktonic food with sediment particles, or to the increasing oxygen deficiency in the sediments.

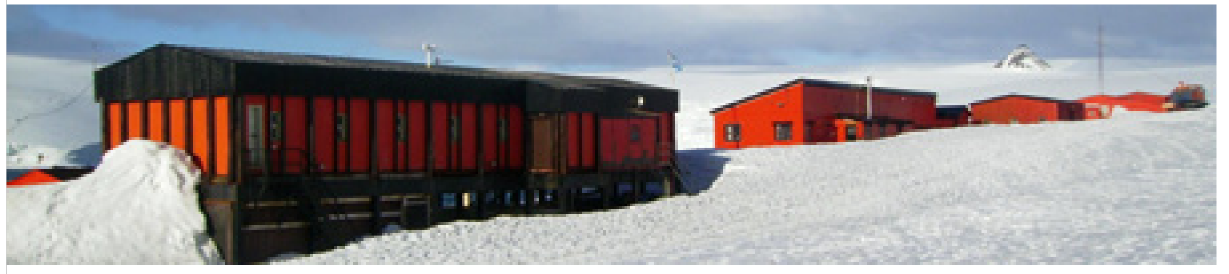
"It is a fact, that the effects of global warming are particularly strongly manifested in the coastal areas of the Antarctic Peninsula and, in turn, have a large impact on coastal oceanic areas" says Dr. Doris Abele from the AWI, the German coordinator of the project IMCOAST in the PolarCLIMATE program of the European Science Foundation. Abele says: "The islands can be regarded as ‚hot spots', indicators and as drivers of changes in the system. Therefore, we need to understand the local processes and link them to the regional models of the Southern Ocean".



The sediment core from Maxwell Bay ('Polarstern' cruise ANT-XXIII / 4) shows how the sedimentary processes have changed over time. The analyses of sediments from different depth horizons enable conclusions to be drawn about geological and climatic history: Smaller grain sizes during warmer climate and increasing grain diameter during cold periods.
Graphics: N. Wittenberg, C. Hass, AWI-Sylt

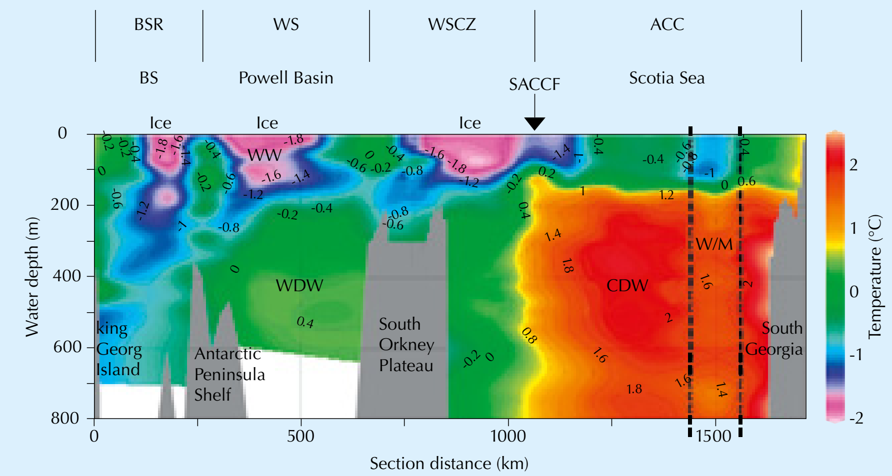


Reconstruction of glacial retreat in Potter Cove over a period of 50 years since 1956. The coloured lines show the glacier front on satellite images from different years.
Graphic: M. Braun, University of Fairbanks, Alaska



Dallmann laboratory on the Argentine station Jubany, King George Iceland, South Shetland archipelago.
Photo: D. Abele, AWI

Elephant seal bull with a satellite transmitter on its head lying in a "seaweed salad" on the beach at King George Island. Data transmitted include the seals position, dive depth, water temperature and salinity. The unit is lost no later than the next moult
Photo: J. Plötz, AWI



Temperature distribution in the ocean region between King George island and South Georgia, as measured by an elephant seal during the period from April to October 2010. The 1700 km long temperature transect comprises 540 dive profiles down to a depth of 800 m. The ice cover in winter is also documented, as is the separation of the oceanic regimes by the Southern Antarctic Circumpolar Current Front (SACCF) and the very deep mixed layer in the Bransfield Strait (BS). Even smaller structures at depth such as the location of the Warm Deep Water core (WDW) in the Powell basin or an eddy or meander of the Antarctic Circumpolar Current (ACC) are shown in detail by the remote sensing data obtained via the seals
Graphic: Ocean Data View: M. Schröder, AWI

In the service of science: Elephant seals explore the Southern Ocean

Elephant seal bulls transmit scientific data from the Southern Ocean onto the computers of biologists at the Alfred Wegener Institute via satellite. Unique are the high-tech sensors glued onto their heads, which in addition to depth also record water temperature and salinity – data, which are also of interest to oceanographers.

King George Island near the tip of the Antarctic Peninsula. With the onset of the Antarctic winter, from mid-March to late April, the portly males of the southernmost elephant seal colony haul out and gather on the beaches to moult, representatives of the largest seal species on our planet. The mighty bulls can weigh up to 4 tons. Out at sea they are rather solitary, while on the beach, they are crowded together and warm each other. Researchers from the AWI have equipped some of these animals with transmitters, which even for experienced researchers like Dr. Joachim Plötz and Dr. Horst Bornemann is not an everyday situation: "The transmitters do not affect the animals, however, for us it is always a challenge when we face some deep booming elephant bulls to glue a palm-sized satellite transmitter onto the skin of their heads" says Plötz. After moulting the bulls return to the water to begin an extensive migration, returning to their beaches to mate, only after six months.

When migrating to their oceanic feeding grounds elephant seals cover distances of thousands of kilometres. They dive to depths of 400 to 800 meters, sometimes up to 2,000 meters for periods over an hour. When a seal with a transmitter dives, it will collect data, even under ice, and when it surfaces after some time to breathe, collected data are transmitted to a satellite, which relays the signals to ground stations. With luck, the transmitter will transmit data continuously for a year until it falls off during the next moult.

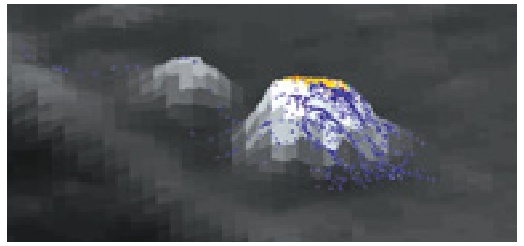
Not only are geographical positions and depths of each seal transmitted almost in real time, but they also provide data on temperature and salinity of the water masses the animals traverse both horizontally and vertically. Thus they provide important physical parameters from which to draw conclusions about ocean circulation and associated information on the heat balance in the Antarctic Ocean. Initial analyses of data collected during the 2010/11 have revealed a wealth of biological and hydrographic information. Data obtained during the winter months are particularly sought after, since continuous measurements during this time of year are rare, because ships seldom travel in the ice-covered regions.

In the icy wastes of the Antarctic Ocean, seals lead a nomadic life. For the researchers, this is interesting because they are constantly in search of rich feeding grounds where they eat fish and squid. Food in the sea is not evenly distributed. "From the migratory behaviour of animals, we can draw conclusions about the spatial and temporal distribution of particularly productive zones in the Antarctic Ocean. If the stocks of fish and squid are reduced by excessive fishing, or as a result of climate change it is likely to affect the behaviour of the elephant seal" says Plötz.

By means of remote sensing, biologists track the seasonal changes in the migratory behaviour of the seals and obtain clues on when, where and in what water depth particularly large prey stocks occur and on the oceanographic conditions associated with the good food availability. But why are certain areas more appropriate for foraging than others and repeatedly frequented? To better understand the ecological relationships, the seal experts work closely with fish biologists and physicists at the AWI. Thus, information on oceanography and fish resources in a region is combined with the studies of the seal researchers. "The migration of seals to specific areas, as well as the knowledge of their diving activities, gained over several years, provide better insights into the temporal and spatial dynamics of plankton and fish stocks than is possible only by fisheries biological research," disclose Plötz and Bornemann.

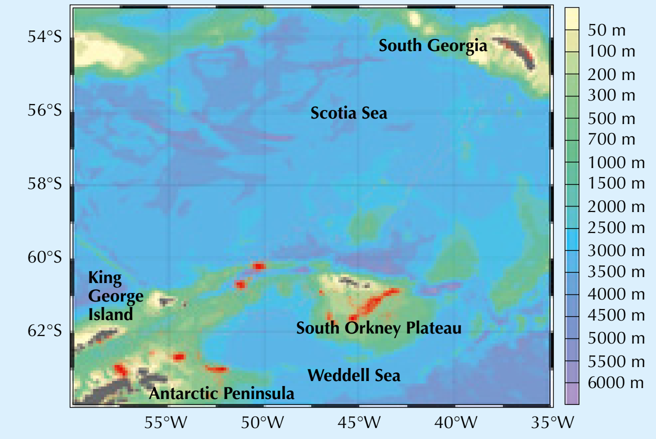
Thus, all data collected by the joint German-South African-Argentine project are made available immediately after evaluation, to world data centres, through the data archive PANGAEA and incorporated into various international collaborative projects. With this project, the AWI also makes an important contribution to the internationally coordinated Scientific Committee on Antarctic Research (SCAR).

Seal researchers during their work on King George Island.
Photo: J. Plötz, AWI



So-called „feeding hot spot" of elephant seals over a submarine elevation. The dotted pattern shows the spatial compression of the individual dives over the top and on the slopes of the seamount.
Graphic: L. Fillinger, AWI

The extensive migrations of the elephant seals in search of food provide an opportunity to explore, via satellite, large areas of the Southern Ocean starting from King George Island, during winter. Productive foraging zones are clearly indicated by dense aggregations of the seals' positions (clouds of red dots). In October 2010, some of the bulls went to South Georgia to mate.
Graphic: Ocean Data View: H. Bornemann, AWI



The call of humpback whales surprised the ocean acousticians of the AWI. They did not expect to find these mammals that far south during the Antarctic winter
Photos: I.v. Opzeeland, AWI

Ocean Acoustics – PALAOA broadcasts live from the Southern Ocean

Sometimes all we hear is a background noise. Then, suddenly, the wonderful whistle of the Weddell seal – how fascinating also the clicking of orcas and the deep powerful vocals of blue whales. It makes one feels so small as a human on this earth. Wouldn't it be fantastic to listen all day? A scientist who is able to do just that is biologist Dr. Ilse van Opzeeland. She is an ocean acoustician and evaluates the sounds recorded by the PALAOA observatory in the Southern Ocean, to study the behaviour of marine mammals. A personal report on the fascinating underwater world of sound.

I have been interested in the behaviour of marine animals for as long as I remember. Particularly their use of sound for communication and orientation in a low light environment. First, I studied Biology in Groningen and Tromsø and specialized in bio-acoustics. For my Masters thesis I studied the acoustic behaviour of harp seals in Greenland and killer whales in Norway. Subsequently I started my PhD at the AWI in Bremerhaven. A great opportunity for me, for the Institute operates the only hydro-acoustic observatory in the vicinity of the Antarctic continent: PALAOA - Perennial Acoustic Observatory in the Antarctic Ocean (or 'whale' in Hawaiian).

Our container stands on the Ekström Ice Shelf in the eastern Weddell Sea at the position 70° 31'S 8° 13'W. It is filled with technology and powered by solar energy panels, a wind generator and a fuel cell. Two hydrophones are positioned under the 100-meter-thick, floating ice sheet. Since December 2005, they continuously record underwater sounds - to date more than 33,000 hours or 6 Terabytes of data. Everyone is welcome to listen into the Southern Ocean live at www.awi.de/PALAOA. We record a wide range of frequencies, for example, the low-frequency sounds of blue whales and the high-frequency clicks of orcas, which these animals use for orientation, similar to an echo sounder.

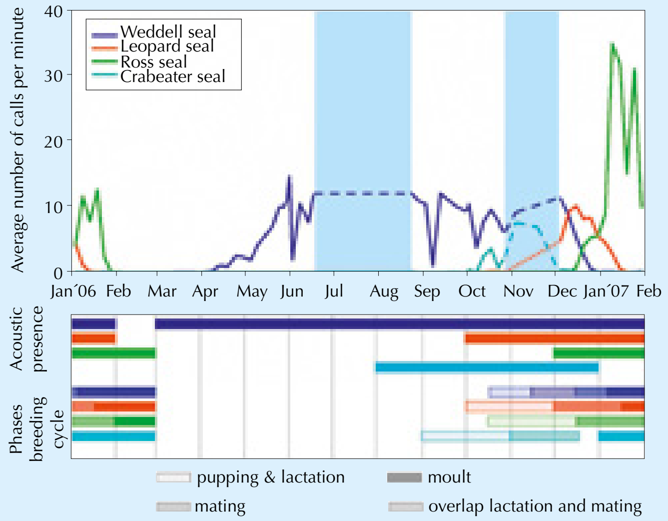
The continuous recording gives us a „look" into a world which is difficult to access due to the extreme climatic conditions. One would seldom see the animals anyway, because they only appear from time to time to breathe. However, listening is always possible, provided of course that the animals vocalize. Our recordings have therefore led to many new insights into areas of distribution, seasonal migration and population dynamics of several species of whales and seals.

