Global Linkages

A graphic look at the changing Arctic

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Change is clearly accelerating in the Arctic, and it has global implications for us all. We all have a stake in this future, but none more than the young people who are coming of age, living in the midst of this change.

FOREWORD

The Arctic in a new state

While this report was being prepared, heat records continued being shattered around the world. Last summer, new maximum temperatures were recorded in Norway, Canada, Japan and California. Fires raged in many countries and the haze from forest fires obscured the view of the melting glaciers of the magnificent Stikine mountains in British Columbia.

The Arctic Council's *Snow, Water, Ice and Permafrost in the Arctic* report succinctly summarizes the situation: "the Arctic's climate is shifting to a new state." The 2017 report says this shift could see the Arctic Ocean largely free of summer sea ice only two decades from now.

Change is clearly accelerating in the Arctic, and it has global implications for us all. We all have a stake in this future, but none more than the young people who are coming of age, living in the midst of this change.

The homes of the Inuit of the Alaskan island community of Shishmaref are being washed into the sea. As part of a photo project called *Portraits of Resilience*, young people from the village documented their struggle.

"Did you ever lose your home?" wrote Renee Kuzuguk, whose family had to move its house from one coast of Shishmaref to the other. On the other side of the world, her words are echoed by Siobhan Turner, a student from Fiji who worries that her community will eventually have to move to the mainland, threatening their way of life and culture.

These two stories from young people thousands of kilometres apart show that the devastating impact of a changing Arctic is being felt across the world.

The Arctic people have a saying: "what happens in the Arctic does not stay in the Arctic." To create awareness about the critical role the Arctic plays in sustaining all life on this planet, UN Environment and GRID-Arendal have produced a series of maps and graphics that illustrate the global consequences of change in this region. By undertaking a visual depiction of the changing Arctic, we hope to alert policymakers to the effects of human activity.

We have the science, we know the facts. It is time to make the right decisions for a sustainable future of the Arctic and the world as a whole.

Joyce Msuya
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The Arctic: Not deserted, quite connected

In many people's imaginations, the Arctic is an isolated region, disconnected from global concerns. Images of polar bears, vast expanses of ice and frozen tundra come to mind more easily than urban centres and villages where people use the Internet to connect with the rest of the world. From outside, the Arctic is seen as distant and out of mind, a vast homogeneous region. But if you look at it from a different perspective, you will see it is very much connected to the rest of the world.

The Arctic is home to just over 4 million people. Around 10 per cent of the population are indigenous, comprising dozens of different cultures and languages (Larsen and Fondahl, 2015). About 70 per cent of the Arctic population lives in the Russian Federation (Glomsrød et al., 2017). Except for Greenland and northern Canada, Indigenous Peoples are a minority. Nevertheless, they have survived and thrived everywhere in the Arctic for millennia. Throughout the region, people live in scattered communities of different sizes, from Murmansk in Russia, with a population of over 300,000, to villages like Paulatuk in the western Canadian Arctic, with just under 300 people.

Like all regional economies, the Arctic economy serves two different markets: diamonds, iron, gold, zinc, oil and natural gas, fish and timber are produced for the international market, while the local economy is largely based on the public sector, which provides jobs and services to local residents (Larsen and Fondahl, 2015). In some areas, the local economy includes traditional activities such as fishing, hunting, herding and gathering, which provide local consumption and support vital cultural traditions of Arctic peoples (IPCC 2014; Larsen and Fondahl, 2015). The strength of the connections between the international and local economies varies across the north (Larsen and Fondahl, 2015).

The diversity of activities also means people in the Arctic are experiencing the socioeconomic effects of rapid change differently. This means the responses to the challenges facing the region outlined in this report need to be tailored to particular circumstances: in the Arctic, one size definitely does not fit all. The third Economy of the North report (Glomsrød et al., 2017) found major differences in the socioeconomic status of people living in the Arctic: inequality is highest in the Russian Arctic, high in North America and lower in the Nordic countries.

