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THE CIRCLE

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ARCTIC REALITY CHECK:

AN UNCERTAIN FUTURE

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COVER: A melting iceberg in Qaanaaq, Greenland.
Photo credit: © Staffan Widstrand / WWF.

THIS PAGE: A polar bear and cubs roam on sea ice in Churchill, Manitoba, Canada with a parhelion (mock sun) in the backdrop.
Photo credit: © naturepl.com / Bryan and Cherry Alexander / WWF.

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EDITORIAL

Facing an uncertain future

THE ARCTIC is teetering on the edge of a cliff—and the speed of climate warming is threatening to push it over the edge. Because of human activities around the globe, Arctic temperatures have increased almost four times faster than the global average over the past 40 years, faster than anywhere else on the planet.

The extent of summer sea ice is now shrinking by 13 per cent each decade, and the sea ice cover continues to become younger and thinner. Even if the world somehow gets its act together and reduces carbon emissions sharply, the first ice-free summer could be as soon as some time in the 2030s—a decade sooner than previous projections indicated.

If we don't limit the global temperature increase to 1.5°C, not only will we lose important biodiversity, communities and industries in the Arctic itself, but as the Arctic melts and releases more carbon emissions, the entire world will face the consequences of continuously rising sea levels and accelerated warming. In fact, we are already seeing the effects of human activity on our natural world in the form of more severe droughts, extreme weather events, and larger and more frequent wildfires, such as those that are devasting parts of North America and Russia this summer.

At the Bonn Climate Change Conference in June, negotiators made some advances towards addressing the climate crisis. But the conference revealed a concerning lack of progress on achieving our climate goals and limiting warming to 1.5 degrees. This apathy doesn't match the urgency of the situation. It does put more pressure on delegates to the COP28 UN Climate Summit in December to bring about the changes needed to avoid catastrophe. The time for action is now.

Unless we plan, enable and implement climate-smart conservation—and do so under conditions that ensure success—we will lose not only nature, but everything we value that is linked to it.

Slaty-backed gull on sea ice in June in the Bering Sea near Kamchatka, Russia.

Photo credit: © Kevin Schafer / WWF

We need to provide nature the space it needs to adapt to changing conditions so we can strengthen the Arctic's resilience. Unless we plan, enable and implement climate-smart conservation—and do so under conditions that ensure success—we will lose not only nature, but everything we value that is linked to it.

We don't have time for delays. That is why WWF is calling on countries to commit to phasing out all fossil fuels and fossil fuel subsidies and to agree on a target to rapidly expand renewable energy, energy efficiency and energy access at COP28.

While I have more than two decades of experience working on conservation in the south, I am a newcomer to the Arctic. It has been an eye-opener for me to see how tangibly and concretely people and ecosystems in the Arctic are being affected by climate change. The Arctic is the epicentre of the climate crisis, and the changes taking place there now are uprooting communities and ecosystems as we speak.

Some of these changes will be irreversible. But many others can still be mitigated or avoided. Over the next seven years, we have a small window of opportunity to work with everyone involved, particularly Indigenous Peoples, to prepare the Arctic for an uncharted future. The stakes are high, and we cannot afford to fail—for the sake of the Arctic and the planet. ●

VICKI LEE WALLGREN is the new director of WWF's Global Arctic Programme. For the past decade, she led WWF-Sweden's forest and wildlife team.

IN BRIEF

Photo credit: © naturepl.com / Martha Holmes / WWF

Bowhead whale under ice.

DISRUPTED WHALE MIGRATION PATTERNS

Bowhead whales on the move

RESEARCHERS HAVE FOUND that some bowhead whales in the Bering-Chukchi-Beaufort population have stopped migrating from the Canadian Beaufort Sea to the northwestern Bering Sea in winter due to declining sea ice in the Beaufort area.

Migration patterns are known from acoustic monitoring, traditional knowledge, aerial surveys and satellite tagging.

The pattern alteration may put the bowhead whales at greater risk of ship strikes, fishing net entanglements, and problems caused by underwater noise—which can interfere with whale signals related to hunting, feeding, navigating, mating and more—because the decline in sea ice may also attract more shipping vessels.

So far, the shift hasn't affected Indigenous communities that rely on whale hunting, but researchers say this could change in future, particularly at the southern end of the whales' range. The change does not seem to have affected the size of the whale population, which has recovered following past commercial whaling.

OZONE PROTECTION BENEFITS THE CLIMATE

Montreal Protocol slows sea ice thaw

CLIMATE SCIENTISTS HAVE been trying to predict how soon the Arctic will experience its first ice-free summer. The date is a moving target—but it seems that at least one climate agreement is having a positive impact.

The Montreal Protocol, an international treaty banning ozone-destroying gases, was agreed upon in 1987, when representatives from around the world gathered in Canada to agree on a plan to phase out chlorofluorocarbons (CFCs) and other aerosols that were eating away at the ozone layer. These same substances are also greenhouse gases, some far more potent than carbon dioxide.

While the protocol's purpose was to preserve the ozone layer, scientists say it seems to have had unexpected climate benefits, and may be delaying sea ice loss in the Arctic. A recent study, published in the Proceedings of the National Academy of Sciences, found that the Montreal Protocol had averted more than half a million square kilometres of Arctic summer sea ice loss by 2020 by limiting warming in the region.

As for the ozone layer, it appears to be on track to recover by the mid-21st century to values first observed in 1980, before the appearance of the ozone hole.

POLLUTION FROM THE BOTTOM UP

Microplastics in Arctic ice algae

ALONG WITH OTHER organisms, algae sit at the base of the food web—so researchers were dismayed to find that the algae known as *Melosira arctica*, which grow under Arctic sea ice, contain 10 times as many microplastic particles as the surrounding sea water. This concentration poses a threat to creatures that feed on the algae at the sea surface. *Melosira arctica* grow at a rapid pace under the sea ice during spring and summer and form an important food source for bottom-dwelling animals and bacteria.

These findings were published by a research team from the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research.

The presence of micro- and nano-plastics in the Arctic isn't new: these have been detected around the world, transported to even the most remote regions by ocean and atmospheric currents and biota from both distant and local sources. But their presence in Arctic ice algae is worrying for a few reasons.

One is that the climate crisis is already making it harder for many Arctic species to survive, and exposure to microplastics could weaken them further. Another is that people in the Arctic are particularly dependent on the marine food web for nutrition, so they are also exposed to these microplastics.

The research team has pointed out that the most effective way to reduce plastic pollution is to reduce the production of new plastic in the first place.

DATA MELTING AWAY

Research station at the top of the world is thawing

AT EARTH'S NORTHERNMOST year-round research station, scientists are having a harder and harder time accessing the data they need to understand the impacts of climate change.

The tiny town of Ny-Ålesund is high above the Arctic circle in the Svalbard archipelago. The town and its research station are a destination for scientists from 11 countries who come to study how climate change is transforming the Arctic and what these changes will mean for the rest of the planet.

The research station's weather records date back more than 40 years. But recently, scientists have been encountering glacier melt where they expected ice cores, and have run into difficulties reaching research sites when earlier-than-usual springtime warmth melts ice paths. Last year, one of the research station's laboratories closed after thawing permafrost cracked its foundation. Polar bear sightings in the area are on the rise.

Svalbard is warming nearly seven times faster than the global average. Scientists who could once plan to travel around the area in June now cannot do fieldwork past mid-May. This year, a team that intended to drill 125 metres to collect two ice cores on the Dovrebreen glacier were taken aback when they hit water at only 25 metres of depth.

Ny-Ålesund, Svalbard.

Photo: credit: Wen Nag, flicr.com (CC BY-NC-SA 2.0)

Climate science

WHY IS THE ARCTIC WARMING FASTER THAN THE REST OF THE PLANET?

While the world as a whole has warmed by around 1.2°C since the start of the industrial revolution, the Arctic has warmed by around 3°C, with devastating impacts for people and ecosystems. This faster pace of warming is often attributed to the melting of sea ice: as it disappears, it is replaced by a growing expanse of dark ocean water that absorbs sunlight rather than reflecting it. But as **MATTHEW HENRY** explains, other important factors are also at play. ➤

