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THE SOUTHERN OCEAN SEA-ICE ECOSYSTEM IS IMPORTANT TO HUMANS

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Did you know that ecosystems support the wellbeing of humans by simply existing? An ecosystem describes the living things in an area, their interactions, and their environment. The ways that ecosystems benefit the wellbeing of humans are called ecosystem services. There are several types of ecosystem services: supporting (they support animals and their homes), provisioning (they provide food and other materials), cultural (they support our hobbies and cultural activities, such as tourism and arts), or regulating (they regulate our climate, for example by taking up carbon dioxide). Understanding the importance of an ecosystem through its ecosystem services helps guide decisions regarding the environment, such as how much fishing or ship traffic should be allowed in an area, or if an area or species should be protected. In this article, we describe the specific ecosystem services of the sea ice and Southern Ocean around Antarctica.

THE SOUTHERN OCEAN SEA-ICE ECOSYSTEM PROVIDES MANY SERVICES TO HUMANS

The Southern Ocean (the ocean around Antarctica) is largely covered by sea ice which expands each winter and retracts in summer. The sea ice supports a thriving ecosystem which provides many services to humans. In the sections that follow, we describe the various types of ecosystem services that are related to sea ice in the Southern Ocean (Figure 1).

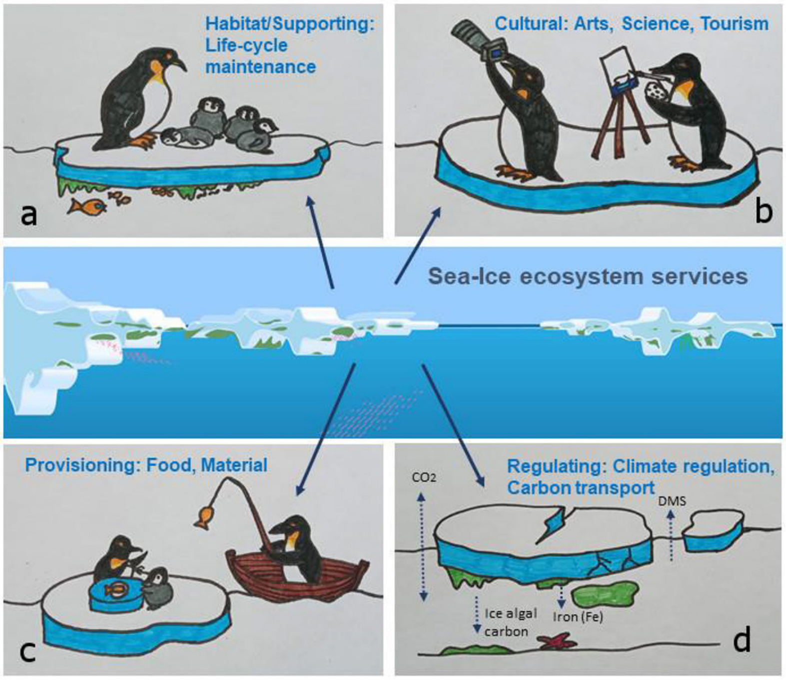

Figure 1

Figure 1

Ecosystem services are the many ways that an ecosystem benefits the wellbeing of humans. Ecosystem services can be **(a)** supporting (they support animals and their homes or habitats), **(b)** cultural (they support our hobbies and cultural activities such as tourism and art), **(c)** provisioning (they provide humans with food, such as seafood), or **(d)** regulating (they regulate the Earth's climate and help us keep climate change under control).

SUPPORTING ECOSYSTEM SERVICES

Supporting services (Figure 1a) allow organisms—from tiny bacteria to large animals—to grow, by providing them with a place to live (habitat), raise their young (nurseries), and eat (feeding grounds). When sea ice forms, channels and pores develop in the ice, filled with cold, salty seawater. In these pores and channels, microscopic organisms (viruses, bacteria, algae, and fungi) manage to live, despite extreme conditions.