We hear the sounds of four seal species, the leopard, Weddell, Ross and crabeater seal as well as various types of toothed and baleen whales. Occasionally we also hear the calving of icebergs, ice floes grinding against each other and sometimes the collision of two icebergs. Mysterious sounds of unknown origin are sometimes also among the recordings. The marvellous thing is, we can hear on-line when marine mammals move through the sea close to the underwater microphones. While working in the office, thousands of kilometres away from Antarctica, one hears the „live stream" from the Southern Ocean. In order not to miss anything, I even switch it on at home, and one morning I heard to my great surprise, the calls of humpback whales – and even more surprising, during the Antarctic winter. Incredible, because this is the time humpback whales usually reside in tropical and subtropical oceans. Presumably some of these baleen whales linger around in their Antarctic feeding grounds to be fit for the coming mating season. Despite the extensive and complete sea ice sheet, which covers the Southern Ocean in winter, the whales seem to be next to the ice shelf edge where they move about in open water areas and can come to the surface to breathe.

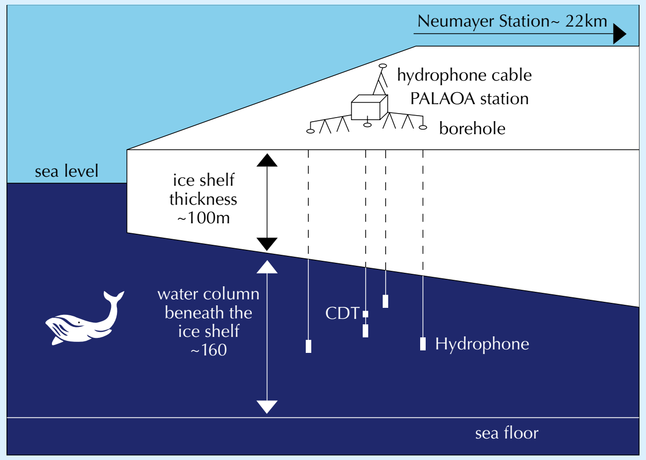
When I began my doctoral work, we were in a position to assign the recorded sounds to the different types of animal species, but we had no clear picture of the full repertoire of their voices. We wanted to know what exactly individual sounds mean and when and why the animals produce them. In my first year I browsed over 10,000 files of PALAOA recordings and worked my way through the spectrograms, which are the visual representation of the sound. This meant a record total of 180 hours of underwater sounds. From this analysis we were able to describe the seasonal behavioural cycle of all species occurring in the PALAOA data base and develop computer-based detectors for further automatic analyses.

Leopard and Ross seals, with their calls, have revealed to us that they were reproducing in the Antarctic coastal waters. Previously, this was known only for Weddell seals and crabeater seals. It amazed us that each of the four seal species would „speak up" at specific times. This acoustic behaviour is also linked to different ice conditions. The timing here is sensational: the mating calls of some species of seals actually start each year during the same calendar weeks.

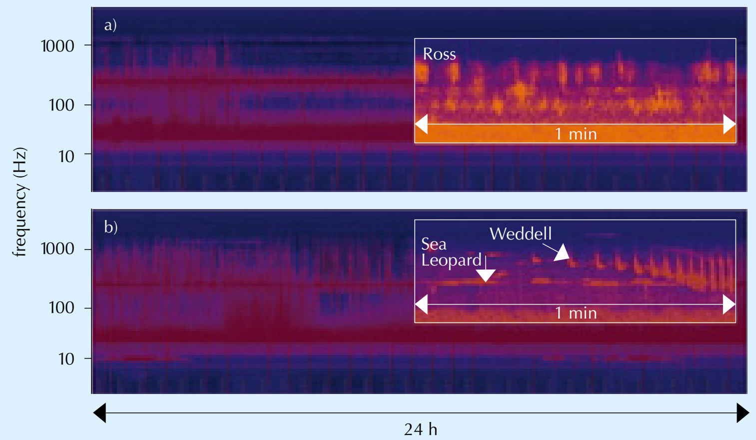
I was able to complete my PhD successfully in December 2010. Now, as a post-doc in the research group „Ocean Acoustics" I am studying the recordings of additional offshore acoustic recorders, to understand the acoustic activity of marine mammals in a wider area and also to assess long-term population trends, such as for the blue whale.



Call activity of four species of seals in the Antarctic during the period January 2006 to February 2007 (above). Light blue areas show data from the year 2007, which were used as a substitute for missing data in 2006. Below: Acoustic presence (upper 4 Bars) and times of birth, rearing, mating and moulting (lower 4 bars).
Graphic: I. v. Opzeeland, AWI

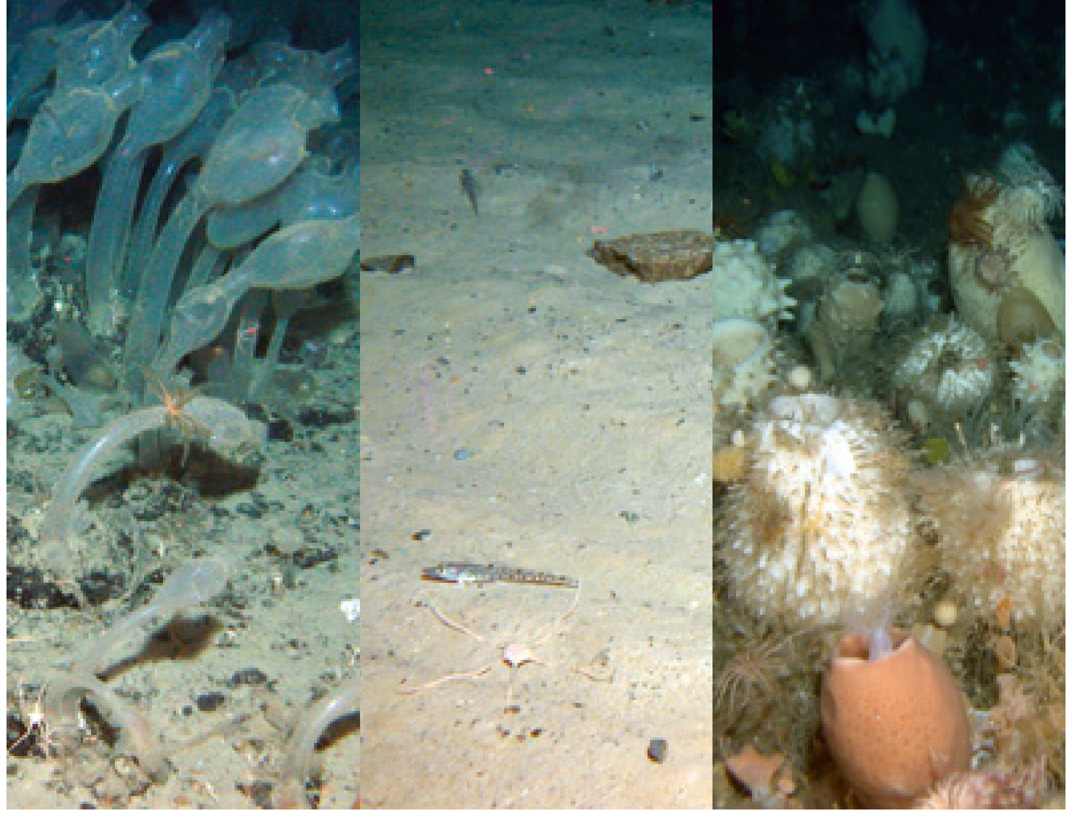


Schematic representation of the PALAOA hydrophone arrays. The actual station is located in the centre of an array of 4 hydrophones, which are located in the water beneath the floating ice shelf. A CTD sensor is attached to the cable of the central hydrophone, which records oceanographic data at the same time. The distance between PALAOA and Neumayer Station III is 22 km.
Graphic: from Klinck 2008



Two long-time spectrograms, each representing 24 hours of PALAOA recordings:
a) Daily spectrogram obtained on 26th December 2009 showing the call of a Ross Seal. The red band comprises calls shown in high resolution in the included image. b) Daily spectrogram obtained on 14th December 2009 with calls of the Leopard and Weddell Seal, with examples of both types of calls inserted in a temporally high-resolution image.
Graphic: PALAOA, AWI

The common sea squirt *Molgula pedunculata* (left) is considered a pioneer species. Since its presence in the Larsen B area is interrupted by iceberg scours (centre), which can only have been produced after the ice shelf collapsed, this population is probably related to that of Larsen A area to the north. There, the ice shelf broke away earlier and since then is the source of food for the sea squirts. Various sponge species are very common in undisturbed areas in the south-eastern Weddell Sea, and together with other species contribute to the diversity of life (right).
Photos: J. Gutt, W. Dimmler, ©AWI/Marum, University of Bremen



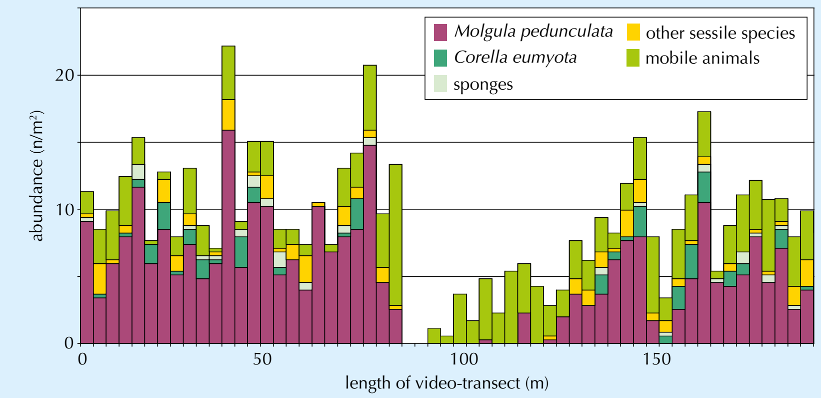
When ice shelves disintegrate – diversity of life on the Antarctic seabed

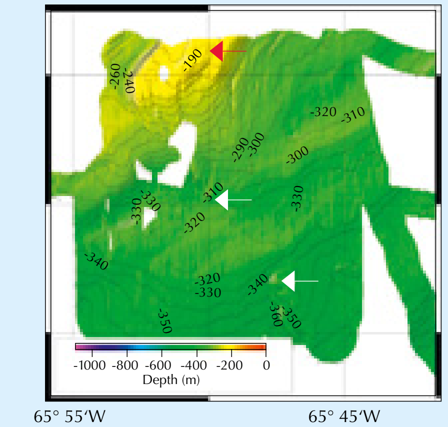
When in 1995 and 2002 a major ice shelf in the Larsen region collapsed, the tabular masses disintegrated into hundreds of icebergs, many of which stranded on the adjacent continental shelf. During their expeditions into the Weddell Sea, AWI biologists together with international partners, study the impact of such events on the colonization of the benthic habitat. High tech equipment and ROVs are the tools which help looking into the depths.

The ecosystem of the Antarctic continental shelf extends around the continent for a distance of 40,000 kilometres, comprising an area almost half as large as Europe. One third of this habitat, which is up to 800 meters deep, lies under floating ice, the so-called ice shelves, which are still attached to the mighty ice cap. These ice shelves when they calve produce icebergs that can strand in the shallower areas of the continental shelf and consequently affect the wildlife in the ice-free areas.

A particularly interesting research region for scientists is the Larsen ice shelf east of the Antarctic Peninsula, which as a result of atmospheric warming collapsed and disintegrated into huge chunks of ice. This led to the exposure of a previously unknown habitat with severe consequences. “The extreme poverty of benthic animals can only partly be explained by the formerly sparse food availability. We are asking ourselves, which additional processes trigger the slow colonisation“ says marine ecologist Dr. Julian Gutt.

From previous expeditions, the researchers know that stranded icebergs sometimes leave a swath of destruction when they pass over a benthic community. The giant icebergs collide with the seabed where they don’t come to a halt but grind over the bottom somewhat like a plough would till a field. Surprisingly, after such events, a more diverse community develops there than in undisturbed areas. To investigate these processes and to determine the community composition, scientists sample the benthos with a box grab. An accurate depiction of the communities is obtained by remotely operated vehicle (ROV), which is deployed from research icebreaker ‘Polarstern’. Its camera sends real-time HD quality videos from 200 meters water depth. “In this way we are able to immediately see what is happening on the sea floor and have found a patchwork of different stages of biological re-colonisation revealing a higher biodiversity than undisturbed areas,“ says Dr. Rainer Knust, the chief scientist. The ROV collects samples of the different benthic species with its robotic arm, which the scientists then accurately identify using modern molecular biological methods.

