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Editorial

Footprints of climate change in the Arctic region

The Arctic region is home to many unique, diverse and vulnerable ecosystems. But the enigmatic and once pristine Arctic environment is being increasingly affected by human activities. This thematic issue presents the latest research into the impacts of climate change and resource extraction on Arctic biodiversity and indigenous communities.

The timing of this special issue reflects the EU's growing engagement in the Arctic following the 2008 Communication 'The EU and the Arctic Region', the Council Conclusions of 2009 and the European Parliament's 2011 report on the High North. The forthcoming Joint Communication of the High Representative and the Commission, due in May 2012, will review recent progress and the next steps towards developing an EU policy towards the Arctic regions.

Across the globe, the effects of climate change are becoming increasingly apparent. But nowhere has the effect been felt more strongly than in the Arctic. During the 20th century, land temperatures rose by an average of 1-2˚C across the entire Arctic[1], which is twice as fast as the average global temperature rise.

Perhaps the most emblematic impact of climate change is the rapid loss of sea ice. At the current rate of decline, the Arctic is expected to be ice-free in summer by 2040, and some experts believe that it could be much sooner. The first article entitled **"Declining sea ice threatens Arctic marine mammals"** explores the consequences for marine mammals, such as whales, polar bears and seals, which depend on sea ice for feeding, shelter and breeding. Collaborating

(Continued on page 2)

Contents

Page

Declining sea ice threatens Arctic marine mammals 4
Rapid sea ice decline impacts on food, shelter and reproductive rates of Arctic marine mammals.

Arctic microbes: Good or bad for mitigating climate change? 5
Microbial communities within Arctic sea ice need close attention, says recent study.

Arctic birds migrate earlier under climate change 6
Researchers trace the effect of rising spring temperatures on birds migrating to Norway.

Reindeer are important in shaping Arctic plant communities 7
Scientists use ArcVeg model to explore the impact of reindeer grazing on Arctic plant species.

Extreme winter warming harms Arctic plant growth 8
Simulation of extreme winter warming events reveal detrimental effects on Arctic shrub species.

Polar and Atlantic cod share habitat, but not diet 9
Scientists reveal that polar cod's diet is currently unaffected by Atlantic invaders.

Climate warming may enhance polar cod survival 10
Projected effects of climate change could favour winter hatching in polar cod.

Arctic methane 'leak' could cause abrupt climate warming 11
Study calls for further research on methane release from thawing subsea permafrost.

Arctic fuel exploration: how far and how fast? 12
Factors affecting future extraction of oil and natural gas in the Arctic are explored.

Reindeer herding: adapting to global change in the Arctic 13
Reindeer herders collaborate with scientists in protecting the future of their industry.

Related articles 14
A selection of recent articles from the *Science for Environment Policy* News Alert.

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with Arctic communities may be one way to increase the number of marine mammal population studies, which have so far been limited by financial and logistical difficulties.

Loss of sea ice will also affect far less visible elements of the Arctic ecosystem. **"Arctic microbes: Good or bad for mitigating climate change"** describes the shift in community dynamics that is occurring within microbial populations deep within the ice. The ecological impact of climate change is increasingly evident in alterations to species migration patterns. **"Arctic birds migrate earlier under climate change"** describes how migrating birds are arriving in the Arctic nearly half a day earlier each year in response to rising spring temperatures, which has significant implications for annual breeding cycles.

The different Arctic subzones are home to many native plant species, including wild flowers, shrubs, grasses, mosses and lichen. Some studies predict the trend towards longer and warmer summers will result in an overall "greening" of the Arctic. However, as the article **"Reindeer are important in shaping Arctic plant communities"** describes, individual species distribution depends on many factors, including the grazing and trampling habits of native reindeer, with the implication that reindeer grazing management strategies could be important in biodiversity protection measures.

Scientists predict that short-lived periods of extreme winter warming will become more frequent under climate change, during which temperatures can rise up to 10˚C in 24 hours. These warming events can cause physiological changes in some dominant shrub species, decreasing their freeze-tolerance and reducing growth and survival over time. This is discussed in the article **"Extreme winter warming harms Arctic plant growth"**.

As the articles **"Polar and Atlantic cod share habitat, but not diet"** and **"Climate warming may enhance survival of polar cod"** explain, the impact of climate change on native polar cod is uncertain. Polar cod do not appear to be in competition for prey with Atlantic cod species, which have shifted their distribution northwards in search of cooler waters. However, this may change if the populations continue to converge. On the other hand, warmer conditions in winter favour the growth and survival of polar cod hatchlings in a phenomenon known as the "thermal refuge" hypothesis.