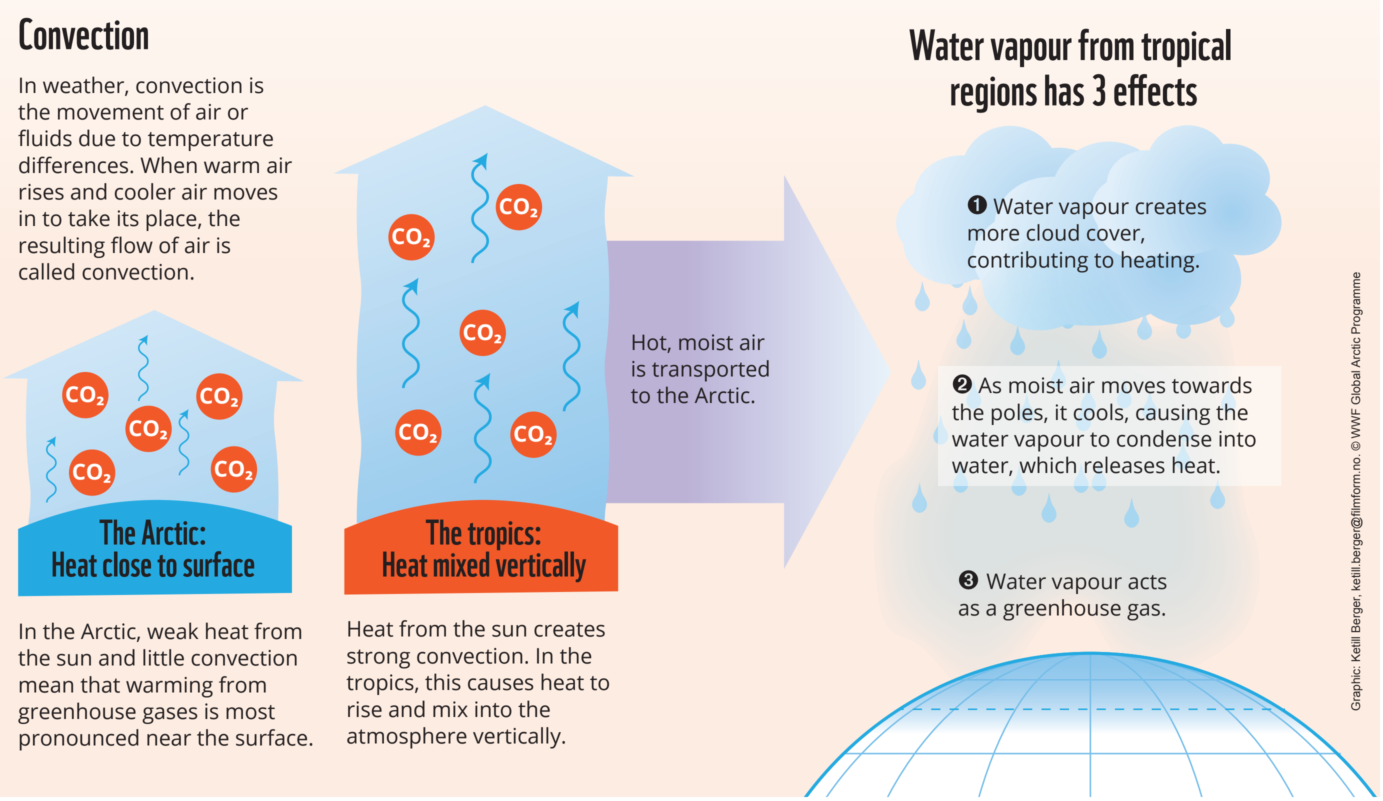
Despite new ideas and advancing technologies, if we want to slow down the ongoing changes to the Arctic climate and ecosystems, our first priority should be cutting our emissions as rapidly as possible.

Remains of a glacier at Alpefjord, Northeast Greenland National Park. Mass loss from the Greenland ice sheet has quadrupled over the past two decades, contributing a quarter of the observed global sea-level rise.

Photo: Peter Prokosch, www.grida.no/resources/3607

Why the Arctic is heating up faster

Although the albedo effect is a major contributor to Arctic warming, there are other important processes at work. A warmer world will have more water vapour in its atmosphere, including the Arctic's. This will accelerate warming in the north because convection is weaker there, so the added warmth stays trapped near the ground.



Graphic: Ketill Berger, ketill.berger@filmform.no. © WWF Global Arctic Programme

AS LONG AGO AS 1896(!), Swedish chemist Svante Arrhenius theorized that places in the world that are covered in snow or ice for most of the year would see accelerated warming from increased carbon dioxide in the atmosphere. His hypothesis was that these locations would reflect less sunlight back into space when the snow and ice began to melt.

Scientists now know that the reasons for the Arctic's amplified warming are more complex than that, but the simplicity of Arrhenius' explanation has captured the narrative around Arctic warming, especially in the public's understanding.

In fact, there are two additional, interacting mechanisms that help explain this intensified warming: convection and the presence of water vapour.

WARM AIR RISES

First, convection occurs when air near the Earth's surface is heated by the warmth of the ground. It becomes lighter than the air above it, and rises.

In tropical regions, the surface is constantly heated by the sun, leading to a lot of convection that mixes in the atmosphere vertically. But in the Arctic, less sunlight reaches the surface. This results in the atmosphere being heated primarily by warm, moist air transported from the tropics—so there is less convection and vertical mixing.

Further, the additional warming caused by carbon dioxide and other greenhouse gases mainly affects the atmosphere near the surface. In the tropics, this extra warmth gets spread vertically due to convection. But in the Arctic, the warming from greenhouse gases is most pronounced near the surface.

WATER VAPOUR WARMS

Secondly, water vapour (water in its gas form) plays a very important role in our climate system. Were it not for the transport of moist air from the tropics to the poles, the temperature difference between these regions would be much greater. In a warmer world, we expect there to be more water vapour in the atmosphere, and as a result, more moisture in the Arctic atmosphere.

This has a threefold impact on Arctic surface temperatures: first, water vapour itself acts as a greenhouse gas, contributing to additional warming. Second, as the moist air moves toward the poles, it cools, causing the water vapour to condense into liquid water, which releases heat into the atmosphere and further warms the region. Third, the increased moisture leads to more cloud cover, which tends to warm the Arctic.

Putting these two influences together, the absence of convection exacerbates the effects of water vapour on Arctic warming.

There is still some uncertainty as to how fast the Arctic will warm in the future, and there is an ongoing scientific debate about when the first ice-free Arctic summer might occur and what effect it might have on weather in the midlatitudes.

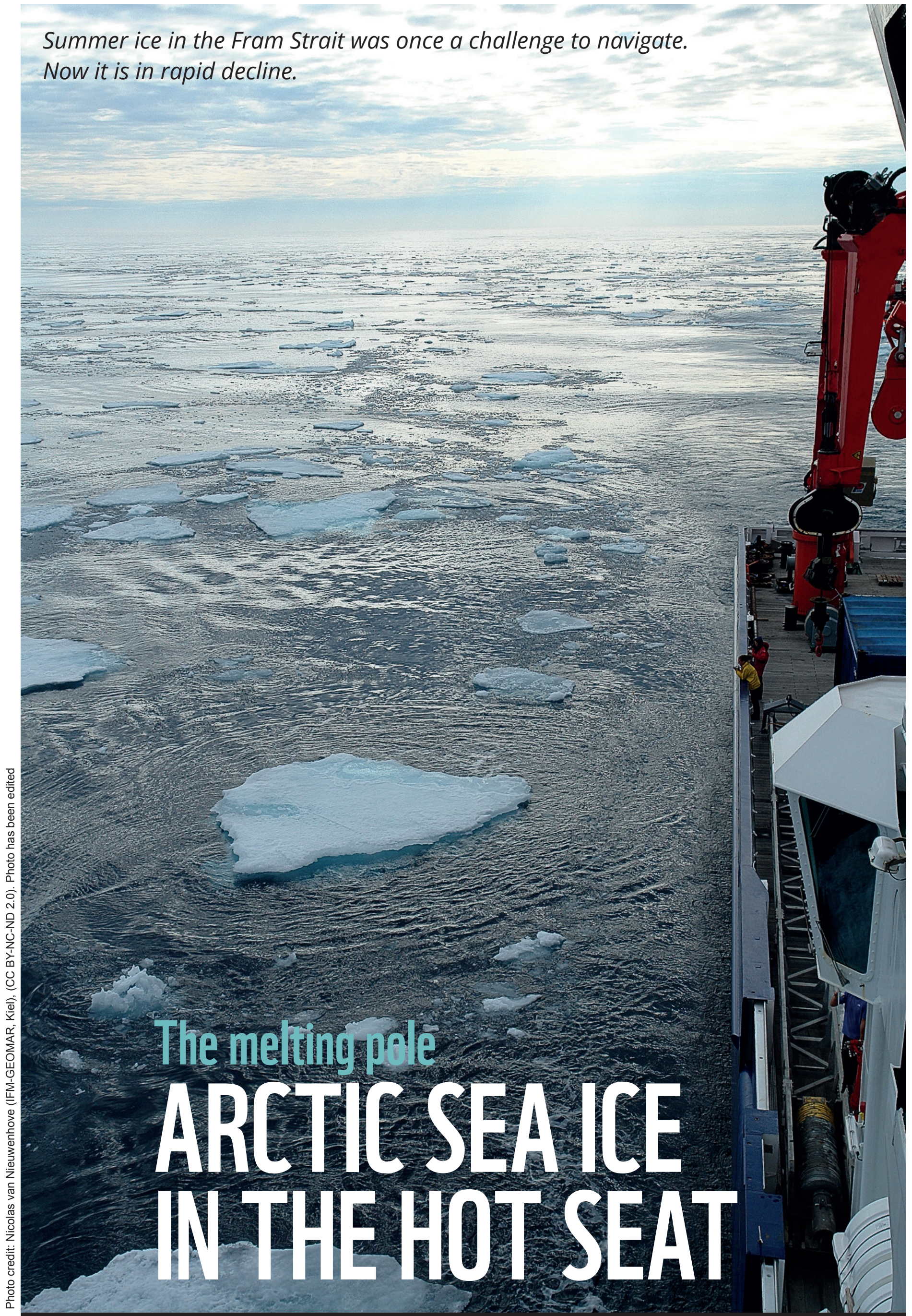
CUTTING EMISSIONS IS STILL THE BEST BET

Cutting emissions can slow the rate of warming until the Earth's temperature stabilizes when we reach net zero. But until we are able to remove more carbon dioxide from the atmosphere than we put in, the temperature will not go down. For this reason, there is increasing interest in so-called solar climate interventions—such as marine cloud brightening and stratospheric aerosol injection—that aim to cool the climate intentionally by increasing the amount of sunlight reflected to space.