Ice algae are tiny, single-celled plants that grow near the bottom of the sea ice (Figure 2a). Most ice algae are photosynthetic, which means they "eat" by using sunlight, carbon dioxide, and water to produce their own food (for more information on photosynthesis in the ocean, see this article). Ice algae are eaten by other organisms like zooplankton (microscopic sea animals), which are themselves eaten by fish, seabirds (including penguins), seals, and whales (Figure 2). Ice algae contribute an enormous quantity of food to Southern Ocean ecosystems—they make up between 10 and 50% of the available food in ice-covered regions! The remaining food comes from other microscopic algae, called phytoplankton, in the open ocean. Phytoplankton are also important to humans because they produce about half of the oxygen that we breathe.

Figure 2

Figure 2

(a) Ice algae at the bottom of sea-ice, so abundant that they turn the ice brown. **(b)** Humpback whale feeding at the ice edge, Weddell Sea. **(c)** Elephant seals and king penguins in South Georgia at Gold Harbor. **(d)** Antarctic krill, Kong Haakon VII Sea, Southern Ocean. Krill form huge swarms and provide food for many animals. **(e)** Fur seal at Shingle Cove, Coronation Island. Elephant and fur seals seasonally migrate to the sea ice to feed. **(f)** Gentoo penguin chicks, South Shetland Islands. Gentoo penguins feed at the edge of the sea ice, where marine life is most productive [photo credits: Finn Steiner—(**a, b, c, e, f)** Rudi Caeyers, Norwegian Polar Institute—**(d)**].

BIOMASS

The total quantity or weight of organisms in an area or volume.

Sea ice provides a habitat for small animals like zooplankton or larval and juvenile (young) fish. One of those is Antarctic krill (Figure 2d), a shrimp-like animal that can live 5–6 years and grow up to 6.5 cm long. Did you know that Antarctic krill is the animal with the highest **biomass** on our planet? There are 400 million tons of Antarctic krill on Earth, which is more than 2.5 million blue whales! Krill are distributed throughout the Southern Ocean; their largest concentration is around the Antarctic Peninsula. In late summer, adult krill lay eggs in deep water. Once the eggs hatch in autumn, they go through several development stages with the funny names, like calyptopis and furcilia. During development, they move up to the sea ice where they graze on ice algae and small zooplankton and grow into young adults. In the summer, they spread out in the water to feed on other zooplankton. Krill are an essential food for fish, seabirds, and whales. Because of their strong association with sea ice, Antarctic krill are highly sensitive to sea-ice changes caused by climate change [1].

Sea ice also supports larger animals. Many penguins, flying sea birds, and coastal Antarctic seals use sea ice for critical parts of their life cycles, such as reproducing or eating. Others, like southern elephant seals and Antarctic fur seals, and some whales, like Antarctic minke, humpback, and blue whales, occasionally migrate to the sea ice to feed.

PROVISIONING ECOSYSTEM SERVICES

Provisioning services (Figure 1c) provide humans with food and other materials through fisheries and harvesting of marine mammals and algae. Humans do not permanently live in Antarctica but come to the Southern Ocean on large fishing vessels and collect many tons of krill, toothfish, and other species.

Provisioning services also include **bioprospecting**, which means the search for novel substances. Since ice organisms tolerate very cold temperatures and high saltiness, they can be a source of **cold-adapted enzymes** and **antifreeze proteins**, which can benefit food-preservation, for example. Polar microorganisms can also be sources of medicines and beauty products.

BIOPROSPECTING

The search for novel biological or biochemical substances.

COLD-ADAPTED ENZYMES

Enzymes which are specifically adapted to function in cold and/or frozen environments.

ANTIFREEZE PROTEINS

Proteins produced by certain organisms that permit their survival in freezing temperatures.

REGULATING ECOSYSTEM SERVICES

When sea ice melts in summer, ice algae detach from the ice. Some of these algae are eaten by zooplankton, but the majority sink toward the seafloor, bringing food to organisms that live there (like sea urchins, sea cucumbers, and sea stars). This process also transfers the carbon (or CO_2) contained in the ice algae away from the atmosphere, into the deep ocean. The carbon can remain there for thousands of years, helping humans to control climate change. Without the oceans, the CO_2 in the atmosphere could be double what it is nowadays!

