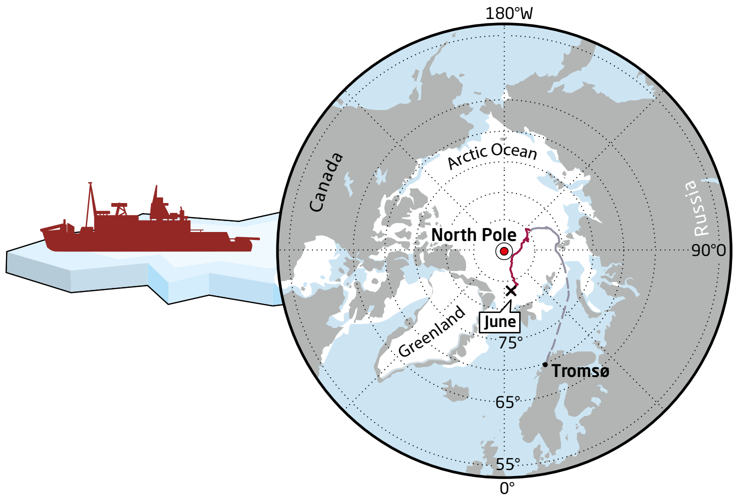
In spring, a variety of algal blooms colour the waters of the Arctic Chukchi Sea. The inflow of cold, nutrient-rich water from the Bering Sea provides the phytoplankton with idea conditions for forming large blooms.



DriftStory 09

Algae in the Arctic: Apparently, anything is possible

For algae, life in the central Arctic Ocean presents two significant challenges: firstly, the sun disappears for more than 100 days per year; and secondly, the pronounced stratification of the water masses slows the transport of nutrients from the depths. How can phytoplankton survive the long periods of darkness and spring to life again once the sun returns? AWI biologist Clara Hoppe and the ECO Team explored these questions during the MOSAiC expedition and discovered some of the remarkable survival strategies of the tiny, green organisms.

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If there were a competition for filtering water, AWI biologist Dr Clara Hoppe would stand a good chance of winning. As a marine biologist focusing on phytoplankton in the Arctic Ocean, she 'trained' in this discipline almost every day of the expedition. The reason: especially in winter, the number of algae (phytoplankton) floating in the water is so small that the researcher had to pass roughly 40 litres of water through a gravity filter in order to concentrate the algal community into a few millilitres before she could start her investigations.

The minute water samples there are teeming with members of a truly die-hard group of organisms. Arctic algae lead a life of extremes: sunlight, which they need for photosynthesis and growth, isn't available for more than 100 days per year. And when the sun does peek over the horizon, the sea ice covers the ocean like a blind so that, at least initially, only a small amount of light reaches the water column. In addition, the algae's supply of vital nutrients, such as nitrate and silicates, is limited. These substances are dissolved in the seawater, but at different depths and in varying concentrations, depending on the water layer. Due to the pronounced temperature and salinity-based stratification of the

Clara Hoppe first began investigating the survival strategies of Arctic phytoplankton six years ago, in the research village Ny-Ålesund on Svalbard. There, she could take water samples directly from the harbour.

water masses in the Arctic Ocean, the nutrient-poor surface water and the nutrient-rich water deeper below rarely mix. That means: once the nutrient supply in the surface water has been exhausted, it is seldom replenished from further down.

BARELY VISIBLE TO THE NAKED EYE

Despite these adversities, several hundred algal species survive the winter in the Central Arctic – and several are able to grow and divide even before the sun climbs above the horizon. Precisely how the algae survive the darkness and where they get the energy for cell division at the end of the long Polar Night is still not completely understood, and the reason why Clara Hoppe absolutely wanted to take part in the MOSAiC expedition. "We have been studying the algal community in Kongsfjord, in the Svalbard region of the Arctic Ocean, for several years, and so we know that the algae in the water column only need tiny amounts of light to activate their metabolism. Here we're talking about changes in light so small that they are barely perceptible for us humans," the researcher explains. Many of the algal species investigated are even active throughout the winter. How they manage this, and whether the sea ice plays a role, are just two of the numerous open questions.