Compared to 2006, the proportion of women and young people in North America is falling, while it is rising in Russia. In the Nordic Arctic, there have been both increases and declines in the proportion of women, with a fall in young people (Glomsrød et al., 2017). Still, many Arctic residents are relatively young and looking for work. This search means that they often have to leave the region where they grew up. Supporting the livelihoods of those who remain in the north and creating conditions for sustainable development is a long-standing challenge. The trade-off between supplying global markets and building sustainable societies in the Arctic is similar to many developing regions around the world.

Nearly 15 years ago, the Arctic Council published the Arctic Climate Impact Assessment (ACIA, 2004). The report raised the alarm about the dramatic effects of climate change on the region's ecosystems and those who depend on them. It also highlighted the implications of a changing Arctic for the global climate system. The ACIA drew attention to a part of the world that for many had always seemed remote and with little bearing on the lives of the billions of people elsewhere. Since then, however, an enormous amount of research has confirmed the key findings of the ACIA, namely that climate change would cause changes in vegetation and animal ranges, as well as

Arctic population and development

Population distribution:
composition by main regions

100 %
50 %
0 %
50 %
100 %

Indigenous

Non-indigenous

Population centres

300,000 · 170,000 · 60,000 · 30,000 · 3,000 and less

Oil and gas fields

Large mines

Main transport routes for raw materials

Potential routes for raw materials

A.O. : Autonomous okrug

Indigenous Peoples

Permanent participants of the Arctic Council

- Russian Association of Indigenous Peoples of the North (RAIPON)
- Sámi Council
- Inuit Circumpolar Council
- Gwich'in Council International
- Aleut International Association
- Arctic Athabaskan Council

coastal erosion and rising sea levels. Consequently, it would impact the lives and cultures of Arctic peoples throughout the region.

The Fairbanks Declaration, signed at the Arctic Council's 2017 Ministerial Meeting, recognized "that activities taking place outside the Arctic region, including activities occurring in Arctic States, are the main contributors to climate change effects and pollution in the Arctic" (Arctic Council, 2017). The Declaration also recognized climate change as the most serious threat to Arctic biodiversity.

While greenhouse gas (GHG) emissions and pollution from global activities mainly originate outside the region, they are causing wide-ranging changes and impacts on the Arctic environment. These changes will, in turn, affect the health of the planet as a whole. This means that people outside the Arctic share a common stake with people living in the Arctic.

The Arctic Council has taken the lead in communicating the effects of environmental change in the region and its implications for the rest of the planet. Using new graphics, this report builds on the Council's work to sharpen the focus on a region at the forefront of environmental change. In doing so, it highlights a common global challenge and the need for solutions. Much of the data behind this report comes from the Arctic Council and the numerous assessments prepared by its working groups on climate, pollution, biodiversity, health, shipping and other matters.[1]

Produced by hundreds of authors, the sixth Global Environment Outlook (GEO-6) is the latest in a series of UN Environment flagship assessments examining the state of the environment, assessing the effectiveness of policy responses and looking at possible pathways to achieve internationally agreed environmental goals. Using many of the same sources, its main messages about the Arctic and the rapid changes under way, highlight the links between the Arctic and the rest of the world explored in this report.

Finally, meeting the challenges faced by the Arctic is part of a global effort to achieve the goals of the 2030 Agenda for Sustainable Development, adopted by the United Nations in 2015. The pursuit of these common goals is yet another example of the inextricable links between the Arctic and the rest of the world.