The Arctic is very closely linked to global climate. Frozen sediment, known as permafrost, is beginning to thaw in response to rising temperatures, releasing vast amounts of methane into the atmosphere. Since methane

(Continued on page 3)

is a far more potent greenhouse gas (GHG) than CO_2, the release of even a fraction of the 2000 billion tonnes[2] stored in the permafrost could trigger a 'positive feedback' mechanism, dramatically accelerating the pace of climate change. This is explained in more depth in **"Arctic methane leak could cause abrupt climate warming"**.

From a different global climate perspective, the Arctic is estimated to contain 30% of the world's undiscovered gas reserves and 13% of undiscovered oil. Dwindling supplies elsewhere and the fact that declining sea ice is making remote parts of the Arctic increasingly accessible means that many Arctic countries are looking to exploit their vast Arctic resources, despite commitments to reduce GHG emissions under the Kyoto Protocol (excluding the United States). **"Arctic exploration: How far and how fast?"** explores the costs and risks of Arctic development and how pressure from scientists and environmental groups for sustainable development is shaping the industry.

The final article, **"Reindeer herding: adapting to climate change in the Arctic"** examines the impact of climate change and the expansion of industrial activities on the indigenous Arctic population. In response to declining reindeer numbers, a unique international initiative is helping native communities adapt to local environmental changes using state-of-the-art satellite observation equipment and working to increase indigenous participation in policy decisions.

Arctic environmental issues will continue to attract wide interest in the EU and elsewhere during 2012-13. Of particular importance is the International Polar Year conference in Montreal in April 2012, where key policy areas covered by this special issue will be discussed, including biodiversity, climate mitigation and adaptation, sustainable development and resource management.

Many of the articles covered in this issue are part of on-going research under the EU Arctic Tipping Points project. Other important EU-funded projects focus on the contribution of continental ice melt to sea level rise (Ice2Sea), the effects of climate change on stratospheric ozone depletion (RECONCILE) and the probability of a reduction in the strength of the Meridional Overturning Circulation, the global conveyor belt system that transports heat around the globe and provides northern Europe with its characteristically mild climate (THOR).

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1. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007 M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (eds) Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

2. Makogon, Y.F., Holditch, S.A. & Makogon, T.Y. (2007) Natural gas hydrates – A potential energy source for the 21st century. *Journal of Petroleum Science and Engineering*. 56; 14-31.

Issue 31 April 2012

Declining sea ice threatens Arctic marine mammals

The rapid decline of Arctic sea ice has had dramatic effects on seals, polar bears, whales and other marine mammals. Changes in distribution, body condition, reproduction and abundance are all consequences of reduced sea ice that may escalate over the coming decade, according to a recent analysis.

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"For polar bears, numbers are expected to decline by 30-70% in the next half-century."

The Arctic is home to 11 species of marine mammals, all of which rely on sea ice for reproduction, food and shelter. In this study, researchers present an overview of changes in Arctic marine mammal populations caused by sea ice decline, and predict what may happen for them in the future.

The loss of ice habitat for breeding has resulted in declining pup production of hooded seals in the Northeast Atlantic, harp seals in the White Sea and ringed seals in Hudson Bay. Walrus calves have been found abandoned at sea, suggesting nutritional stress, perhaps as a result of fewer resting platforms over feeding areas. For polar bears, a change in distribution, reduced breeding rates, lower body mass and poor survival rates have been associated with longer ice-free periods in the Alaskan Beaufort Sea. In the Hudson Bay, increased consumption of food from the land, such as geese eggs and berries, rather than from the sea, is reducing the quality of polar bears' diets.

Killer whales have expanded their geographical range northwards in response to changing sea ice conditions in the Canadian High Arctic, along with other typically temperate cetaceans, such as sei whales, harbour porpoises, fin and minke whales. This is likely to cause competitive stress to native species if food resources overlap.

Current estimates suggest that the Arctic may be free of multi-year (older, thick) ice during the period 2013-2035, intensifying the risks to marine mammals. Ecosystem responses will vary regionally but there is particular concern for the future of bearded and ringed seals, which are heavily ice-dependent, and walruses, which may become more vulnerable to hunting. Ice-associated cetaceans will have to adapt to altered food webs, increased competition for prey and reduced shelter from predators and extreme weather conditions.

For polar bears, habitat losses are expected to be greatest in the southern seas of the Polar Basin and numbers are expected to decline by 30-70% in the next half-century. In addition, the parasite *Toxoplasma gondii* has increased significantly in ice–associated marine mammals in the last decade, suggesting increased risk of disease may become an issue.