Many humans think of bacteria only as causes for diseases. However, in the oceans bacteria recycle ("eat") **organic material** that is released e.g. when animals and plants die. While "eating" organic material, bacteria can convert nutrients into a chemical form that can be used again by other organisms, such as algae. This is a very important service since—without it, dead material from organisms would fill up the ocean.

ORGANIC MATERIAL

Carbon-based material from plants and animals.

Ice algae also produce a compound involved in forming clouds. That compound has the super complicated name **dimethylsulphoniopropionate**, but we call it DMSP for short. Bacteria can transform DMSP into the gas **dimethylsulfide (DMS)**, which gets emitted into the atmosphere. There, DMS can help to form clouds that protect Earth from the sun's incoming radiation and help humans to reduce the greenhouse effect and, thus, climate change. Without these algae, there would be less clouds over the Southern Ocean.

DIMETHYLSULPHONIOPROPIONATE (DMSP)

An organic sulfur compound with the complicated chemical formula (CH3)2S CH2CH2COO which is produced by some phytoplankton and ice algae in the ocean.

DIMETHYLSULFIDE (DMS)

An organic sulfur compound with the chemical formula (CH3)2S. DMS is a gas with a smelly odor.

Due to its special physical and chemical properties, sea ice holds exceptionally high concentrations of iron, which is otherwise very scarce in the Southern Ocean. All living organisms need iron, even if just a tiny amount. Iron first helps ice algae to grow and, when it is released into the ocean, the iron helps phytoplankton to grow.

CULTURAL ECOSYSTEM SERVICES

Cultural services (Figure 1b) support human interests through tourism, science, and the arts. Sea-ice ecosystems can inspire humans to explore, paint, compose music, or make movies. Many people visit Antarctica every year on tourist ships, hoping to follow in the footsteps of polar explorers and see the abundant life around the Antarctic continent. They may have been inspired by books or movies and they may ask questions related to what they have heard. Tourists often travel to the Antarctic region with an incomplete understanding of the Antarctic ecosystem and its function. Antarctic tourism guides are like interpreters or educators. They help fill knowledge gaps, explain the impact humans have on the ecosystem, and tell people what they can do to limit these impacts.

WHAT THREATENS SOUTHERN OCEAN ECOSYSTEM SERVICES?

Climate change is known to impact ecosystems and **ecosystem services** all over the world. In the Southern Ocean, climate change has especially been felt in Western Antarctica where temperatures are rising rapidly [2]. When higher temperatures melt the sea ice, ice algae and other sea-ice organisms lose their habitats, penguins and seals lose their platform, and marine organisms get exposed to changing environmental conditions. This impacts the species of algae and phytoplankton that live there, as well as their ability to absorb CO_2 from the atmosphere [3]. Temperatures are now also rising faster in East Antarctica, and sea ice is decreasing more abruptly, as it is in the Arctic Ocean.

ECOSYSTEM SERVICES

The services an ecosystem provides to humans.

In addition to climate change, increasing human activities including fisheries, tourism, and scientific research may harm vulnerable polar ecosystems. Therefore, these activities need to be regulated to protect the ecosystems, prevent pollution, and prevent **overfishing**.

OVERFISHING

Taking too much fish out of the ocean so there are hardly any left.

WHAT CAN WE DO?

These threats can sound scary, but there are potential solutions. Solutions range from global efforts to reduce greenhouse gas emissions to local protections of marine ecosystems, along with regulations regarding fisheries, tourism, and shipping. Globally, the countries of the world are trying to tackle climate change by committing to reduce their national greenhouse gas emissions, for instance, by helping industries and households to be more energy efficient or by encouraging people to reduce automobile and air travel. Some global efforts are coordinated through the Paris Agreement, an international treaty developed in 2015 and signed by nearly 200 countries that aim to limit global warming.

MARINE PROTECTED AREAS

Regions of the ocean where governments have restricted human activities to conserve the ocean and ocean ecosystems.