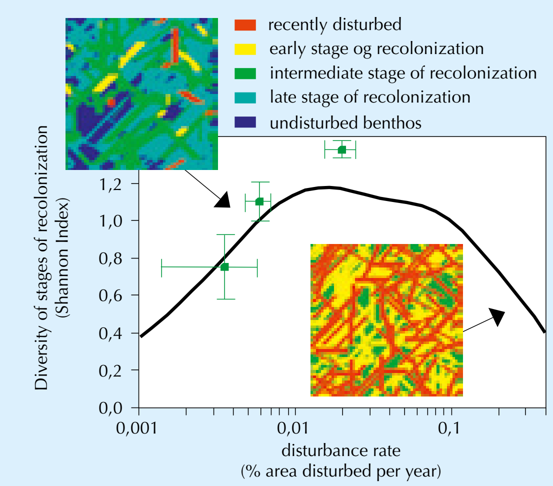




ROV videos showed that the ascidians (sea squirts) *Molgula pedunculata* and *Corella eumyota* occurred mainly on submarine elevations (right, red arrow) where they are exposed to food-rich currents. In contrast they were almost completely absent in close proximity to the mounts (white arrows). The bar graph (left) shows the analysis of a video strip taken by ROV along a 195 m long in the area marked with the red arrow in the right graphic. From left to right there is seen the frequency of sea squirts and the accompanying fauna, such as other mobile and sessile animals, as well as sponges.The community composition of these animals is interrupted by iceberg scratches, shown in the middle of the video, where only mobile animals occurred, which are capable of migrating.
Graphics: left: J. Gutt & Lieb, AWI; right: AWI Bathymetric working group, changed after Gutt et al. 2011

A long-term field experiment will now provide information about the rate of re-colonisation. In addition, computer models simulate, in time lapse, the relevant processes and enable the development of future scenarios under an higher or lower intensity of disturbance. The models show that the Antarctic benthic fauna is well adapted to space-constrained natural disturbances.

After the collapse of the Larsen Ice Shelf, for example, the filtering sea squirts reacted with “explosive“ growth to a change from nutrient-poor conditions to a nutrient-rich regime. They grow only in areas with favourable current conditions such on submarine elevations and are the harbinger of a broader transformation in the benthic colonisation. Grazing sea cucumbers, on the other hand are actually regarded as deep-sea organisms representative of the old ice-covered situation. However, the genus *Elpidia* obviously responds to improved food conditions with a particularly successful reproductive rate. This was confirmed by comparing data with results obtained by U.S. colleagues. Sediment sampling during a ‘Polarstern’ expedition shows the improved but still not favourable food conditions. A first fine-scale survey of the seafloor supports the biological studies and enables more comprehensive answers to the question of how this ecosystem actually functions.



A biodiversity model simulates the effects of stranded iceberg disturbance (X-axis) on diversity (Y-axis), shown as a black curve. The green squares with standard deviation bars are values that were calculated from direct field observations. The upper value denotes an area of particularly intense disturbance. The graph shows that the benthic diversity attains an optimum at intermediate disturbance intensity and only decreases when the disturbance increases significantly. The two spotted patterns in the model show how the stages of re-colonization are distributed on the ocean floor.
Graphic: K. Johst, UFZ, Leipzig & J.Gutt, AWI, modified after Johst et al. 2006 & Turner et al. 2009

Waterfall of melt water, partially frozen while falling, at the ice shelf edge, Larsen A.
Photo: W. Arntz, AWI

RV ‘Polarstern’ in Antarctica – observations in the ice

RV ‘Polarstern’ is the most sophisticated polar research vessel in the world. The AWI’s icebreaker every year spends nearly 310 days at sea. Between November and March, she usually travels in Antarctica, in the northern summer, in Arctic waters. Work on board is tough, the impressions unforgettable. Observations in the ice - narrated by Prof. Dr. Wolf Arntz during a research cruise in the Larsen area east of the Antarctic Peninsula.

We are in a landscape of iceberg rubble. Miserable visibility due to fog or heavy snowfall is preventing ice reconnaissance and slowing our progress. It is impossible to find leads or open water in which we can work. Compact fields of ice and growlers are a danger for wires, cables and instruments. High seas are breaking on deck, causing devices such as the Multi-corer to swing about and difficult to hold. The light plankton nets turn into kites.

Larsen A: The marine life in the area of the collapsed the ice shelf has some surprises in stall for us: sea urchins, brittle stars and feather stars alongside sea squirts and sponges, some of which reach a considerable size. Covering the sea floor, are hundreds of small sea anemones (Actiniaria) resembling a meadow of snowdrops. Overall, however, the benthic community here is not very rich.

At Larsen-B the Remote Operated Vehicle (ROV) is returning fascinating images to us, live from the ocean floor: yellow, stalked „sea lilies“ (crinoids) in small groups on stones, holding the underside of their tentacle crown into the current. Unbelievable that this group has inhabited Earth for 500 million years. The stalked forms are actually restricted to the deep sea and here at Larsen probably represent a relic of the nutrient poor deep-sea conditions under the ice shelf. The free-swimming form most likely immigrated only after the collapse of the ice shelf and will probably prevail in the long term. Other conspicuous organisms are the cucumbers, especially the „sea pig type“, which are also usually found at great depths. Despite these interesting observations, it is clear that the faunal composition of Larsen-B, nine years after the collapse of the ice shelf, is still far from normal.

The real surprise, however, is Larsen-C. The Agassiz and bottom trawl catches there are poorer than at Larsen B. They contain sea cucumbers and brittle stars, but hardly any fish. Why do so few species live here? Even under these apparently miserable conditions, the ROV provides us with unique images: a large, red starfish, which is usually damaged by the trawls, sits on rocks like the feather stars, and with its tentacles filters particles out of the water. On two occasions the ROV encounters octopus with bright green eyes. We use the benthic-pelagic trawl to see which fish live in the water column. The result is meagre with 20 kilos of ice krill and two dozen little fish up to 7 cm in length, which corresponds to the poor situation on the sea floor. We conclude the work in Larsen C with the realization that there is no richer shelf fauna, out of which the cleared areas in A and B could be recruited. For the time being we can only speculate about the reasons.

A rock overgrown with hydrocorals (pink), bryozoans (brown), tube worms (white) and a brittle star, from outside area formerly covered by the Larsen ice shelf shows the potential settlement capacity in this area.
Photo: T. Lundälv

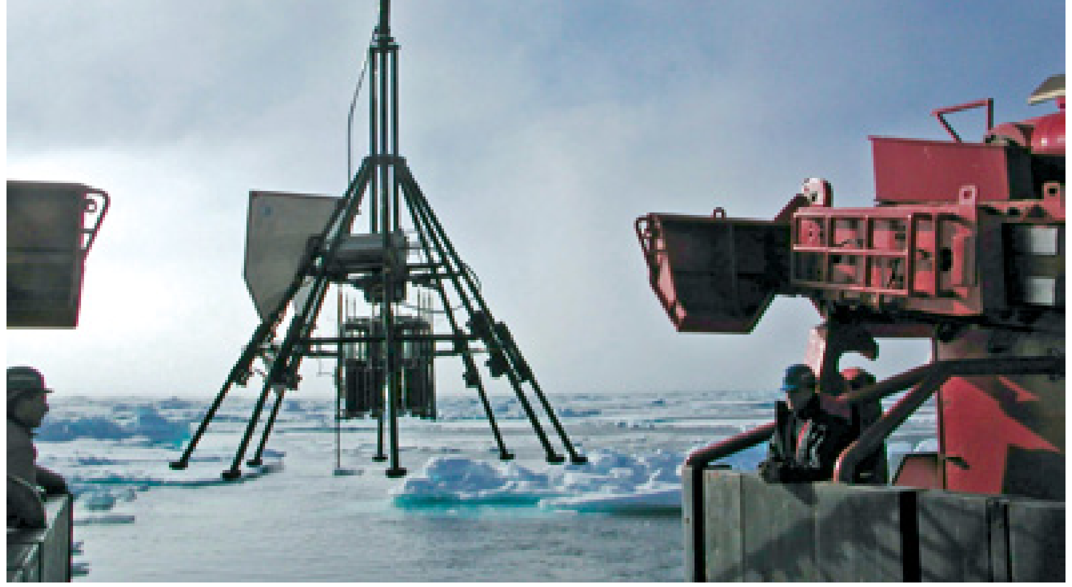
The research vessel ‘Polarstern’ in the ice shelf coast .
Photo: AWI

Huge dark clouds ominously droop over the largely consolidated sea ice cover. It is predominantly multi-year ice of considerable thickness, with a snow cover of up to one meter. After a helicopter reconnaissance flight it is clear that we can only use the corers. Several hauls with multi-corer produce sea cucumbers. Video images show „sea pigs“ on pale soft sediment as well as other sea cucumbers, worms and brittle stars.

We steam north, between giant icebergs, probably originating from the Larsen ice shelf. Sometimes they tower above the superstructure of the ‘Polarstern’. The view ahead is poor, and it is difficult for Captain Pahl to estimate the size of the growlers in the ship’s path, however, he and his officers always manage to find a gap. A few days later the weather improves and the ROV can once again be deployed at the coastal station Larsen A South. We see many krill swimming around the spotlights, near the bottom. The community here resembles that at Larsen B; medium sized glass sponges are often seen, however, younger ones are less common. The stalked ascidians, which we encountered here a few years ago, largely as a mono-specific community, have completely disappeared. Overall, this community has developed a considerable biodiversity, one and a half decades after the ice shelf collapsed.

After several days of work we say goodbye to Larsen and once again enjoy one of those unforgettable days in Antarctica. At half past nine ship’s time, the sun rises from the sea like a ball of fire and bathes the young sea ice around the ship, and the snow and ice covered mountains of the Peninsula in rapidly changing colours of red, white and pink. And after the orange buoy of a mooring appears on the sea surface, our luck seems to have no boundaries. But of course we know that this is a great moment, which no doubt will be followed by other days - the painstaking analysis of our data obtained on this expedition after we return home.

Washing a sediment haul from the Agassiz trawl in heavy snowfall on board the ‘Polarstern’. The sea cucumber *Protelpidia murrayi* contracts when it comes on deck, and takes on the shape of a sea pig.
Photos: W. Arntz, AWI



Multicorer (MUC) used to obtain undisturbed sediment samples. The MUC is lowered to the sea floor by cable. Plexiglas tubes about 30 cm take sediment cores from the seabed, which to study the meiofauna (microscopic sediment organisms).
Photo: I. Schewe, AWI

Deep-sea observatory in the Arctic: Climate change affects life on the ocean floor

The Arctic is one of the world´s most climate-sensitive regions. The past decade has seen a remarkable decrease of both sea-ice extent and thickness. The changes due to global warming are visible, not only at the ocean surface, but also on the deep-sea bottom - with unpredictable consequences for the marine ecosystem. With the help of long-term studies AWI scientists get valuable information to monitor those influences on the benthic communities for the Arctic.

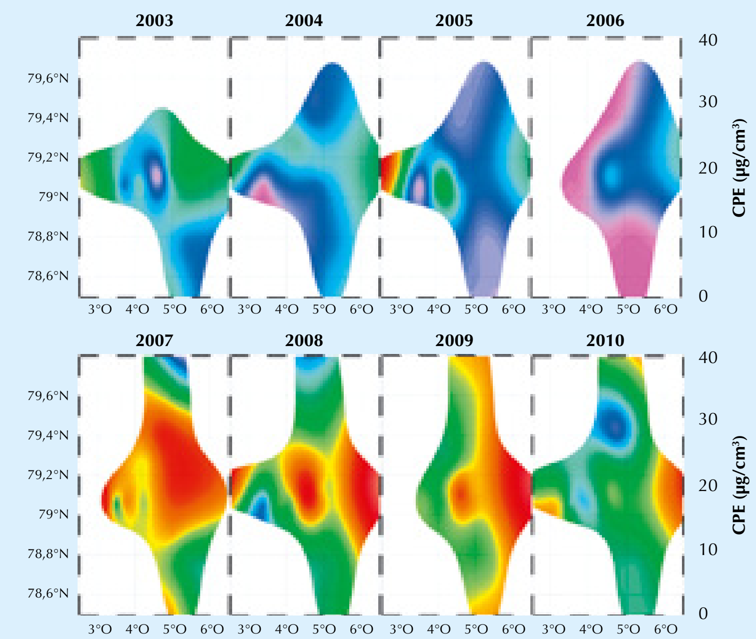
Polar organisms have become highly adapted to cold environmental conditions with strong seasonal forcing. Even the slightest changes imply an immense challenge to these organisms. Since 1999, AWI deep-sea scientists have been investigating life on the ocean floor at their HAUSGARTEN, a long-term observatory in the Fram Strait. HAUSGARTEN is located in a transition zone between the northern North Atlantic and the central Arctic Ocean, where relatively warm Atlantic water flows through the deep gateway between Greenland and Spitsbergen at 79° north latitude. The effects of global warming on this particular ecosystem are already clearly visible. “Our investigations at HAUSGARTEN show that changes in biogeochemical and physical processes in the water column, contrary to earlier expectations, also rapidly affect the composition and processes within the deep-sea ecosystem“ says the ecologist Dr. Ingo Schewe.

