

THE BOTTOM OF THE ARCTIC'S FOOD WEB IS OF TOP IMPORTANCE

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As our planet's climate warms, its most rapidly changing region is the Arctic Ocean and surrounding seas. Warming causes many changes, including the melting of sea ice and a decline in the amount of water that is covered by ice. These changes impact organisms at every level of the food web. In this article, we explain how changes in temperature affect the quality of food available for animals that live in the Arctic. We focus on changes near the bottom of the food web, involving tiny plants that dwell inside and below sea ice, and tiny animals that drift in the Arctic seas. Shifts in the abundance and quality of the smallest organisms in the Arctic Ocean affect larger organisms, such as polar bears and whales. Changes at the base of the food web must be considered if we want to protect the creatures that call the Arctic home.

HOW A CHANGING CLIMATE AFFECTS THE ARCTIC

Since the start of the Industrial Revolution, over 200 years ago, our planet's climate has changed drastically. Temperatures have soared at a faster rate than any other time in the past 65 million years! At the most northern and southern tips of our planet are the polar regions, the Arctic and the Antarctic. These are the coldest regions of Earth, where temperatures average well below 0°C. In winter, the top layer of the ocean freezes, creating what is called sea ice. Sea ice can range from paper thin ice, which melts very quickly, to incredibly thick ice that reaches heights of 3 m and can survive for many years. Sea ice has a cooling effect on the climate, acting as a refrigerator and keeping the rest of the planet at habitable temperatures.

As the temperature of our planet has increased, the environment has reacted in unique and alarming ways. In polar regions, large areas of sea ice are melting. The once snowy, white polar regions are being transformed into large areas of blue, open ocean. The warming of the polar regions has created a lot of questions that need answering. So, let us shed some light on how rising temperatures could affect the Arctic's marine ecosystem.

PHYTOPLANKTON

A drifting plant that performs photosynthesis.

PHOTOSYNTHESIS

A process in which plants use the sun's energy to convert carbon dioxide and water to oxygen and sugar.

BIOMASS

The total weight of an organism, or group of organisms in a specific region.

¹ <https://www.changing-arctic-ocean.ac.uk/>

DIATOM

A large type of phytoplankton that is an important food source for zooplankton.

WHY ARE PHYTOPLANKTON SO IMPORTANT?

At the base of the marine ecosystem, we find very small, but very important, plant-like creatures that drift in all seas. These creatures are called **phytoplankton**. Due to the microscopic size of phytoplankton, they are measured on the scale of microns (μm). One micron is 10,000 times smaller than a centimeter!

Phytoplankton typically live in what we call the **euphotic zone**, simply put, the depths where there is enough light for their **photosynthesis**. Through photosynthesis, they take in carbon dioxide (CO_2) from the atmosphere and produce oxygen, just like plants on land. Together, all the phytoplankton in the world's oceans produce half of the Earth's oxygen. This is an immense amount of oxygen considering that phytoplankton make up <1% of the world's plant **biomass** [1]! In comparison, large plants like trees make up around 70% of global plant biomass yet produce about the same amount of oxygen as microscopic phytoplankton¹. To demonstrate just how hardy phytoplankton are, it is worthwhile to note that they have been around a pretty long time. The first sign of phytoplankton was preserved in rocks from western Australia around 3.5 billion years ago!

Diatoms are the largest phytoplankton in our oceans (Figure 1). They can be circular or elongated plants and are responsible for almost 20% of the Earth's photosynthesis. Though diatoms primarily live in the open ocean, they also thrive in bizarre places. Large masses of diatoms have been found within the sea ice of both polar regions, dwelling

Figure 1

A circular diatom (left)² and a phytoplankton community (right)³
Scale bars are approximations of size.

² <https://www.gercekbilm.com/inanilmaz-elekt ron-mikroskopu-fotograf lari-2/diatom-sem/>

³ <https://ethz.ch/de/news-und-veranstaltungen/eth-news/news/2019/05/weltweite-plankton-verteilung.html>