In Antarctica, an international commission is responsible for regulating **marine protected areas** and fisheries. Several marine protected areas have been proposed to the commission to protect the most important ecological areas of the Southern Ocean. Of these protected areas, two have been approved, and others are still being discussed (Figure 3). Fisheries are usually regulated by how many fish are allowed to be caught, which depends on how many fish there are in the first place. The idea is to take only as many as the ecosystem can rebuild, so the ecosystem can sustain itself over years to come.

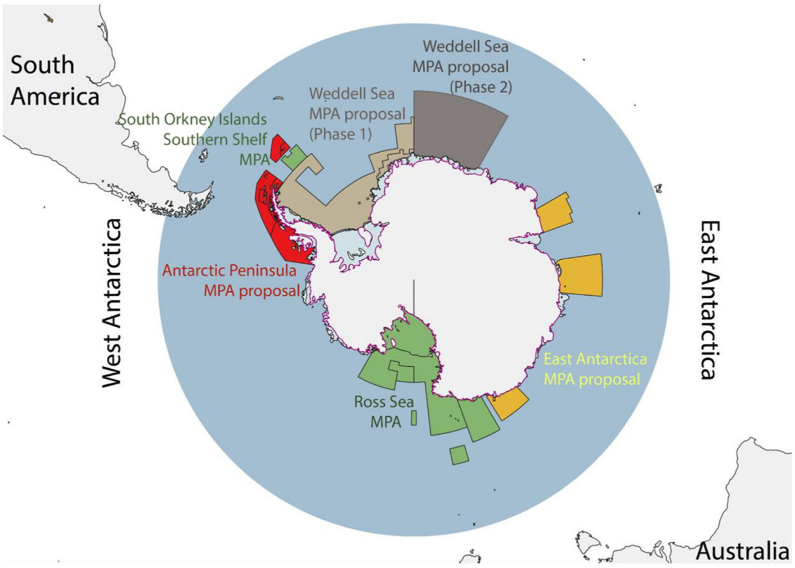

Figure 3

Figure 3

Existing and planned/proposed marine protected areas (MPAs) in the Southern Ocean around Antarctica. The Ross Sea MPA and the South Orkney Islands Southern Shelf MPA already exist. The other MPAs are in various stages of planning. It can take many years from a proposal to the final establishment of an MPA.

Tourism in Antarctica is regulated by an international tourism association. Their regulations include how many ships are allowed to visit and how many people are allowed to go on land. The association also promotes education. By demonstrating the beauty of southern polar regions, tourism can inspire visitors to become ambassadors and caretakers of Antarctic ecosystems.

SUMMARY

The Southern Ocean around Antarctica is an incredible place. Like a pulse, large areas of sea ice form and melt each year. Sea ice supports an abundance of life and provides multiple ecosystem services to humans. However, climate change and other human activities threaten the health and stability of the sea-ice and ocean ecosystems as well as the ecosystem services they support. By reducing our carbon emissions globally, protecting ecologically important areas, and limiting our impacts in the Antarctic, we can help the ecosystem support us for many years to come.

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REFERENCES

1. Flores, H., Atkinson, A., Kawaguchi, S., Krafft, B. A., Milinevsky, G., Nicol, S., et al. (2012). Impact of climate change on Antarctic krill. *Mar. Ecol. Prog. Ser.* 458:1–19. doi: 10.3354/meps0983
2. González-Herrero, S., Barriopedro, D., Trigo, R. M., Lopez-Bustins, J. A., and Olivia, M. 2022. Climate warming amplified the 2020 record-breaking heatwave in the Antarctic Peninsula. *Commun. Earth Environ.* 3:122. doi: 10.1038/s43247-022-00450-5
3. Montes-Hugo, M., Doney, S. C., Ducklow, H. W., Fraser, W., Martinson, D., Stammerjohn, S. E., et al. 2009. Recent changes in phytoplankton communities associated with rapid regional climate change along the western Antarctic Peninsula. *Science* 323:1470–3. doi: 10.1126/science.1164533

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We are the Laurus Y6B. We are very interested in SDGs. Many of us are life library rangers and like to take care and learn about animals. Together we can create a better planet for everyone!

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