



The View from the Top

Searching for responses to a rapidly changing Arctic

In the fragile Arctic region the extent of sea ice was at a record low in September 2012. Land ice is also retreating, while snow is disappearing and permafrost is thawing. Rapid environmental change in the Arctic, as a result of climate change, is providing new development opportunities including easier access to oil and gas, minerals and fisheries. It is also threatening ecosystems – with ice-associated animals especially at risk. Changes in the Arctic will have consequences far beyond this region, including a global rise in sea levels and probably more extreme weather across much of the northern hemisphere. These current and future consequences of climate change require urgent responses. Arctic and non-Arctic countries share responsibility for protecting this region, in particular by limiting their greenhouse gas emissions.

Accelerated summer meltdown

Arctic sea ice extent is rapidly diminishing. The minimum sea ice cover in 2012, at 3.4 million km², was 18 per cent below the previous recorded minimum in 2007 and 50 per cent below the average in the 1980s and 1990s (**Figure 1**). Every year from 2007 the minimum has been lower than in any year before 2007 (NASA 2012a, NSIDC 2012). Floating ice has covered much of the Arctic Ocean for most of the past three million years (Polyak et al. 2010). But how much longer will this be the case?

The retreat of sea ice has been much more rapid than projected in the Intergovernmental Panel on Climate Change's latest report (IPCC 2007, Polyak et al. 2010, Stroeve et al. 2012) (**Figure 2**). More recent modelling studies have come closer, but none has yet reproduced the observed trend (Stroeve et al. 2012). Nor have these studies been able to project precisely when ice-free conditions will first be observed during the Arctic summer.

◀ Sea ice is frozen seawater that floats on the ocean surface. It forms in the winter and partly retreats in the summer. The extent and thickness of sea ice covering the Arctic Ocean is significantly decreasing. *Credit: Peter Prokosch*

Authors: Robert Corell (chair), Tom Barry, Joan Eamer, Lawrence Hislop, Lars Kullerud, Jerry Melillo, Christian Nellemann, Lev Neretin, Lars-Otto Reiersen, Jon Samseth
Science writer: Fred Pearce



Figure 1: Every summer the Arctic sea ice melts down to its minimum in mid-September, before colder weather rebuilds the ice cover. The figure shows the 2012 minimum (recorded on 16 September), compared with the average minimum extent between 1979 and 2010 (yellow line). *Source: NASA (2012a), NSIDC (2012)*

The IPCC report warned that this could happen around 2100 (IPCC 2007). One extrapolation of recent trends suggested that September could be ice-free before the end of this decade (Wadhams 2012). However, the most common prediction is that this will take place around 2035 (Wang and Overland 2012).



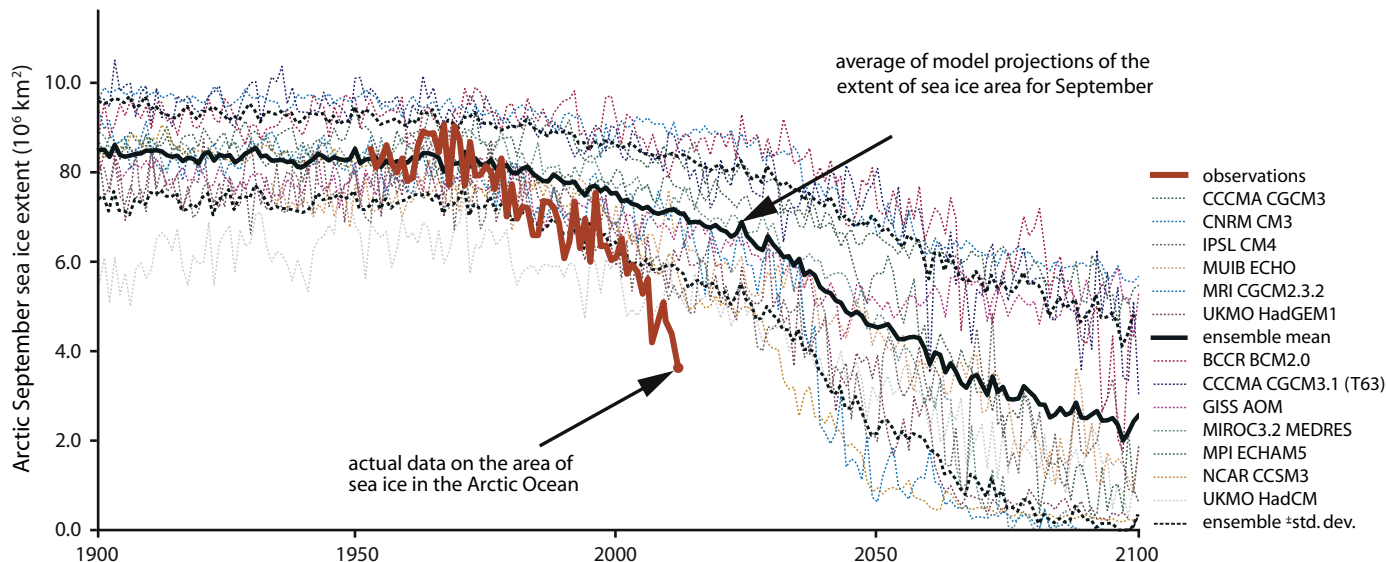


Figure 2: Plots of September sea ice extent, based on observations (red) and model runs (black/dotted), show that melting is taking place more rapidly than projected by any models. Source: Stroeve et al. (2012)

Every winter the Arctic sea ice reforms. While this will probably continue to happen, the amount of thick, old ice surviving from one year to the next is diminishing (Maslanik et al. 2011). The multi-year ice is at its maximum extent in March. However, it made up only 45 per cent of the total in 2010 compared to 75 per cent in 1988 (Figure 3). The Arctic's thinned winter ice is thus primed for destruction in summer (Lenton 2012, Livina et al. 2012).

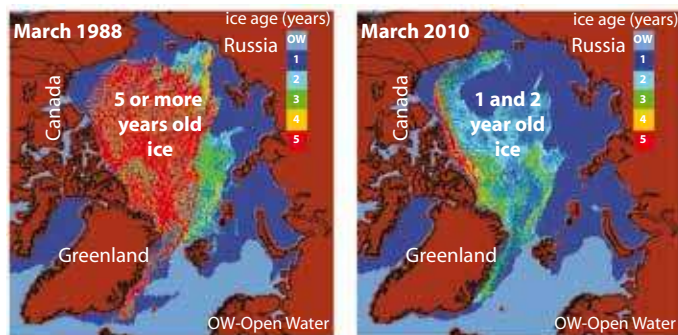


Figure 3: Each winter new sea ice forms and covers the Arctic Ocean. The amount of old ice that survives from year to year is diminishing, as shown by the ice age distribution in March 1988 and March 2010. Because of a continuous counterclockwise rotation the older multi-year sea ice is extruded into the North Atlantic and replaced during the winter by new sea ice, which is much younger. Historically, these processes were slower and less ice was extruded, hence remaining in the Arctic for longer periods of time. Source: Maslanik et al. (2011)

Loss of sea ice has been accompanied by melting of the Greenland ice cap, thawing of permafrost on the tundra (the region where tree growth is hindered by low temperatures and short growing seasons), less snow on land due to earlier snow melt, and melting of some snow cover on glaciers (Philip 2005, AMAP 2011a, Gardner et al. 2011, Jacob et al. 2012, NOAA 2012). The average snow cover remaining in the northern hemisphere in June – virtually all of which is within the Arctic – has declined by more than 50 per cent in the past three decades, to less than 4 million km². The five lowest values were all recorded since 2007 (Derksen and Brown 2012).