Any intervention that cools the planet globally will cool the Arctic more because of the albedo effect, convection, and water vapour mechanisms described above. However, there are still deep uncertainties about the possible effects and impacts of these climate interventions. Much more research is needed on these from both the physical and social science perspectives before we can consider applying them.

In other words, despite new ideas and advancing technologies, if we want to slow down the ongoing changes to the Arctic climate and ecosystems, our first priority should be cutting our emissions as rapidly as possible. ●

MATTHEW HENRY is a postdoctoral research fellow in climate science at the University of Exeter in the UK. His work focuses on solar climate interventions and the Arctic climate.



Summer ice in the Fram Strait was once a challenge to navigate. Now it is in rapid decline.

Photo credit: Nicolas van Nieuwenhove (IFM-GEOMAR, Kiel), (CC BY-NC-ND 2.0). Photo has been edited

The melting pole

ARCTIC SEA ICE IN THE HOT SEAT

Recent observations and climate model predictions point toward the rapid loss of Arctic sea ice. This change will have severe consequences for people and ice-dependent species in the Arctic—as well as for humans, wildlife and plants far beyond the Arctic region. And as **MATS GRANSKOG** and **MORVEN MUILWIJK** write, these dramatic changes to the Arctic's environment are occurring at an astonishing pace. ➤

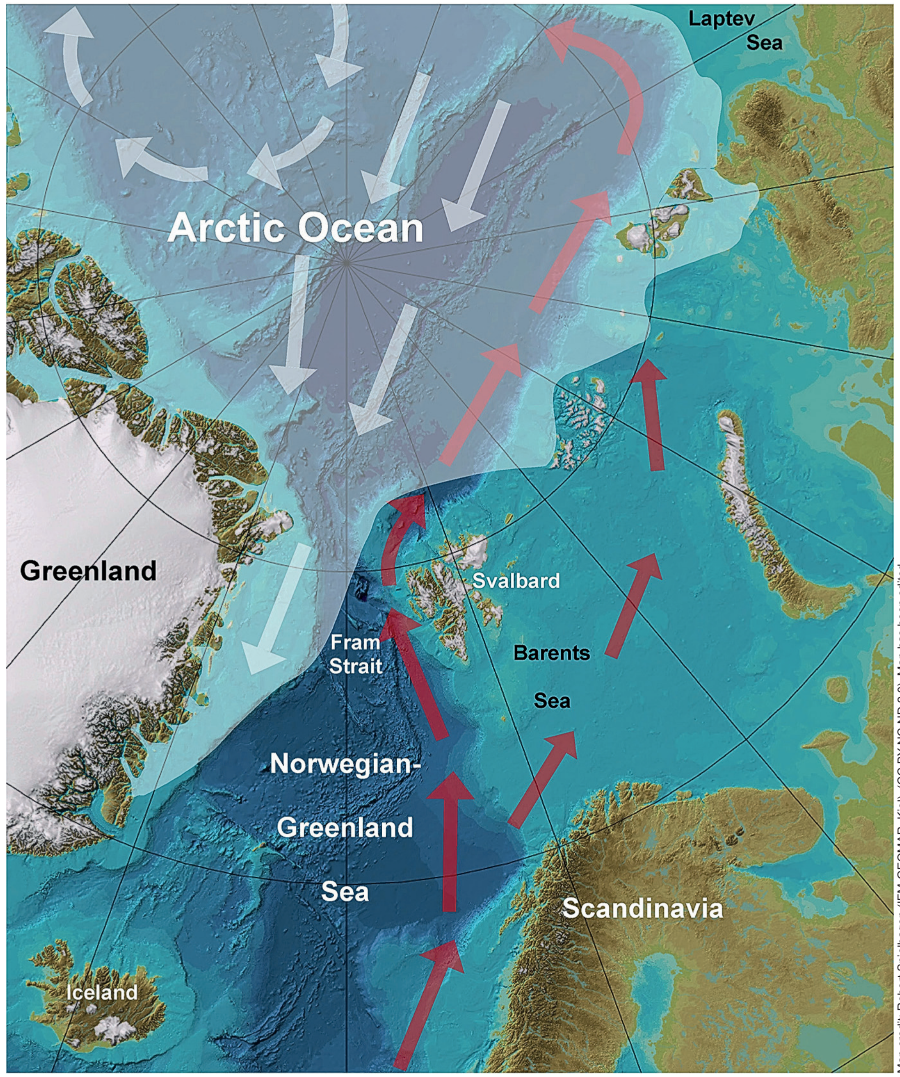
IN THE CONTEXT of the global climate, a decade is a very short period of time. Even a human lifetime has generally been considered too short a span for someone to be able to notice changes. But not in the Arctic of today. Researchers working in the region over the past decade (or several) have seen significant changes in the icescape.

A mere decade ago, venturing out to the Fram Strait (the narrow strait between Greenland and Svalbard) in late summer meant encountering formidably thick Arctic sea ice. While the ice posed challenges for ship navigation, finding a suitable ice floe to work on was no problem for researchers. Today, the tables have turned. Only small, thin remnants of ice floes persist at the end of summer.

Sea ice plays a vital role in regulating the Earth's climate by reflecting most of the sun's energy back into space (in contrast to darker seawater, which absorbs nearly all of it). And the more sea ice melts, the faster the pace of melting becomes. This is what we call a positive feedback loop.

RARE LONG-TERM ICE RECORDS TELL A CHILLING STORY

The Arctic Ocean has a history of being difficult to access. Within our lifetimes, we needed heavy icebreakers and submarines to reach the interior of the Arctic year-round. Because of challenges like these, the Arctic is among the oceans with the scantiest available data.



Map credit: Robert Spielhagen (IFM-GEOMAR, Kiel), (CC BY-NC-ND 2.0). Map has been edited.

White shading indicates average summer sea ice cover. White arrows indicate ice drift directions. Red arrows indicate the transport path of warm Atlantic water entering the Arctic, where it drops beneath the cold, ice-covered surface layer.

> There is no question that Arctic ecosystems are poised to undergo profound transformations, potentially beyond recognition.

This scarcity underscores the immense value of the few long-term records of observations that we do possess for this region.

One of these records comes from the Fram Strait. As hypothesized and proven by Fridtjof Nansen back in the early 1900s, sea ice drifts across the Arctic Ocean. Due to the prevailing winds and currents, it ends up in the Fram Strait, which acts as a funnel. This is why the strait is an optimal location from which to monitor sea ice changes without the need to venture too far into the interior.

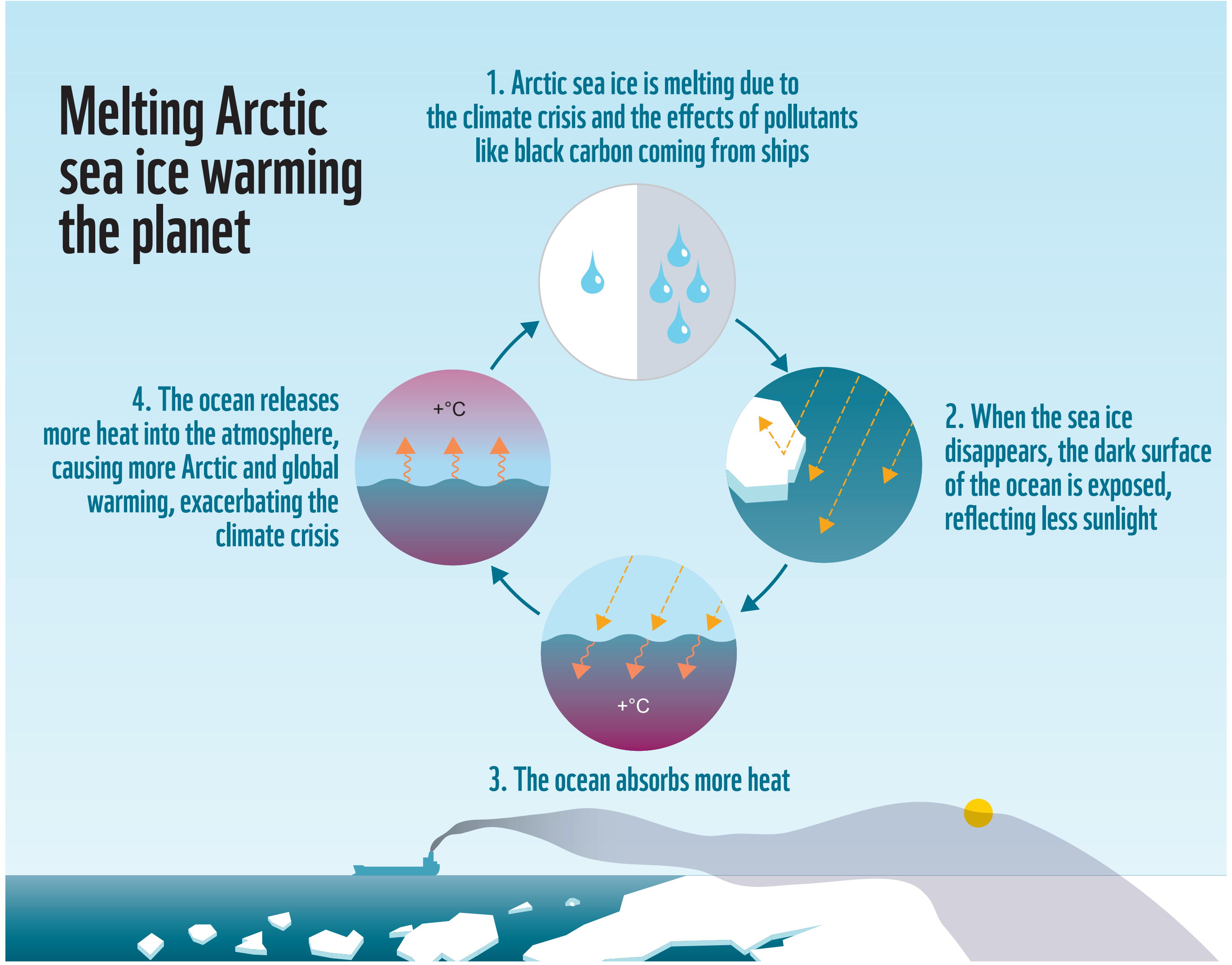
Our records from the Fram Strait date back to 1990, when the ice was still thick and present year-round. Since then, we have observed that the ice has decreased from 2.7 metres in thickness to approximately 1.7 metres, on average. Satellites have also recorded a significant decrease in sea ice extent. Putting these changes together tells us that the Arctic has lost nearly 50 per cent of its sea ice volume in the past few decades.