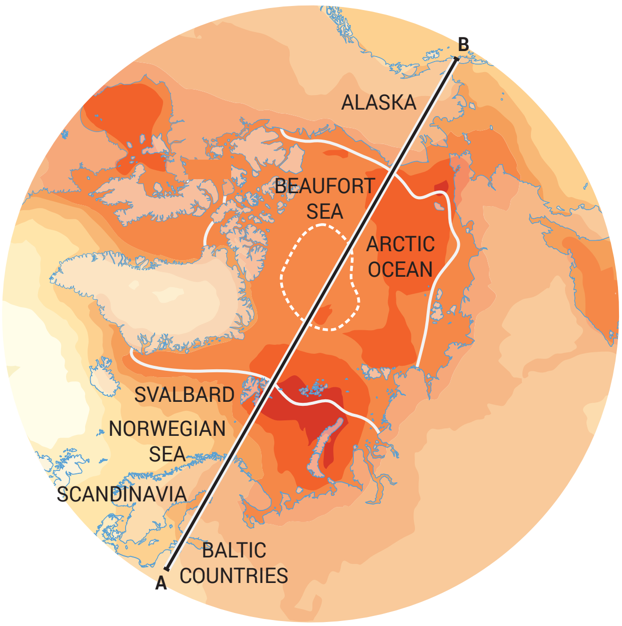
1. Arctic Contaminants Action Programme (ACAP), Arctic Monitoring and Assessment Programme (AMAP), Conservation of Arctic Flora and Fauna (CAFF), Emergency Prevention, Preparedness and Response (EPPR), Protection of Arctic Marine Environment (PAME), Sustainable Development Working Group (SDWG).

Climate change

Global warming from anthropogenic emissions of carbon dioxide (CO_2) and other GHGs continues. While the effects of a warming climate on terrestrial and marine ecosystems, health and livelihoods are extensive, they are less obvious for now, especially to those not directly and immediately affected. Yet, every year, there are more noticeable signs of a changing climate, such as the increased number of intense hurricanes or the heat waves and wildfires in the northern hemisphere in 2018 (Samenow, 2018; Schiermeier, 2018). Such extreme weather is probably the main immediate consequence of climate change on societies worldwide. Nevertheless, the effects of change in the Arctic have long been felt by people living in the region.

Representative Concentration Pathways

The Intergovernmental Panel on Climate Change (IPCC) uses four Representative Concentration Pathways (RCPs), each associated with the expected path or direction in the change in greenhouse gas concentrations based on a number of socioeconomic and other variables. RCP2.6 is the strictest mitigation scenario, followed by two intermediate scenarios, RCP4.5 and RCP6.0, and one very high GHG emission scenario, RCP8.5 (IPCC, 2014).



Arctic climate change

Projected changes in near-surface temperature (°C) along the 30° longitude east for the 2080s relative to 1986-2005 under the IPCC RCP4.5 scenario

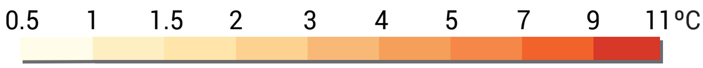
... during the cold season (December–February)

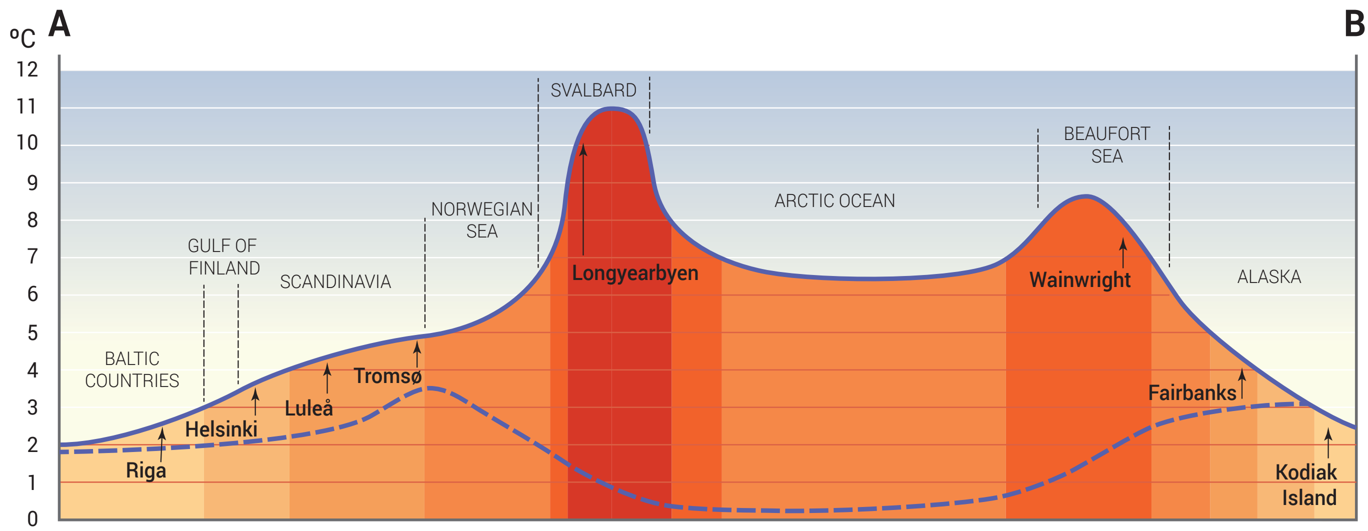
... during the warm season (July–August)