A changing energy balance

The world is warming, and with it the Arctic (Figure 4). However, the Arctic has been warming at least twice as fast as the global average (ACIA 2005, Arndt et al. 2012). One reason is that more heat is brought into the Arctic through the atmosphere and with ocean currents. Several local factors are also increasing warming by changing the region's energy balance.

The greatest local amplification is due to the melting itself, which reduces the reflection of incoming sunlight. White ice and snow act as a mirror, reflecting about 85 per cent of solar radiation back to the sky. Dark ice-free areas of the ocean reflect only about 10 per cent and absorb the rest, while bare tundra reflects about 20 per cent (Climate Data Information 2012). As ice and snow melt, the exposed ocean and land absorb about 80 per cent of incoming radiation from the sun, increasing local surface warming. Heat in the ice-free ocean also directly warms the air above it.

Black carbon (or soot), a short-lived climate pollutant, darkens snow and ice and may also contribute to warming in the Arctic (AMAP 2011b) (**Box 1**). Dust and volcanic ash contribute to cooling while in the atmosphere, but have the same effect as black carbon when they fall on snow or ice. Furthermore, shrubs and trees moving into the tundra increases absorption of sunlight by making the land surface darker (Chapin et al. 2005).

Other accelerators of atmospheric warming involve water vapour (Callaghan et al. 2011a). With more open sea in the Arctic, more water will evaporate, increasing the amount of water vapour in the air. Water vapour is a powerful, locally acting greenhouse gas. It traps heat, further escalating warming. On the other hand, more water vapour may increase cloud cover, which generally has a cooling effect during daylight hours. The overall balance of these different feedbacks has not been established, but strong warming suggests that positive feedbacks dominate (AMAP 2011a).

Box 1: The role of black carbon (soot)

Carbon dioxide (CO₂) is the main anthropogenic greenhouse gas responsible for warming the atmosphere. However, short-lived climate pollutants in the Arctic, such as organic carbon, methane and ozone, also increase warming. Soot, which scientists often refer to as black carbon, is produced by burning many things from diesel to dung. In the air, black carbon absorbs solar radiation and radiates it out again as heat, warming the surrounding air. But the tiny particles only stay aloft for a few days before falling to the ground (Ramanathan and Carmichael 2008).

In most places that is effectively the end of black carbon's climatic impact. In the Arctic, however, where particles may fall onto white snow and ice, its warming effect continues. As the particles accumulate, they darken the snow and ice, increasing heat absorption, warming the air and accelerating snow melt (Flanner et al. 2007, Doherty et al. 2010, AMAP 2011b).

Typical levels of black carbon in Arctic ice and snow are around 5-10 parts per billion. This "dirtying of the mirror" increases the amount of heat absorbed by an estimated 1-4 per cent, raising local temperatures and melting snow and ice (Flanner et al. 2007, AMAP 2011b). As a result, the black carbon's warming effect remains greater in the Arctic than in most of the rest of the world (AMAP 2011b). The fallout of black carbon in the Arctic is at its maximum in late winter. Modelling studies suggest that this fallout may be increasing spring snow melt rates by between 20

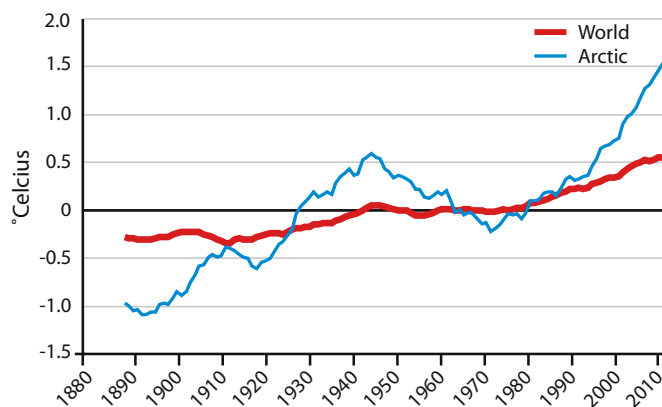


Figure 4: The combined sea-surface and air temperatures, globally (red) and in the Arctic (blue), show temperature anomalies for the period 1880-2011 compared to a 1951-1980 baseline. The Arctic strongly amplifies global signals of cooling and warming. As global temperatures increase or decrease, so do temperatures in the Arctic, but multiplied by a factor two or three. Source: NASA/GISS 2012

and 30 per cent (Flanner et al. 2007, AMAP 2011a). There is, however, uncertainty related to the models used for calculating how strong the effect is (AMAP 2011b). Models need to be verified with data collected in the Arctic.

Although some black carbon is generated within the Arctic and adjacent areas – from diesel-powered electric generators and ship engines, flaring during oil and gas exploration, agricultural burning, forest fires, and use of wood stoves – much originates outside the region (Sharma et al. 2006). Better controls on air pollution in northern countries outside the Arctic have recently reduced black carbon fallout (AMAP 2011b). As the Arctic is opened to increased shipping and industrial activity, that trend could be reversed. One modelling study has suggested a possible five-fold increase in black carbon emissions from Arctic shipping by 2030 (Corbett et al. 2010). Whether this will happen greatly depends on future emission controls.

Global controls on black carbon could slow global warming by about a decade, according to some estimates, while saving the lives of up to 2 million people in the world killed annually as a result of inhaling indoor smoke from cooking stoves (Streets 2006, Kandlikar et al. 2010, UNEP/WMO 2011). A number of concrete measures have been identified that could produce this slowdown of the warming in the Arctic (UNEP/WMO 2011) (Chapter 1, Box 2). Reducing black carbon emissions is therefore important, but clearly is not a substitute for reducing emissions of CO₂ and other greenhouse gases.



Warming of the Arctic could unleash other contributions to warming with global consequences. Of particular concern is the thawing of frozen tundra soils and continental shelf seabed (Abnizova et al. 2012, Schaefer et al. 2012, UNEP 2013). Permafrost soils often contain large volumes of organic carbon – the remains of plants accumulated over thousands of years (Tarnocai et al. 2009). If the soils thaw, the release of some of this carbon as CO₂ or methane will be irreversible.

Methane is stored in permafrost and in frozen marine sediments in the coastal seabed as gas hydrates. It is released at temperatures above the freezing point. Methane is a more powerful greenhouse gas than CO₂ although it does not last as long in the atmosphere, most of it eventually turning into CO₂. Along the East Siberian Arctic shelf of Russia and elsewhere throughout the Arctic, extensive methane venting to the atmosphere has been reported (Anisimov 2007, UNEP 2013). These releases may account for 5 per cent of world methane emissions (Walter et al. 2007).

Permafrost has retreated northwards in many places (AMAP 2011a, Callaghan et al. 2011b). Up to 50 gigatonnes (Gt) of predicted amount of hydrate storage could be released, increasing the methane content of the planet's atmosphere by a factor twelve (Shakhova et al. 2008). There is, however, considerable uncertainty about how big a threat such emissions may prove to future climate. Much will depend on the speed of their release (IPCC 2007). According to one recent modelling study, significant releases are likely by the end of the 21st century, raising global temperatures by a further 0.8°C (MacDougall et al. 2012). This temperature increase could be still greater in the Arctic (AMAP 2011a).



