AFTER THE ICE GOES

Researchers look into the Arctic's future for clues to save species and maybe even bring the ice back.

BY JULIA ROSEN

As the Arctic slipped into the half-darkness of autumn last year, it seemed to enter the Twilight Zone. In the span of a few months, all manner of strange things happened.

The cap of sea ice covering the Arctic Ocean started to shrink when it should have been growing. Temperatures at the North Pole soared more than 20 °C above normal at times. And polar bears prowling the shorelines of Hudson Bay had a record number of run-ins with people while waiting for the water to freeze over.

It was a stark illustration of just how quickly climate change is reshaping the far north. And if last autumn was bizarre, it's the summers that have really got scientists worried. As early as 2030, researchers say, the Arctic Ocean could lose essentially all of its ice during the warmest months of the year — a radical transformation that would upend Arctic ecosystems and disrupt many northern communities.

Change will spill beyond the region, too. An increasingly blue Arctic Ocean could amplify warming trends and even scramble weather patterns around the globe. "It's not just that we're talking about polar bears or seals," says Julienne Stroeve, a sea-ice researcher at University College London. "We all are ice-dependent species."

With the prospect of ice-free Arctic summers on the horizon, scientists are striving to understand how residents of the north will fare, which animals face the biggest risks and whether nations could save them by protecting small icy refuges.

But as some researchers look even further into the future, they see reasons to preserve hope. If society ever manages to reverse the surge in greenhouse-gas concentrations — as some suspect it ultimately will — then the same physics that makes it easy for Arctic sea ice to melt rapidly may also allow it to regrow, says Stephanie Pfirman, a sea-ice researcher at Barnard College in New York City.

She and other scientists say that it's time to look beyond the Arctic's decline and start thinking about what it would take to restore sea ice. That raises controversial questions about how quickly summer ice could return and whether it could regrow fast enough to spare Arctic species. Could nations even cool the climate quickly through geoengineering, to reverse the most drastic changes up north?

Pfirman and her colleagues published a paper[1] last year designed to kick-start a broader conversation about how countries might plan for the regrowth of ice, and whether

In waters north of Alaska, ice is melting and disappearing at an accelerated rate.

© 2017 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.

PAUL NICKLEN/NGC

they would welcome it. Only by considering all the possibilities for the far future can the world stay one step ahead of the ever-changing Arctic, say scientists. "We've committed to the Arctic of the next generation," Pfirman says. "What comes next?"

BLUE PERIOD

Pfirman remembers the first time she realized just how fast the Arctic was unravelling. It was September 2007, and she was preparing to give a talk. She went online to download the latest sea-ice maps and discovered something disturbing: the extent of Arctic ice had shrunk past the record minimum and was still dropping. "Oh, no! It's happening," she thought.

Although Pfirman and others knew that Arctic sea ice was shrinking, they hadn't expected to see such extreme ice losses until the middle of the twenty-first century. "It was a wake-up call that we had basically run out of time," she says.

In theory, there's still a chance that the world could prevent the total loss of summer sea ice. Global climate models suggest that about 3 million square kilometres — roughly half of the minimum summer coverage in recent decades — could survive if countries fulfil their commitments to the newly ratified Paris climate agreement, which limits global warming to 2 °C above pre-industrial temperatures.

"IT'S NOT THIS IRREVERSIBLE PROCESS. YOU COULD BRING IT BACK EVEN IF YOU LOSE IT ALL."

But sea-ice researchers aren't counting on that. Models have consistently underestimated ice losses in the past, causing scientists to worry that the declines in the next few decades will outpace projections[2]. And given the limited commitments that countries have made so far to address climate change, many researchers suspect the world will overshoot the 2 °C target, all but guaranteeing essentially ice-free summers (winter ice is projected to persist for much longer).

In the best-case scenario, the Arctic is in for a 4–5 °C temperature rise, thanks to processes that amplify warming at high latitudes, says James Overland, an oceanographer at the US National Oceanic and Atmospheric Administration in Seattle, Washington. "We really don't have any clue about how disruptive that's going to be."