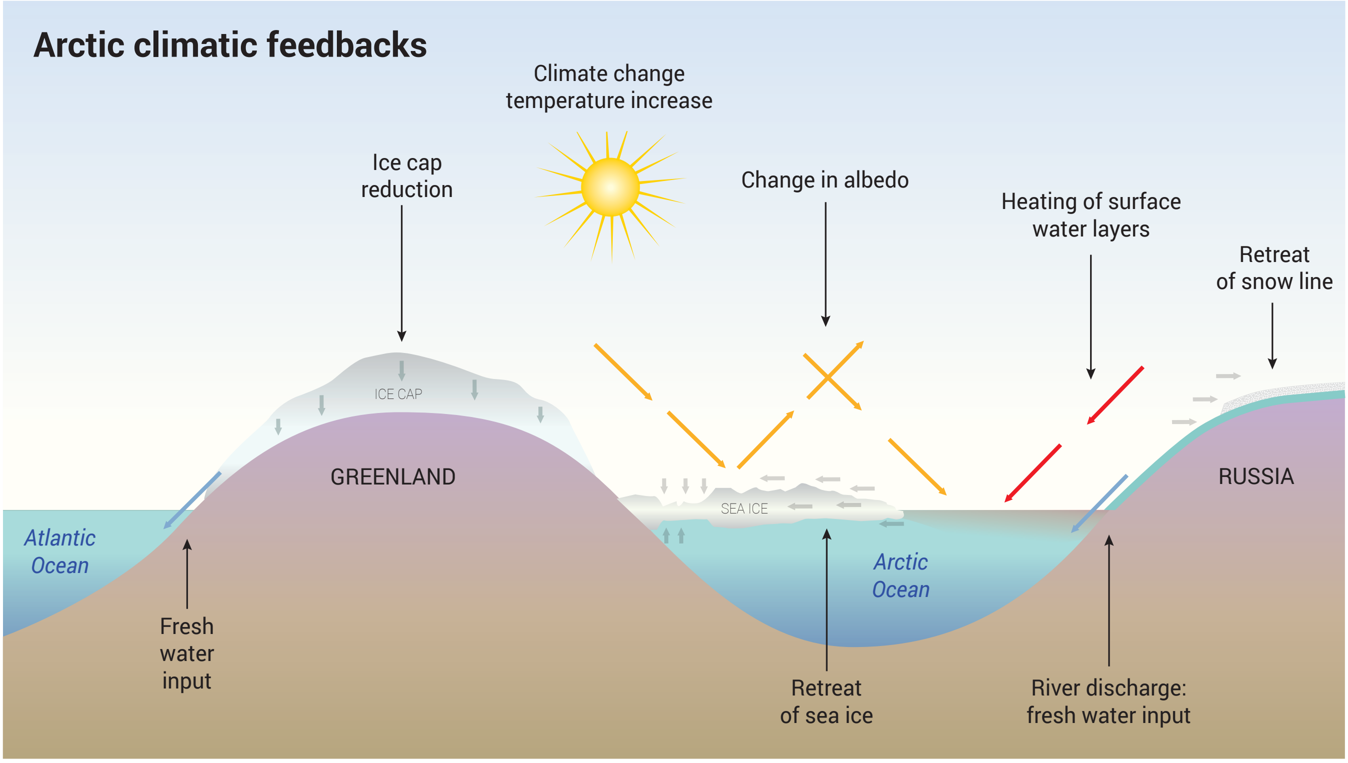
Sea ice extent

In September 1981

Projection for autumn 2080–2100







Some recent Arctic winters (2016 and 2018) showed extreme warm temperature anomalies as well as record lows in the winter sea ice extent (2015 to 2018) (NSIDC, 2019; Overland et al., in press). Indeed, under a medium- or high-emission scenario, projected air temperature changes for the Arctic will follow a winter warming trend more than double the rate for the northern hemisphere (AMAP, 2017a; IPCC, 2018).

To meet the Paris Agreement target of keeping global average temperature increase well below 2°C and particularly to pursue efforts to limit it to 1.5°C above pre-industrial levels, countries need to dramatically step up their commitments to reduce GHG emissions (IPCC, 2018; UNEP, 2018). Continuing global emissions at rates of a medium-emission scenario (RCP4.5) projects global warming of 2.4 ± 0.5°C above pre-industrial levels by 2100 (Collins et al., 2013 (AR5)). At this rate of emissions, winter temperatures over the Arctic Ocean would increase 3 to 5°C by mid-century and 5 to 9°C by late century (relative to 1986–2005 levels) (AMAP, 2017a). Due to past, present and near-future greenhouse gas emissions and heat stored in the ocean, Arctic winter temperatures will follow a similar pathway under all emission scenarios until mid-century; only afterwards, projections start to substantially diverge (AMAP, 2017a).

Increasing temperatures mean the Arctic will be a very different place in decades to come. This will not only have regional and local implications but will affect ocean circulation, sea levels and climate and weather patterns worldwide, with profound consequences for ecosystems and human populations. The AMAP (2017a) report emphasizes the urgency of adopting adaptation and mitigation actions. These must run in parallel, including and respecting indigenous knowledge and local knowledge, together with socioeconomic drivers.

Arctic Amplification

"Arctic Amplification" is a phenomenon that causes higher temperatures near the poles compared to the planetary average because of a combination of feedback processes. For example, when sea ice melts in the summer, it opens up dark areas of water that absorb more heat from the sun, which in turn melts more ice. This "feedback loop" also includes the effects of melting snow and thawing permafrost. Arctic Amplification is most pronounced in winter and strongest in areas with large losses of sea ice during the summer (Dai et al., 2019).

The need for stronger and more urgent efforts to build resilience and limit climate-related hazards and natural disasters have resulted in the adoption of the Paris Agreement in 2015 and a Sustainable Development Goal (SDG 13) exclusively focused on climate change.

While climate mitigation and adaptation are daunting tasks, successful action will have benefits for people in the Arctic and the rest of the world. As many GHGs are also air pollutants that adversely affect human health and ecosystems, the positive impact of lowering emissions will be twofold: first directly on health and second on climate change.

As this publication was being prepared, the Intergovernmental Panel on Climate Change (IPCC) issued its special report on the implications of global warming of 1.5°C (IPCC, 2018). The picture it paints is compelling and its main message – that the world has very little time in which to act – is urgent.