Ponds in the Siberian Lena Delta, Russia, formed by melting permafrost. Permafrost is likely to be an important source of atmospheric methane in the future, though the timing and volume of methane releases remains unclear. Credit: Peter Prokosch

Global impacts

Melting of ice and snow on land in the Arctic adds to the amount of water in the ocean, raising global sea levels possibly even more than models used by IPCC have predicted (Rhamstorf et al. 2012). The biggest long-term concern in the Arctic is Greenland, which is covered by ice up to 3 km thick – enough to raise global sea levels by an eventual 7 metres if it melted (Dahl-Jensen et al. 2011). Such a catastrophe is not imminent, as it would take several hundred years at current and projected rates of warming, but Greenland is increasingly surrounded by open water and experiences air temperatures reaching 11°C in summer, when large shallow lakes form on the ice pack. Recently melting has extended, particularly in southern Greenland. It now lasts up to five months (Tedesco et al. 2011). The United States National

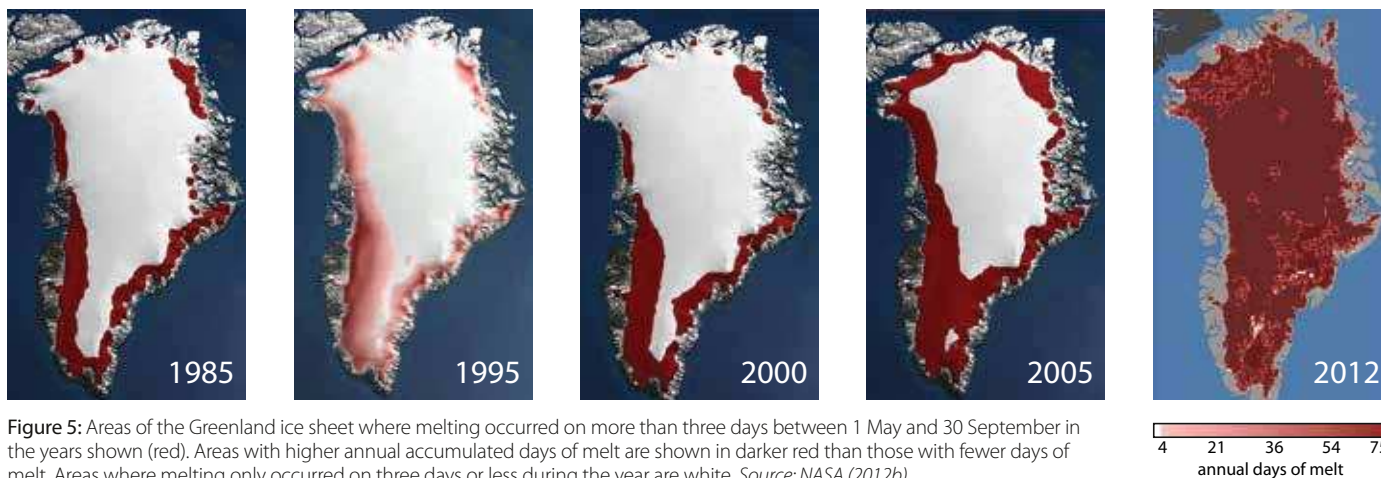


Figure 5: Areas of the Greenland ice sheet where melting occurred on more than three days between 1 May and 30 September in the years shown (red). Areas with higher annual accumulated days of melt are shown in darker red than those with fewer days of melt. Areas where melting only occurred on three days or less during the year are white. Source: NASA (2012b)

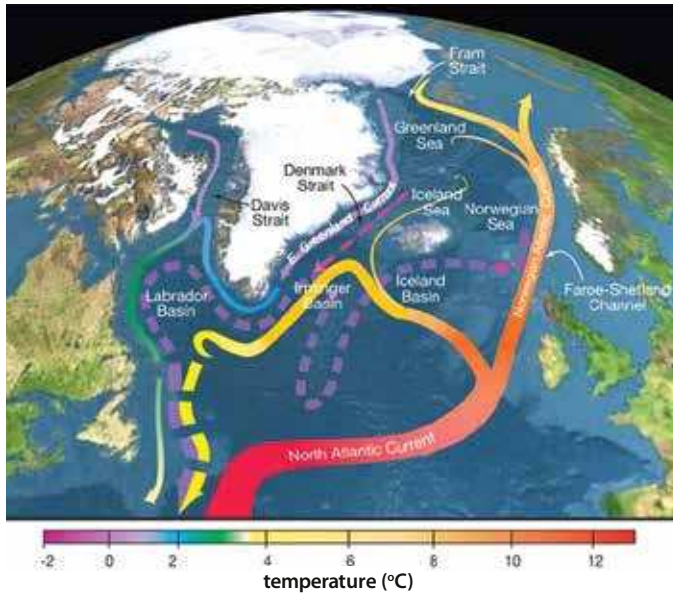


Figure 6: Climate change at high latitudes has the potential to alter circulation patterns in the global ocean through the process known as the thermohaline circulation. Water becomes heavier as it gets saltier and colder. Both warming and freshening of surface water may lead to a reduction of the density of surface water, thus inhibiting or at least slowing the formation of deep, dense water that sinks down and drives global ocean circulation. Such a breakdown of the thermohaline circulation has the potential to further amplify global climate change. Surface currents on the map are shown as solid pathways; deep currents are dashed, and colour indicates the water temperature. *Credit: Woods Hole Oceanographic Institution*

Aeronautics and Space Administration (NASA) reports rapid melting of ice in Greenland during the past two decades (**Figure 5**). By mid-July 2012, the melting area covered an estimated 97 per cent of total surface area (NASA 2012b). These trends suggest that current predictions of Greenland's future snow and ice cover are conservative (Wang and Overland 2012).

The loss of ice in Greenland and the shrinking of glaciers in other parts of the Arctic currently contribute up to 40 per cent of the average 3 mm of global sea level rise per year (AMAP 2011a). Ice caps decline through melting, evaporation or collapsing into the sea, but scientists do not understand these mechanisms well enough to predict the fate of Arctic land ice with any accuracy. A number of studies suggest Greenland could be a major contributor to a potential rise in sea levels of 0.5 to 1 metre by the end of the century (Kopp et al. 2009).

The Arctic's influence on the rest of the world extends beyond its contribution to rising sea levels. Lost Greenland ice, along with runoff to the ocean from thawing of permafrost and melting of smaller glaciers, contributes to changes in the global ocean's circulation system, with potentially major consequences for weather systems globally (Dmitrenko et al. 2011, Rignot et al. 2011) (**Figure 6**).

There is increasing evidence that rapid Arctic warming may already be responsible for a shift in weather patterns and changes in the frequency and intensity of extreme weather events at lower latitudes (AMAP 2011a, Francis and Vavrus 2012). Because the Arctic is warming faster than regions further south, temperature differences between the Arctic and mid-latitudes are becoming smaller. This appears to have been responsible for a slowing down of the jet stream (the strong wind in the upper atmosphere that steers weather systems from west to east around the northern hemisphere) by about 14 per cent since 1980 (Francis and Vavrus 2012, Overland et al. 2012). The slower jet stream causes weather systems to linger, creating "blocking" formations that produce more intense and longer periods of rainfall and drought, summer heat waves, and cold snaps in winter (Francis and Vavrus 2012, Hanna et al. 2012). This may explain some recent unusual weather phenomena, including Russia's record heat wave in 2010, prolonged cold spells in Europe in 2012, heavy snow in the United States and Canada in 2011, and droughts in North America in 2011 and 2012 (Francis 2012, Francis and Vavrus 2012, Inoue et al. 2012).

