Feature

Life changes as polar regions thaw

Spiders and shrubs grow bigger, while ice shields are shrinking. Climate change is already affecting biotopes in both polar regions, while scientists are trying to establish what is happening and why. **Michael Gross** reports.

The Earth had been a very warm and pleasant planet for more than 200 million years, when its climate changed drastically. The disaster happened quite recently (if you ask a geologist). Just over 30 million years ago, the Antarctic tundra began to disappear under a permanent ice cover, and only 2.58 million years ago, at the start of the Quaternary period, the northern polar region followed suit.

It is not quite clear why, at the end of the Pliocene epoch and the beginning of the Pleistocene, the arctic became white. Astronomic triggers must have played a role, but feedback mechanisms within the Earth system, including the concentration of greenhouse gases in the atmosphere, determined the way in which climate change proceeded. One of the current theories invokes a 'Pacific snowgun'. According to this view, reduced mixing in the Pacific led to relatively high-temperature surface waters, which gave off more moisture in an otherwise cold climate, which was blown across the North American continent and towards Greenland, where it came down as snow and compacted to form the ice shield. (For more details on this and further insights into the history of our climate, see *The Goldilocks Planet* by Jan Zalasiewicz and Mark Williams (2012), Oxford University Press.)

Once a permanent ice cover was established, its high reflectivity contributed to cooling the northern regions and thus helped the ice to grow. Since then, there have been periods of climate oscillations with more widespread glaciation, widely popularised as the ice ages, reaching well into central Europe and North America, as well as a period of relative warmth, the Holocene, which has persisted for the last 10,000 years.

Throughout the last 2.5 million years, however, Earth would have been clearly recognisable from space as a green and blue planet with ice caps on both poles. Based on current trends, this could come to an extremely sudden end (geologically speaking), and we may be on our way back to the single-capped planet of the Pliocene.

Ice loss

In the last 30 years, the extent of the sea ice in the Arctic summer has diminished consistently, as temperatures in the Arctic have risen twice as fast as the global averages. This June, new record melting was observed, with 814,000 square kilometres less coverage in the third week of June than in the corresponding period in 2007, which held the previous record. Generally, new records of ice melting in the Arctic are set regularly, and there have been predictions that the North Pole could be ice-free during the summer within the next 10 to 20 years.

The shrinking of sea ice means imminent habitat loss for a range of polar species, from polar bears to snowy owls, narwhals, seals, and Arctic foxes. It also affects the livelihoods of some four million people in the polar areas.

Loss of sea ice will not affect the sea level (remember Archimedes and the bath tub), but if the ice caps of Greenland or Antarctica were to melt (or slide into the ocean), the effect would be apocalyptic. Greenland's ice cover alone would raise the sea level by six metres, the West Antarctic ice sheet would add five metres, and the much larger East Antarctic one a rather frightening 60 metres.

No wonder scientists are keeping an eye on these continental ice masses, even if their loss appears to be a less imminent threat than that of the arctic sea ice. An international team led by Hamish Pritchard from the British Antarctic Survey has recently shown that the increasing flow rate of Antarctic continental ice into the sea is in many locations linked to the thinning of the sea ice shelf lining the coast (Nature (2012) *484*, 502–505). The floating ice shelves, if they are strong enough, can buttress the glaciers and slow down their descent into the sea. The measurements using satellite-based

Ice melt: Sea ice in the Arctic is shrinking at a record speed, and the ice shelves surrounding Antarctica are also thinning dramatically. As the exposed sea water is much darker than the ice, loss of sea ice reduces our planet's reflectivity (albedo), which contributes to further warming. (Photo: Greenpeace.)

Bird watch: The snowy owl (*Bubo scandiacus*) is among the Arctic species threatened with habitat loss both from the disappearance of sea ice and from human activities such as oil and gas exploration. (Photo: Rose Sjolander.)

laser altimetry show, however, that the ice shelves lose height at rates of several centimetres per year.

The researchers find that in most cases the thinning is caused by exposure to warmer water from below, and only on the Antarctic peninsula can it be blamed on warm air from above, but ultimately both phenomena are linked to changes in wind patterns around Antarctica. The authors conclude that almost all the currently observed mass loss of continental ice in Antarctica can be explained with these mechanisms. Similar conclusions have also been drawn regarding some Greenland glaciers.