However, since there is barely any sea ice remaining in the area around Svalbard, Clara Hoppe wasn't able to comprehensively investigate its impact on the algae's chances of survival. Furthermore, when it comes to collecting water samples in Svalbard, she couldn't be sure whether the algae investigated actually spent the entire winter in the Arctic, because off the west coast of Spitsbergen flows the West Spitsbergen Current, which transports relatively warm water from the North Atlantic northwards. Consequently, it was quite possible that part of the algal community in Kongsfjord originated in the North Atlantic and didn't experience the full extent of the Polar Night. During the MOSAiC expedition, however, these possibilities were almost completely ruled out. The drift offered the marine biologist the unique opportunity to observe the overwintering and revival of the Arctic phytoplankton over several months using methods and additional measurements that wouldn't have been possible without the interdisciplinary research team on board the icebreaker Polarstern.

THREE HYPOTHESES – BUT WHICH IS CORRECT?

The question of how Arctic algae survive the cold and dark has occupied polar biologists for more than a century. As socalled primary producers, algae form the basis of the food web in the Arctic Ocean. Without phytoplankton, neither copipods nor Arctic cod, ringed seals or polar bears would be able to find food. To date, three different explanations have been proposed:

At first, researchers long assumed that it was not only the well-known ice algae that allowed themselves to become frozen in the sea ice, where they overwinter, but the entire algal community, including those algae that are mainly found in the water column. According to this hypothesis, in spring, when the air and water temperatures rise, the algae are released from the melting ice, colonise the water column and begin forming large algal blooms. "This seedbank hypothesis is now considered outdated, since the range of species in the water column differs significantly from the algal community in the sea ice. While there are certainly species that are found in both habitats, they represent only a small proportion," comments Clara Hoppe.

Diatoms are microscopic, single-celled algae, whose cell wall predominantly consists of silicon dioxide. There are ca. 6,000 known species.

The second hypothesis assumes that the algae in the water survive the winter thanks to special preventive measures. "Before the onset of the Polar Night, many Arctic **diatoms** form extremely thick, hard shells to protect them from being eaten by copipods and other zooplankton," explains the marine biologist. In the coastal waters, the tiny organisms sink to the seafloor, where they spend the winter before rising up through the water column when the light returns once again. "We know from other deep ocean regions that the algae that are prepared for the winter accumulate in the thermocline; in other words, at a depth where the density differences are particularly great. As a result of winter and spring storms they are then carried back up towards the ocean's surface." However, as yet no evidence of algal accumulations in the Central Arctic has been found. "I hoped that we would be able to gather relevant samples during MOSAiC. But in our investigations we were unable to find any such layer beneath our floe," she says.

Does that mean that the third explanation is more likely? It has found a host of new supporters in recent years, and posits that algae are not pure plants that solely survive on photosynthesis. Instead, like animals, they take up organic material, by (in some cases very actively) eating bacteria or respiring organic compounds dissolved in the water. "We see this survival strategy, known as mixotrophy, in all groups. Whatever algae we look at, they are all able to do it. So it appears that among the Arctic algae there are scarcely any pure plants, which rely solely on photosynthesis," says Clara Hoppe.

HOW MANY ALGAE DO COPIPODS AND CO. ACTUALLY EAT?

To avoid overlooking any clues when it comes to searching for new insights, the team of biologists pushed themselves to their limits on the MOSAiC floe. According to Clara Hoppe: "We measured an unbelievable number of parameters – from nutrients and carbonates to chlorophyll content, pigment composition, primary and bacterial production, biodiversity, and DNA and RNA analyses, to name just a few. Added to this were the microscope work, experiments on board, food-web studies ranging from zooplankton to fish, and sampling numerous chemical parameters. Just keeping track of it all was a real challenge."