"BEYOND RECOGNITION"

With the Arctic warming at a rate four times faster than the global average, climate models indicate that the decline in sea ice will persist. This will amplify the warming of the waters below and enhance the exchange of gases between the ocean and the atmosphere. Models also show that more open water results in stronger winds and, as a result, strengthened ocean circulation. The total impact of these environmental changes on Arctic ecosystems remains uncertain, but it is undeniable that the species that depend on sea ice—from small ice algae to polar cod, seals and polar bears—will face significant challenges in the near future. Other species may benefit at the expense of polar species.

There is no question that Arctic ecosystems are poised to undergo profound transformations, potentially beyond recognition. This change clearly affects Arctic communities, but some of the greatest impacts of sea ice loss will extend beyond the Arctic region. Weather patterns in Europe, North America and Asia are already affected, and other risks associated with climate change—such as wildfires, droughts and floods—are being amplified.

The most recent findings project that if greenhouse gas emissions continue unabated, the Arctic could be ice-free in summer within the next decade. As a result, early-career polar researchers can expect to witness even more significant changes than those observed by their older colleagues. It is crucial for us to be prepared for the reality that the Arctic of tomorrow will be vastly different from the Arctic of the past, and that these changes will affect the whole planet. ●



Graphic: Ketill Berger, ketill.berger@filmform.no © WWF Global Arctic Programme

MATS GRANSKOG is a senior research scientist working on Arctic sea ice and the physical processes linked to its interaction with the ocean and atmosphere.

MORVEN MUILWUK is an early-career scientist working on Arctic oceanography and sea ice with a focus on climate model projections for the future Arctic Ocean.

Oil spill risks

AS INDUSTRIAL ACTIVITY AND SHIPPING TRAFFIC GROW, WE NEED FIRM REGULATIONS TO PROTECT ARCTIC WATERS

The probability of a major oil accident in Arctic seas is increasing alongside the ongoing growth in maritime traffic. As **JARNO VANHATALO** writes, there is a pressing need to understand the risks that oil spills pose to these unique and sensitive areas—and for solutions to prevent accidents and mitigate their consequences. ➤

Different types of oil will cause a range of ecological risks and impacts. For example, even though all types can do significant harm to Arctic marine ecosystems, heavy fuel oil is understood to cause the most severe consequences.

A newborn harp seal. Seal populations are among the most vulnerable to the acute effects of an oil spill in spring.

Photo credit: © Staffan Widstrand / WWF

Walrus populations are particularly vulnerable to oil spills in the summer.

Photo credit: © naturepl.com / Steven Kazlowski / WWF

Given that scientists do not yet have a full understanding of the scale of the risks, my view is that regulations on Arctic activities should be firm and precautionary.

AS ARCTIC SEA ice melts, the number of ships navigating the area is multiplying. From 2013 to 2019, the number swelled by 25 per cent, and the total distance sailed rose by 75 per cent. Similarly, oil and gas exploration and transportation activities are intensifying and can also have serious impacts on the Arctic's fragile marine and coastal environments. Oil spills can harm Arctic biota both physically (from smothering) and chemically (from toxicity).

The Arctic Council has stated that preventing oil spills must be a top priority. Two key approaches are designing ships to handle harsh Arctic conditions safely, and planning operations to avoid areas where accidents have a higher likelihood of happening. However, given that the probability of an accident is never zero, companies should also consider the potential ecological consequences of an accident when planning the seasons and locations for their proposed operations.

GATHERING INFORMATION TO MANAGE RISK

Ecological risk assessments can help companies mitigate risks. If two routes have equal accident probability, the company should choose the one where the ecological consequences would be less severe if an accident were to take place.

The potential ecological consequences of an accident can vary considerably across locations and seasons. In addition, the risks for particular species are higher in certain locations and at specific times of the year. For example, according to our results, among marine mammals, polar bear and seal populations are most vulnerable to the acute effects of an oil spill in spring, when their pups' exposure potential and sensitivity to oil are high and spilled oil spreads well because ice cover is not continuous. On the other hand, walrus populations are more vulnerable in summer. Polar bears and seals also tend to inhabit different geographic areas than walrus.

In addition, different types of oil will cause a range of ecological risks and impacts. For example, even though all types can do significant harm to Arctic marine ecosystems, heavy fuel oil is understood to cause the most severe consequences.

Fortunately, despite the near-Arctic *Exxon Valdez* oil spill in the south coast of Alaska in 1989, no major spills have yet occurred in truly Arctic marine areas. While this is excellent news (so far), it creates challenges for ecological risk assessors: while we have a good understanding of the types of risks posed by Arctic marine traffic, we don't have a comprehensive appreciation of their likely scale, mainly because we lack firsthand experience and data about the impacts of oil spills. Basic data on Arctic marine ecosystems are scarce as well.

The upshot is that when it comes to the risk of ecological disaster, ships sail under high uncertainty in the Arctic today.

The absence of data from actual Arctic oil spills is a challenge that I would love to keep facing. But I would welcome more data on Arctic ecosystems to support our risk assessment work.

Ultimately, given that scientists do not yet have a full understanding of the scale of the risks, my view is that regulations on Arctic activities should be firm and precautionary. ●

JARNO VANHATALO is an associate professor of environmental and ecological statistics at the University of Helsinki, Finland.

A fast-changing island

WILL THE CLIMATE CRISIS TAKE THE "ICE" OUT OF ICELAND?

Iceland is famous for its unspoiled natural beauty. People flock to the small Nordic country to see its majestic waterfalls, geysers and volcanoes as well as the hundreds of glaciers that cover more than a tenth of the island. But Iceland is also one of the fastest-warming places on the planet: it is heating up as much as four times faster than the northern hemisphere average.

ANDRI MAGNASON is an Icelandic writer based in Reykjavik who has dedicated many of the past years to exploring the words, myths and metaphors we need to grasp the climate crisis. He's the author of several books, including *On Time and Water*, which looks at our relationship to time in an age of ecological crisis. *The Circle* spoke to him about the changes he's noticing in Iceland and some of the environmental challenges that the country might face in the future.

Andri Magnason.

Photo credit: Anton Smári

> What makes me feel sad is the idea that seabirds could disappear. If we saw a big decline in the Arctic tern, for example, and it stopped coming to the north of Iceland where we have our farm, that would make me quite sad as an old man.

What changes have you witnessed in Iceland as a result of the climate crisis?

One major change is that the glaciers are collapsing. That's been very visible since around 2000. In the last 20 years, they have receded more than in the previous 100. In some places, they are retreating around 100 metres a year. For instance, I've been out walking in the highlands using maps that were 10 years old. According to these maps, I should already have been on the glacier, but in reality, I still had more than a kilometre left to walk on barren land. That's kind of mind-blowing. And it's not only that the peripheries of the glaciers are receding—it's also how thin they are becoming.

Why should we care that these glaciers are disappearing?

Glaciers are good for us. The world needs them to stay intact. Iceland's glaciers are not only beautiful—they have a big impact on marine life in the area. They are important for the rest of the world because if they were to vanish, global sea levels would rise by about one centimetre. That might not sound significant, but Iceland represents about one per cent of the one-metre global rise that is expected.

Iceland is like a canary in a coal mine—it's an indicator of what is going to happen next. I'm actually less worried about the glaciers of Iceland than I am about the fact that glaciers in general around the globe are disappearing at the same rate. That's a very serious thing for people who rely on glacier water, such as those who live in the Himalayas.

Are you already seeing negative impacts from the glaciers receding in Iceland?

Mostly, only the temporary "positive" effects are noticeable right now—for example, the higher volume of water from melting glaciers means energy companies can produce more power. But eventually, that will change.

We have also seen enormous changes in vegetation. Iceland is actually greening. Glacial rivers have been diverted because the glacier recedes and the river changes its outlet, so Iceland's largest bridge is now over black sand that is slowly becoming a birch forest. But it is possible that there will be more volcanic eruptions in the future because of the decreasing pressure exerted by glaciers on the Earth's crust.

What other changes are you seeing in Iceland due to the climate crisis?

Sea bird populations are struggling, and some Arctic species, such as ptarmigan and puffins, are having big trouble surviving. Puffin colonies have decreased by something like 70 per cent. Those are the most visible changes. Southern fish species that did not live here before, like mackerel, are coming into the waters around Iceland.