Due to the lack of light, photosynthetic primary production cannot take place in the deep sea. Below 600 meters water depth, it is almost completely dark. The organisms of the deep sea therefore rely on the food produced in the light flooded surface layers of the water column, which sinks to the bottom. The already observed changes in the composition of plankton communities, affects the quantity and quality of the food supply and its distribution pathways. In order to follow these changes and to assess the impact more effectively, AWI scientists conduct sampling and carry experiments on an annual basis during the summer month in water depths between 1000 and 5500 meters. They investigate organisms of all sizes – from bacteria that are invisible to the naked eye, to megafauna organisms, which can measure several centimetres. Because the colonisation of the seabed by deep-sea organisms is to a large extent influenced by sinking food particles and their rearrangement on the sea floor by currents and bottom topography, large and small-scale distribution patterns and the species composition of seafloor assemblages provide information on the dynamics of the living conditions at the deep-sea floor.

Life on the ocean floor exist in and on the sediment. Samples are collected from the bottom of the deep sea using a video-guided multiple-corer (MUC) or with remotely operated vehicles (ROVs). With these sampling gears it is possible to obtain undisturbed sediment samples to study distribution and activity patterns of sediment-inhabiting bacteria. Shifts in bacterial communities were analysed by means of micobiological and biochemical techniques.

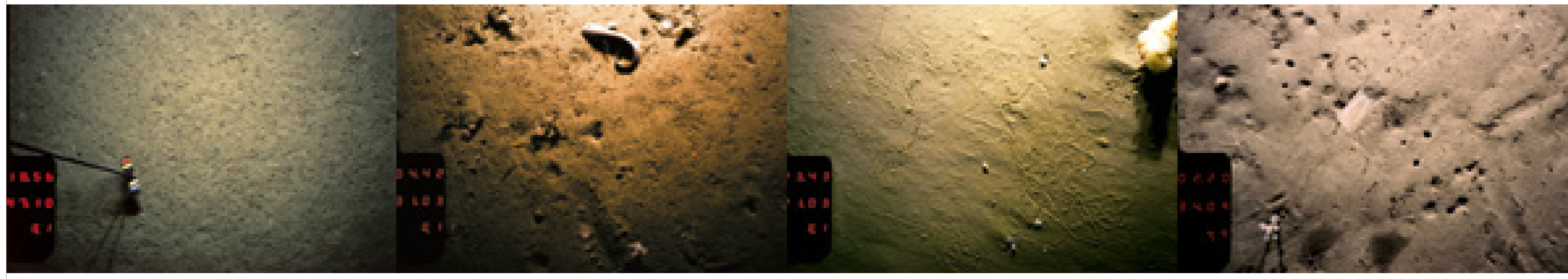
Spatial and temporal distribution patterns of meiofauna organisms (size range: 32 – 1000 µm) are analysed with special focus on community composition of foraminifera (unicellular protists) and nematodes (roundworms). Sediments obtained with a box corer are analysed to describe the population density, composition and diversity of macrofaunal communities, (organisms in a size range between 0.5 to 2 cm). Towed photo-/video systems are used to record large scale distribution patterns of epi-megafaunal communities (organisms larger than 2 cm). Specimen sampled by bottom trawls were used for ground-thruthing of the organisms recorded from the images. To determine the flux of organic material to the sea floor, scientists measure the concentration of chloroplastic pigments in the sediments and the overall respiration of all benthic organisms. Both depend on the flux of organic material derived from the primary production in the upper water column. “We have already observed a gradual shift in the quantity and quality of the food availability in different water depths. These changes are also reflected in the composition of the communities“ reports the benthic ecologist Dr. Melanie Bergmann. The content of organic matter at 2500 meter water depth decreased in the years 2000 to 2006, but increased again in the subsequent years. In the same period, scientists observed not only a decrease in the number of individuals of megafaunal organisms, but also significant changes in the species composition, that may be attributed to the sea ice retreat, increased sea-surface temperature and a changing food supply to the benthos.

Life at the sea floor is thus closely tied to the processes near the water surface. The biologist Dr. Christiane Hasemann explains: “The proportion of carbon that sinks through the twilight zone to the deep seafloor is one of the key issues. Once organic material has reached the sea floor, it will be oxidized by benthic bacteria and microorganisms and thus removed from the atmospheric carbon cycle for a long time.“



Food flux to the sea floor at 2,500 m water depth, as sediment-bound chloroplastic pigments (CPE) in the HAUSGARTEN area between the 2003 and 2010. The pigment concentration decreases from 2003 to 2006 and increases exponentially after 2007.
Graphic: I. Schewe, AWI

Meiofauna: *Leptolaimus* spec. de Man 1976. A male free-living nematode (Nematoda) from the deep-sea sediment.
Photo: K. Vopel, AWI



Images of the sea floor at 2500 meters water depth. The pictures show megafaunal organisms and their tracks, such as burrowing and feeding tunnels, mounds and hollows.
Photos: M. Bergmann, AWI

Recovery of sediment trap. Several sampling bottles are attached at the base of large funnel with a diameter of 0.5m^{2}. The bottles, which collect the sinking particles, are driven by a mechanism, which is programmed to move a bottle under the funnel opening at preselected time intervals. Sediment traps can be deployed for long periods (months/years) and enable the year-round collection of sinking particles, which are later analysed in the laboratory using a variety of methods.
Photos: E. Bauerfeind, A. Kraft, AWI

Plankton rain in the vicinity of the Arctic HAUSGARTEN: What do sinking particles tell us?

Scientists collect sinking particles in the ocean using sediment traps. The analysis of these samples indicate changes of the phytoplankton community in the area of the HAUSGARTEN. Biologists at AWI have now found that these changes point to an influx of warmer water from the Atlantic.

Biological-chemical analysis

Phytoplankton requires light to grow and it maintains buoyancy in order to live in the upper water layers. Once the nutrients here are used up, the algae produce and excrete slimy substances, which cause the plankton cells to stick together and form aggregates that are heavier and thus begin to sink. In addition, the particles in faecal pellets produced and excreted by zooplankton, the consumers of phytoplankton, also sink and ultimately land on the ocean floor. Through this process of sinking, organic material and thus carbon dioxide (CO_2) is transported from the surface to the sea floor. Scientists collect these sinking particles in so-called sediment traps, and subsequently analyse these in the laboratory. The results of the analyses enable conclusions to be drawn on the dominant processes and the composition of plankton communities in the upper water layers during an entire year.

Chemical, microscopic and molecular genetic analysis

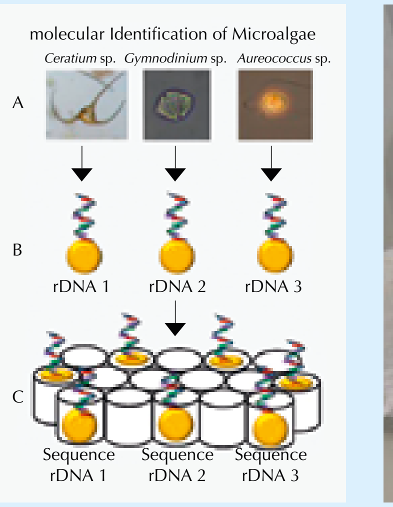
In the past, the occurrence and changes in the population and community structure of skeletal-forming phytoplankton (diatoms, coccolithophorids) or small zooplankton organisms (small crustaceans, pteropods), were studied using microscopic techniques. Recently, however, the use of modern molecular methods also allows the reliable characterization of organisms that could not be identified in the past with microscopic methods such as species of nano-and picoplankton. Molecular methods are independent of size and morphology of micro-algae. The characterization of micro-algae is based on the investigation of species-specific sequence differences in ribosomal genes, which are particularly well suited for the identification of organisms.

Shift in the phytoplankton community towards nano-and picoplankton species

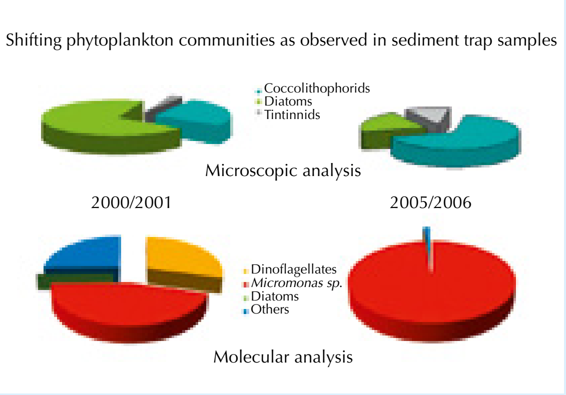
The region around the HAUSGARTEN is responding particularly sensitively to global warming, which is reflected in the significant changes in the sedimentation pattern of different planktonic organisms. Scientists are not so much registering these changes in the amount of sedimented material, but rather in its composition. The annual amount of sedimenting organic carbon, about 2-3 grams per square meter, has not changed. However, the amount of particulate biogenic silicate, an indicator of diatoms, has decreased from about 1.5 grams to values less than 0.6 grams. Microscopic studies show an increase of coccolithophorids.

"Furthermore, our molecular genetic analyses show that, during September, certain types of picoplankton make up most of the phytoplankton numbers and that concentrations were significantly higher when less diatoms occurred, than in the years with high occurrence of diatoms" says the biologist Dr. Katja Metfies. A correlation analysis with environmental parameters in the application area of the sediment traps suggests that temperature and ice cover impact the composition of the micro-algal community. In the years when the average surface temperature at the HAUSGARTEN was low and ice cover more extensive, diatom numbers were higher than in warmer years when picoplankton was dominant. Warmer water temperatures thus appear to nurture the growth of small micro-algae in the Arctic, while they have a negative effect on the growth of diatoms and other larger microalgae.

The biologist Dr. Eduard Bauerfeind surmises: "The observed changes in phytoplankton composition in the region of the HAUSGARTEN concurrently to rising surface temperatures, and the decrease of cold-adapted small crustaceans, are the first signs of an increased heat influx to the region." The experts of the AWI deep-sea group are trying to find out how changes in the phytoplankton composition due to warmer surface temperatures in the Arctic will affect the future of the entire marine ecosystem in the region.

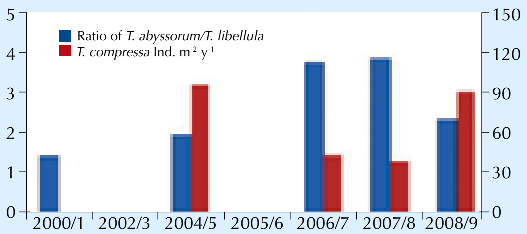


Molecular identification of microalgae in high-throughput (454-pyrosequencing): Like all other organism micro-algae also have ribosomal genes (rDNA) with a specific sequence on the basis of which different species can be identified (A). New high-throughput sequencing methods are making it possible to rapidly characterize the composition of marine micro-algal communities. For this, the ribosomal genes of different species are multiplied and isolated on miniature beads (B). These isolated ribosomal genes are then highly parallel sequenced, (C). In this way it is possible to simultaneously identify thousands of species of a community.
Graphic / Photo: K. Metfies, AWI

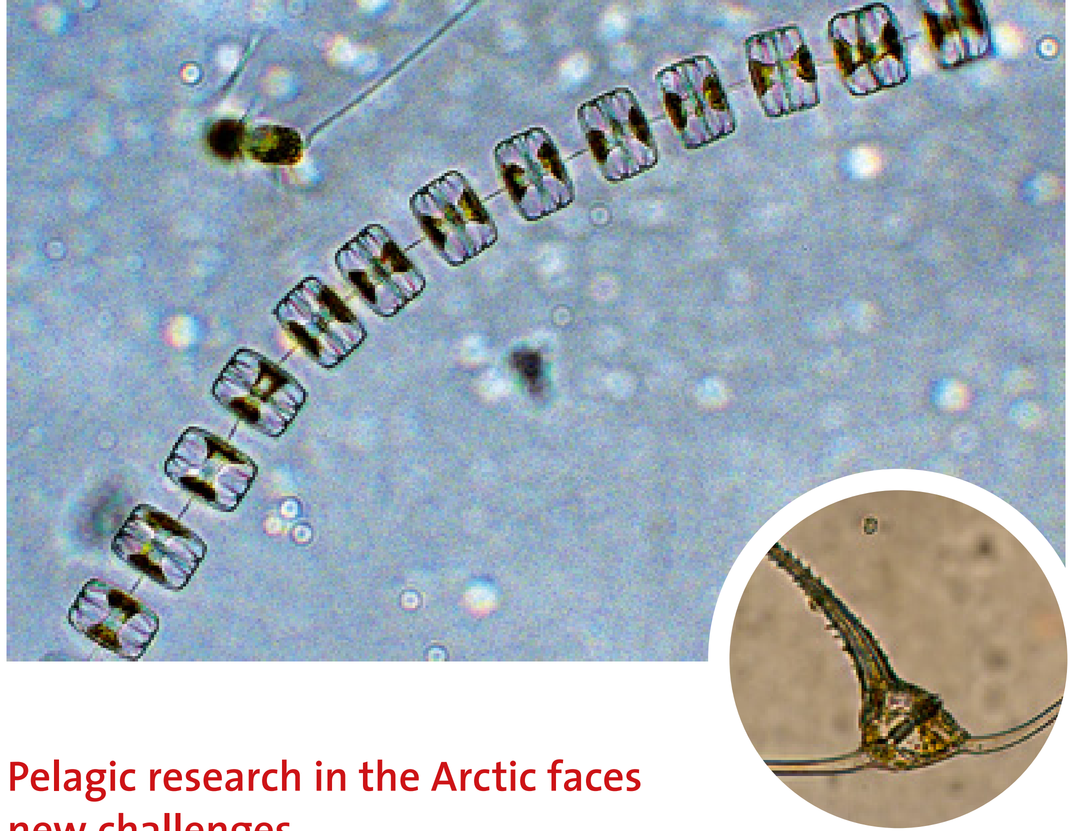


Relative composition of plankton from sediment trap samples from the beginning of the study and during a period with increased inflow of warm Atlantic Water (2005 / 6) in the Fram Strait. Shown are the results of microscopic and molecular analyses.
Graphic: E. Bauerfeind, K. Metfies, E.-M. Nöthig, AWI

Above: Three different species of amphipods, from left to right: *Themisto compressa*, *Themisto abyssorum* (both thermophile) and the cold-loving specie *Themisto libellula*.
Below: Occurrence of small crustaceans (amphipods) in sediment traps and the change in numbers during the period 2000-2009.
Graphic/Photos: A. Kraft. AWI



Pelagic Amphipoda
Ratio between Atlantic and Arctic species.