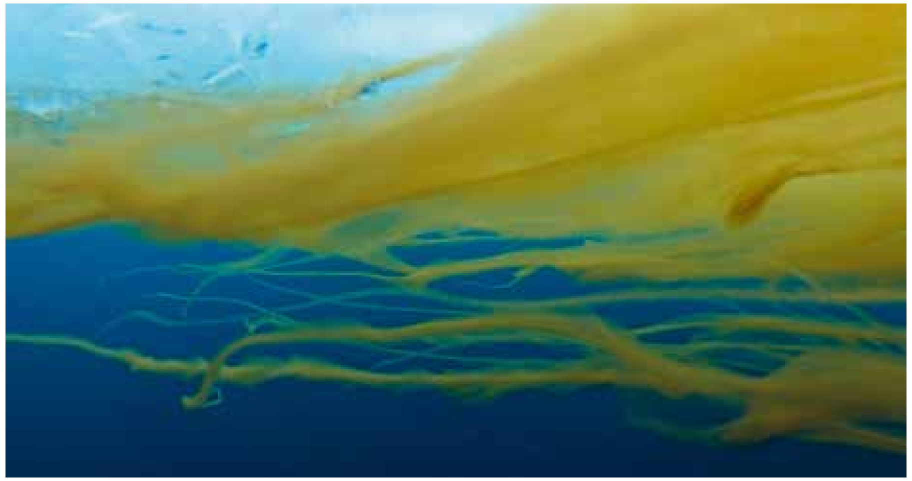
For example, to discover the extent to which hungry copipods decimate the numbers of algae, the researchers placed a handful of carefully selected crustaceans in bottles filled with water and algae and then counted how many phytoplankton were left after a day. In a second experiment, they filled bottles with sea ice and water from the ocean's surface

Clara Hoppe reconstructed the testing array used at the research lab on Svalbard (l.) on board the research icebreaker Polarstern. But before their various algae experiments could begin ...

... the marine biologist (r.) and her colleague Dr Anders Torstensson (l.) had to first bore a hole in the ice, feed a tube through the hole, and pump copious amounts of surface water and algae into their sample canisters.

and from greater depths, exposed them to increasing amounts of light over a period of weeks, and observed which life forms developed. "Sometimes it took up to two and a half months before we saw an actual bloom. But in all the samples there were enough organisms that can be found in a typical spring bloom. That tells us that sea ice as well as surface and deep water are all possible sources of algal blooms in the water column. Which one actually creates blooms probably depends on a wide variety of parameters," the scientist explains.

The MOSAiC team used a so-called light harp, developed by Hamburg-based sea-ice expert Dirk Notz, to take high-resolution measurements of the light spectrum in the sea ice. When the researchers combined this data with the below-ice light measurements taken by the AWI underwater robot and the rosette water sampler, they were able to determine how the light fields beneath the MOSAiC ice floe changed over time. "I'll compare the various light data with my primary production data – in the hope that in the end I'll be able to say whether the algae realy did grow as strongly as they could have done at the respective light level, or not. If the answer is no, it could be due, for example, to



An expedition member carefully inserts the newly developed light harp (l.) in a hole bored in an older section of the MOSAiC floe. The instrument, which measures the amount of light in the ice, will yield data that helps marine biologists like Clara Hoppe understand how much light is available to algae living within and below the ice at a given time. The Arctic diatom Melosira arctica (top) can be seen with the naked eye, since the single-celled organisms, measuring just 30 micrometres, form several-metre-long chains and algal mats, which float like curtains beneath the sea ice.

zooplankton," says the marine biologist, adding: "I now believe that the algae in the water column don't have a real survival strategy in winter. They are simply there and because it's cold and dark, their chlorophyll doesn't suffer any damage. If the algae somehow manage not to get eaten, at the end of the Polar Night, they're still there and ready for the new season."

What do these new insights mean for the big question concerning the productivity of Arctic algae? According to Clara Hoppe: "My conclusion is that, in our analyses and computations, we have to take the grazing on algae by zooplankton, as well as the recycling of nutrients, much more into account." Detailed knowledge and an accurate understanding of the processes are important, not just when it comes to clearly visible parameters like spring blooms, but also at a much earlier point in time. "In science, there has long been a debate about what can be defined as an algal bloom and when their formation starts. Personally, I consider it to be an algal bloom when I see a constant increase in biomass, even when the total percentage of algae is still incredibly small. It can definitely be relevant for the food web and nutrient cycle in the Arctic Ocean," she explains.

This approach doesn't necessarily make her research easier, especially since the chlorophyll sensors on satellites, on buoys and on ARGO gliders (autonomous buoys used to measure temperature, salinity, currents and increasingly also chemical and biological components) are not yet able to detect algal blooms that are just beginning to form. As Clara Hoppe concludes: "That's why, every day we went back and started filtering the water again – litre after litre after litre!" ■

Zooplankton are all fauna that drift freely in the ocean. Some of the best-known representatives are foraminifera, conches, rotifers, fish larvae, radiolarians, ciliates and bryozoans, as well as various tiny crustaceans like copepods, krill, amphipods and many others.