The financial and logistical difficulties of Arctic research mean that population surveys of marine mammals are infrequent and incomplete. The researchers urge that international monitoring programmes, including satellite tracking of animal movements, are put in place immediately. Forming research partnerships with Arctic residents may be a feasible approach in some regions of the Arctic.

Source: Kovacs K.M., Lydersen, C., Overland, J.E., Moore, S.E. (2011) Impacts of changing sea-ice conditions on Arctic marine mammals. *Marine Biodiversity*. 41: 181-194.

Issue 31 April 2012

Arctic microbes: Good or bad for mitigating climate change?

The rapid loss of Arctic sea ice affects not only animals that live on the ice but also microbial communities that live *within* the ice. A recent study discusses how microbes are affected by climate change, in some cases providing an early warning of major environmental shifts but in other cases amplifying them.

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"Ice shelves are disappearing rapidly and diverse species of Bacteria, Achaea and Eukarya are now facing extinction."

Arctic microbial communities, living in brine channels between ice crystals, are major contributors to ecosystem biomass, biodiversity, nutrient cycling and energy flow. Yet the effects of climate change on such communities are poorly studied. Evidence suggests that some microbial ecosystems are in rapid decline, whereas others are shifting towards new states, with serious implications for food webs and greenhouse gas (GHG) emissions.

'Epishelf lakes' are an unusual ecosystem created when ice shelves dam bays and fjords, layering freshwater over saltwater. The breakup of ice shelves is diminishing their associated microbial communities and today only one such ecosystem remains in the Arctic. Once composed of 3 metre thick ice accumulated over many years (multi-year ice), ice shelves on the northern coast of Ellesmere Island in high Arctic Canada are also disappearing rapidly and diverse species of Bacteria, Achaea and Eukarya are now facing extinction.

A reduction in salinity (salt content) caused by melting ice and increased freshwater input from rivers is leading to an increase in bacterial concentrations and a decrease in the size and structure of marine plant species (phytoplankton). Smaller species are less efficient at transferring organic material through the marine food web, reducing the energy flow to fish and higher level organisms. It is predicted that a warmer Arctic Ocean will be more susceptible to invasive species from the south that may affect food quality and ecosystem services, such as fish and shellfish harvesting.

Non-marine microbial communities are also affected by climate change. The drying up of Arctic freshwater sites is being counteracted by increased permafrost thawing, leading to the expansion of thermokarst lakes and ponds. These are hotspots of microbial methane generation, with the potential to release globally significant emissions of GHGs. The production of CO_2 from microbes in thawing permafrost may also represent a potentially large source of carbon to the atmosphere.

Changes in the structure and function of microbial ecosystems in the Arctic are likely to intensify with further climate warming in combination with increased shipping, oil and gas exploration, urbanisation, pollution and ocean acidification. According to the researchers, close attention needs to be paid to better understand how microbial communities interact with their Arctic environment in order to take advantage of these ecosystems as indicators of climate change and to limit their potential to exacerbate global warming.

Source: Vincent, W.F. (2010) Microbial ecosystem responses to rapid climate change in the Arctic. *The ISME* Journal. 4: 1089-1091.

Issue 31 April 2012

Arctic birds migrate earlier under climate change

New research has found that birds migrating to a breeding ground in northern Norway are arriving on average 0.41 days earlier every year, in response to rising spring temperatures. Studies such as these are useful indicators of the ecological impact of climate change.

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"For 38 of the 42 species, arrival dates were considerably earlier in 2010 than in 1980, advancing by an average of 0.41 days per year."

In general, studies on migratory birds have found a trend towards earlier arrival dates in European breeding grounds over the last three to four decades, linked to increasing ambient temperatures. In this new study, arrival dates were analysed for birds migrating to Troms in Norway, which is within the Arctic Circle and is the northernmost breeding region in Europe. A previous study in this region had been unable to identify a trend.

The study collected data from a Norwegian database on the date that individuals from 42 species were first sighted each year between 1980 and 2010. This included 11 years of more recent data than the earlier study. The researchers then compared the trends in bird sightings with monthly atmospheric temperatures in Troms and in two locations along the migratory pathway, Nordland and northern Sweden.

For 38 of the 42 species, arrival dates were considerably earlier in 2010 than in 1980, advancing by an average of 0.41 days per year. Species that overwinter in southern and eastern Europe advanced their arrival dates more than those migrating from Africa. Species that tend to appear earlier in the year also advanced their arrival dates more than those appearing later. This is despite a much larger temperature increase over the study period for May than for March or April. Interestingly, the results revealed a stronger link between arrival times and temperatures in Nordland and Sweden, suggesting that conditions experienced en route northwards are more important in determining arrival time than conditions at the destination.