The Arctic's 4 million residents — including 400,000 indigenous people — will feel the most direct effects of ice loss. Entire coastal communities, such as many in Alaska, will be forced to relocate as permafrost melts and shorelines crumble without sea ice to buffer them from violent storms, according to a 2013 report[3] by the Brookings Institution in Washington DC. Residents in Greenland will find it hard to travel on sea ice, and reindeer herders in Siberia could struggle to feed their animals. At the same time, new economic opportunities will beckon as open water allows greater access to fishing grounds, oil and gas deposits, and other sources of revenue.

People living at mid-latitudes may not be immune, either. Emerging research[4] suggests that open water in the Arctic might have helped to amplify weather events, such as cold snaps in the United States, Europe and Asia in recent winters.

Indeed, the impacts could reach around the globe. That's because sea ice helps to cool the planet by reflecting sunlight and preventing the Arctic Ocean from absorbing heat. Keeping local air and water temperatures low, in turn, limits melting of the Greenland ice sheet and permafrost. With summer ice gone, Greenland's glaciers could contribute more to sea-level rise, and permafrost could release its stores of greenhouse gases such as methane. Such is the vast influence of Arctic ice.

"It is really the tail that wags the dog of global climate," says Brenda Ekwurzel, director of climate science at the Union of Concerned Scientists in Cambridge, Massachusetts.

But Arctic ecosystems will take the biggest hit. In 2007, for example, biologists in Alaska noticed something odd: vast numbers of walruses had clambered ashore on the coast of the Chukchi Sea. From above, it looked like the Woodstock music festival — with tusks — as thousands of plump pinnipeds crowded swathes of ice-free shoreline.

Normally, walruses rest atop sea ice while foraging on the shallow sea floor. But that year, and almost every year since, sea-ice retreat made that impossible by late summer. Pacific walruses have adapted by hauling out on land, but scientists with the US Fish and Wildlife Service worry that their numbers will continue to decline. Here and across the region, the effects of Arctic thawing will ripple through ecosystems.

In the ocean, photosynthetic plankton that thrive in open water will replace algae that grow on ice. Some models[5] suggest that biological productivity in a seasonally ice-free Arctic could increase by up to 70% by 2100, which could boost revenue from Arctic fisheries even more. (To prevent a seafood gold rush, five Arctic nations have agreed to refrain from unregulated fishing in international waters for now.) Many whales already seem to be benefiting from the bounty of food, says Sue Moore, an Arctic mammal specialist at the Pacific Marine Environmental Laboratory.

But the changing Arctic will pose a challenge for species whose life cycles are intimately linked to sea ice, such as walruses and Arctic seals — as well as polar bears, which don't have much to eat on land. Research[6] suggests that many will starve if the ice-free season gets too long in much of the Arctic. "Basically, you can write off most of the southern populations," says Andrew Derocher, a biologist at the University of Alberta in Edmonton, Canada. Such findings spurred the US Fish and Wildlife Service to list polar bears as threatened in 2008.

THE LAST OF THE ICE

Ice-dependent ecosystems may survive for longest along the rugged north shores of Greenland and Canada, where models suggest that about half a million square kilometres of summer sea ice will linger after the rest of the Arctic opens up (see 'Going, going ...'). Wind patterns cause ice to pile up there, and the thickness of the ice — along with the high latitude — helps prevent it from melting. "The Siberian coastlines are the ice factory, and the Canadian Arctic Archipelago is the ice graveyard," says Robert Newton, an oceanographer at Columbia University's Lamont–Doherty Earth Observatory in Palisades, New York.

Groups such as the wildlife charity WWF have proposed protecting this 'last ice area' as a World Heritage Site in the hope that it will serve as a life preserver for many Arctic species. Last December, Canada announced that it would at least consider setting the area aside for conservation, and indigenous groups have expressed interest in helping to manage it. (Before he left office, then-US president Barack Obama joined Canadian Prime Minister Justin Trudeau in pledging to protect 17% of the countries' Arctic lands and 10% of marine areas by 2020.)

But the last ice area has limitations as an Arctic Noah's ark. Some species don't live in the region, and those that do are there in only small numbers. Derocher estimates that there are less than 2,000 polar bears in that last ice area today — a fraction of the total Arctic population of roughly 25,000. How many bears will live there in the future depends on how the ecosystem evolves with warming.