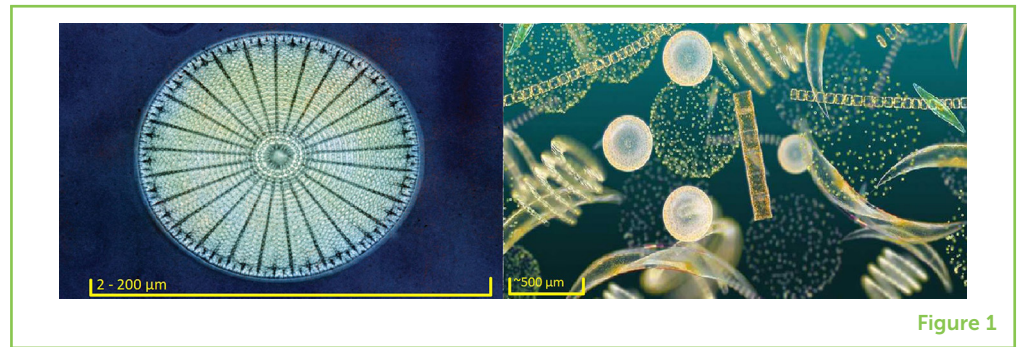


Figure 1

inside salty, liquid, ice channels that have enough nutrients and light for them to perform photosynthesis. When diatoms are found in ice they are no longer classified as phytoplankton. As they are fixed in one place and do not drift we call them ice-dwelling algae or simply ice algae. They are often trapped in the ice as the top layer of the ocean starts to freeze. To find ice algae, ice cores roughly 10 cm in diameter are drilled out of the ice. Figure 2 shows the bottom of an ice core that has an abundance of algae inside.

WHAT EATS PHYTOPLANKTON?

Zooplankton are the “middlemen” of the Arctic, performing the essential role of distributing nutrients to creatures throughout the food web as they are eaten by larger predators (Figure 3). At some point in their lives, crabs, fish, and squid are all ocean drifters, and therefore termed zooplankton. Diatoms are a major food source for many zooplankton, because they contain many nutrients that give zooplankton the energy and raw materials to carry out activities, such as growing and reproducing.

As sea ice melts in summer, nutrients stored in the ice are released back into the ocean. Light also becomes more available because there is less sea ice to reflect the light back into the atmosphere. These spring changes favor phytoplankton, zooplankton, and everything that consumes these bottom-of-the-food-web residents. Since zooplankton eat diatoms, the zooplankton themselves become nutritious for larger animals, such as fish, seabirds, and whales [2]. If zooplankton were not present, the rest of the ecosystem, including humans, would face a great loss of food. Humans in Inuit communities have relied on fish (zooplankton predators) and seals (fish predators) in the Arctic for over 10,000 years!

There is a dirty aspect of zooplankton that is particularly important—their poo. When zooplankton excrete their bodily waste, it becomes a food source for many other creatures. If it does not get eaten, it can end up in the seabed where it stores carbon for millions of

ZOOPLANKTON

A drifting animal unable to swim against an ocean current.

Figure 2

An ice core showing sea ice algae (brown layer inside the ice), including diatoms, dwelling within the bottom 10 cm of the ice⁴.

⁴ <http://www.antarctica.gov.au/science/climate-processes-and-change/oceans-and-marine-ice-in-the-southern-hemisphere/measuring-algae-in-the-fast-ice-research-blog/sea-ice-algae-project-blog/blog-8-first-ice-algae>

COPEPODS

A type of zooplankton with oar shaped feet. A very abundant type of copepod is called *Calanus*.

CALANUS

Some of the most abundant and nutritious copepods in the Arctic Ocean belong to this group.

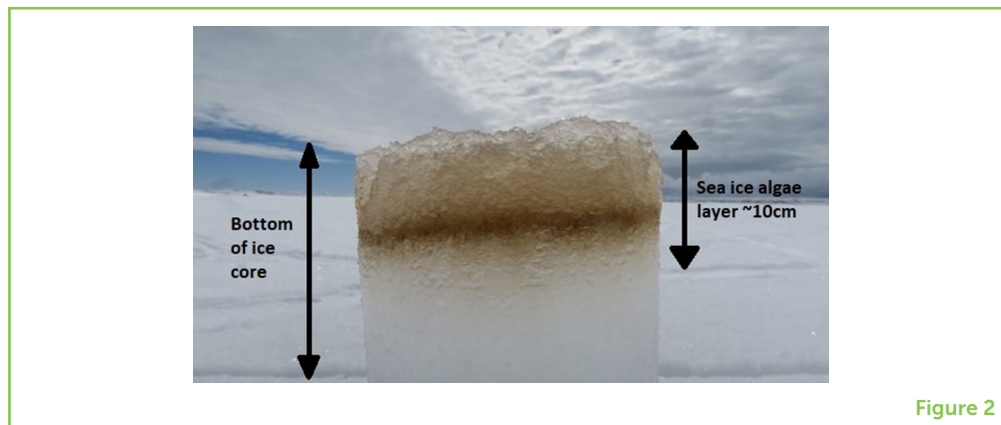


Figure 2

years, slowing down the process of climate change, and keeping our planet cool.