Ocean acidification is also a big issue—and it is worse in the Arctic, where aragonite saturation decreases when the pH level drops. Aragonite is the building material for shell-building animals, such as shellfish and corals. The pH level has already dropped by about 0.1 pH units in the past 30 years, and it's expected to drop 0.2 or 0.3 units more. (Although this might not sound like much, every 0.1 pH unit represents an increase in acidity of approximately 30 per cent.)

We really don't know where the tipping point is, but by 0.3 pH units, it could become a huge challenge for all shell-building animals. So, we could have an ocean that doesn't build corals or shells, but instead dissolves them.

How concerned are you personally about Iceland's future when it comes to the environment and the climate crisis?

You know, I would not say that glaciers stir up a lot of feelings for me personally, even though I like them. But what makes me feel sad is the idea that seabirds could disappear. You know, if we saw a big decline in the Arctic tern, for example, and it stopped coming to the north of Iceland where we have our farm, that would make me quite sad as an old man.

In the short run, I am pessimistic, but in the long run I think there are reasons to be optimistic. I think there is a critical mass of young people in the current generation who deeply understand the issue of climate change, and they are putting their knowledge and education toward solving it. It is actually a very interesting time to be alive and be a part of that change. ●

A reindeer herd in Finnmark, Norway.

Culture

CLIMATE CHANGE AND GREEN COLONIALISM IN THE SÁPMI

How can an Indigenous culture in the Arctic adapt to rapid climate change and shifts in biodiversity? The cultural knowledge and skills that have kept Indigenous cultures alive in harsh conditions are facing a daunting challenge. Indigenous Saami culture is adapting—but as **KLEMETTI NÄKKÄLÄJÄRVI** writes, the process is resulting in the loss of cultural knowledge and skill. The international community has promised to halt warming from climate change at 1.5°C. But the land of the Saami—the Sápmi—has already warmed more than that, and the warming continues. ➤

Young people are hesitant to start reindeer herding. They fear the effects and the future. And if they don't start, then our reindeer herding culture will disappear.

Photo credit: Lawrence Hislop, https://www.grida.no/resources/2014

SAAMI REINDEER HERDERS report that changes in climate and biodiversity are accelerating. The Arctic is greening, with trees and shrubs slowly conquering the tundra and replacing the lichen. In addition, climate mitigation has brought a new, serious threat to the Sápmi: green colonialism. Climate mitigation measures—such as wind turbines and mines to unearth minerals for the green industry—are challenging Indigenous Saami in their struggle to adapt.

A CHANGING LANDSCAPE

For example, pine trees are encroaching on the northern Sápmi region. Their invasion means less room for lichen, a key food source for reindeer. It also affects snow formations, melting and the landscape.

"I tear off the seedling roots whenever I see them in the mountain region," one Saami reindeer herder told me. "But there are hundreds more every year, and we can't remove all of them without help."

I have lived all my life in Sápmi. There were no spruce trees in my home region when I was a child. Now there is a whole forest of them. The changes brought about by the climate crisis are not only environmental, but also affect livelihoods, cultures and even languages. Changes in vegetation, seasonality, temperature, weather conditions, precipitation, and wildlife behaviour—and an increase in extreme weather events—have all been observed by Saami reindeer herders.

Climate change has also made the work of reindeer herding more difficult both physically and mentally. In recent years, such as from 2019 to 2021, many reindeer died due to difficult winter conditions and predation, leaving only a few to sell. As another herder concluded, "Climate change is a great threat to reindeer Saami culture because it is the reason why young people are hesitant to start reindeer herding. They fear the effects and the future. And if they don't start, then our reindeer herding culture will disappear."

BEARING AN EXCESSIVE BURDEN

As the effects of climate change accelerate, the debate about how to fairly share the harms and benefits is intensifying. Saami feel they are being asked to bear too much of the burden. For example, climate mitigation efforts are driving a voracious need for the minerals needed to power batteries for electric vehicles. There are now wind turbine parks in the Sápmi area and new plans for wind turbines and more mines, and these initiatives are likely to accelerate.

The question is: who pays the multidimensional price of climate change—the harmful environmental and climatic changes, the effects of adaptation and mitigation? According to one herder, "Finland is working very hard to become a leading green economy. So it is trying to cut down pine trees in the Saami region and planning mines so the people of the South can drive electric cars and compensate for greenhouse gas emissions. But it can't go that way."

WHAT ARE THE CULTURAL LIMITS TO ADAPTATION?

Reindeer herds need expansive grazing lands to survive—and reindeer herders have already had to hand over more and more of their lands to tourism, to the forest industry and to infrastructure. But the Saami do not consider it fair that their territories should be used to solve the climate mitigation challenge for the whole of Europe. Ever since colonialism, from the 1500s onward, the resources of the Saami homeland have been sought after to meet the needs of the state, the church, industry, hydropower, tourism and more. The colonial land grab continues in this time of climate change.

But there are limits to adaptation. How much can a culture adapt before it loses its uniqueness? This is a question that Saami, like other Indigenous Peoples around the world, must address in their everyday lives. The Saami did not cause climate change and are not contributing to its progression, yet are the ones who are suffering from it the most.

Recent reports from the Intergovernmental Panel on Climate Change (IPCC) and other research papers have begun to focus more on the social and cultural impacts and inequalities of climate change and adaptation measures. Environmental activists, Indigenous Peoples and states affected by rising sea levels have made a significant contribution to the discussion. But to meet the challenge, action is urgently needed. Herders are afraid of what the future will bring to the Saami and Saami culture. A key question is whether Saami traditional knowledge, the Saami way of practising reindeer herding, and the Saami way of life will be preserved in a changing climate.

Climate mitigation and adaptation measures are not sufficient for Indigenous Peoples. We need concrete actions to stop the world from warming and stop the cultural loss. The genuine participation of Indigenous Peoples in these discussions, along with state subsidies, research collaboration and monitoring, are needed.

KLEMETTI NÄKKÄLÄJÄRVI (Juvvá Lemet in the North Saami language) is a cultural anthropologist and linguist who is studying the effects of climate change on Saami culture. He belongs to the Reindeer Saami community in East-Enontekiö.

Climate mitigation measures—such as wind turbines and mines to unearth minerals for the green industry—are challenging Indigenous Saami in their struggle to adapt.

The Kvitfjell and Raudfjell onshore wind farm in Norway is located in an area that is important for reindeer herding.

Humpack whale fluke, near Sermilik Fjord, East Greenland.

Photo credit: © WWF-US / Chris Conner

The lack of pack ice in summer, together with a warming ocean, has generated cascading effects on the Southeast Greenland ecosystem that have altered fish populations.

Sea change

TRANSFORMATIONS IN SOUTHEAST GREENLAND'S MARINE ECOSYSTEM ARE AFFECTING THE DISTRIBUTION OF MARINE SPECIES

Two major oceanographic changes have been reverberating through the marine ecosystem in Southeast Greenland: the summer sea ice has virtually disappeared, and sea temperatures have increased. **MADS PETER HEIDE-JØRGENSEN** describes how this regime shift has affected a number of whale and fish species in the area.

DOING FIELDWORK IN the fjords of East Greenland in the 1980s, we had to be careful to avoid getting trapped in ice in the Greenland Sea. At that time, the ice was notably thick and moving rapidly, posing a high risk to small boats. The conditions then were starkly different from the scenario today, where minimal ice cover is observed along the coast during the summer months.

Time-series data play a vital role in helping researchers to monitor and understand changes in Arctic marine ecosystems, particularly because most of these changes are subtle and can require retrospective analysis. The sea ice that originates in the polar basin is carried from the Arctic Ocean through the Fram Strait, progressing southward along the East Greenland coast until it reaches the southern tip of Greenland. From there, it advances northward along the West Greenland region, where it can be observed in fjords and along the coastline.

Consequently, we can derive an index that quantifies the volume of ice transported through the Fram Strait by examining the presence of this specific type of ice in West Greenland. A continuous record of such observations has been diligently maintained since 1820.

UNPRECEDENTED PHYSICAL CHANGES

When you analyze this sea ice time-series, a striking trend emerges: the summer sea ice in Southeast Greenland has essentially vanished since 2003. Simultaneously, the temperature of the East Greenland Current south of 73.5°N has undergone a significant upward increase, surpassing 2°C since 1980. Furthermore, the warm Irminger Current, responsible for transporting warm, saline Atlantic water into the region, has experienced a gradual rise in temperature since 1990.

These physical changes have significantly affected the delicate balance of life in the region, and they have far-reaching implications for both the ecosystem itself and the communities that depend on it.

The lack of pack ice in summer, together with a warming ocean, has generated cascading effects on the ecosystem in Southeast Greenland that have altered fish populations, with an influx of boreal species in the south and sub-Arctic capelin further north.

FOOD CHAIN IMPLICATIONS

Further up the food chain, there has been an increase in the abundance of several boreal cetaceans—such as humpback, fin, killer and pilot whales and dolphins—that are either new to the area or now present in historically larger numbers. Most boreal whale species are not well-adapted to dense, multi-year sea ice, and would not have ventured into the coastal areas of Southeast Greenland under past ice conditions. These new cetacean species in Southeast Greenland are thought to be responsible for an annual predation level of two million tonnes of biomass per year.