The progression towards earlier arrival dates has not occurred at a steady pace. For approximately 70% of species, the rate of change was slow before 1995-1999 (approximately 0.34 days per year) and increased rapidly thereafter (around 1.2 days per year). This 'break' in the trend is also reflected in the temperature data in Troms for May. This pattern may explain why the earlier study (until 2000) did not detect a strong trend in arrival time, but contrasts with results from other regions that have found continuous advancement over the last 30-40 years. This suggests that the signs of global warming and the response of migratory birds have occurred more recently in this region of Norway than elsewhere in Europe.

The study suggests that, since migration is clearly affected by short-term temperature change (i.e. since the late 1990s), further advancement in arrival dates can be expected if local temperatures continue to rise in response to climate change.

Source: Barrett, R.T. (2011). Recent response to climate change among migrant birds in northern Norway. *Ringing and Migration*. 26: 83-93.

Issue 31 April 2012

Reindeer are important in shaping Arctic plant communities

Reindeer grazing and climate change both affect Arctic plant communities, according to new research. The study suggests that reindeer grazing management strategies could significantly influence the future Arctic landscape.

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"Reindeer grazing management strategies could significantly influence the future Arctic landscape."

Arctic plant communities comprise a range of species, including evergreen and deciduous shrubs, lichen, mosses, wild flowers (forbs) and grasses (graminoids). These species are distributed differently across different Arctic subzones, from the coldest high Arctic desert to warmer low Arctic tundra.

Predicting the impact of climate warming on Arctic plant communities is complex. Previous studies using aerial photography have documented expansion of the geographical range of shrubs, particularly the deciduous *Salix* and *Alnus* species, and attribute this to increased temperatures. Other studies suggest that warming enables the expansion of deciduous shrubs and grasses and causes moss and lichen species to decline.

Reindeer grazing and trampling have also been shown to influence plant communities, with studies finding decreases in overall biomass accompanying grazing. However, plant species are unlikely to be affected uniformly by grazing, as reindeer prefer to eat deciduous shrubs and lichens.

In the new study, researchers modelled the response of different Arctic plant species to climate warming and reindeer grazing. The study used the ArcVeg model to explore the impact of these pressures on five different climate zones in the Yamal peninsula in northwest Siberia. In the model, grazing was accounted for by considering the amount of biomass removed by grazing and the frequency of grazing (e.g. the probability that reindeer will graze a particular site on any given year).

The model suggests that reindeer may have an important role to play in determining Arctic plant diversity. Since reindeer prefer deciduous shrubs and lichens, these species are most affected by grazing. For example, grazing may help limit the expansion of deciduous species caused by climate warming, enabling evergreen shrubs to maintain a foothold. In the High Arctic tundra, grazing may cause a shift from lichen- to moss-dominated tundra, although continued grazing may force reindeer to also forage moss.

However, a more complex picture arises when the impact of grazing on soil nutrients is considered. For example, forb species generally decrease in response to grazing, except in some nutrient-poor sites. In these sites, forb growth increases when grazing is managed on a 10-year rotation, but decreases with more frequent grazing. The researchers suggest that in these sites, grazing may reduce cover by deciduous shrubs, leaving soil nutrients available for other species.

High levels of grazing can reduce both deciduous and evergreen shrub levels when the resilience of evergreen shrubs is affected, causing a shift to grass and moss dominated tundra. A decrease in shrub coverage may be beneficial to understory plants as more light and nutrients are likely to be available.

Source: Yu, Q., Epstein, H.E., Walker, D.A, Frost, G.V., Forbes, B.C. (2011) Modeling dynamics of tundra plant communities on the Yamal Peninsula, Russia, in response to climate change and grazing pressure, *Environmental Research Letters*. 6 045505.

Issue 31 April 2012

Extreme winter warming harms Arctic plant growth

A new study has explored the effects of climate change on Arctic plants by simulating extreme winter warming events and measuring plant responses. The researchers found that considerable damage occurred to dwarf shrub species, in terms of shoot mortality, leaf and root growth.

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"Root growth was reduced by 25% across all species and primary production was reduced by more than 50%."

The majority of studies analysing the impact of climate change on Arctic plant ecosystems have focused on long-term warming that occurs during summer. However, climate models forecast greater climate change in winter than in summer and an increase in the frequency of short-lived warming events. Therefore, research that analyses the response of plants to extreme winter warming events (e.g. a change from -20 to + 5°C or even +10°C in 24 hours) is particularly valuable.