Changes in the Arctic biosphere

Climate change is emerging as a major stressor on Arctic biodiversity (CAFF 2010). Habitat fragmentation, pollution, industrial development and overharvesting of wildlife are also having impacts. As a result, unique habitats for flora and fauna such as tundra, ponds and lakes, and permafrost peatlands have been disappearing in recent decades (CAFF 2010, AMAP 2011a). This threatens wildlife, including many birds and mammals that migrate annually from as far as Africa, Latin America and South-East Asia to the Arctic to breed (**Figure 7**).

The lifecycles of many Arctic species are synchronized with the onset of spring and summer to take advantage of peaks in food availability. Earlier melting of snow and ice, or flowering of plants, can cause a mismatch between the timing of reproduction and the supply of food. At the same time, warming may allow non-Arctic species to expand their range northwards, displacing and outcompeting native Arctic species. For example, the red fox is replacing the Arctic fox in parts of the European Arctic (Fuglei and Ims 2008, Angerbjörn et al. 2012). There has been a northward shift in the distribution of some fish species and their prey due to warming sea temperatures (Meier et al. 2011). Such changes may, in turn, have caused breeding failures in some sea birds, and subsequent population decline, as fish species that used to be a major food source for seabirds move out and are replaced by other, unsuitable ones (CAFF 2010, Harris et al. 2007).

accelerated rate in summer (Hunter et al. 2010). This brings into question the management of populations and other wildlife management decisions affecting their resilience (**Box 2**).

The narwhal, one of three whale species that live in the Arctic year round, is also vulnerable. The majority of the world's narwhals winter in Baffin Bay, where they dive for Greenland halibut in areas with heavy pack ice, but shrinking ice cover is reducing their feeding areas (Laidre and Heide-Jorgensen 2011). Narwhals are also at increased risk from killer whales, which are becoming more common as the ice disappears.

Warmer springs and longer ice-free periods mean longer growing seasons for vegetation on land and in the sea (Vincent et al. 2011). Algae production, the basis of the marine food web, has increased by about 20 per cent since 1998 (Arrigo and van Dijken 2011). Algal blooms provide a moving feast at the edge of retreating ice that is critical for the reproduction of tiny floating creatures such as copepods, which are in turn eaten by fish, birds and marine mammals (Hunt et al. 2011, Leu et al. 2011). This may sound like good news, but many creatures dependent on algae are vulnerable to changes in the timing, quality and location of these blooms (**Figure 8**). For example, thick-billed murres at some nesting colonies in Canada used to feed on Arctic cod that gorge on copepods at the ice edge. But because the ice melts earlier, the cod are no longer concentrated near the murres' nesting area when the birds need food for their chicks. The murres have partly adjusted, laying eggs five days earlier than they did 20 years ago. However, the ice is melting on average 17 days earlier. The birds have turned to new food sources and have found it more difficult to feed their chicks, which are growing more slowly as a result (Gaston et al. 2009, Meier et al. 2011).



Thousands of Pacific walrus on the beaches at Cape Kojevnikova, Chukotka, Russia. Walrus rest on ice when feeding. As the Arctic sea ice recedes, they are forced ashore to rest. Increasing numbers are congregating on "haul-out sites" as shown here. Credit: Varvara Semenova, MMC

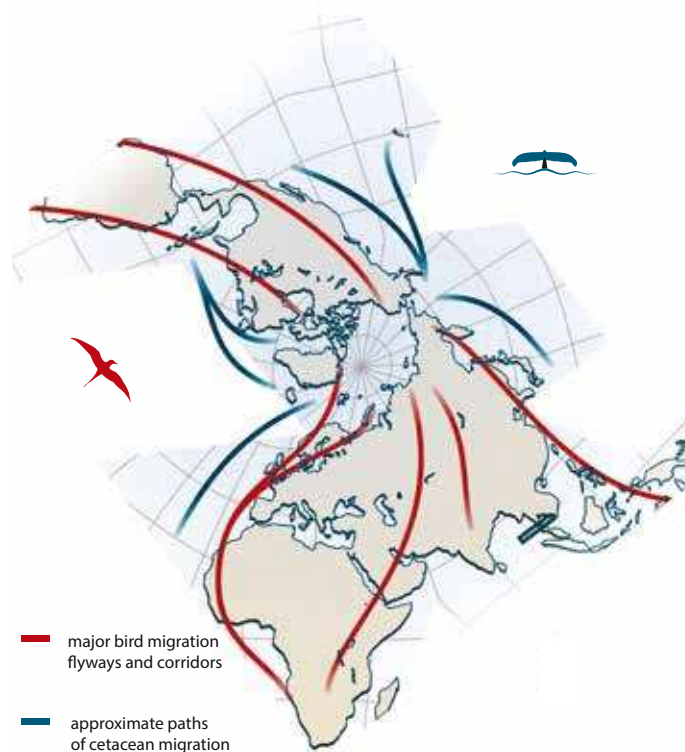


Figure 7: Many species, particularly birds (red) and marine mammals (blue), migrate to the Arctic annually from all parts of the world to breed. Migratory birds evolved over millennia to fly long distances to make use of many different habitats and seasonally abundant resources across a range of climatic zones. Source: ATMP (2009), ACS (2013), Wetlands International (2013)

Arctic marine mammals are particularly vulnerable to the loss of summer sea ice. Polar bears, walrus and some seals spend all or part of the year under, on top of, or on the edges of sea ice. These ice-edge zones are rich in food and serve as vantage points and resting places during hunting. Pacific walrus, for example, rest on ice when feeding. As the ice recedes, they are forced ashore to rest. Increasing numbers are congregating at a handful of locations on land. There have been ten-fold increases in the number of walrus at some sites along the coast of the Chukchi Sea in the past decade, with an estimated 97 000 at one location in Russia in 2010 (Kochnev 2010). Packed together, often far from their feeding grounds, the walrus go hungry and lose weight while the young may be crushed to death (Garlich-Miller 2012, MacCracken 2012).

Polar bears use sea ice as a base for hunting seals. Drastic reductions in their range and population are projected by the end of the century as sea ice continues to disappear at an

Box 2: Quandry over polar bears

Polar bears are perceived as an iconic species threatened by climate change (Ford 2011, Wenzel 2011). They are frequently shown clinging to remnants of ice, giving the impression that they are on the brink of extinction (Festa-Bianchet 2010).

While this is not yet true, there is cause for concern. Polar bears use ice to travel and to find the seals on which they feed. If there is no ice, the polar bears fast. Reduced populations, poorer body condition, and changes in distribution and behaviour have all been recorded, especially among populations at the southerly extent of their range (Stirling and Derocher 2012).

Polar bears undoubtedly also risk a drastic reduction of their range as population declines (Amstrup et al. 2010, Derocher 2010). So far, though, only a few populations are actually known to be in decline (Vongraven and Richardson 2011). Currently numbering between 20 000 and 25 000, polar bear populations

may have increased overall in recent decades due to improved management of hunting. Thus, any suggestion that polar bear hunting should be banned remains controversial (Freeman and Foote 2009, Wenzel 2011).