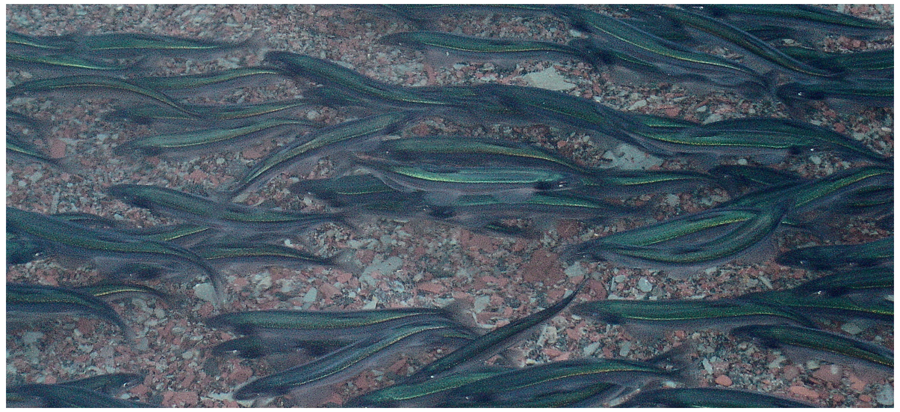


Photo credit: © Anna Olafsdottir / WWF-Canada

Capelin spawning in Newfoundland, Canada. Capelin are a key driver in the northward migration of humpback whales.

A key species for predation by some of the migratory marine mammals is the capelin, which in the past two decades has shifted its distribution from the Iceland Sea north of Iceland towards the East Greenland coast and shelf region. The capelin is a cold-water species known to be an important prey of humpback whales in West Greenland and Iceland. A redistribution of capelin alone could explain the increase in humpback whales in coastal areas of East Greenland.

From 2010 to 2019, there was a rapid increase in the population of mackerel in the Irminger Sea and on the East Greenland shelf. This significant growth can be attributed to various factors, including rising summer sea temperatures. But competitive interactions with other species that have also been affected by the physical transformations in the region play a role too.

Finally, the presence of bluefin tuna, which feed on schools of mackerel, was first observed in waters near East Greenland in 2012. These sightings occurred consistently until 2018, mainly as a result of incidental catches in mackerel fisheries. The increased sea temperatures and expanding area of open water have likely contributed to the expansion of thermal habitats that are suitable for both the tuna and the mackerel.

WARMTH CHASING OTHER SPECIES FURTHER NORTH

In contrast, there has been a decline in the abundance and catch of narwhals and walrus in Southeast Greenland, indicating that these species, which are not just cold-tolerant but ice-dependent, are facing challenges. Additionally, the abundance of polar cod in the East Greenland and Iceland areas has decreased as temperatures have risen. As summer ice continues to disappear, we expect that the southern range limit of this keystone species in Southeast Greenland will shift north.

The observed regime shift in Southeast Greenland's marine ecosystem is a clear indication of the ongoing changes taking place in the Arctic. But it is likely the initial manifestation of a more widespread scenario that will increasingly characterize the region. ●

MADS PETER HEIDE-JØRGENSEN IS a professor at the Greenland Institute of Natural Resources. He has more than 40 years' experience working in all Arctic countries.

Permafrost thaw

WHAT LURKS BELOW: WAKING A SLEEPING CARBON GIANT

Northern tundra and taiga ecosystems contain the world's largest stores of soil carbon, much of which has been frozen in permafrost for millennia. As **DAVID OLEFELDT** explains, climate warming and permafrost thaw will accelerate soil decomposition and release large amounts of greenhouse gases into the atmosphere.

YOU CAN STORE frozen berries in your freezer for years, but if you take them out and place them on the kitchen counter, they will start to decompose rapidly. Similarly, plant material from trees, shrubs, grasses and mosses frozen in the soils of northern regions can remain unchanged for millennia if temperatures stay below freezing, but will start to decompose when the soil thaws. The problem for the climate is that this decomposition converts the carbon in the plant materials into greenhouse gases—primarily carbon dioxide, though waterlogged soils can also produce methane, a more potent gas. Understanding what quantity of greenhouse gases will be released from thawing permafrost in the future is challenging due to the scale of the Arctic, but researchers have made significant progress over the last few years.

Greenhouse gas emissions from northern ecosystems can be studied either by directly measuring emissions in the field or by bringing soil samples back to the lab to assess how fast they decompose. Hundreds of sites have been investigated this way, though there are still large unstudied regions in the Arctic, especially in Russia.

Plant material from trees, shrubs, grasses and mosses long frozen in soil will start to decompose and release greenhouse gases when the soil thaws.

Researchers began studying permafrost thaw and the release of greenhouse gases in the 1970s, but most of the research has been done since the late 1990s. Recent advances in satellite imagery and computer modelling are helping us to make progress. In the last 10 years, we have finally gathered enough data to put all the parts together and predict future emissions.

ANSWERING THREE KEY QUESTIONS

To make these predictions, we need to focus on three main questions: How fast will permafrost ground and soil carbon thaw? How easily will this thawed soil carbon decompose? And how warm and wet will the soil be after it thaws?

A fundamental difficulty in predicting future emissions is that the answers to these questions will differ between regions and between different types of ecosystems. Permafrost thaw in the Alaskan tundra will have a different outcome from thaw in a peatland in Canada, which in turn will be different from thaw in the Siberian taiga forest. A key factor is the amount of ice in the permafrost ground. Some permafrost ground contains abundant ice, which means that thaw causes land surface collapses (known as thermokarsts), which can lead to landslides or the formation of lakes and wetlands. This scenario favours methane production.

Current research also aims to understand the role of wildfires in accelerating permafrost thaw, how important greenhouse gas emissions are during the long winters, and to what degree increased plant growth in a warmer climate can offset some of the soil greenhouse gas emissions.

Our current predictions suggest that permafrost thaw will lead to the release of greenhouse gases during the 21st century that are similar in magnitude to the emissions from large, industrialized nations today.

LIMITING EMISSIONS TO SLOW WARMING

Our current predictions suggest that permafrost thaw will lead to the release of greenhouse gases during the 21st century that are similar in magnitude to the emissions from large, industrialized nations today. The predictions range from adding the equivalent of Japan's emissions to adding the equivalent of those generated by the United States. The upshot is that while greenhouse gas emissions from thawing permafrost may not cause runaway climate change, they will accelerate climate change beyond what is expected from other anthropogenic emission sources.

These emissions are likely to be large enough that they will need to be considered in international negotiations on emissions reductions. In the meantime, the only action we can take to minimize greenhouse gas emissions from thawing permafrost is to limit anthropogenic greenhouse gas emissions in the first place. ●

DAVID OLEFELDT is an associate professor in catchment and wetland sciences at the University of Alberta in Canada. He studies the impacts of climate change on northern ecosystems.

Small businesses

THE FUTURE OF ECOTOURISM IN A CHANGING ARCTIC

Wyatt Daley (in red), whose family runs Wapusk Adventures, leads a dog carting tour in Churchill, Manitoba, Canada. Warmer temperatures are making it harder to offer these tours during the summer.

Photo credit: Daniel Raiti Photography

The northern Canadian town of Churchill, Manitoba has no roads in or out and fewer than 1,000 year-round residents, but it attracts tourists from all over the world. In fact, Churchill was named one of *TIME Magazine's* great places to visit in 2023. Situated on the shores of Hudson Bay, its main draw is that it is on the migration path of two Arctic species: polar bears and beluga whales. But what does the future hold for a tourist town that is being reshaped by the impacts of climate change?

WYATT DALEY, 27, was born and raised in Churchill. His family owns and operates Wapusk Adventures, a dog-sledding and Indigenous cultural tour company. He talked to *The Circle* about the changes he's seeing in his home town and what they could mean for tour operators like himself.

> Although people can still expect to see bears when they visit Churchill, climate change could alter things quickly, and the change could be massive because our identity is really based around the bears.

How important is tourism to Churchill today?

Back in the nineties, when I was born, tourism was still in its infancy here, and the port was a big part of our economy. But the port shut down in 2014, and tourism has since become a huge part of our economy. It's what keeps the restaurants open, what keeps things running up here. In the polar bear season during the fall, when tourism is at its peak, there's a different kind of hum here. Whereas after the bear season is over in late November, the town shuts down and we go back to being a one-restaurant town, basically.

What makes Churchill so attractive to tourists?

We're the polar bear capital of the world. That's what we're famous for. That's because Churchill is where the sea ice forms first. We have the Churchill River, which meets the Hudson Bay and a bunch of other watersheds as well. So, there is all this fresh water flowing into the bay, and it dilutes the salt water so that it freezes first. The polar bears have always known to come to Churchill.

The other thing we're famous for in the summertime is beluga whales. Churchill has some of the best whale-watching in the world because we have an estuary with around 4,000 beluga whales that visit every year to have their babies. We're also one of the best places in the world to see the Northern Lights.

Churchill, Manitoba in Canada is one of the best places in the world to see the Northern Lights.

Photo credit: Travel Manitoba

What changes are you seeing as a result of climate change?

This year we had a polar bear show up quite early. The river and Hudson Bay let go super early—I think it was May 27. That makes a huge difference in how far the bears have to swim and where they get off the ice. But other years, we have had icebergs in the bay until July. So I feel like it's more about the weather becoming more unpredictable. Some years, we have really brutal cold, and other years, like this one, it's the opposite—we break heat records in May and June.

When I was a kid growing up here, we didn't have a lot of 30-plus days. But last summer and the summer before, we had long stretches where it was 33, 34 or even 35 degrees. We were the hot spot in Manitoba.

How have these fluctuations in the weather affected your business?
I find that it's really changed our summertime tours. In the past, we've offered dog carting in the summertime—but those summers were a lot cooler. We had more days when it was overcast and rainy. You can't really run the dogs in warmer weather. We're not running dogs in the summertime much anymore because it's just too consistently hot.