"What's really interesting is just how sensitive these glaciers seem to be," Pritchard said. "Some ice shelves are thinning by a few metres a year and, in response, the glaciers drain billions of tons of ice into the sea. This supports the idea that ice shelves are important in slowing down the glaciers that feed them, controlling the loss of ice from the Antarctic ice sheet. It means that we can lose an awful lot of ice to the sea without ever having summers warm enough to make the snow on top of the glaciers melt — the oceans can do all the work from below."

Monitoring change

There is no doubt that the conditions in both polar regions are changing too fast for comfort, but in order to distinguish between real climate change and short-term weather fluctuations, long-term monitoring of conditions is essential.

"Logistical constraints in the past have limited much Arctic ecological research to ship-based expeditions largely confined to the peak of the Arctic summer," explains Toke T. Høye from Aarhus University, Denmark. "With the growing concerns about Arctic climate change in the late 20th century, more site-based experiments and permanent infrastructures were set up. One early initiative was to establish experimental evidence for plant community responses to climate change in the form of the International Tundra Experiment (ITEX: http://www.geog.ubc.ca/itex/)." Researchers from ITEX have recently compiled a critical assessment of 61 studies using experimental local warming to predict the effects of climate change on tundra biotopes (Ecol. Lett. (2012) *15*, 164–175).

Only in recent decades have permanent field stations started to appear in remote arctic locations including Svalbard, Zackenberg in northeastern Greenland, and Toolik in Alaska. The Zackenberg station (www.zackenberg.dk) was established in 1995 for the long-term monitoring of effects and feedback processes induced by climate change in the Arctic ecosystem. "This [programme] is providing researchers with unique data sources to tackle the broader questions of how entire food webs will respond to climate change as a result of both direct as well as indirect effects of climate change," says Høye, who published a first assessment of such changes in *Current Biology* (Curr. Biol. (2007) *17*, R449–R451). "Recently, the Arctic Council has initiated the circumpolar biodiversity monitoring programme (CBMP, http://caff.is/monitoring) in an attempt to establish common protocols and coordinated efforts to monitoring biological responses to future change in the Arctic."

Together with the more recently established research station at Nuuk, southern Greenland, Zackenberg takes part in the Greenland Ecosystem Monitoring (GEM) programme, for which a strategy document has been published last year.

Scientific questions that GEM is planning to address by 2016 cover a wide range of issues including:

- greenhouse gas exchange with the atmosphere and nutrients balance (e.g. how does climate change and variability control the annual and seasonal exchange of greenhouse gases between arctic terrestrial ecosystems and the atmosphere?);
- ecosystem function and resilience (e.g. are there important thresholds in arctic ecosystems that might lead to sudden and significant shifts of their overall biodiversity and function?);
- water balance, including glaciology and water circulation in the marine environment (e.g. how does climate variability and change affect the water balance (including availability of water in terrestrial ecosystems, glacier mass balance and extreme run-off events) of the arctic ecosystem?);
- snow and ice, including effects on phenology, energy and carbon balance (e.g. how does climate-induced changes of permafrost-affected landscapes/soils (mainly thickness of active layer, thermal and moisture regime) affect the function of arctic ecosystems and specifically their carbon balance?);
- up-scaling, modelling and prediction (e.g. to what extent can results from GEM be used for up-scaling and prediction to address the questions above on a regional scale covering Greenland and the sea around Greenland (now and for the

Arctic bloom: The Arctic willow (*Salix arctica*) has over recent decades responded to climate change by growing to tree height, rather than as low shrubs. (Photo: Toke T. Høye.)

future) and what are the constraints for such up-scaling and prediction efforts?)

GEM plans to publish a comprehensive synthesis of scientific results in 2014 and hold an international workshop meeting on the effects of climate change on the Arctic in 2015. First results are already in the publication pipeline. "Together with Eric Post from Penn State University in the US, I am currently editing a synthesis of current knowledge on changes in Arctic tundra ecosystems as a theme issue for the journal *Philosophical Transactions of the Royal Society B*. This issue will provide an updated overview of changes detected in long-term observations across geographical and taxonomic scales in the Arctic," Høye says.