One group of zooplankton found in marine ecosystems worldwide is particularly noteworthy. The **copepods** were given their name due to their “pods” (or feet), which are shaped like the oars used for rowing a boat. Their oar-like feet (Figure 4) help to give these microscopic animals superhero powers! Copepods could win prizes for having some of the most outstanding features in the animal kingdom. Copepods are the strongest animal, the fastest jumpers, and may be the most numerous type of animal on the planet! The favorite food of many copepods is phytoplankton, which must live near the ocean surface where there is enough sunlight for photosynthesis. Feeding on phytoplankton is good, but not always safe; fish, birds, and other predators also hunt in the well-lit surface water, and they are waiting for copepods to make a mistake. Every day, copepods deal with the threat of predators by only entering the shallow water at night, when there is no light. After eating, copepods quickly migrate down to deeper, darker waters before shallow-water predators can see them. This daily migration of copepods and other zooplankton is the largest migration of biomass on the planet, a humongous daily movement spanning depth of tens, hundreds, or thousands of meters.

Some of the most abundant copepods in the Arctic Ocean are members of a group called **Calanus**. Packed with nutritious fats after intense spring and summer feeding, the *Calanus* copepods are so nutritious that some seabirds, fish, and whales travel massive distances across the oceans every year to gorge on them, typically in spring and summer. When most of the phytoplankton and zooplankton have been eaten, many of the birds, fish, and mammals leave the Arctic, to return the following year (but not all).

Figure 3

The Arctic's marine food web [2]. Phytoplankton and ice algae are eaten by zooplankton, and in turn, zooplankton are eaten by polar cod, seabirds, and the bowhead whales. This shows how both phytoplankton and zooplankton are an incredibly important food supply to the rest of the Arctic's ecosystem.

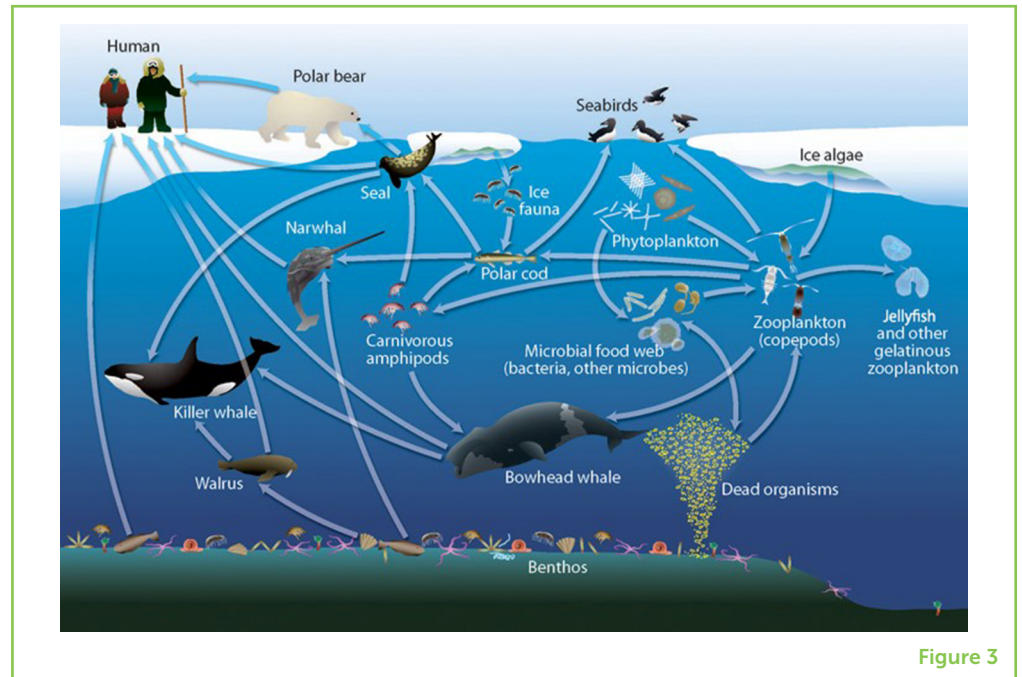


Figure 3

THE DARKNESS

The dark months of winter may not be the best time to be an herbivore dependent solely on photosynthesising plants for survival! Some copepods become omnivores in the winter, while others stop eating altogether and enter hibernation in safe waters far below the sea ice. Intense feeding during peak phytoplankton abundance is crucial for building the necessary fat stores to hibernate during winter. Copepods can look very different in February (after a winter of hibernation and starvation) compared to June (after feeding). In the Arctic, waking up before the phytoplankton **bloom** can be beneficial to copepods. It allows them to feed on diatoms that hang and fall off the bottom the sea ice in spring. Following months of hibernation, an individual *Calanus* typically appears skinny, with limited fat reserves. It is only after feeding in spring and summer that a *Calanus* copepod can replenish its fat stores to their former glory (Figure 4) [3]! After their return to algae-rich surface waters in the spring, many successful copepods reproduce during the spring ice algal bloom, allowing their offspring to hatch during the phytoplankton bloom that occurs below the ice a few months later [3]. This may be essential for their offspring to survive.