There is growing tension between several of the Inuit communities, for whom polar bear hunting is central to their culture as well as an economic resource, and some outsiders who favour full protection (Meek 2011, Wenzel 2011). In the view of local wildlife managers, some polar bear populations could continue to support limited hunting (Ferguson 2010). However, climate change and loss of habitat make such management decisions more complex (Peacock et al. 2011, Rode et al. 2012). Approaches to minimizing these conflicts may require less rigid conservation regimes that involve local people and make use of their knowledge in reaching decisions that affect their well-being (Chapin 2010, Meek 2011).

Marine species with limited distributions or specialized feeding habits are particularly vulnerable (Laidre et al. 2008). As the ice disappears, major changes will take place in pelagic species and in ice-associated plankton. The marine ecosystem is also affected by changing water temperatures and ocean acidification (**Box 3**). Moreover, climate change may alter the fate of Persistent Organic Pollutants (POPs) such as some pesticides, and of mercury, which accumulate in Arctic species, especially those at the top of the food chain (Kallenborn et al. 2012). Melting may also cause the release of “old” pollutants immobilized and stored in snow and ice over the years (Ma et al. 2011).

Along with the increase in ocean algae, there has been a 20 per cent increase in production of green plants on land since 1982 (Epstein et al. 2012). While there are more shrubs, there has been a loss of lichen, an important food source for caribou and reindeer (Myers-Smith et al. 2011). Additionally, lichens suffer with the thawing of the frozen peatlands on which they grow (Vincent et al. 2011). There are also concerns that thawing permafrost, by adding cold underground water to rivers, is changing their flow, temperature and chemistry. This type of change could have major implications for freshwater ecosystems and fisheries depending on them (Frey and McClelland 2009).

Although the overall biological productivity of the Arctic is increasing, changing conditions mean there is often less food at critical periods for many species. It is likely that the rate and extent of change will outstrip the adaptive capacity of many species to respond (Gilg et al. 2012).

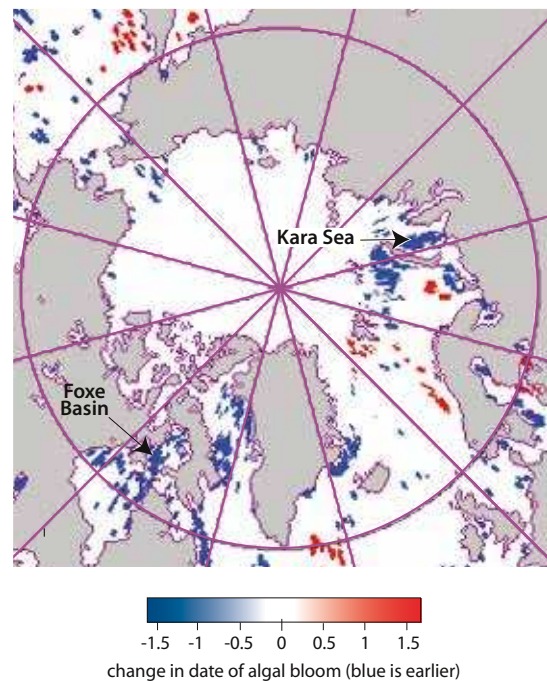


Figure 8: Trends in peak algal blooms in the Arctic Ocean, 1979–2009. Algal blooms are occurring earlier in about 11 per cent of the Arctic Ocean. The change is in areas where ice is melting in early summer, creating gaps that make these earlier blooms possible. The rate of change is very rapid at some locations. For example, peak algal bloom occurred in early September in Foxe Basin and in the Kara Sea in the mid-1990s but had shifted to mid-July by 2009, a change of about 50 days. Source: Kahru et al. (2011).

Box 3: Ocean acidification in the Arctic

The ocean has become 30 per cent more acidic in the past two centuries (UNEP 2009). This is largely because some of the CO₂ emitted to the atmosphere by human activity dissolves in ocean waters, forming carbonic acid. However, changes in freshwater balance, heat budgets and land-ocean exchange may also play a locally significant role. Modelling studies suggest that even if the atmosphere recovers its former chemistry, acidification will take thousands of years to reverse.

Polar regions are particularly prone to acidification because colder water can hold more CO₂ than warmer water. In addition, changes in ocean chemistry due to melting sea ice lead to calcium carbonate being less available to animals that need it to build shells and external skeletons (Carmack et al. 2012). This has potentially serious implications for molluscs, corals and crustaceans.

In parts of the Canadian Arctic and the East Bering Sea, researchers have reported seasonal shifts in seawater chemistry, from conditions that enable molluscs to form shells to conditions in which shells dissolve (Yamamoto-Kawai et al. 2009, Mathis et al. 2011). Pteropods, tiny sea snails that are important in the Arctic marine food web, may be particularly vulnerable. The common



The pteropod, or “sea butterfly”, is about the size of a small pea and a major food source for animals ranging from krill to whales. When placed in seawater with an acidity and carbonate concentration at levels projected for the year 2100 the shell slowly dissolves. Credit: Russel Hopcroft

pteropod *Limacina helicina* could become extinct by the end of the century (Comeau et al. 2012). This would have major ecological and economic impacts, including on North Pacific pink salmon fisheries. Only urgent global action to reduce CO₂ emissions can prevent such impacts (Turley and Gattuso 2012).

The rush for Arctic resources

Resource exploitation is not new in the Arctic. Major longstanding developments include oil drilling on the North Slope of Alaska, natural gas or methane extraction on Russia's Yamal peninsula, and mining of metals around Norilsk, Russia, the world's largest source of nickel and palladium. But as ice and snow recede, making access and transport easier, the Arctic is expected to play a greatly expanded role in world energy and minerals supplies.

The United States Geological Survey (USGS) estimates that 30 per cent of the world's undiscovered natural gas is in the Arctic, mostly on the continental shelves beneath the Arctic Ocean. More than 70 per cent of the undiscovered oil resources are estimated to occur in northern Alaska, the Amerasian Basin, the eastern side of Greenland, the eastern Barents Sea region, and the Davis Strait of Greenland and Canada. An estimated 84 per cent of the undiscovered oil and gas in the Arctic occurs offshore. The largest gas resources are likely to be off the coast of western Siberia in the Kara Sea region (USGS 2008).

One insurance company expects up to US\$100 billion in Arctic investment in the coming decade, largely in the minerals sector

(Emmerson and Lahn 2012). Exploration and mining are already accelerating, triggering construction of roads, ports and new settlements. In 2012 Shell constructed a new oil rig offshore of Alaska's Arctic National Wildlife Refuge (McClatchy 2013) and the Canadian government gave the green light for a giant iron-ore mine at the Mary River, which will be linked to a port on Baffin Island by the world's most northerly railway (North of 56 2012). Another target for early economic development will be the southwest coast of Greenland, which may have the world's largest deposits of rare earths (GME 2012).

While foreign companies are keen to exploit Arctic reserves, indigenous and local communities hope that some of the profits will benefit their development and employment opportunities. In 2012 the Inuit-owned Nunavut Resources Corporation began raising money on Wall Street to prospect for gold and other minerals in the Kitikmeot region (MacDonald 2012).

Public funding is often essential to such enterprises. Russia reportedly spent US\$19.3 billion subsidizing its oil and gas industries in 2010 (Gerasimchuk 2012). Even so, not all schemes are realized. In August 2012 Statoil decided to pull

out of the US\$15 billion Shtokman gas project in the Barents Sea due to rising costs and falling global gas prices (Macalister 2012). The start of this project in one of the world's largest gas fields is now delayed until at least 2017.