Arctic micro-plankton (> 20 microns), a chain-forming diatom *Thalassiosira* sp and the autotrophic dinoflagellate *Ceratium arcticum*. Both are representatives of the larger phytoplankton, which often form blooms (accumulation of biomass) in the vicinity of melting ice (diatoms) or in stable light flooded layers of water in late summer and autumn (dinoflagellates).
Photos: S. Pfaff, E. Bauerfeind, AWI

Pelagic research in the Arctic faces new challenges

New methods in molecular biology and experiments on warming and acidification of the oceans provide deeper insights into the world of the previously poorly studied pico-and nano-plankton, which is gaining more importance in the food web of the Arctic open ocean in the wake of global warming.

The newly established AWI working group PEBCAO (Plankton Ecology and Biogeochemistry in a Changing Arctic Ocean) is using new methods to study the various changes in Arctic plankton communities. In combination with results from the HAUSGARTEN, the researchers are obtaining a more complete picture of the climate induced transformations in the Arctic.

Since the dramatic decline of sea ice, the interest in a more intensive exploration of the Arctic ocean and its inhabitants has increased. Previously it was assumed that primary production was low due to the exposed position and reduction of light due to the sea ice cover. With a retreating sea ice cover, more light will be available, however only a limited amount of new biomass will be produced. This is because algal growth is limited by nitrogen and phosphorus availability. However, a different population will develop in nutrient-depleted water, than in the nutrient-rich ocean. The marine biologist Dr. Eva-Maria Nöthig explains: "A shift from large, rapidly growing diatoms with sufficient nutrients to a dominance of smaller species of phytoplankton, which is also favoured by rising water temperatures will have a number of consequences for the entire marine food web, including polar bears."

Plant pigments enable the identification of algae groups

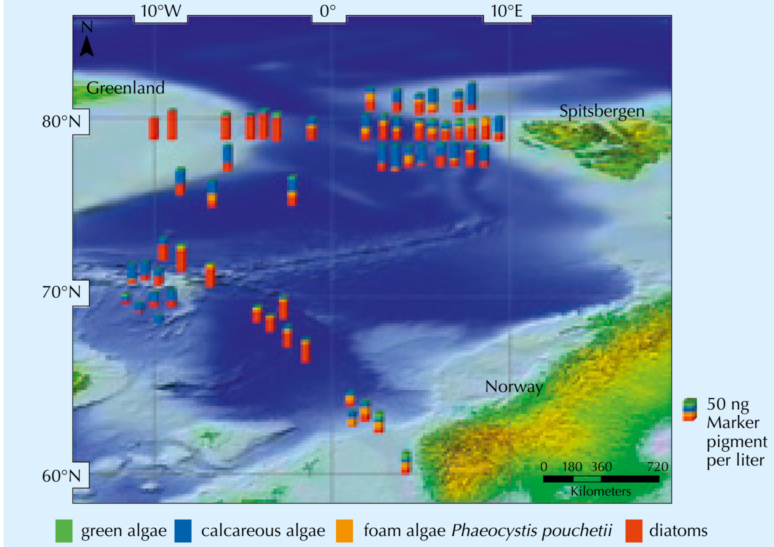
Phytoplankton uses chlorophyll to build up organic biomass. By measuring additional plant pigments called marker carotenoids, scientists can easily identify algal groups. "Knowing which groups of algae dominate the study area, gives us insight into the growth conditions and the influx of non-polar species in the Arctic," reports the marine biologist Dr. Ilka Peeken. Atlantic water masses are essentially dominated by calcareous algae such as *Emiliania huxleyi*. Diatoms are found in areas that are affected by the ice edge. In the area of the HAUSGARTEN there is a mixing of different polar and Atlantic water masses, where the foam algae *Phaeocystis pouchetii* frequently appears and in this confined space a high variability of different algal groups is present. In addition, this region is dominated more and more by particularly small flagellates that belong to the group of green algae and due to their very small size are attributed to the pico-and nanoplankton.

Previously unknown „plankton dwarves" discovered

It is difficult if not impossible to recognise pico-and nanoplankton under a microscope. That is why scientists use modern molecular biological techniques with which they break down the tiny plankton into their hereditary components. Only in this way does the previously hidden biodiversity come to light. Initial analyses indicate a large number of previously unknown picoplankton species. "We call this hidden biodiversity", says the graduate biology PhD student Estelle Kilias. Despite their small size, they dominate the phytoplankton and with rising temperatures, may even displace the diatoms. The consequence being that copepods in the next level of the pelagic (free swimming) food web will find a different type of food. "We already have observed an immigration of non-polar copepods", adds the zooplankton ecologist Dr. Barbara Niehoff.

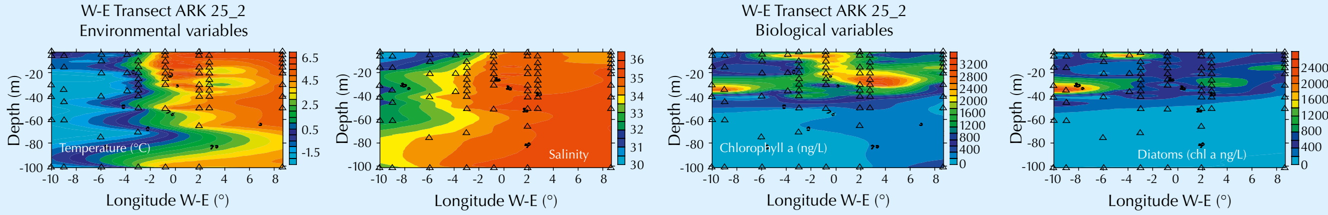
Changes in the Arctic carbon cycle

Climate change is altering the living conditions of planktonic micro-organisms, which are responsible for a large proportion of metabolic turnover in the ocean. More than 40 gigatons of carbon in the ocean are fixed by means of photosynthesis, growth and cell respiration and converted and recycled each year. It is also expected that the increased concentration of atmospheric carbon dioxide (CO_2) will acidify – decrease in pH – the oceans.

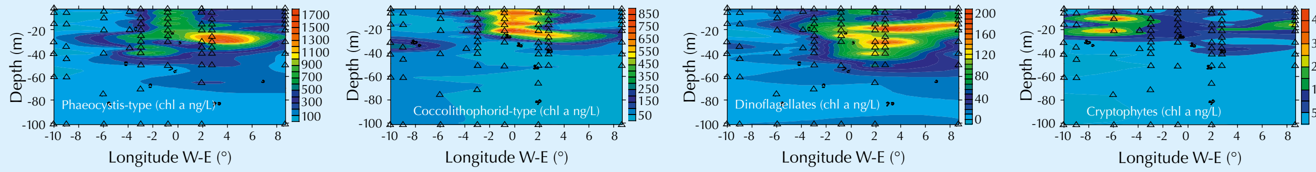


Map showing the biomass of different algal groups from the sunlit upper ocean, which were calculated from different characteristic marker pigments.
Graphic: I. Peeken, A. Haas, AWI

To understand future changes in the carbon cycle of Arctic and to assess these quantitatively, biologists at the AWI carried out simulation experiments on board the research icebreaker 'Polarstern' in the Greenland Sea. Initial results show a clear influence of temperature and pH on the activity of marine microorganisms (bacteria). When water temperature increases in the future, more slimy substances (transparent exopolymer particles, TEP) will potentially be produced, which could contribute to increased transport of particulate carbon in deeper waters (export). The graduate environmental scientist Mascha Wurst reports: "While many organisms may benefit from an increase in dissolved organic compounds produced by the bacteria, of which a small portion goes to the formation of biomass, the majority is, however, respired again and thus returned as CO_2 into the sea water and very likely released into the atmosphere. The relationship between recycling and export processes decides whether the microbial metabolism in the sea is a sink or source for CO_2 in the atmosphere."



Depth profiles between Greenland and Spitsbergen at 79°N, showing the environmental parameters, temperature, salinity and algal biomass as well as the biomass calculated from the marker pigments of different ecologically relevant algal groups. Graphic: A. Wisotzky, I. Peeken, AWI



The autonomous underwater vehicle (AUV) dives to 3000 metres depth, to obtain in situ measurements and samples, even under the sea ice.
Photo: M. Wust, AWI

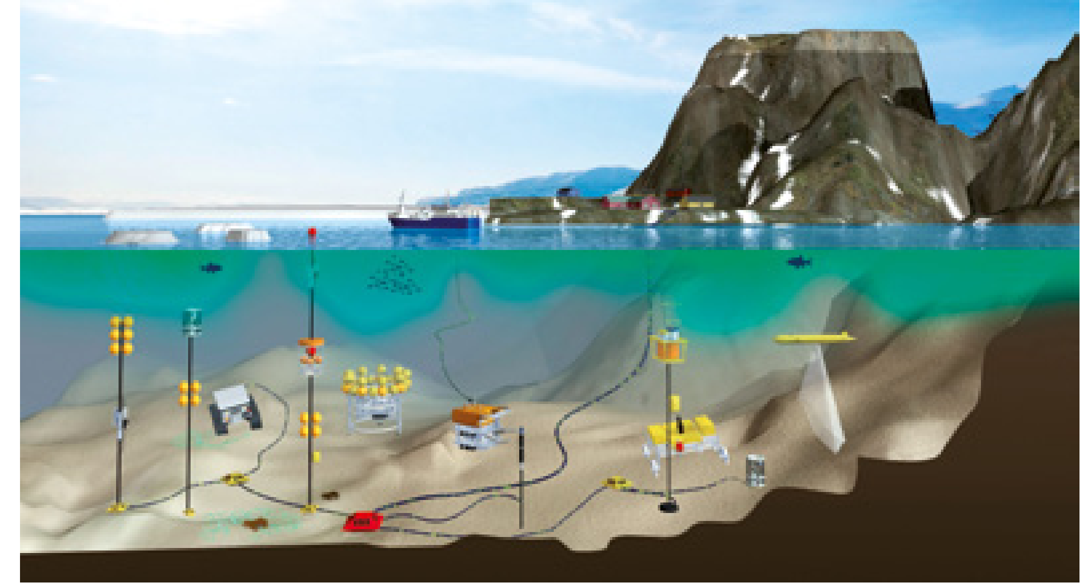
FRAM Observatory – live conference with the arctic deep sea in preparation

With the deep-sea observatory HAUSGARTEN, the AWI has set high scientific standards – now we are planning for the next steps. New, autonomous sensor packages as well as satellite communication systems that guarantee a rapid data transfer will enhance our observation capabilities. The connection to a German-Norwegian cable network from Svalbard would not only allow data acquisition and transmission in real time but at the same time provide unlimited power supply for our sensors and instruments. Using the Internet, scientists all over the world will be able to interactively access the recording instruments.

Life at the ocean floor? – Impossible! – that's how earlier generations of scientists thought. Today we know: The bottom of the deep sea is a structured environment and its biodiversity is actually comparable to that of tropical rain forests and coral reefs. These findings have been explained with different, sometimes controversial hypotheses. In order to explain the high diversity in the deep sea, AWI scientists developed the idea of a permanent observatory in a transition zone between the North Atlantic and the central Arctic Ocean. The site was initially called HAUSGARTEN a working title that has been retained and today is tantamount to top international research in the deep sea.

The interdisciplinary work at the Earth Systems Observatory HAUSGARTEN provides valuable new insights into processes and dynamics within an arctic deep-sea ecosystem. Today, more than a decade after the installation, the observatory comprises 17 stations on an east-west transect (water depth 1000-5500 m) and a north-south transect in 2500 meters, ranging from the (summer) ice edge to permanently ice-free zones in the southern Fram Strait. Since the beginning of data collections in 1999, HAUSGARTEN stations are sampled at least once a year. Moorings equipped with various scientific instruments including sediment traps are deployed annually at a maximum of three stations. This permits the collection of environmental data and biological samples to investigate processes in the water column over an entire year. Biological short- and long-term experiments at the central and the southernmost HAUSGARTEN site complete our activities. "These complementary methodological approaches are necessary to relate biological findings with geochemical, physical and sedimentological parameters. Finally this will help us to discriminate between seasonal and interannual changes," says the deep-sea biologist Dr. Michael Klages.