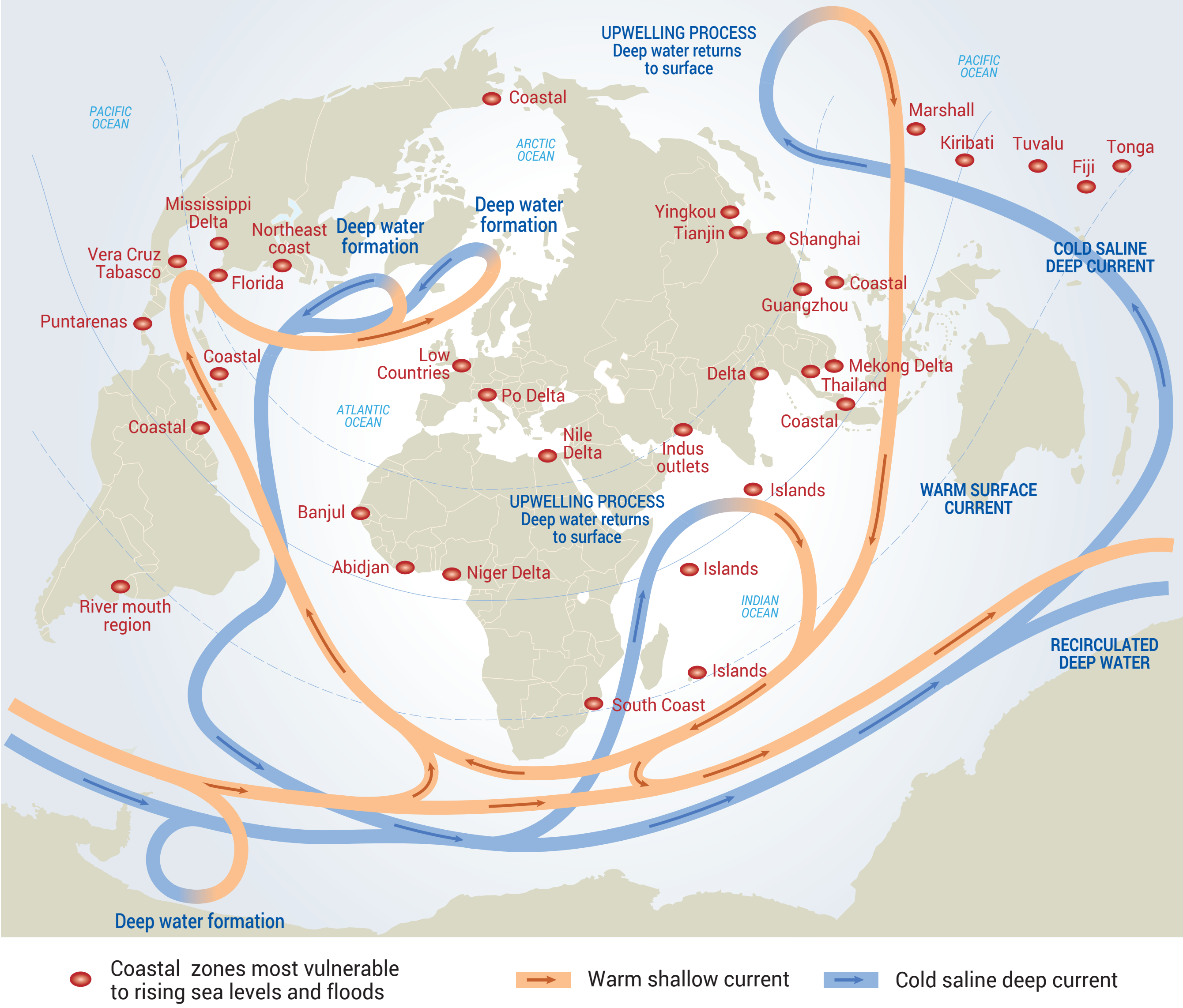
Cryosphere: The melting continues

Ice, snow and permafrost – the elements that form the cryosphere – are highly sensitive to heat. Alterations to the cryosphere caused by anthropogenic climate change will therefore alter the Arctic's physical, chemical and biological terrestrial and marine systems, with complex consequences inside and outside the region (AMAP, 2017a).

Based on satellite monitoring from 1979 to the present, Arctic sea ice area has declined by around 40 per cent (Parkinson and DiGirolamo, 2016). There is a clear link between CO_2 emissions and the extent of summer sea ice. Climate models predict that at the current rate of rising atmospheric CO_2 concentration, the Arctic will be ice-free in summer by as early as the 2030s (AMAP, 2017a), although there is considerable uncertainty between model estimates (Jahn et al., 2016). Given the energy already released into the environment in the form of carbon, the IPCC estimates we will pass the threshold of a 1.5°C increase in 12 years (IPCC, 2018). This temperature is considered a "guardrail" beyond which the effects of climate change will become increasingly severe and difficult to adapt to.