In the new study, week-long winter warming events were simulated in a mountain birch forest sub-Arctic heathland in northern Sweden, using infrared lamps and soil warming cables. The effects after three years of simulated warming events were recorded for three dwarf shrubs, *Empetrum hermaphroditum, Vaccinium vitis-idaea* and *Vaccinium myrtillus*. The researchers measured reproductive effort, shoot and root growth, plant community composition, soil nutrient availability and the transfer of carbon through the ecosystem.

After the second and third warming events, bud development was delayed by up to a week in *E. hermaphroditum* and *V. myrtillus* compared to control plants in non-test conditions. For the same species, berry production decreased by up to 75% and 95%, respectively. Flower production was reduced by 100% in *V. myrtillus* but remained unaffected in the other two species.

Shoot mortality increased by 52% in *E. hermaphroditum*, 51% in *V. vitis-idaea* and 80% in *V. myrtillus* after the second winter warming event. Root growth was reduced by 25% across all species and primary production was reduced by more than 50% after the third warming event.

Although all three species showed considerable damage, *V. myrtillus* experienced the strongest effects overall, followed by *E. hermaphroditum* and *V. vitis-idaea*, indicating the potential shift in community structure as well as the overall decline in plant biomass that may accompany increased winter warming. Previous research has shown that extreme warming events can initiate physiological responses that result in loss of freeze tolerance over time. The observed differences between species are attributed to the strength of this effect over the study period.

These results suggest that even a small number of consecutive winter warming events have the potential to reverse the increase in plant productivity (known as the greening of the Arctic) resulting from the long-term increase in the length and warmth of Arctic summers. This further increases scientists' uncertainty over the effects of projected climate change on Arctic ecosystems.

Source: Bokhorst, S., Bjerke, J.W., Street, L.E., Callaghan, T.V., Phoenix, G.K. (2011) Impacts of multiple extreme winter warming events on sub-Arctic heathland: phenology, reproduction, growth and CO2 flux responses. *Global Change Biology*. 17: 2817-2830.

Issue 31 April 2012

Polar and Atlantic cod share habitat, but not diet

Despite Atlantic cod and haddock extending further into Arctic waters, a new study reveals there is little competition for food between the invaders and native polar cod. However, it is uncertain whether climate change will increase competition between the species as range expansion of the Atlantic species progresses.

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"Atlantic cod and haddock fed on some of the same species but overlap with polar cod diets was found to be less than 40%."

Changes in sea temperature, circulation patterns and ice-cover caused by climate change are expected to have profound effects on ecology and biodiversity in the Arctic Ocean. Under an increasingly warming climate, the distribution of Atlantic cod and haddock are known to be expanding their geographical range into the Arctic Circle, where polar cod have been the dominant species until now.

Recent studies have found that young polar cod can coexist with others of closely related species. However, few studies have so far sought to understand how polar cod populations respond to competitors. In this study, researchers under the EU-funded Arctic Tipping Points (ATP) project set out to investigate the extent to which the diets of polar cod overlap with those of Atlantic cod and haddock. Polar cod are an important food source for seabirds, marine mammals and other fish, so disturbances to their diet and habitat would have a wide impact on Arctic Ocean ecosystems.

The researchers analysed the stomach contents of young cod and haddock collected in fjords near Svalbard, Norway, in 2006, 2008 and 2009. They found that native cod fed mainly on krill and crustaceans, such as *Pseudocalanus, Calanus* and *Thermisto* species. Atlantic cod and haddock fed on some of the same species, including *Thermisto* species and krill, but where all three species inhabited the same waters, overlap in their diet was found to be less than 40%. Researchers identified only one of the regions – near a glacier in Billefjorden – where the diets of Atlantic cod and haddock were similar to each other, but overlap with polar cod was still low at just 37%.

Because stomach contents only reveal what fish have eaten very recently, the researchers also carried out stable isotope analysis, a method that can be used to investigate diet through chemical analysis of muscle tissue. Again, their results suggested distinct diets for all three species.

However, the scientists highlight that most studies to date have focused on fish collected during the summer and autumn months. Thus, variations in feeding behaviour during other seasons when less prey is available could be key to understanding the potential effects of climate change on diet.

They also suggest that competition and predation is likely to increase for polar cod if Atlantic cod and haddock become more abundant in the Arctic. The potential shifts in populations could present a challenge to managers, particularly since it would involve commercially valuable species.

Source: Renaud, P.E. Berge, J., Varpe, Ø. *et al.* (2012). Is the poleward expansion by Atlantic cod and haddock threatening native polar cod, *Boreogadus saida? Polar Biology.* 35: 401-412.