What about tourism in general in Churchill? How has it been changing?
Hudson Bay can be unpredictable: in some years it freezes early, and in others it freezes later, which impacts our tourism in different ways. When the bears have to wait longer for the bay to freeze, they become more restless. More bears wander into town instead of staying out in the wildlife management area and along the coast. Also, with the higher temperatures in the summertime, the bears are less active out on the land. They're just kind of hunkering down and trying to wait it out. So although people can still expect to see bears when they visit Churchill, climate change could alter things quickly, and the change could be massive because our identity is really based around the bears.

I think Churchill is kind of at a crossroads. As a community, there a couple different roads we could go down. I know that there are people in Churchill who are trying to change the way they do things a little because of climate change. My family's business has always had an ecotourism focus because we run dogs and we're not burning gas. But we also just started offering e-bike tours and rentals. We're trying to diversify now that we can't run dogs as often in the summertime.

I think that moving forward, ecotourism is going to be one direction that Churchill could take, but it's hard to say how it will turn out. Really, all we can do is the best that we can. ●

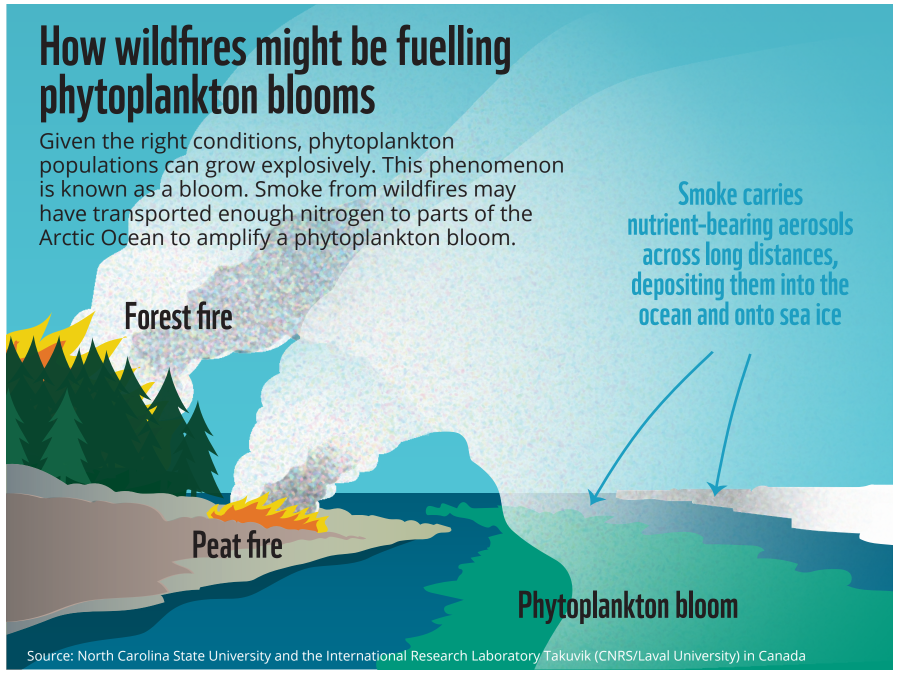
Wildfires

FIRE, WATER AND THE AIR WE BREATHE

As wildfires in the Arctic continue to blaze, **MATHIEU ARDYNA** and **DOUGLAS HAMILTON** are trying to figure out if they may be having an unforeseen effect. Could they be responsible for an increase in phytoplankton?

Forest fire in Kenai National Wildlife Refuge, Alaska.

Photo credit: Alaska Region U.S. Fish & Wildlife Service, Public domain



Graphic: Ketill Berger, ketill.berger@filmform.no. © WWF Global Arctic Programme

PHYTOPLANKTON ARE the primary source of photosynthesis in the ocean: they take in carbon dioxide and nutrients, then use the energy from sunlight to generate the building blocks of life, releasing oxygen in the process. But the availability of the three primary nutrients—nitrogen, phosphorus and iron—needed to fuel this process is not uniform across the world's seven seas. In many open ocean areas, nitrogen is abundant in surface waters, but iron is not. The opposite is true for the Arctic Ocean, where it is the nitrogen supply that limits primary productivity.

In the summer of 2014, we observed an unusually large phytoplankton bloom in the Laptev Sea—approximately 850 kilometres south of the North Pole—from satellite-derived maps of chlorophyll a (a form of chlorophyll used in photosynthesis). But an analysis of the "usual suspects" to see where the nitrogen was coming from—such as sea ice melt, river discharge or ocean upwelling—didn't turn up any source that would account for the large supply of nitrogen necessary for the bloom to have occurred.

So we looked up and out of the water, to the atmosphere and land, to consider the potential role of wildfires. We rapidly discovered that a large wildfire had occurred upwind in Siberia that same summer. Could this be the nitrogen source we were looking for?

A SMOKY NUTRIENT COCKTAIL

It turns out that because of biomass consumption and the entrainment of local soils by warm updrafts, fire smoke is a cocktail of the nutrients, including nitrogen, needed for phytoplankton growth in the Arctic. Climate models are designed, in part, to simulate the atmospheric lifetimes of elements like nitrogen from their source through their chemical evolution in the atmosphere to their return to the land or ocean surface. But in the first simulations we examined, the mass of nitrogen being deposited into the Arctic Ocean was not enough to match the amount needed to support the bloom we had observed.

The first reason we considered for this shortfall is that because fires in Siberia are remote, they are rarely measured directly. This means the extent of fire emissions may be underestimated, as is the case in other parts of the world. But reconciling this gap with the scientific literature did not fully explain the situation, so we dug a little deeper.

There has been a lot of media coverage about the increase in peat fires in Siberia due to thawing permafrost. In particular, the "zombie fire" aspect of peat fires (a phenomenon whereby peat can continue to burn deep underground and resurface somewhere else) has attracted a lot of attention.

We began to wonder what the nitrogen contribution of peat fires might be, and that was when we found the second cause of our "missing" nitrogen: peat was not represented at all in our initial emissions estimates, but as a dense organic material that has accumulated over a long period of time, it is likely to release more nitrogen per unit mass consumed than a traditional tree or shrub fire would.

By putting these elements together, we were able to reconcile the nitrogen budget and formulate a hypothesis: smoke from boreal forest fires could have a fertilizing effect on life in the Arctic Ocean.

ANOMALY VS. PRECURSOR

The question is: If fires in the Arctic are providing a sufficient source of fertilizer to support ocean life, then what does a future with more fires mean for the delicate balance of ecosystems in the Arctic region?

Our study raised more questions than answers. More observations are needed to understand this emerging climate-driven change in biogeochemical cycles, including the impact on sea ice. It is important to ask whether the anomalous bloom we observed in 2014 was a rare example of multiple processes "lining up" to create the conditions for life to flourish, or a climate change-induced sign of trouble ahead. Making observations in the remote and challenging Arctic environment is logistically challenging, but the use of autonomous profiling systems, coupled with improved satellite observations, could provide access to critical data.

"Can fire and water mix to create life?" is a fascinating question that is beginning to take hold in the research psyche. More evidence and a deeper understanding of how climate change affects nutrient cycling in the Arctic are clearly needed. ●

MATHIEU ARDYNA is an oceanographer and a biologist at the Takuvik International Research Laboratory at Laval University in Canada who studies phytoplankton dynamics in changing polar environments.

DOUGLAS HAMILTON is an assistant professor of Earth system science at North Carolina State University.

A rainy day in Lofoten, Norwegian Arctic.

Photo credit: Vidar Nordli-Mathisen on Unsplash

Arctic snow

NATURE'S BLANKET IS THINNING

The Arctic's enduring snow cover and vast ice fields make up its characteristic polar cryosphere. It is impossible to imagine the Arctic any other way. But as climate change spirals out of control, and the goal of limiting warming to 1.5°C becomes harder to reach every day, we must prepare ourselves for a drastically different polar region—and, as **PEKKA NIITTYNEN** writes, so must the unique biota that inhabit the region.

DESPITE THE RAPID warming of the Arctic over the past few decades, most precipitation in the area still falls as snow. But numerous recent studies suggest that as the Arctic continues to warm at a rate faster than the rest of the planet, rainfall will soon surpass snowfall as the dominant form of precipitation. This shift will lead to a novel hydrological state with far-reaching consequences for Arctic ecosystems and beyond.

Although many ecosystem processes in the North are resistant to change—which means their transformations may lag behind the rising temperatures—the delicate Arctic snow cover may be different. The seasonal snow cover emerges and disappears each year, and each year, the snowpack is renewed. As a result, changes in temperature and precipitation patterns can have an immediate impact on snow timing and properties. A single heavy rain-on-snow event, for example, can dramatically alter snow conditions for the entire winter, devastating the life cycles of the Arctic fauna and flora that depend on specific snow conditions for necessities like insulation, dens, camouflage and access to food sources.

WETTER, HEAVIER, ICIER SNOW

In a warming world, the physical properties of snow will change. Snow is likely to become wetter and heavier, with a greater probability of hard icy layers within the snowpack. Most northern regions will experience thinner snowpacks, and snow seasons will be shorter across all regions. This drastic alteration of the snow blanket—which has provided protection for low-growing Arctic flowers and overwintering insects—will have profound consequences.