The snow season is becoming shorter and permafrost is thawing. Between 1982 and 2011, the Eurasian Arctic region had 12.6 fewer snow-covered days per year while Arctic North America had 6.2 fewer snow-covered days (Bokhorst et al., 2016). These changes affect snow properties and run-off, with implications for the ecosystems and people who inhabit and use these areas (Bokhorst et al., 2016). Some of the coldest permafrost of the Arctic and High Arctic has warmed by more than 0.5°C since 2007–2009 (AMAP, 2017a). Warmer permafrost grounds such as in Scandinavia have shown smaller temperature increases. These regional differences are partly linked to differences in air temperature (AMAP, 2017a). Thawing permafrost leads to unstable mountain slopes, coastal erosion and threatens human settlements and infrastructure (Hovelsrud, et al., 2011).

Sea level rise and ocean currents



The melting cryosphere

Changes in sea ice extent

- Median ice edge in autumn for the period 1981-2010
- Sea ice extent in September 2018
- Sea ice extent in September 1981
- Retreat of sea ice
- Freshwater input

Changes in snow cover

- Area where seasonal snow cover was 2–3 weeks shorter in the period 2005–2015 compared to 1980–1990

Changes in glacier extent

- Main glaciers and Greenland ice sheet
- Retreat of glaciers
- Freshwater input

Discharge of main rivers at mouth

590 km^3/y 300 km^3/y 120 km^3/y

- Main marine transport routes during summer

Further warming may also surpass tipping points for the stability of the Greenland ice sheet (AMAP, 2017a). The melting of ice on Greenland, Antarctica and other glaciers and ice caps each account for one-third of the land-based contribution to global sea level rise (Bamber et al., 2018). This will affect coastal communities and low-lying islands and ecosystems throughout the world (Noël et al., 2017), causing coastal flooding, erosion, damage to buildings and infrastructure, changes in ecosystems and seawater contamination of sources of drinking water.

Less Arctic sea ice means a prolonged period of open water that may in turn result in the expansion of economic activities, such as fisheries, oil and gas exploration and mining, in addition to more regular use of polar shipping routes. Furthermore, the freshening – and warming – of the Arctic Ocean from melting glaciers, sea ice and increased river flows affects ocean circulation by decreasing the formation of cold, dense, deep water, which may in turn weaken the Gulf Stream in the Atlantic Ocean, with further implications for global weather systems.

Climate induced changes to habitats and wildlife are increasing food insecurity for many Arctic peoples. Other effects include worsening travel conditions due to thawing of tundra and less time to use ice roads on frozen rivers in spring and autumn due to the lack of thick ice. This limits access to hunting and reindeer herding areas and affects the transportation of food from southern regions to northern communities. In addition to the threats they pose to food sources, declines in some species will also have cultural impacts. Within the Arctic, the integrity of ecosystems and the sustainability of communities are being challenged, affecting people's lives and livelihoods (AMAP, 2018).