Since its beginning, HAUSGARTEN has been operated as an autonomous, so-called "stand-alone" observatory. However, numerous scientific questions cannot be answered adequately by this approach, e.g. because the energy supply of recording instruments is restricted to a limited battery capacity. As episodic events become only evident in the data after the recovery of instruments in the following northern summer, there is no possibility

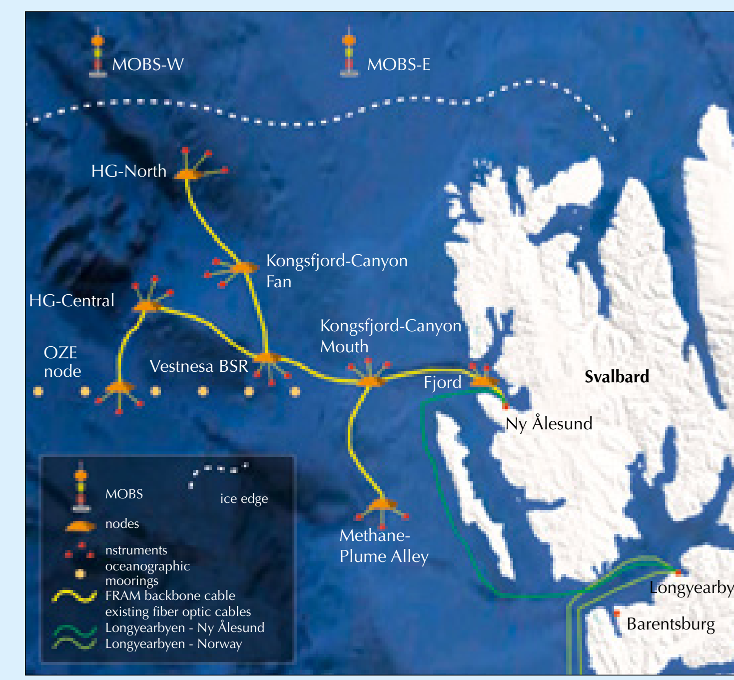


Sketch showing the proposed multi-disciplinary, modular observatory FRAM (FRontiers in Arctic marine Monitoring) west of Spitsbergen. Autonomous measuring systems with newly developed sensor packages will be installed and satellite communications systems will ensure real-time data transfer.
Graphic: S. Lüdeling für Konsortium Deutsche Meeresforschung

to react spontaneously to such occasions. "A cable connection to the mainland could overcome these and many other restrictions," said Klages. Optical fibres and power cables are already installed in other deep-sea observatories off the Canadian Pacific coast, in the Mediterranean or off Japan, where they are doing valuable scientific services.

Thus, an extension of the HAUSGARTEN observatory is now under consideration. With the recent IPCC (Intergovernmental Panel on Climate Change) report, which comes to the conclusion that climate change will affect the Arctic much faster than elsewhere, the interest in long-term interdisciplinary research in the particularly sensitive interface between the North Atlantic and the central Arctic Ocean has increased internationally. The future FRAM observatory (FRontiers in Arctic marine Monitoring) will have autonomous measuring systems deployed near the sea surface. These instruments will carry specifically developed biogeochemical sensor packages, and by means of moored winch systems, will enable the repeated profiling of the upper few hundred meters of the ocean surface layer.

Repeated data transfer will be realized by satellite-based communications systems. In the next step, the FRAM observatory will be integrated into a planned German-Norwegian cable network from Svalbard. In this way data collection and transfer would be possible in real time. Researchers can then interactively access instruments via the Internet. This would allow a direct response to episodic or periodic events, such as the deep-water formation, algal blooms or sedimentation events. Deep-sea expert Dr. Thomas Soltwedel concludes: "By combining and speeding up the availability of data, FRAM does not only improve fundamental research, but also substantially contributes to the improvement of forecasting capabilities based on integrated ecosystem and climate models, and to the sustainable use and protection of the ocean".



Schematic representation of the planned multidisciplinary FRAM (Frontiers in Arctic marine monitoring) observatory west of Spitsbergen. Autonomous measuring systems and new sensor packages are also installed as well as a satellite communications system that will allow real-time data transfer.
Graphic: N. Lochthofen, AWI

Major sources of dissolved organic matter: Sea ice in the Polar Regions and Arctic permafrost.
Photos: AWI

DOM – the oceans' molecular memory

Carbon is the building block of all life on Earth. One of the largest active organic carbon reservoirs on earth is DOM. The acronym stands for „dissolved organic matter". This dissolved organic matter in the sea has for a long time been an enigma to scientists. However, AWI scientists were first to unravel some of these riddles and show what great importance DOM has in the global carbon cycle.

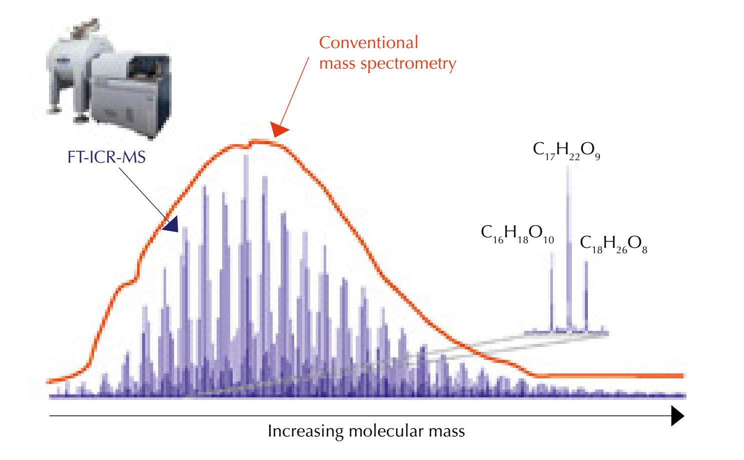
It is almost unimaginable: The global amount of carbon stored in DOM is 622 billion tons (622 Gt) and is comparable to the total amount of carbon in atmospheric carbon dioxide (CO_2), which is estimated at 790 Gt, or the land plants with 610 Gt. It exceeds by far the amount of carbon stored in marine animals, plants and bacteria, which is approximately 3 Gt, by a factor of 200.

Organic material is formed from CO_2 by land plants and plankton, the so-called primary producers, during photosynthesis. The DOM, resulting from this organic material, is transported to the oceans via rivers, or is directly released into the water by marine plankton or sea ice algae as well as during the degradation of these organisms. This DOM can bind to trace metals such as iron and is therefore also responsible for their distribution in the sea.

Over the continental shelves and in the open ocean, a portion of the DOM serves as the most important organic energy source for bacteria which consume and mineralize this DOM. The resulting CO_2 dissolves in the water and is again in exchange with the atmosphere. A small amount, however, is chemically altered and resists degradation for an average of 5,000 years. From a chemical point of view, this process is very unusual. The oxygen-rich water column should be conducive to a rapid microbial degradation of organic matter and subsequent release of CO_2. Contrary to this expectation, however, a significant portion of the atmospheric carbon remains in the DOM of the oceans and circulates in global ocean currents on long time scales. Thus marine DOM acts as a buffer in the organic carbon cycle. The release of only 1% of the carbon stored in the ocean DOM would result in an increase of CO_2 in the atmosphere, corresponding to the annual contribution by anthropogenic burning of fossil fuels.

Despite the obvious importance of the DOM its role in the global carbon cycle has been almost impossible to assess. The complex composition of DOM is an enormous analytical challenge, resulting in sparse information on the exact sources, the degradation and formation processes and the binding mechanisms to minerals and heavy metals.

A key to answering these questions is to identify the molecular composition of DOM. With the help of specific substances, so-called biomarkers, it is possible to draw conclusions about sources and transformation processes. A prerequisite for the use of such biomarkers is their stability over long time scales.

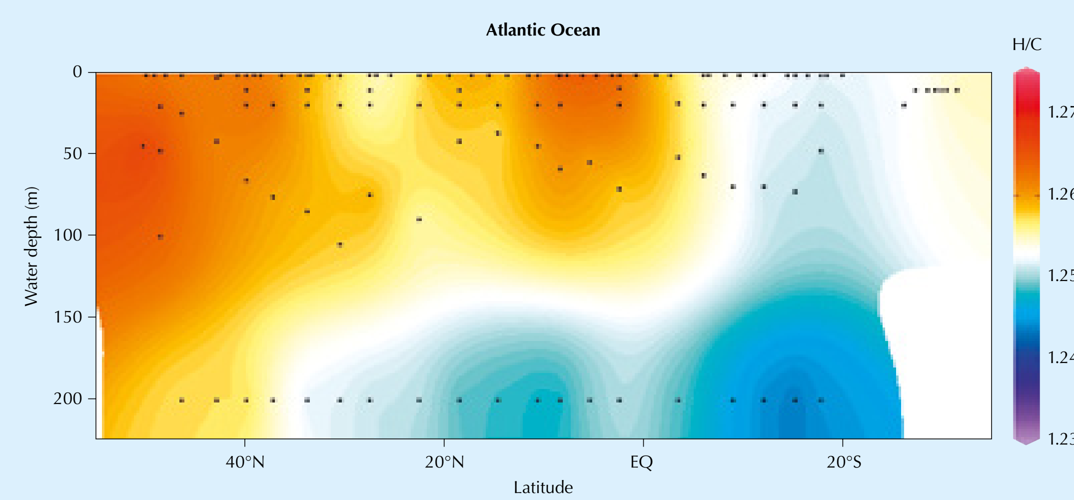


Fourier Transform Ion Cyclotron Resonance Mass Spectrometery (FT-ICR-MS): In contrast to conventional mass spectrometry (red spectrum) thousands of substances can be detected separately and the related element composition (molecular formula) be determined.
Graphic: B. Koch, AWI

The application of the "Fourier transform ion cyclotron resonance mass spectrometry (FT-ICR-MS) marked a milestone for the analysis of highly complex natural organic compounds and a significant advance for the objectives in marine DOM research. The FT-ICR-MS is characterized by an extremely high mass resolution. This means that the weight of individual molecules can be precisely determined comparable to a high-precision balance. One is able to determine molecular weights that differ by less than the mass of one electron. This requires a very strong magnet, which generates a magnetic field 250,000-times the strength of the geomagnetic field.

For the thousands of compounds, which can be identified in a single DOM sample, it is possible to calculate the elemental composition of individual molecules. This has for the first time provided an opportunity to gain extensive molecular information on DOM. It became evident, for example, that the Antarctic deep-water DOM contains a significant proportion of polyaromatic hydrocarbons, probably resulting from combustion or thermal processes such as in hydrothermal vents, or the combustion of fossil fuels.

Recent studies have shown that the molecular composition of organic matter in the ocean depends on many factors. It changes for example with the algal composition, climate zones and the availability of nutrients in various ocean regions. DOM thus acts as a data storage base and constitutes a mirror image of the "history" of a water mass, the potential of which, for global biogeochemical cycles, is as yet unused. With this potential information it should be possible to answer questions on, why for example parts of the organic material in sea ice and in permafrost regions of Siberia are released to the atmosphere as CO_2, while other parts are retained as stable molecules in the marine DOM buffer of the oceans.



From the North to the South Atlantic: the chemical signature (ratio of Hydrogen to Carbon, H / C) in the DOM of the ocean surface varies with the algal composition, climate zones and the availability of nutrients in various ocean regions.
Graphic: B. Koch, AWI

The ice-covered Lake El Gygytgyn („White Sea“) in the treeless landscape of north-eastern Siberia.
Photo: S. Quart

Siberian forests moving north – impact on the climate and biodiversity

The Arctic tundra - a unique ecosystem. The biologists of the AWI Research Unit Potsdam are studying lake sediments there, in which the undisturbed vegetation history of the northern latitudes is reflected. Details of previous warm periods, serve as analogues to compare and predict the future development of vegetation and its effect on climate change and biodiversity.

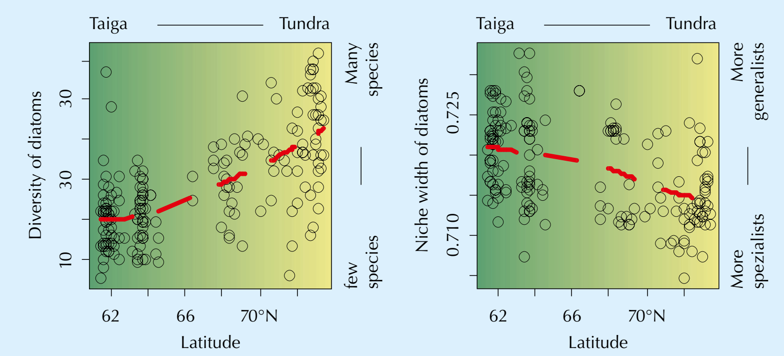
The Arctic tundra from a geological perspective, is a very young ecosystem. Only at the end of the Pliocene, 3 million years ago, with the onset of glacial cycles on Earth, was it cold enough for a treeless vegetation to develop in the northern latitudes. Over time, a unique ecosystem has developed, which is now threatened by the northerly progression of the tree line, in the wake of global climate change. The danger of this happening is particularly great in Siberia, since there is only a thin strip of arctic tundra between the boreal forest and the continental border of the Arctic Ocean.