Shipping

Receding sea ice is opening the Northern Sea Route and Northwest Passage for shipping. In 2011 the Northern Sea Route was open for five months. More than 30 ships passed through, including Russian gas tankers and Nordic iron ore carriers (Helmholtz Association 2012, Macalister 2012). In September 2012 the icebreaker *Xue Long*, or *Snow Dragon*, became the first Chinese vessel to complete the route (NZweek 2012). The Northern Sea Route is a substantially shorter passage (35-60 per cent savings in distance) for shipping between northern European ports and those of the Far East and Alaska than routes through the Suez or Panama Canals (Figure 9). The implications for global trade could be considerable, as some 17 000 ships per year pass currently through the Suez Canal.

In 2011 the then Prime Minister of Russia, Vladimir Putin, announced that Russia intends to turn the Northern Sea Route into a shipping highway “of global importance” with a 40-fold increase in shipping by 2020. In June 2012 a new Russian federal law regulating commercial shipping in the Northern Sea Route was signed. There will be a new hydrographic survey to improve seabed mapping, and ten search and rescue centres along the Arctic coast (Marinelink 2012). Another major development will be the opening of a route away from the coast through deeper waters north of the New Siberian Islands.

The Northwest Passage through the Canadian Arctic was open in 2011, but partially blocked by ice throughout 2012. It, too, may soon be sufficiently free of ice to allow ships to pass during part of the year. Meanwhile, the Arctic is set to become a growing tourist destination, particularly for cruise ships (PAME 2009). More shipping will, however, increase the likelihood of accidents and of environmental damage.



Figure 9: The Northern Sea Route (orange) will provide a shorter passage from the North Atlantic to the Pacific than the current shipping route through the Suez Canal (blue). Credit: Danish Institute for International Studies

The challenges of development

Approximately 4 million people live in the Arctic region, about half in Russia (SDWG 2004) (Figure 10). One-tenth are indigenous peoples, a high proportion of whom (including almost all Inuit communities) live along the coasts, where loss of sea ice increases opportunities for fishing but also increases climate-related risks (Forbes 2011).

Historically, coastal populations have been protected from winter storms by ice. The shorter period of ice cover today exposes coasts to storms that erode the shoreline, typically by 1-2 metres a year but up to 30 metres in certain locations (Forbes 2011). Some villages, such as Shishmaref in Alaska, have made plans to move inland as a result (CAKE 2010).

Elsewhere, thawing permafrost buckles roads and destroys pipelines, and ice roads sometimes unexpectedly become impassable. On rivers, changes in ice cover damage hydropower infrastructure and bridges (Prowse and Brown 2010). In Alaska, the costs for upkeep of public infrastructure could add US\$3-6.1 billion to normal maintenance costs from 2008 to 2030 (Schaefer et al. 2012).

Resilience – the long-term capacity to deal with change and continue to develop and adapt within critical thresholds – is vital (Arctic Council 2012). Indigenous communities, in particular, have developed subsistence lifestyles based on hunting, herding, fishing and gathering that are adapted to the Arctic's climatic extremes and variability. Changes to the Arctic may threaten their way of life.



Protection against severe erosion of the coastline in Shishmaref, Alaska, United States. The reduced period in which there is sea ice has made sandy sediments more vulnerable to erosion. Credit: Lawrence Hislop



Box 4: The Nenets – a test of resilience in the face of industrial development

The nomadic Nenets are reindeer herders living on the Yamal peninsula in Western Siberia, Russia. They have faced rapid development of gas fields on their grazing grounds since the end of the 1980s. The peninsula has recently been producing 17 per cent of the world's natural gas.

The Yamal peninsula is largely flat, but is crossed by strips of higher terrain traditionally used by the Nenets as camp sites and migration routes for their herds. Industrial development has often targeted the same elevated terrain. While the physical footprint of the gas fields remains small, pipelines and other facilities have blocked two of the four main Nenets migration routes, obliterating grazing areas and closing access to 18 traditional camping grounds (EALÁT 2011).

So far, the Nenets have been able to reorganize their lives and survive. But expansion of infrastructure (**Figure 11**), combined with degradation of terrestrial and freshwater ecosystems, rapid climate change and a massive influx of industrial workers, will test their resilience (Forbes et al. 2009).

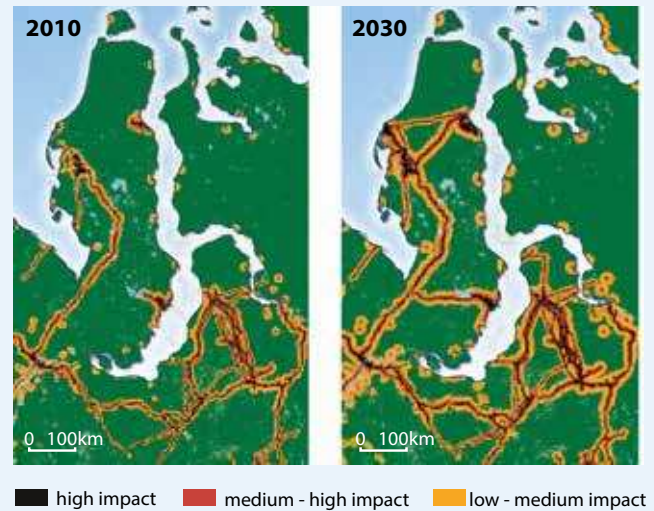


Figure 11: Current industrial development (2010) and expansion of infrastructure projected for 2030 in the Yamal region. Source: Magga et al. (2011)

the Alaskan North Slope, for example, some Inuit welcome the oil industry because it brings jobs and civil amenities (AMAP 2010). But for many indigenous peoples, protection of access to their lands is the top priority and fundamental to the survival of their traditional livelihoods. The challenge is how to respect the traditional way of life of local and indigenous communities while

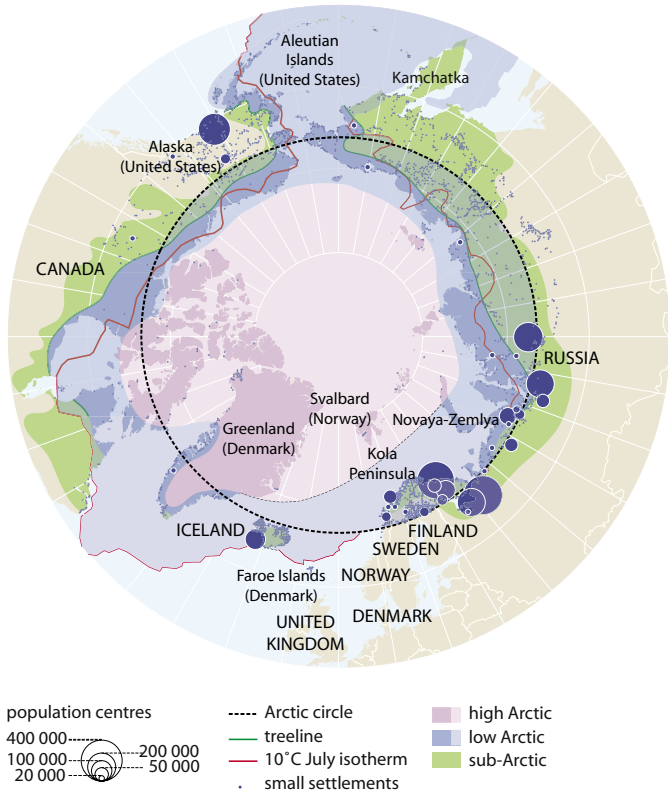


Figure 10: The Arctic can be divided into the low Arctic and high Arctic according to various environmental and biological characteristics. Tundras are most common in the low Arctic and polar barrens are dominant in the high Arctic. The circumpolar Arctic covers 14.8 million km² of land and 13 million km² of ocean. Seven of the ten largest remaining wilderness areas on Earth are located in the Arctic region. The Arctic is also home to diverse and unique societies, including indigenous cultures depending on and maintaining close ties to the land and ocean. Credit: Adapted from Vital Arctic Graphics, GRID-Arendal