[1] Arctic Tipping Points (ATP) is supported by the European Commission 7th Framework Programme. See: www.eu-atp.org

Climate warming may enhance polar cod survival

Researchers have demonstrated that hatching in polar cod can begin as early as January in Arctic seas that receive large freshwater input, compared to April-July in seas with little freshwater input. Since early hatching leads to higher survival rates, the effects of climate change may enhance polar cod's survival by favouring conditions that allow winter hatching to occur.

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"Importantly, 97% of the polar cod that reached a length greater than 35mm were from regions with high freshwater input."

The polar cod, *Boreogadus saida*, plays an important part in the food web of the Arctic seas. Young fish are preyed on by birds at the sea surface in late summer and then by adult cod as they migrate to deeper, overwintering grounds. Since the chance of survival is higher for larger individuals, selection pressure pushes hatching to occur as early as possible, in late winter or early spring, to allow individuals to reach a larger size before migration begins.

The study hypothesises that early hatching occurs in under-ice river plumes, where the input of freshwater keeps temperatures relatively high in winter (just below 0˚C) compared to -1.8˚C under the ice. These warmer temperatures accelerate embryonic development and allow successful feeding when the larvae first hatch out.

To test this 'thermal refuge' hypothesis, the researchers studied six oceanographic regions of the Arctic Ocean ranging from inland and coastal seas, which are heavily influenced by rivers, to recurrent polynyas, which are areas of open water surrounded by sea ice and with little freshwater input. Results showed that the hatching period became shorter in duration and shifted from winter to summer with decreasing freshwater input. For example, hatching started as early as December and January in the Laptev Sea, Hudson Bay and Beaufort Sea, where freshwater input is high, and was delayed until spring (April or May) in Baffin Bay and the Northeast Water, where freshwater input is minimal.

The scientists estimated individual fish lengths at the end of summer in the different regions sampled between 2003 and 2006 by measuring the thickness of annual growth layers in the inner ear – just like tree rings. Lengths ranged from less than 10mm to 50mm, corresponding to larvae hatched in July and those hatched in December and January, respectively. Importantly, 97% of the polar cod that reached a length greater than 35mm were from the regions with high freshwater input.

The results from this study suggest that the projected effects of climate change in the Arctic Ocean, including earlier ice break-up, more frequent winter polynyas and freshwater-induced temperature changes caused by increased river discharge, could enhance the growth and survival of polar cod by promoting conditions that favour winter hatching. Further research is now needed to confirm the thermal refuge hypothesis by directly observing whether winter hatching occurs within plumes of rivers under sea ice.

Source: Bouchard, C., Fortier, L. (2011) Circum-arctic comparison of the hatching season of polar cod *Boreogadus saida:* A test of the freshwater winter refuge hypothesis. *Progress in Oceanography.* 90: 105-116.

Arctic methane 'leak' could cause abrupt climate warming

For thousands of years, vast amounts of methane – a potent greenhouse gas – have been stored in frozen deposits on land and under the ocean in the Arctic. A new study has found that rapidly rising temperatures are accelerating the release of methane by thawing subsea 'permafrost', releasing nearly 8 million tonnes into the atmosphere each year and potentially increasing global warming.

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"Rapidly rising temperatures are thawing subsea 'permafrost', releasing nearly 8 million tonnes of methane into the atmosphere each year".

Permafrost acts like a lid, keeping natural reservoirs of methane in place. Some scientific studies have found that thawing permafrost on land in the Arctic tundra is responsible for vast releases of methane to the atmosphere. However, few studies have looked at whether this is happening under the Arctic Ocean.

In the new study, scientists took more than 5000 water samples between 2003 and 2008 at different depths in the East Siberian Arctic Shelf (ESAS). The permafrost there holds at least as much methane as land deposits, but is more vulnerable to thawing, with average annual seawater temperatures of -1.8 to 1°C, up to 17 °C warmer than on land.

Their measurements revealed that seawater in the ESAS contains large amounts of methane, distributed throughout, from the bottom to the surface. Slow mixing processes and plumes of bubbles carry methane released from the permafrost up through the water towards the surface. In deeper waters, most of the methane would be oxidised before reaching the surface, but in shallow water like the ESAS, it is released to the atmosphere.

Air measured above the ESAS contained higher (up to 400% below a height of 250m and 10% at 1800m) and more variable methane concentrations than expected for the area, which is evidence for methane venting from the underlying water. The scientists estimated that nearly 8 million tonnes of methane is released to the atmosphere from the ESAS each year. A third of this comes from localised 'hotspots', where release from the permafrost is particularly strong.