THE FUTURE

Researchers believe that if *Calanus* copepods failed to eat ice algae, the size of the copepod population could be drastically reduced. As sea ice declines due to climate change, this important food source for copepods is removed. Over long time scales, sea ice loss and other factors could decrease the availability of nutrients for the

BLOOM

Rapid growth of algae or phytoplankton.

Figure 4

Calanus copepods sampled in February (left) and June (right). Though the lengths of the two copepods are relatively similar (4.4 and 4.8 mm), the February copepod is smaller overall than the June copepod, and the February animal, which is approaching the end of hibernation, also contains less fat in its oil sac (2019).

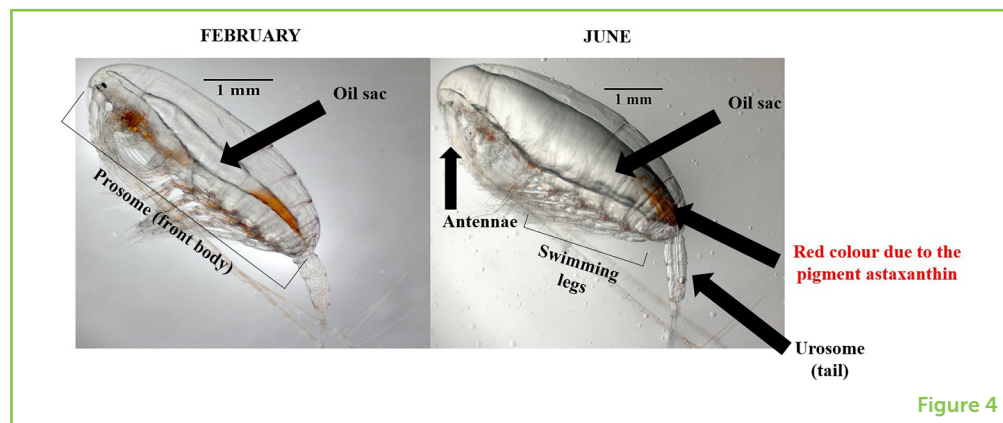


Figure 4

phytoplankton that are trying to grow below the ice [4]. This decrease of food for phytoplankton could mean that smaller phytoplankton would become more numerous than bigger, more nutritious diatoms. So, instead of having an abundance of high-quality food like large diatoms, copepods in a warmer, ice-free Arctic might be forced to eat less nutritious, smaller phytoplankton. Scientists are already seeing smaller-sized organisms in both the copepod and phytoplankton communities [5].

PROJECTED CHANGES IN THE ARCTIC AND WHAT WE CAN DO TO HELP

As the Arctic region changes, it is likely that we could see food stocks, such as diatoms and other phytoplankton decline, while also becoming smaller and less nutritious. Changes in the lowest part of the food web can have immense consequences for larger animals. Extinction of species at the bottom of the food web can be terrible news for specialized predators that have evolved to eat them. Changes in the amount and type of plankton affect humans and animals in many direct and indirect ways, ranging from changes in air quality, to how we interact with the environment and its resources. With less phytoplankton in the Arctic, CO₂ concentrations in the atmosphere would increase causing our planet to continue warming.

As a society, we need to be more aware of the fact that our activities at home, work, or school can all affect ecosystems in places that are far away from us. Small changes, such as walking or cycling instead of driving can drastically help to limit CO₂ emissions. Research programs like the Changing Arctic Ocean¹, based in the UK, are providing governments and the public with the most up-to-date information on biological changes in the Arctic. Two groups from Changing Arctic Ocean have collaborated on writing this manuscript, and we have additional resources available if you would like to learn more^{5,6}.

⁵ <https://www.changing-arctic-ocean.ac.uk/project/eco-light/>

⁶ <https://www.changing-arctic-ocean.ac.uk/project/chase/>

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We are a synthetic biology team with the international Genetically Engineered Machine (iGEM) in Lima, Peru. We are the only high school team in Latin America and are proud of our work with creating a detector for cadmium using bacteria. Most of us are second language learners and the age range of our group is 14–17 years old. We love GMOs!



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Dr. Jordan Grigor is a marine biologist with several years of focusing on the ecology of small animals, such as copepods and arrow worms. He works within the Arctic, where many animals are being affected by rapid changes in climate. He has revealed information about little known species (e.g., <https://www.researchgate.net/project/Ecology-of-chaetognaths-arrow-worms-in-Arctic-waters>), showing that arrow worms feed on diatoms and copepods. Now working on the CHASE project (<https://www.changing-arctic-ocean.ac.uk/project/chase/>) at the Scottish Association for Marine Science, he is trying to understand the influence of environment and genetics on swimming behavior in copepods. *jordan.grigor@sams.ac.uk