For nomadic peoples their resilience depends on unfettered access to land and water, allowing them and migrating wildlife to move with the seasons. Changes in access to resources can pose real threats. Even minimal development of infrastructure in terms of surface areas, such as roads and pipelines, can be extremely disruptive (**Box 4**). The footprint of new economic development in the Arctic remains small. Yet by fragmenting the landscape, economic development can interrupt hydrology, endanger ecosystems, and prevent the passage of migrating caribou and reindeer in search of grazing spots and calving areas.

Industrial and infrastructure developments may bring short-term economic benefits for some indigenous communities. On

making economic development environmentally safe. Meeting this challenge is associated with rights to land and natural resources, as reflected in international agreements such as the 2007 United Nations Declaration on the Rights of Indigenous Peoples.

Environmental governance

The Arctic has been called a bellwether for global climate change (Post et al. 2009). Due to its rapid warming, impacts often show up here first. The combination of rapid environmental transformation and the rush for resources in a previously remote region raises important geopolitical issues that are likely to have ramifications far beyond the Arctic (Conley 2012). It can therefore also be considered a bellwether for tackling environmental governance challenges.

Central to any discussion of Arctic governance is the role of the Arctic Council, established in 1996 based on the 1991 Arctic Environmental Protection Strategy (Stokke 2011, Kao et al. 2012). The eight Arctic countries forming the core of this high-level forum are Canada, Denmark (including Greenland and the Faroe Islands), Finland, Iceland, Norway, Russia, Sweden and the United States (Arctic Council 2013). A number of indigenous peoples' organizations, including the Inuit Circumpolar Council (ICC) and Russian Association for Indigenous Peoples of the North (RAIPON), became permanent participants. Several non-Arctic countries, as well as international organizations, have observer status. A number of other countries and organizations are seeking to become observers to the Arctic Council.

The Council leadership rotates every two years. In 2013 it passes from Sweden to Canada. The Council has considered sustainable



Thousands of indigenous peoples living in the Yamal peninsula, Russia, practise traditional reindeer herding. Since the 1980s, rapid development of gas fields has occurred on these nomadic herders' historic grazing lands. *Credit: Anna Degteva*

development of the Arctic through reports on pollution, climate change impacts, snow, water, ice and permafrost, shipping, human development and biodiversity. The Arctic Council countries have also taken steps recently to strengthen governance, including through the adoption of a first agreement on Cooperation in Aeronautical and Maritime Search and Rescue in the Arctic (Kao et al. 2012).

Resource exploitation and shipping

Under the United Nations Convention on the Law of the Sea (UNCLOS), coastal states have the right to establish a 200 nautical mile Exclusive Economic Zone (EEZ) where they have sovereign rights and jurisdiction over the continental shelf unless there is a need for maritime delimitation with another coastal state (**Box 5**). States that have a continental shelf that stretches at least 200 nautical miles have to document its outer limits. According to UNCLOS Article 77 "the coastal State exercises over the continental shelf sovereign rights for the purpose of exploring it and exploiting its natural resources".

Box 5: Legal questions

In 2010 Norway and Russia ended 42 years of negotiations on their disputed maritime delimitation line in the Barents Sea and the Arctic Ocean, opening up parts of the continental shelf to natural resource development. This is one of a series of Arctic geopolitical issues being resolved.

Outstanding issues include border disagreements between Denmark/Greenland and Canada; issues concerning the Northwest Passage; and a difference in opinion in regard to the interpretation of the Treaty concerning Spitsbergen. The Svalbard archipelago, situated midway between Norway's mainland and the North Pole, is under Norwegian sovereignty, but particular provisions of the Treaty accord certain rights to nationals and companies of its Parties, and there are different views on the geographical scope of application of these provisions.

The largest territorial question over a maritime delimitation line may be between Canada and the United States in the Beaufort Sea, an area expected to be rich in petroleum resources. Another contentious issue will be where to draw the border on the seabed between Denmark/Greenland, Russia and Canada on the Lomonosov ridge, a section that stretches over the North Pole from Russia to Greenland and Canada. The five countries bordering the Arctic Ocean (Canada, Denmark/Greenland, Norway, Russia and the United States) have confirmed their commitment to UNCLOS as the legal framework to orderly settlement of any overlapping claims in the Arctic Ocean (Ilulissat Declaration 2008, Kullerud et al. 2013).



Rapid changes in the Arctic environment and increased opportunities for exploitation of the region's resources create challenges for the region, for co-operative bodies such as the Arctic Council, and for the wider world. The international community is keen – at different times – both to exploit those resources and economic opportunities and to protect the region's fragile environment. For example, British parliamentarians have called for a halt to oil and gas drilling in the Arctic Ocean until a pan-Arctic response system has been established to handle large spills (House of Commons 2012).

Exploitation of natural resources such as minerals and hydrocarbons remains largely a national issue, but it is one in which the global community is taking an interest. With the opening of new shipping routes and the exploration of oil, gas

and mineral deposits in the Arctic, non-Arctic countries are eager to gain a foothold in the region. China opened its first Arctic scientific research station in Ny-Ålesund, Svalbard, in 2004. Singapore, which has an extensive ship-building industry, has also expressed an interest in the region.

Increasing ship traffic will require attention to shipping lanes and pollution risks. UNCLOS sets out a legal framework for rights of passage and navigation on shipping. Other related issues include responsibilities for ensuring the structural safety of ships operating in the Arctic, search and rescue, security, crew training, hydrographic surveys, charting, and pollution prevention. The International Maritime Organization (IMO) is currently developing international requirements for the safety of ships navigating ice-filled water, known as the Polar Code.

Box 6: A fisheries boom?

The Arctic is already the base for large commercial fisheries, including salmon and walleye pollock in the Bering Sea and cod and haddock in the Barents Sea. Future decades may see a boom thanks to warmer waters nurturing growing stocks, as well as more open ocean in which to catch fish. One modelling study projects that, by 2055, fish catches at high latitudes, including in the Arctic, could increase by 30-70 per cent, while those in the tropics decrease by 40 per cent (Cheung et al. 2010).

A widely predicted northward shift in subarctic fish species, including Atlantic and Pacific cod, is now being detected (Meier et al. 2011). Six species have recently extended their ranges through the Bering Strait into the Beaufort Sea (Sigler et al. 2011). The number of voyages by fishing vessels in the Canadian Arctic increased seven-fold between 2005 and 2010.

Not all the effects will be beneficial for fishing. In the Bering Sea longer warm periods with less ice cover are expected to reduce walleye pollock stocks, while higher sea temperatures may increase winter mortality of juvenile sockeye salmon (Farley et al. 2011, Hunt et al. 2011).