Eco warrior: The actress Lucy Lawless, known for her role as Xena the warrior princess, has helped to launch the Greenpeace campaign 'Save the Arctic' and has taken part in a three-day protest on an Arctic oil exploration ship, for which she is now charged with trespass. (Photo: Greenpeace.)

Changing sizes

While the scientists are still patiently ploughing on with the long-term monitoring work, some Arctic species have already responded to climate change with a clear change in their morphology. In 2009, Toke Høye and colleagues reported that, over a ten-year monitoring period, the average thickness of the exoskeleton of the Arctic wolf spider (*Pardosa glacialis*) increased by 2%. By year-on-year comparisons, they can link larger spiders to warmer weather, so the ten-year increase is thought to reflect the general warming of the Arctic climate (Biol. Lett. (2009) *5*, 542–544).

Researchers led by Bruce Forbes at the University of Lapland, Rovaniemi, Finland, have also studied size changes, but in plants. They looked into the shrubs of the northwestern Eurasian tundra, which over the last few decades have increased in size and are now much more likely to reach tree height. "The landscape is now more like parkland with thickets of forest in specific places, for instance in concave parts such as in places where a landslide had taken place," explains Marc Macias-Fauria from the Biodiversity Institute at the University of Oxford, who is the first author of this study (Nature Clim. Change (2012) doi: 10.1038/nclimate1558).

Nomadic reindeer herders had noticed the change years ago, as they kept losing sight of their reindeer hidden behind the much taller shrubs, and they have had to adapt their routes to avoid the denser patches.

Thanks to the gulfstream, the northwest Eurasian tundra, located just to the east of Scandinavia, is the warmest part of the Arctic. "In terms of warmth, this area is ahead of other parts of the Arctic," Macias-Fauria says, "so we are expecting similar things to happen in other places around the Arctic Circle a little bit later."

A very notable feature of the ecological change observed in that area is that it can proceed very quickly, in a matter of decades, as it relies on the species that are already present (willow and alder shrubs). By contrast, change relying on plant species from lower latitudes migrating northwards would take centuries, Macias-Fauria says.

As for the causes of the vegetation change, the research has shown that the sea ice plays a less significant role than was previously thought. While surface temperatures are under the influence of nearby sea ice in the spring, this period has little influence on the overall growth height of the shrubs. Their main growth period is in the summer, and the dominant influence on temperatures and growth are the weather systems, which are linked to the Scandinavian pattern. Shifts of these weather systems have in recent decades led to generally warmer summers in this region, explaining the stronger growth of the shrubs.

How this significant change of vegetation patterns will affect the rest of the ecosystem remains to be discovered. New ecological niches may arise for other species, and other, slower changes may result from the relatively rapid change observed. It is also unclear whether the increased growth is good news for climate. "On the plus side, the larger growth captures more carbon," Macias-Fauria says, "but on the other hand, its effects on the melting of permafrost remain unknown, which can release large quantities of greenhouse gases." The positive feedback loop that could result from the loss of permafrost is a major concern among the possible scenarios for climate change. In addition, the larger trees tend to disrupt the snow coverage in winter and thus reduce the albedo of the surface, again creating a feedback effect in favour of further warming. "The overall effect on the carbon balance is an open question," Macias-Fauria concludes, "as there are too many uncertainties and feedbacks involved."

Another recent surprise was the discovery of a phytoplankton bloom under the sea ice of the Arctic during investigations in the north Pacific led by Kevin Arrigo from Stanford University (Science (2012) *336*, 1408). This, the authors conclude, could mean that productivity in the icy polar waters may have been underestimated by a factor of up to ten, which underlines that we still know far too little about the polar environments.

Feedback

Beyond the direct impact on the local ecosystems, the warming of the polar areas is likely to affect the entire biosphere via feedback mechanisms such as the albedo effect and the release of methane from thawing permafrost. A recent report from Katey M. Walter Anthony, of the Water and Environmental Research Center, University of Alaska Fairbanks, of methane release along the borders of permafrost regions confirms the concern about this issue (Nature Geosci. (2012) doi:10.1038/ngeo1480).