In the far north of Russia there is a lake, formed 3.6 million years ago by a meteorite impact. The Chukchi call it “El Gygytgyn” (White lake), because it is only free of ice for a few weeks every year. When the ice melts, all the particles deposited on or in the ice are released and sink to the bottom of the lake. Over the past millions of years several hundred meters of sediment, have thus accumulated. Cores from this sediment were collected during an international drilling campaign. This climate archive of the Tundra is much more complete than the deposits from the Siberian coast, which have continuously been disrupted by ice movement.

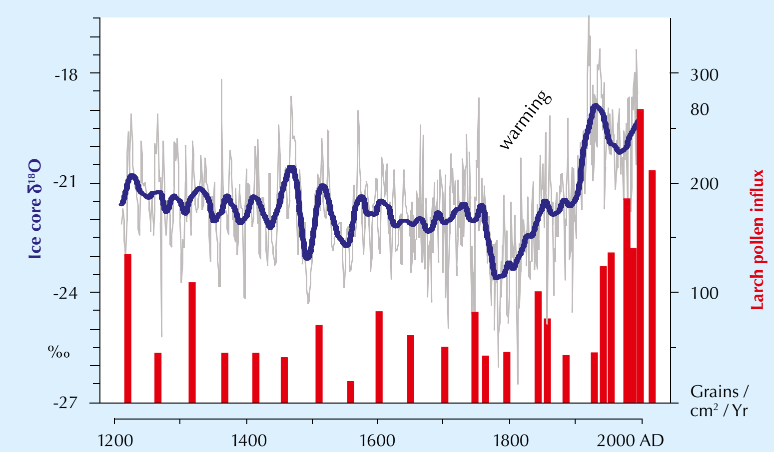
Investigations of the pollen in these sediments, by an international team of scientists from Germany and Russia, have revealed how the biodiversity of the Arctic tundra has developed since its origin in the Pliocene. Prof. Ulrike Herzschuh reports: “We hypothesize that the species poverty of tundra vegetation is due to a reduction in the arctic plant habitat during the course of interglacial warm periods. During these phases some cold-tolerant plant species became extinct, and a succession of these phases finally resulted the observed impoverishment. Our studies thus provide evidence of how the expansion of the tree line to the north is expected to affect the biodiversity”. The AWI scientists are not only considering the impact on land vegetation, they are also interested in lake ecosystems. Their composition and function is dependant on which side of the tree line they exist. “Our studies of diatom assemblages from lakes along a north-south transect through Yakutia, revealed that the diversity in most arctic lakes, was especially high and that very many specialized diatom species existed there i.e., those that occupy only a narrow ecological niche. A decrease of the biological diversity of diatoms in Yakutia is attributable primarily to the change in the tree line and only indirectly to the increase in regional temperatures.“ says Herzschuh.

In contrast to the well-documented progress of the tree line in northern Europe or North America our knowledge of changes in forest boundary due to global warming in northern Siberia is based almost exclusively on simulation. Since in Siberia, in contrast to all other circum-Arctic regions the larch, a deciduous conifer, forms the tree line, the reliability of most ecological models in this region is questionable. It is still unknown, with which time delay the larches, with their very long generation cycle, respond to temperature increases. Our studies therefore not only focus on research into the treeline shifts during the geologic past, but also to the changes since the beginning of the anthropogenic temperature increases since about 200 years. “In the absence of observational time series, we also use lake sediment cores as environmental archives of the recent past, which we investigate with high temporal resolution,“ says Herzschuh. A comparison of the annual sedimentation rate of larch pollen - an indicator of the presence of these conifers around the lake - with high-resolution climate records, for example, from ice cores from the Arctic archipelago of Severnaya Zemlya, shows that forests development does not completely parallel the temperature fluctuations. It appears that there is a delay in the propagation. The objective of such studies enabled the scientists of the Potsdam Research Unit to develop new ideas to improve ecological models and thus to permit more accurate forecasts of the development of forests in future climate scenarios.

The position of the tree line, however, is not only dependent on the climate, but also influences it. The positive feedback between reflectance (albedo) and forest distribution in high latitudes also plays an important role. There are conflicting results with regard to the question of how sensitive the climate reacts to changes in vegetation distribution. i.e. what proportion the vegetation-climate feedbacks have on global warming in the future. This information can only be obtained with earth-system model simulations (coupled atmospheric, ocean and vegetation models). The information on the vegetation development during early analogues warming phases, such as the middle Pliocene or the last 200 years is therefore important to verify the significance of climate simulations.



Representation of the change in the diversity of diatoms in lakes (left) and their average niche range along a transect in the taiga-tundra, northern Siberia. Lakes in the tundra regions are characterized by a high diversity and very many specialized species, which decrease as the tree line progresses further northwards.
Graphics: U. Herzschuh, AWI; Data: L. Pestryakova, Federal University of North-East Russia, Yakutsk



Change in the flux of larch pollen in a lake at the tree line in northern Siberia, within the last 800 years (higher flux = expansion of the taiga to the north). Compared to the strong temperature increase since 1800, which can be deduced from the isotopic signal of an ice core from Severnaya Zemlya (investigations at AWI Potsdam by D. Fritzsche, T. Meyer and H. Opel), the tree line only started moving north since about 1940. These time delays in the response of vegetation to climate signals must be considered to further improve earth system modelling
Graphic: C. Kopsch, AWI

The 2006 HIGHSEA I, III and IV classes at the awards ceremony NaT-Working Prize (1st prize, 50,000 €) of the Robert Bosch Foundation together with the then Prime Minister of Baden-Württemberg, Günther Oettinger.
Photo: Robert Bosch Stiftung

The 2008 HIGHSEA V group on the sailing ship „Noorderlicht“. The ship had to be regularly freed of ice and snow.
Photo: M. Ginzburg

2010, with HIGHSEA VII on Greenland. Sampling of freshwater diatoms for the AWI working group of Christian Hamm.
Photo: M. Ginzburg

Promoting young talent: High school pupils learn together with AWI scientists

Discovering polar marine research. Learning together with scientists. Carrying out your own experiments or even joining a research expedition at sea - the Alfred Wegener Institute offers high school students many opportunities to experience research first hand. Encouraging the next generation to shape the future, because today‘s pupils are tomorrow‘s young academics.

Boring biology class, annoying physics lessons, painful chemistry? Many pupils are put off natural sciences at an early age at school. Moreover, in the light of full curricula teachers today are rarely able to include current research themes in their classroom-teaching load. AWI scientists recognized this at an early stage. They developed a unique educational program - even by international standards. To this end, the project director Dr. Susanne Gatti conveys: “Today, schools alone are not in a position to present a realistic picture of the natural sciences. Such a challenge requires external partners. Working with teachers in long term projects our goal is to better prepare pupils for university-level studies in natural sciences and to open up perspectives for their future careers“.

SEA

With the aim to promote scientific interest at a very early stage, the AWI has established the staff unit “SEA“ (Science & Education @ the AWI). The student laboratory “SEASIDE” (SIDE: Single Day Experiments) offers single day experiments for groups of pupils. Classes of all ages can take advantage of this offer if the teachers provide for full integration of the visit into their regular class work.

HIGHSEA

The most important part of the “Early promotion of young talent“ SEA is the cooperation project HIGHSEA (High School of SEA). Every year, 22 young pupil are taken on. During their last three years at school, they exchange their classroom with the laboratory for two days a week: scientists and teachers join to give lessons in what is called “team teaching“ and without a fixed timetable. They follow up scientific questions that are derived from current research areas of the AWI. The different contents of the science subjects are incorporated when they are relevant to the answering of research questions. Biology (advanced course), chemistry, English and mathematics (basic courses) are fully covered in this curriculum, and physics are also partly included. Additionally an expedition based on a specific scientific is organized every year.

Biology can be exciting

Research on living creatures: Working groups, three or four pupils for example examine an organism or group of organisms of the Polar Regions. Pupils are planning their own experiments. They learn to develop research goals and are intensively supervised by a scientist during this process. About every three weeks the individual groups then report in plenary sessions on the metabolism of Antarctic scallops, on Antarctic sponges, pteropods, ice algae, macro algae or on polar fish. As they are working with live animals or plants, the pupils can often be found in the laboratories of the AWI in the afternoons or during the weekends. Again and again they are unlocking areas of knowledge, which are new even to the teachers involved. Thus mechanisms of adaptation to life in the Polar Regions, special metabolic processes and interactions in polar ecosystems are often new territory for both, pupils and teachers, at the same time. Knowledge acquired this way forms the basis for exams and performance assessments.

Success confirmed by external evaluation

HIGHSEA is almost 10 years old and has been externally evaluated meanwhile. The outcome concerning the motivation of the pupils was exceptionally pleasing. While in „normal“ schools pupil motivation diminishes over three-year in high school, the Alfred Wegener Institute succeeds in maintaining a high level of motivation. In addition, the evaluation demonstrated very clearly that both the learning yield in each subject, and the relationship between the subjects as well as the scientific literacy of the pupils were measurably improved.

All results are available in the form of a PhD thesis and are posted at: http://www.awi.de/en/discover/school_projects_sea/highsea_bremerhaven/achievements_evaluation/

Learning for life - enthusiastic former HIGHSEA pupils

“Taking HIGHSEA prepared me for my science degree in biochemistry much more than school did”
Michael Ginzburg, former HIGHSEA V pupil (School leaving exam 2009)

“I have dreamed of becoming a marine biologist for ages. With HIGHSEA I came a good deal closer to this dream during my school years and have since completed my bachelor‘s and master‘s thesis in marine botany“
Anique Stecher, former HIGHSEA II pupil. (School leaving exam 2006)

“HIGHSEA isn’t like school. It’s learning among friends and with friends, which also includes teachers and scientists“.
Christopher Gardel, former HIGHSEA IV pupil (School leaving exam 2008)

With the 'Polarstern' in the Arctic for a PhD: Plankton nets used during the expedition ARK XXV-2 to collect samples.
Photo: V. Strass, AWI

The ice-amphipod *Eusirus holmii*
Photo: A. Kraft, AWI

Work on the microscope
Photo: M. Greenlaw, Atlantic Reference Centre, St. Andrews, Canada

Dream job – polar scientist – How a student achieved her goal over an icy path

Very few believed that I would study biology or even do my PhD on the subject. However, my love of the sea was stronger than all the prescribed curricula. First secondary school followed by an artisanal high school. A University entrance exam seemed unachievable in the rigid German school system and when I decided to enter business college anyway, I was told that someone with secondary school background had no chance here.

I always spent my holidays at the seaside. My father, a marine engineer had sailed the seven seas, took us to the sea every summer, sometimes in France, sometimes Spain. I stood at the Atlantic, with my nose in the wind, looked at the eternal up and down of the waves and got carried away by the immense power of the sea. I managed to pass my university entrance exam and completed a business internship. After a year in marketing management, I knew this was not my world.

Inwardly, I've always been an explorer, scientist and adventurer. I wanted to explore the sea, to know how the system Ocean works. And with my university entrance exam in the bag, a degree in biology was now possible, as were two semesters abroad on Canada's east coast. It was no question that I wanted to become a marine scientist. I was particularly interested in the polar ecosystems and fortunately I was able to write my Masters thesis in the plankton research section at the AWI. This was followed by my first expedition on the research icebreaker 'Polarstern'. Four weeks in the Arctic, research on water samples and the organisms living therein, working under the midnight sun between 75°N and 80°N as a student assistant.

And today? Lucky to be working towards my PhD in the field of life sciences at the Alfred Wegener Institute. My topic is the investigation on Arctic amphipod species in the plankton. The name *Amphipoda* means „different-footed", and describes a small, often free-swimming crustacean, which is an important food source for fish, seabirds and marine mammals in the Arctic. The plankton composition of large Arctic species and varying proportions of small invasive species from the warmer North Atlantic including the long-term trends are of particular interest to me. What are the effects of Arctic climate change on these organisms? Will their geographic distribution change? Do typical Arctic species have the same food sources as the Atlantic species? Will changes in amphipod community composition have consequences for higher levels of the food web, perhaps even for the fishing industry? Three years ahead and many questions to be answered.

Personal highlights during this time of course are the expeditions with RV 'Polarstern': It is a real honour to be taken seriously by the experienced senior fellow scientists on board. Because part of me is still sometimes the girl from Swabia, who in secondary school was told by teachers that there is little prospect of taking up a career as a scientist.

I'm hooked on Polar research. The cold, the shimmering blue ice, the roar of diesel engines when the ship breaks ice up to 1 meter thick. The daily work and life on board ship. The coordinated workflow between the crew and the scientists. The use of large plankton nets, which will catch my amphipods and provide samples for the next 12 months of picking and sorting in the laboratory. The drift of sea ice - always a risk and the uncertainty of whether the moorings anchored on the sea floor have collected samples, or whether the plankton net gets hooked up on the next ice floe and tears off.