The area may also be more vulnerable than global climate models suggest. Bruno Tremblay, a sea-ice researcher at McGill University in Montreal, Canada, and David Huard, an independent climate consultant based in Quebec, Canada, studied the fate of the refuge with a high-resolution sea-ice and ocean model that better represented the narrow channels between the islands of the Canadian archipelago.

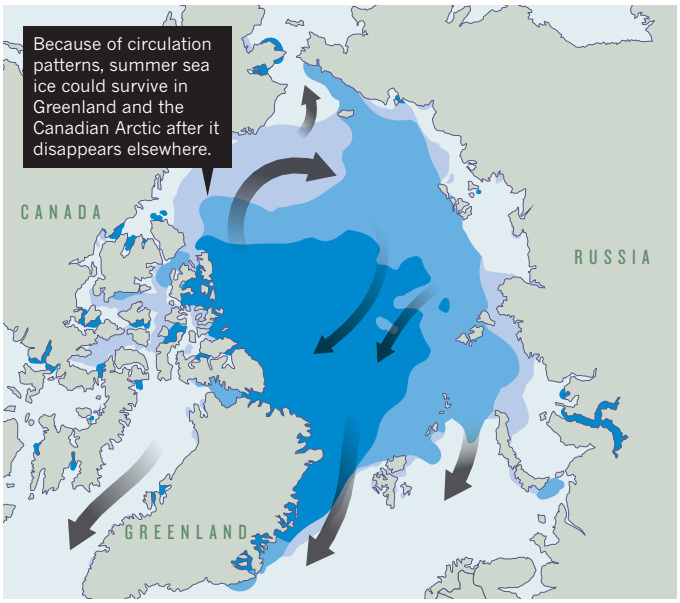
In a report[7] commissioned by the WWF, they found that ice might actually be able to sneak between the islands and flow south to latitudes where it would melt. According to the model, Tremblay says, "even the

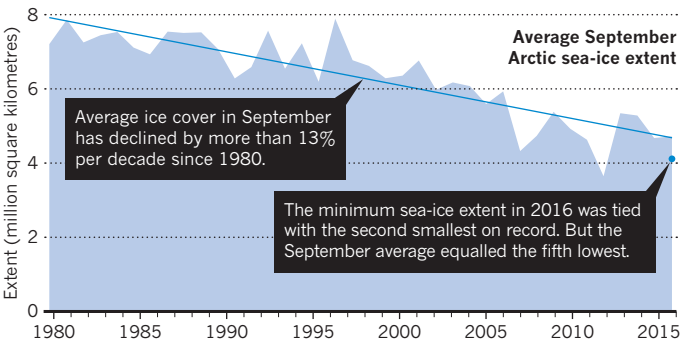
© 2017 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.

GOING, GOING...

The Arctic Ocean is rapidly losing its summer ice cover. The yearly cycle reaches its minimum each September and hit a record low in 2012.

Sea-ice extent: 1980 1998 2012 Ice flow





SOURCE: US NATL SNOW AND ICE DATA CENTER

last ice area gets flushed out much more efficiently".

If the future of the Arctic seems dire, there is one source of optimism: summer sea ice will return whenever the planet cools down again. "It's not this irreversible process," Stroeve says. "You could bring it back even if you lose it all."

Unlike land-based ice sheets, which wax and wane over millennia and lag behind climate changes by similar spans, sea ice will regrow as soon as summer temperatures get cold enough. But identifying the exact threshold at which sea ice will return is tricky, says Dirk Notz, a sea-ice researcher at the Max Planck Institute for Meteorology in Hamburg, Germany. On the basis of model projections, researchers suggest that the threshold hovers around 450 parts per million (p.p.m.) — some 50 p.p.m. higher than today. But greenhouse-gas concentrations are not the only factor that affects ice regrowth; it also depends on how long the region has been ice-free in summer, which determines how much heat can build up in the Arctic Ocean.

Notz and his colleagues studied the interplay between greenhouse gases and ocean temperature with a global climate model[8]. They increased CO_2 from pre-industrial concentrations of 280 p.p.m. to 1,100 p.p.m. — a bit more than the 1,000 p.p.m. projected by 2100 if no major action is taken to curtail greenhouse-gas emissions. Then they left it at those levels for millennia.