An additional, potentially even more harmful feedback mechanism involves human use of resources in the Arctic. Neighbouring countries and international corporations are already beginning to exploit the oil and gas reserves that are now becoming more accessible due to the retreat of the ice cap. In a bitter irony, climate change itself enables us to accelerate its causes. Talk of 'peak oil' has been proven wrong, and we are now on track to burn our way back to a climate that the Earth hasn't seen for over two million years, back to the Pliocene.

The recent Rio+20 Earth Summit has shown that governments are not going to stop this development, so NGOs are stepping in. Greenpeace, for example, used the Rio+20 gathering to launch a campaign to 'Save the Arctic', with the help of celebrities including actress Lucy Lawless, who played Xena the warrior princess in the eponymous 1990s TV series. Saving the climate (and sea level) we are used to will be quite a fight.

Michael Gross is a science writer based at Oxford. He can be contacted via his web page at www.michaelgross.co.uk

Obituary

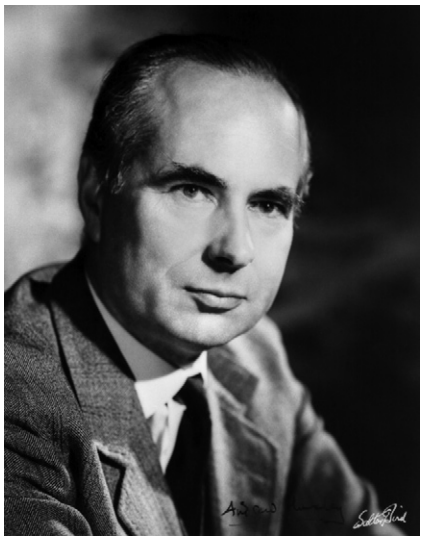
Sir Andrew Huxley: 1917–2012

Robert Simmons

Sir Andrew Huxley, who died on 30th May this year, was one of the greatest scientists of the 20th century. He was a physiologist, very much in the quantitative tradition of Cambridge physiology established by Lucas, Hill, Adrian, Rushton and Hodgkin. He is best known for his Nobel Prize-winning work with Alan Hodgkin on the mechanism of the action potential in the squid giant axon and for his major contributions to the field of muscle contraction.

Andrew Fielding Huxley was born in 1917. He was a son from the second marriage of Leonard Huxley and a grandson of Thomas Henry Huxley, the white knight of the Darwinist cause (and a notable biologist and thinker in his own right). His father, Leonard Huxley, was not a scientist: he pursued a literary career, as did his most famous son from his first marriage, Aldous Huxley, the novelist. Leonard's eldest son, Julian, was however a well-known biologist and very much a public figure in science. As it happened, neither of the two half-brothers had much influence on the young Andrew, who was twenty years and more their junior. Andrew Huxley went up to Trinity College Cambridge to read natural sciences in 1935, with the intention of eventually engaging in one of the physical sciences, but he discovered physiology and reset his sights on medicine (which was the career his grandfather had pursued initially). But he started research work with Alan Hodgkin in 1939, the war broke out during his first year of clinical studies, and he never returned to medicine.

Alan Hodgkin was only four years older than Huxley, but he was already a Fellow at Trinity and was beginning to make a name for himself in studies of the nerve action potential. He had learned about the use of the squid giant axon from Curtis and Cole at the Marine Biology Laboratory in Woods Hole in



Andrew Fielding Huxley (1917–2012). Credit: US National Library of Medicine/science photo library.

1938, and because of its large size it was clearly the preparation of choice for many fundamental studies. The only drawback was that squid are available only in the summer in the north Atlantic, and do not survive well in captivity, so research work has to be done at a marine biology station, in Hodgkin's case the Laboratory of the Marine Biology Association in Plymouth.

In their first work together in 1939, Hodgkin and Huxley succeeded in introducing an internal electrode axially into the axon without damaging the cell membrane, and they measured the action potential accurately for the first time. Their results immediately showed that the membrane, in the resting state polarised with a negative charge inside, more than depolarised during the action potential; there was a positive overshoot, which was most likely due to an increased conductance to sodium ions. Further work had to be delayed until after the war.

During the war, Huxley was engaged on gunnery research, though he was given a Fellowship at Trinity in 1941 and discussed work with Hodgkin, who was working on radar research, whenever they met. It was in late 1945 that the two were reunited in Cambridge, but the Plymouth Marine Biology Laboratory had been bombed during the war and it was only in 1947 that experiments on squid