As well as being released from sediment within the permafrost, methane can be generated in other ways, for example, through microbial activity or decomposition of organic material in the sediment. However, methane levels were much higher in the ESAS than could be explained by these sources, ruling them out as major contributors.

Methane released from permafrost is likely to have a 'positive feedback' effect on climate warming, by further contributing to greenhouse gases in the atmosphere. The total amount of methane stored in the Arctic Ocean – in the sediment and the permafrost - is estimated to be about 2000 billion tonnes. More research is therefore needed to determine whether these observations signal a slow and gradual release of methane or the beginning of a massive release event, which could result in abrupt and severe climate warming.

Source: Shakova, N., Semiletov, I., Salyuk, A. *et al.* (2010). Extensive methane venting to the atmosphere from sediments of the East Siberian Arctic Shelf. *Science.* 327: 1246-1250.

Issue 31 April 2012

Arctic fuel exploration: how far and how fast?

There are signs that oil and gas exploration in the Arctic will expand in the next few decades to keep up with Europe's growing energy demand. However, a number of factors will determine future Arctic exploration, according to a new study, including the state of the global economy, environmental concerns and climate change.

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"An estimated one quarter of the world's undiscovered oil and natural gas is located in the Arctic."

An estimated one quarter of the world's undiscovered oil and natural gas is located in the Arctic. Coupled with an expected rise in global gas consumption of 50% in the next 25 years, some nations with Arctic territories (Canada, the US, Norway and Russia) have already begun extracting oil and gas and are keen to expand their activities. However, future production will not simply be driven by demand, according to research conducted under the EU-funded Arctic Tipping Points project[1]. A number of other factors will contribute.

With its remote locations and harsh conditions, fuel extraction in the Arctic is expensive (up to 100 US$ per barrel), so the most important driver of development is likely to be the state of the global economy. A sudden shift in demand or market price, such as the drop to record lows caused by the 2008 financial crisis, will affect whether Arctic production is profitable or not. In the long-term, demand for fossil fuels may fall as result of government actions to mitigate climate change, i.e. taxes on CO_2 emissions, or if alternative energy becomes more competitive. Governments therefore need to weigh up Arctic exploration against greenhouse gas reduction commitments under the Kyoto protocol.

Climate change will bring further opportunities and challenges. A decline in ice cover of 3.7% per decade, as reported in the Arctic Climate Impact Assessment[2], has opened up new shipping routes making remote Arctic resources more accessible. Ice-free summers, which are predicted by 2040, will mean longer drilling seasons. However, scientists believe that the structure of sea ice has been altered so that icebergs are moved more easily by strong currents and winds, potentially disrupting drilling operations. An increase in the frequency of polar storms and hurricanes could create even more unpredictable conditions. Emerging technology, such as platforms that are able to withstand the impact of icebergs, will be essential.

National governments must also consider strong environmental concerns over disruption to pristine Arctic ecosystems and the potential impact of oil spills. The ability to transport gas as Liquefied Natural Gas (LNG) may remove the need for remote pipelines in the long-term, but the emerging technology is so far only operational in the Arctic in one Norwegian site. The cost of adhering to strict new safety rules, following the Macondo disaster in the Gulf of Mexico in 2010, will also significantly affect the attractiveness of future Arctic projects.

Source: Harsem, Ø., Eide, A. & Heen, K. (2011). Factors influencing future oil and gas prospects in the Arctic. *Energy Policy*. 39: 8037-8045.

[1] Arctic Tipping Points (ATP) is supported by the European Commission under the 7th Framework Programme. See: www.eu-atp.org

[2] Impacts of a Warming Arctic: synthesis of the Arctic Climate Impact Assessment report, Arctic Council and the International Arctic Science Committee (2004). Free to download from: http://amap.no/acia/

Reindeer herding: adapting to global change in the Arctic

Reindeer herding has a long history in the Arctic, but climate change and industrial activity are bringing this important economic and cultural tradition to breaking point. In a unique initiative, reindeer herders across the Arctic are leading an international team of scientists in using modern technology to adapt to global change and empower indigenous communities.

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Themes: Agriculture, Climate change and energy, Environmental information services

"In Russia, which has 67% of all domesticated reindeer, numbers fell from 2.5 million in 1969 to 1.2 million in 2000."

More than 100,000 indigenous people in the Arctic rely on reindeer for their livelihoods. Not only are reindeer important as a food source and for the local economy, they also represent a core cultural tradition. With knowledge passed down through generations, reindeer herders are finely tuned to the harsh Arctic environment as they search for the best grazing pastures for their herds.