This obliterated both winter and summer sea ice, and allowed the ocean to warm up. The researchers then reduced CO_2 concentrations to levels at which summer ice should have returned, but it did not regrow until the ocean had a chance to cool off, which took centuries.

By contrast, if the Arctic experiences ice-free summers for a relatively short time before greenhouse gases drop, then models suggest ice would regrow much sooner. That could theoretically start to happen by the end of the century, assuming that nations take very aggressive steps to reduce carbon dioxide levels[1], according to Newton, Pfirman and their colleagues. So even if society cannot forestall the loss of summer sea ice in coming decades, taking action to keep CO_2 concentrations under control could still make it easier to regrow the ice cover later, Notz says.

GLOBAL COOLING

Given the stakes, some researchers have proposed global-scale geoengineering to cool the planet and, by extension, preserve or restore ice. Others argue that it might be possible to chill just the north, for instance by artificially whitening the Arctic Ocean with light-coloured floating particles to reflect sunlight. A study[9] this year suggested installing wind-powered pumps to bring water to the surface in winter, where it would freeze, forming thicker ice.

But many researchers hesitate to embrace geoengineering. And most agree that regional efforts would take tremendous effort and have limited benefits, given that Earth's circulation systems could just bring more heat north to compensate. "It's kind of like walking against a conveyor the wrong way," Pfirman says. She and others agree that managing greenhouse gases — and local pollutants such as black carbon from shipping — is the only long-term solution.

Returning to a world with summer sea ice could have big perks, such as restoring some of the climate services that the Arctic provides to the globe and stabilizing weather patterns. And in the region itself, restoring a white Arctic could offer relief to polar bears and other ice-dependent species, says Pfirman. These creatures might be able to weather a relatively short ice-free window, hunkered down in either the last ice area or other places set aside to preserve biodiversity. When the ice returned, they could spread out again to repopulate the Arctic.

That has almost certainly happened during past climate changes. For instance, researchers think the Arctic may have experienced nearly ice-free summers during the last interglacial period, 130,000 years ago[10].

But, one thing is certain: getting back to a world with Arctic summer sea ice won't be simple, politically or technically. Not everyone will embrace a return to an ice-covered Arctic, especially if it's been blue for several generations. Companies and countries are already eyeing the opportunities for oil and gas exploration, mining, shipping, tourism and fishing in a region hungry for economic development. "In many communities, people are split," Pfirman says.

Some researchers also say that the idea of regrowing sea ice seems like wishful thinking, because it would require efforts well beyond what nations must do to meet the Paris agreement. Limiting warming to 2 °C will probably entail converting huge swathes of land into forest and using still-nascent technologies to suck billions of tonnes of CO_2 out of the air. Lowering greenhouse-gas concentrations enough to regrow ice would demand even more.

And if summer sea ice ever does come back, it's hard to know how a remade Arctic would work, Derocher says. "There will be an ecosystem. It will function. It just may not look like the one we currently have." ■

Julia Rosen *is a freelance journalist in Portland, Oregon.*

1. Newton, R. *et al. Earths Future* **4,** 396–405 (2016).
2. Overland, J. E. & Wang, M. *Geophys. Res. Lett.* **40,** 2097–2101 (2013).
3. Bronen, R. *Climate-Induced Displacement of Alaska Native Communities* (Brookings-LSE, 2013); available at go.nature.com/2jw3bkx
4. Vihma, T. *Surv. Geophys.* **35,** 1175 (2014).
5. Lam, V. W. Y., Cheung, W. W. L., Reygondeau, G. & Sumaila, U. R. *Sci. Rep.* **6,** 32607 (2016).
6. Hamilton, S. G. *et al. PLoS ONE* **9,** e113746 (2014).
7. Huard, D. & Tremblay, B. *WWF Last Ice Area Technical Report* (2013); available at go.nature.com/2jhgsmg
8. Li, C., Notz, D., Tietsche, S. & Marotzke, J. *J. Clim.* **26,** 5624–5636 (2013).
9. Desch, S. J. *et al. Earths Future* http://dx.doi.org/10.1002/2016EF000410 (2017).
10. Polyak, L. *et al. Quat. Sci. Rev.* **29,** 1757–1778 (2010).

© 2017 Macmillan Publishers Limited, part of Springer Nature. All rights reserved.