Meanwhile, these movements can create international tensions. The northward migration of North Atlantic mackerel has caused disputes between Iceland and other countries. The movement of fish stocks can also be bad news for local fisheries. The village of Narsaq in southern Greenland once prospered due to catching and processing of local shrimps. But as local waters warmed, the



Fish stocks are moving towards polar regions due to the effects of climate change. This, coupled with the increased accessibility of Arctic areas due to melting sea ice, will further raise interest in future large-scale fisheries in the region. *Credit: Corey Arnold*

shrimps headed north, the fleet of eight vessels was reduced to one, the shrimp factory closed, and the village's population was halved (Hamilton et al. 2000).

Some northern communities, dependent on subsistence fisheries, could be crowded out by the arrival of commercial vessels. The currently fragmented fisheries management in the Arctic is not up to the task of either managing such issues or protecting stocks. As ecosystems change and economic opportunities are pursued, there is an urgent need to reassess fisheries management in the Arctic.

Management of fisheries and ecosystems

The management of Arctic fisheries is currently based on a patchwork of regional conventions, agreements and regimes. This is unsatisfactory now that melting ice is allowing passage, particularly as there is considerable uncertainty about how fish will respond to the ecosystem changes under way (**Box 6**). The United States has reacted to this uncertainty by placing a moratorium on all fishing in its Arctic Ocean waters until research is completed (Stram and Evans 2009, Pew Environment Group 2012). The Canadian government and the Inuvialuit, the Inuit of the Canadian Western Arctic, signed a formal agreement in 2011 to freeze expansion of fishing in the Canadian Beaufort Sea.

As ecosystems change, current approaches to the management of wildlife and conservation of habitats within countries will no longer be adequate. The risks to ecosystems are great because many changes may be sudden and unforeseen. The development of the Arctic Marine Biodiversity Monitoring Plan 2011 is a

Box 7: Ecosystem-based management of the marine environment

The importance of addressing multiple stressors to the marine environment in an integrated way has long been recognized. Ecosystem-based management is an approach that considers the health, productivity and resilience of the entire ecosystem. The Arctic Council follows this approach in several of its initiatives, including the Circumpolar Biodiversity Monitoring Programme (CBMP).

Marine spatial planning is an important tool to implement ecosystem-based management. Key features include consideration of multiple scales; a long-term perspective; recognition that humans are an integral part of ecosystems; an adaptive management perspective; and concern for sustaining ecosystem goods and services.

A successful example is the Barents Sea Management Plan, which provides a framework for managing the oil and gas industry, fishing and shipping (Olsen et al. 2007). The plan requires strict regulation of activities in ecologically valuable areas. To reduce conflict between fisheries and shipping, Norway has applied to move shipping lanes outside Norwegian territorial waters. Some areas may be restricted or closed to oil and gas exploration and exploitation in order to avoid future conflict. There are also plans to extend marine protected areas and seasonally close areas to protect fish reproduction.



The *Xue Long* or *Snow Dragon*, an icebreaker, became the first Chinese vessel to cross from the Pacific to the Atlantic via the Arctic. Less sea ice may open new trade routes and near-term opportunities for exploration of oil, gas and mineral deposits in the Arctic. Credit: Yong Wang, State Ocean Administration of China

welcome step (Gill et al. 2011). However, in many cases monitoring systems are not in place to detect changes at an early stage (Chapin et al. 2010, Vincent et al. 2011, Young 2012). Bringing together science and the traditional knowledge of indigenous and local communities to better monitor and understand ecosystem changes is vital (Huntington 2011). At the same time, monitoring and understanding are of little use without the ability to respond. Marine spatial planning is emerging as an important ecosystem management tool (**Box 7**). As many species migrate to the Arctic from other parts of the world, there may also need to be changes in the management of such species outside of the Arctic (Boere and Stroud 2006).

The way forward

The Arctic is no longer a world apart. It has resources of global interest far beyond its wildlife. But its fragile environment is one compelling reason why non-Arctic countries are becoming involved in discussing just how much and what form of global governance is needed in this region.

There are a series of urgent issues to be addressed, both to reduce the pace of change in the Arctic and to increase its resilience to that change. Some emerging issues are national and some can be addressed by the region collectively, while still others will require global input and sometimes global action.

Reducing greenhouse gas emissions remains the most important measure, as climate change dominates the current transformation of the Arctic environment. While action within the United



In 2009 Russia turned the Franz Josef Land archipelago into the Russian Arctic National Park. There are plans to introduce ecotourism. *Credit: Peter Prokosch*

Nations climate process is essential, there may be scope for agreements on curbing regional emissions of fast-acting but short-lived climate pollutants such as black carbon to complement global action to reduce emissions of CO₂ and other greenhouse gases.

The transformations occurring in the Arctic require the people who live there to find ways to adapt to inevitable climate change. Finding these ways will involve both national governments and local institutions. Adaptation and coping strategies could build on the 2010 Cancun Adaptation Framework on climate change. However, as in other parts of the world, the contribution of local and traditional knowledge is essential. Those living and working in the Arctic know the region's environment best, and so are eminently placed to observe changes and respond accordingly.

It is also vital that no steps are taken to "exploit" the new environmental state of the Arctic without first assessing how exploitation would, intentionally or unintentionally, affect ecosystems, the peoples of the North and the rest of the world. In view of the potential for major environmental damage, a precautionary approach to economic development needs to be carefully considered. Such an approach requires measures such as development moratoriums until full assessments have established risks to the environment and human systems, and until adequate management frameworks have been put in place. The moratoriums imposed by Canada and the United States on expansion of commercial fishing in the Beaufort Sea, pending assessment of sustainability and ecological and economic costs and benefits, could serve as models.

The challenges posed by climate change and, in turn, by social and economic development in the Arctic require a long-term vision and innovative policy responses. There is a need to assess options in areas such as maritime trade and shipping, tourism, commercial fisheries, and oil, gas and minerals development. Such assessments should explicitly include indigenous peoples and other stakeholders of the Arctic, as well as non-Arctic countries.

Arctic climate change will have major and irreversible impacts on the livelihoods and well-being of indigenous peoples and other Arctic communities. It will also have impacts on the rest of the planet. Policy dialogues could consider the need for new international policy regimes, using the precautionary approach adopted in, for example, the proposed Polar Code for ship operations.

The rapid pace of physical, chemical and biological change in the Arctic means that strengthened systems for monitoring and providing early warnings of the unexpected are essential. Additional environmental research is urgently needed in the following critical areas:

- The present and future climate impact in the Arctic of short-lived climate pollutants such as black carbon and methane, and the possibilities for taking immediate measures to curb their emissions in the Arctic and beyond.
- The mechanisms of changes to snow and ice, such as melting of the Greenland ice cap and loss of Arctic sea ice, and their implications for global sea level rise, regional shipping, coastal development and international trade.
- Present and future changes in the biosphere, and their consequences for fisheries, food webs, habitats and Arctic cultures.
- The use of traditional knowledge and direct observations by indigenous peoples to inform policy and management actions.

Effective governance is the key to sustainable development of the Arctic. The fate of its ice and snow, frozen land and open waters, along with its wildlife and peoples, crucially depends on how the world addresses climate change and the resulting changes in human activities. Building upon existing institutions and scientific expertise in the region, the Arctic could set an example of environmental governance for the rest of the world. While Arctic countries need to take the lead, inputs from non-Arctic countries are vital, as the rest of the world stands to lose – or gain – from Arctic change.

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