Some will not have to go such an icy path to become a scientist. The paths in polar research are manifold. All have in common, however, the human compulsion to discover - and in a time of great climatic changes, this yearning is probably more important than ever.

Not always on expedition: PhD student Angelina Kraft at work in her AWI office.
Photo: E.-M. Nöthig, AWI

During an iron fertilization experiment in the Southern Ocean: To enable scientists to deploy the trace element iron, the RV 'Polarstern' in an unfavourable position in the swells taking on a lot of water astern.
Photo: AWI

Marine biosciences in the scientific-societal context of the 21st century

The human imprint on the ocean has reached vast and deep proportions. The impacts range from ocean-wide decimation of top predators to large-scale deterioration of entire ecosystems as disparate as Arctic sea ice, coral reefs, fjords and estuaries. The effects of ocean acidification and ongoing global warming will pose further strains on the ocean of which sea level rise will have the biggest effect on human society and coastal ecosystems. Ocean scientists are busy tracking the disturbing trends with experiments, field assessments and computer models. But is this effort enough? Should we be doing more than merely tracking trends? If humankind manages to successfully rise to the global challenges of this and coming centuries, future generations will be busy with atmospheric and ecosystem restoration; should we not be doing our best to lighten their burden?

Public awareness of the inevitability and dire consequences of climate change caused by rising levels of green-house gases is growing and specific issues concerning the oceans are well covered by the media. Clearly business as usual is not an option for global society. However, the fundamental changes in life style that are required to at least slow the rate of change will have to be based on public understanding of the manifold problems based on sound, scientific arguments. Public perception will have to move from awareness of, to understanding the range of problems facing modern society and its changing environment.

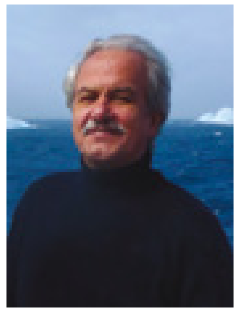
The real problem facing marine biosciences is that we don't understand how coastal, polar and ocean ecosystems function. For instance, the seasonal cycles of coastal plankton and benthos have changed radically over the past 4 or 5 decades at most sites where such long-term data are available. In places where eutrophication has come and gone the current cycles differ from the original, hence no longer fit past explanations. This fact is slowly dawning on the community at large. In the Southern Ocean, krill stocks were expected to increase following decimation of the great whales but appear to be in steady decline for decades and are below 10% of the former stocks. Had the whales not been decimated, they would have starved to death by now. If the current explanation - retreat of the ice edge in the krill breeding grounds – were correct, Antarctic whales would have been the first spectacular victims of global warming. But there are serious problems with this explanation for krill decline.

There are more basic facts about plankton ecology we do not understand. For instance, how cells without swimming appendages regulate their buoyancy when alive but sink rapidly when dead. This mysterious ability must have evolved with the first planktonic microbes and was a prerequisite for initiating the biological carbon pump which ultimately led to oxygenation of the atmosphere. Today, the components comprising the pump are still under debate, as also its role in regulating atmospheric CO_2 levels in the past and the future. Further, the many striking shapes and skeletons exhibited by phyto- and protozooplankton remain an enigma because we do not understand which evolutionary forces selected them. Yet their remains in the underlying sediments are the foundations on which marine geosciences are built. Since a mechanistic understanding of these basic properties and functions of the planktonic life-style is lacking, predictive models of the effects of the many human impacts on the ocean listed in the opening paragraph will continue to be biased by arbitrary assumptions.

Luckily, there has also been progress and there is hope: the former paradox of low productivity in nutrient-rich, land-remote oceans including the Southern Ocean, has been unambiguously shown to be due to iron limitation. However, the implications for the carbon cycles of past and future oceans have yet to be established. The rapid development in genomics has started the "-omics revolution" with unforeseeable avenues of insight ahead: will it be possible to pry out the mechanisms for the above enigmas by studying the molecular information level? In the field of ecology, the previously neglected impact of higher trophic levels on ecosystem structure and functioning is coming under focus. Indeed, the only factor common to the entire ocean is the drastic reduction in stocks of commercial species and their by-catch by uncontrollable fisheries. That this will have an impact on seasonality of zooplankton and ultimately phytoplankton biomass is logical based on the premise that the ocean is food limited. However, the trends run contrary to expectations. Thus, the krill decline is not accompanied by increasing phytoplankton stocks, on the contrary, phytoplankton biomass has also declined significantly since records were first taken in the whaling era. Clearly, the current concept of bottom-up driven trophic cascades in which prey populations increase when their predators decline is apparently simplistic and needs rethinking.

An alternative explanation is provided by the concept of bio-engineering in which dominant animals condition their environment and its productivity to their needs. Well established examples are herbivorous megafauna (elephants and ungulates) which maintain grasslands by controlling trees and algae-grazing fish which maintain healthy coral reefs. The effects of bio-engineering on the above space-holding ecosystems are evident to the unaided eye, however, their effects on pelagic ecosystems will have to be constructed from comprehensive data sets obtained from the entire range of instruments used by physicists, chemists and biologists to describe the dynamics of ocean processes. This will be necessary to separate environmental, i.e. climate driven effects, from the ecological effects of selective removal of dominant predators on the changing ecosystems. This is a prerequisite to test the hypothesis that trophic levels above the phytoplankton and microbial levels, ranging from zooplankton to sharks and whales, condition the structures and temporal succession of the pelagic ecosystems. Unfortunately, most of the long-term data sets are either on phyto- or zooplankton so it is difficult to adequately test this hypothesis by mining the archives. Integrated field studies at the ecosystem level with the full complement of grazers and predators and including the underlying benthos will have to be carried out to investigate how biogeochemical cycles, in particular the ocean's ability to take up CO_2, have changed and will continue to change in the future ocean.

The eminent geneticist and bio-philosopher J.B. Haldane remarked in the 1930s: "Biology is too important to be left to the biologists." With climate change knocking on the door, it is time that ocean scientists of other disciplines got their act together, literally, and joined forces with the biologists to direct research aimed at understanding how ocean ecosystems function and what effect the changing global carbon cycle will have on them. As a parting remark, I would like to draw attention to the fact that the 100 ppm anthropogenic CO_2 in the atmosphere, which is already causing problems, is equivalent to 212 Gigatonnes of carbon which is equivalent to one third of the biomass of terrestrial vegetation. To which sink can we entrust this amount?



Prof. Victor Shahed Smetacek, world-renowned marine biologist and plankton specialist and international awardee. Professor of bio-oceanography at the AWI and the University of Bremen since 1986.


Photo: F. Rödel

Work on the ice: A winter camp of red plastic igloos and a polar tent used by krill scientists in the Antarctic.
Photo: L. Tadday, AWI

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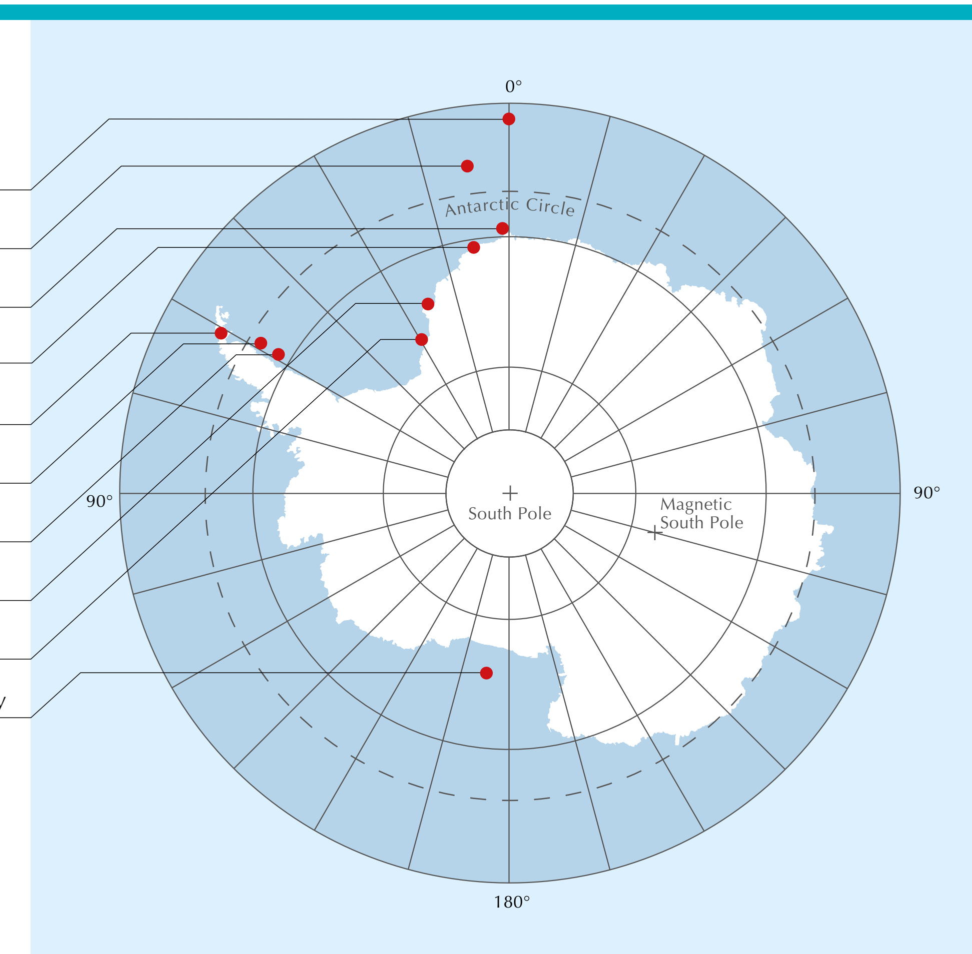
Photos: AWI

Geographic locations of the research reports of this broschure

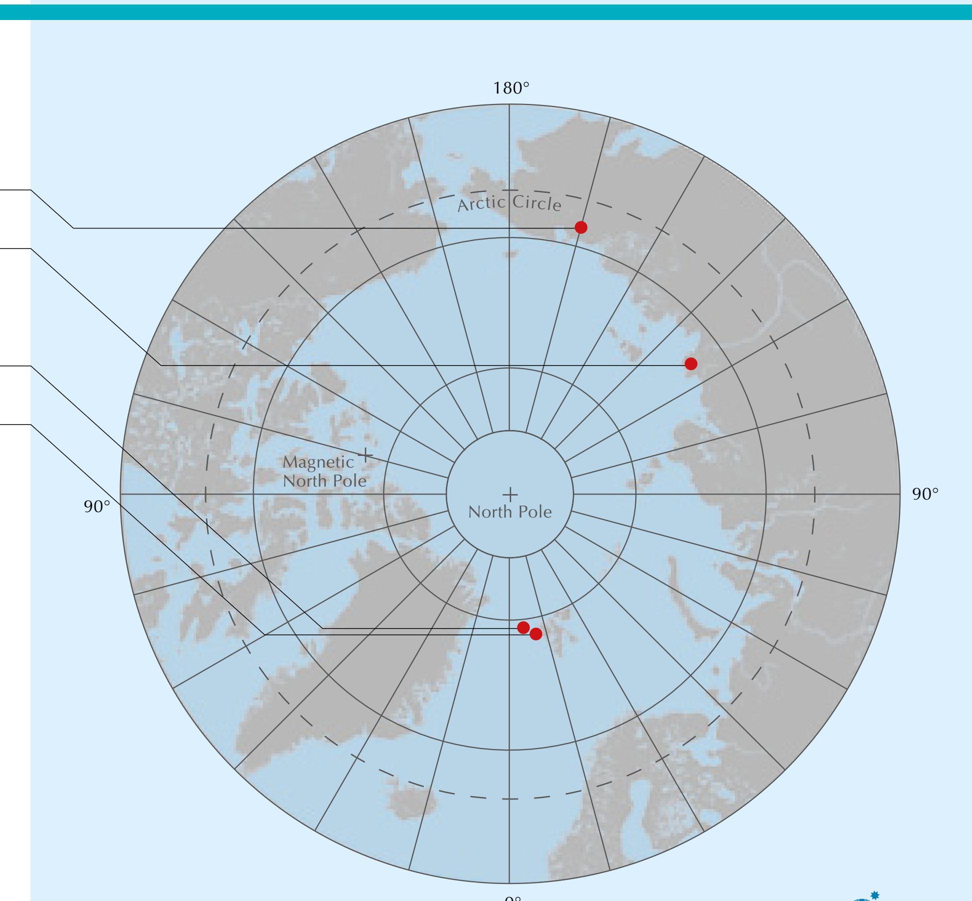
The Antarctic

- Ice edge blooms
- Krill
- Sea ice algae
- PALAOA
- Melting glaciers
- Diversity of life
- Observations in the ice
- Elephant seals
- Spider crabs and ice fish
- Ocean acidification and iron deficiency



The Arctic

- Siberian forests
- DOM
- Deep-sea observatory
  Plankton rain
  Pelagic research
- FRAM Observatory



Maps without sea ice cover

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