However, climate change and human development are bringing new challenges. Changes in temperatures and snow/ice cover make annual migration routes increasingly hazardous for the reindeer, especially the young calves, and limit their access to food. Grazing land is also being lost to tourism, oil and gas development, roads and infrastructure. As a result, reindeer numbers are in serious decline. In Russia, which has 67% of all domesticated reindeer, numbers fell from 2.5 million in 1969 to 1.2 million in 2000.

In response to these challenges, the Association of World Reindeer Herders (WRH) have initiated a project in collaboration with scientists to better understand the consequences of global change on their industry. The aim of the EALÁT project[1] is to combine herders' traditional knowledge with cutting edge scientific and technical tools to assess the vulnerablity of the herding industry and develop local adaptation strategies.

Preliminary studies in collaboration with NASA have used satellite data to assess pasturelands and migration routes as well as snow cover over large geographical areas, helping herders modify feeding grounds and seasonal transport routes. Herders' observations of weather conditions are also being combined with meteorological measurements (i.e. temperature, precipitation, humidity) to help them predict and avoid severe weather events.

Data collected during the project will be integrated into a central Geographical Information System (GIS), known as EALÁT-*Monitoring*, to provide real-time information (i.e. daily temperature, hourly snowfall) to help herders make critical decisions. This will be a unique resource that enables indigenous communities to monitor global change themselves and contribute to local and regional policy decisions.

To raise awareness in the wider community about the value of indigenous cultures, news from the project will be disseminated locally and via websites open to the public, such as The Reindeer Portal. The UArctic Institute for Reindeer Husbandry has also been set up to ensure the legacy of the research and the training provided to Arctic herders continues long after this phase of the EALÁT project has ended in September 2014.

[1] EALÁT – Reindeer Pastoralism in a Changing Climate. See: www.ealat.org

Source: Maynard, N.G., Oskal, A., Turi, J.M., Mathiesen, S.D.,et al. (2011). Impacts of Arctic Climate and Land Use Changes on Reindeer Pastoralism: Indigenous Knowledge and Remote Sensing. In: Gutman, G.,Reissell, A.(Eds.) *Eurasian Arctic Land Cover and Land Use in a Changing Climate.* Dordrecht: Springer, pp. 177-205.

A selection of articles on Arctic Science from the *Science for Environment Policy* news alert.

New ozone hole discovered over the Arctic (15/11/11)

For the first time, scientists have identified an 'ozone hole' over the Arctic, in addition to the well-known ozone hole over the Antarctic. Unusually persistent low temperatures over the Arctic in early 2011 caused an unprecedented amount of chemical destruction of stratospheric ozone there. The authors warn that this is likely to happen again, although it is presently difficult to predict when this might be.

Toxic mercury could be produced within seawater (01/09/11)

New research has shed light on the source of highly toxic monomethylmercury (MMHg) in Arctic marine waters. A study of polar seawater suggests that relatively harmless inorganic mercury is being transformed into the toxic MMHg within the water itself.

Climate system elements could reach point of no return this century (06/03/08)

Key elements of the earth's climate system could pass their 'tipping point' this century, according to new research. The research explored the views of world experts on climate change and sought to define those aspects of climate change that are most affected by human activity, and that could be relevant to current policy on global warming.

Abrupt Ice Retreat in the Arctic Possible by 2040 (18/01/07)

According to a recently published study, the recent retreat of Arctic sea ice could accelerate so rapidly that the Arctic Ocean could become nearly ice-free during summertime as early as 2040. Nevertheless, the authors highlight that reductions of future greenhouse gas emissions could reduce the probability and the severity of the predicted events.

Ecosystem Shift in the Northern Bering Sea Driven by Climate Change (20/04/06)

New research has assessed changes in ecosystems in the Northern Bering Sea in response to climate change. Results support the evidence of a reorganization of the marine ecosystems driven by climate changes in the Arctic region. These changes might have irreversible effects on Arctic marine mammal and seabirds populations, and commercial and subsistence fisheries.

To view any of these articles in full, please visit: http://ec.europa.eu/environment/integration/research/newsalert/index_en.htm, and search according to article publication date.

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A new online database which brings together key environmental research for evidence-based policy. Free to access, the Research Repository lists studies that have undergone a rigorous selection process to ensure that only high quality, policy-relevant research is featured. The resource will grow as new research becomes available.

Studies are catalogued by topic, across an extensive range of policy themes, from ecosystem services to ecolabelling, and from soil management to urban water management. This is designed to help ensure that individual policymakers can find studies that are relevant to their specific project.

See: http://ec.europa.eu/environment/integration/research/newsalert/research_repository/research_repository.htm

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