Our biodiversity projections indicate that the future of Arctic vegetation is critically linked to the evolution of snow conditions. If the decrease in the duration of snow cover remains moderate—for example, shortening by 10 to 20 per cent—then the loss of local biodiversity may also be relatively small. However, if snow loss exceeds these levels, it will trigger accelerated rates of local extinctions among Arctic and alpine flora that are uniquely adapted to the cold.

Surpassing the 1.5°C warming limit will likely lead to exponential detrimental effects on Arctic biodiversity. Consequently, every tenth of a degree increase in warming must be limited: it will safeguard Arctic nature more effectively than any other conservation act can.

We should also remember that what happens in the Arctic will not stay in the Arctic. The circulation of matter and energy does not obey country borders or biome boundaries. Arctic snow and ice, particularly the enduring white blankets that have normally persisted until late summer, play a crucial role in regu-

The circulation of matter and energy does not obey country borders or biome boundaries. Arctic snow and ice play a crucial role in regulating the Earth's energy balance by reflecting sunlight back into space.

lating the Earth's energy balance by reflecting sunlight back into space.

IMPACTS OF A POSITIVE FEEDBACK LOOP

If this late-lying snow disappears, the Earth's surface albedo will be affected. Darker, less reflective surfaces, such as exposed land or sea, absorb more solar energy, amplifying warming. This positive feedback loop, known as the snow-albedo feedback, will accelerate melting and lead to further temperature increases. It is one of the reasons why the Arctic is already warming faster than the rest of the world. But it is also contributing to climate change on a global scale.

A world where warming exceeds 1.5°C will have profound consequences for Arctic snow cover. Beyond that target, substantial changes to the unique life forms and overall biodiversity of the Arctic are inevitable. Shifting vegetation zones, alterations in plant phenology and productivity, and the loss of specialized Arctic biota underscore the urgent need to address climate change and protect the delicate ecosystems of the Arctic.

Many climate change-induced alterations in Arctic ecosystems will not follow a linear trajectory, but an exponential one. In other words, each additional unit of warming will trigger new ecosystem changes that are likely to be more detrimental than the previous ones. This means that every effective action we take to mitigate climate change matters. By preserving the Arctic's snowy blankets, we can safeguard much more, including the area's rich environment and biodiversity, cultural heritage and overall well-being. ●

PEKKA NIITTYNEN works as a scientist in Finland to untangle the effects of changing snow cover on biodiversity. He is a mountain lover and likes them served cold and icy.

Microbes

SMALL BUT MIGHTY:

The invisible yet serious impacts of microbial communities in a warming Arctic Ocean

Climate-related changes in the Arctic Ocean have already resulted in a shift in microbial communities that has the potential to significantly alter the delicate and interconnected Arctic ecosystem. As **ARTHI RAMACHANDRAN** writes, microbes are notoriously quick to adapt to changing conditions—and rapid changes in the composition of their communities could have unknown consequences, not only for the marine food web but even for greenhouse gas emissions.

THE ARCTIC OCEAN is a unique and fragile ecosystem that is particularly vulnerable to the impacts of climate change. If the Arctic region experiences a temperature increase of 1.5°C or more, warmer sea surface temperatures and unprecedented melting of sea ice will alter the ocean's water masses, circulation patterns and more, including the communities of bacteria at the base of the food web.

In terms of total biomass, most life in the Arctic Ocean is microbial—and these microbes are essential to the health and stability of Arctic marine ecosystems. They provide critical ecosystem services, such as nutrient cycling, carbon sequestration, decomposition, primary production, water purification and climate regulation. Yet the consequences of climate warming on the microbial food web—and, in turn, the Earth's biogeochemical cycles—are not yet well understood.

One thing we do know is that the climate crisis has significant implications for these microbial communities. Rising temperatures have already led to observable shifts in their composition and abundance, and these shifts have the potential to alter the entire Arctic food web.

As the Arctic continues to warm, there will be a continued increase in sea ice melt and an influx of freshwater, which will decrease the salinity of the Arctic Ocean's upper waters. This means that previously dominant bacterial groups may decline, while others that are better adapted to less saline environments will thrive. We do not yet know what the downstream effects of this might be, including whether these will be positive or negative.

TINY ORGANISMS, GLOBAL IMPACTS

Changes in microbial communities may even affect greenhouse gas emissions. For example, certain bacterial species are known to consume methane and carbon dioxide. Changes in their composition and abundance in response to climate warming might alter the rates at which these greenhouse gases are consumed.

An increase in the presence of bacteria that consume greenhouse gases, like methane, could be positive in the short term—but there could be long-term consequences because this could mean a decrease in other types of bacteria, and it's unclear how the ecosystem services they provide might shift. We're still trying to figure out if and how shifts in microbial communities due to climate change will have negative effects on the ecosystem as a whole.

Sunglint melt pools and sparkles of light on ice floes in the Arctic Ocean.

Furthermore, shifts in the composition and abundance of microbial communities may have cascading effects on fish and marine mammals because these species rely on microbial communities for their food.

The rapidly changing environmental conditions in the Arctic Ocean have led to questions about whether there will be an increase in adaptation, evolution and/or migration of microbial organisms. The Arctic Ocean's microbial communities can be seen as both sentinels and amplifiers of global change. Their responses to climate warming can provide important insights into the overall health and functioning of Arctic marine ecosystems as well as the potential of these systems to influence global biogeochemical cycles.

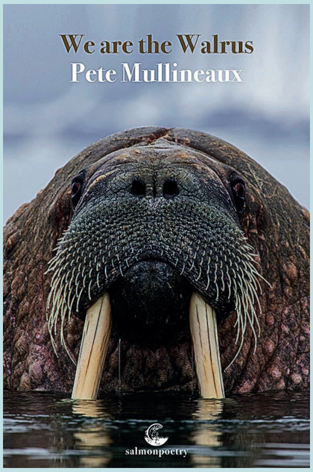
These invisible changes may have drastic and irreversible impacts on Arctic and global ecosystems, especially if we continue on the current pathway to a future where the global temperature rise exceeds 1.5°C. ●

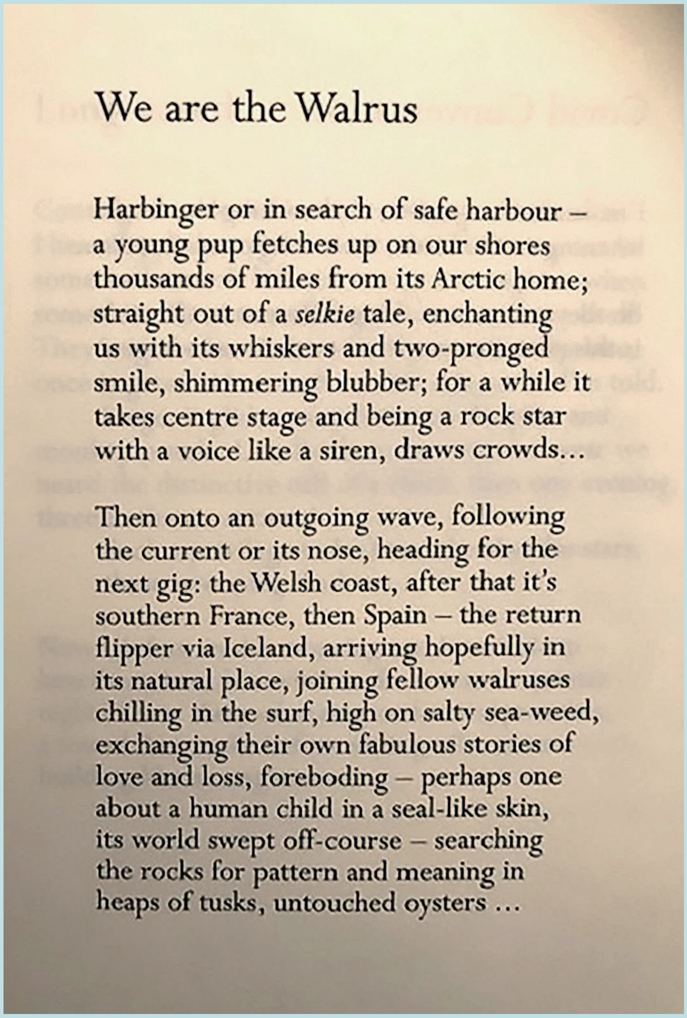
ARTHI RAMACHANDRAN is a doctoral candidate at Concordia University in Montreal, Canada who is studying bacterial adaptation and evolution in the Arctic Ocean. She is also a polar science advisor at Arctic Basecamp.

THE BACK PAGE

How human-induced climate change is throwing nature off-course: A poet's take

We are the Walrus is a new collection of poetry by Pete Mullineaux, a poet, dramatist, songwriter, author, musician and teacher living in Galway, Ireland. The title poem explores how the natural world is being thrown off course—quite literally—by human-caused climate change.





We are the Walrus

Harbinger or in search of safe harbour –
a young pup fetches up on our shores
thousands of miles from its Arctic home;
straight out of a *selkie* tale, enchanting
us with its whiskers and two-pronged
smile, shimmering blubber; for a while it
takes centre stage and being a rock star
with a voice like a siren, draws crowds…

Then onto an outgoing wave, following
the current or its nose, heading for the
next gig: the Welsh coast, after that it's
southern France, then Spain – the return
flipper via Iceland, arriving hopefully in
its natural place, joining fellow walruses
chilling in the surf, high on salty sea-weed,
exchanging their own fabulous stories of
love and loss, foreboding – perhaps one
about a human child in a seal-like skin,
its world swept off-course – searching
the rocks for pattern and meaning in
heaps of tusks, untouched oysters …