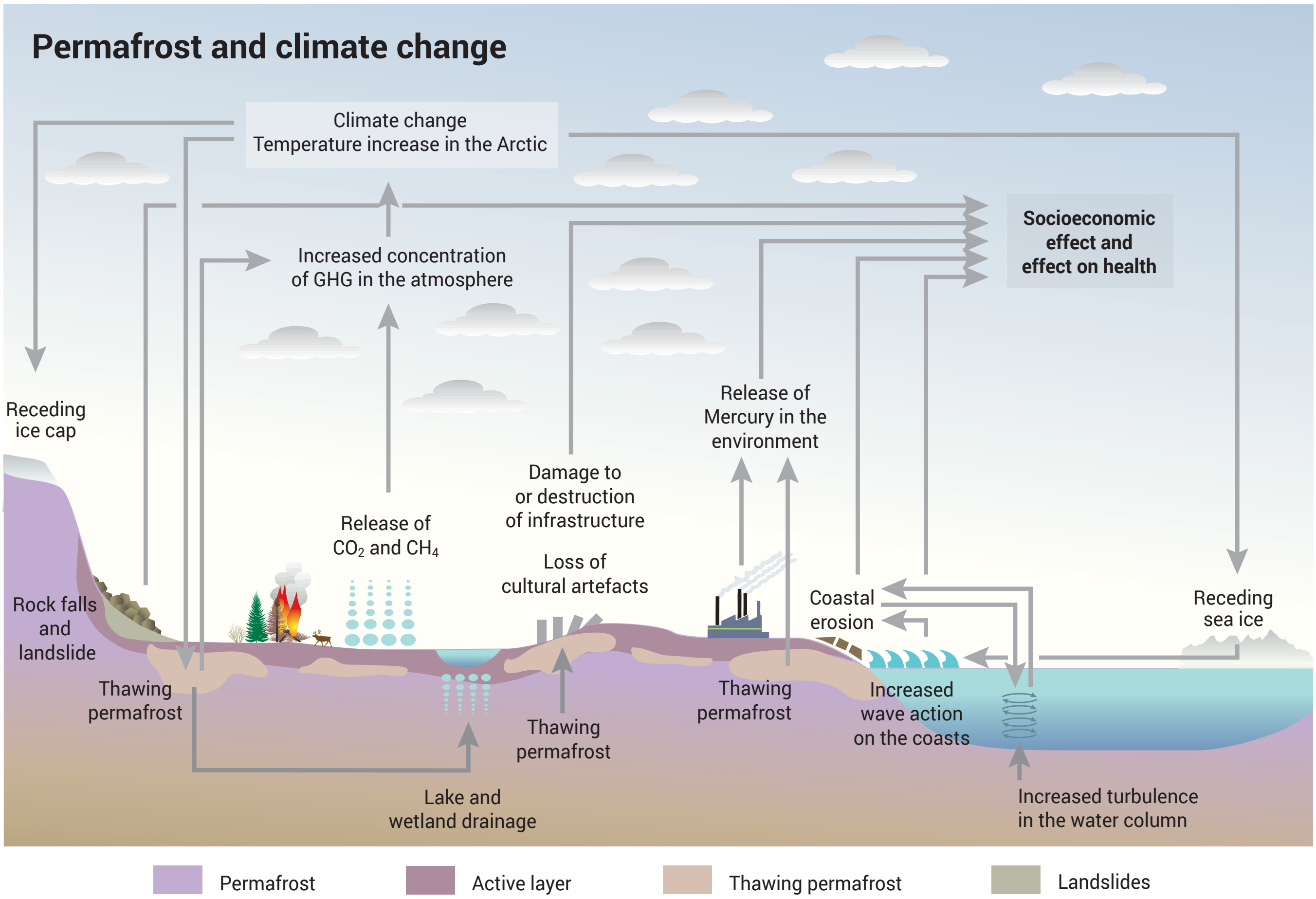
Permafrost thaw: A sleeping giant awakes

Thawing permafrost is an important part of the changing cryosphere which scientists have been documenting – and many communities have been living with – for years. Permafrost is ground that remains frozen for two or more years and occurs in high latitudes and altitudes, as well as under Arctic continental shelves. It occupies approximately 22 per cent of the Earth's surface (NSIDC, 2018). Across the world, these frozen soils hold an estimated 1,500 billion tons of carbon – double the amount of carbon currently in the atmosphere (Schuur et al., 2008) – and half the world's soil carbon (AMAP, 2017a).

This carbon reservoir is stable as long as it stays frozen. However, as the climate changes and temperatures increase, these soils start to release their stored carbon. While the amount of GHG emissions attributed to thawing permafrost has been relatively low in recent decades, increased thawing is expected to make a significant contribution to CO_2 and methane emissions. More GHGs entering the atmosphere will lead to further warming, which in turn will lead to even more thawing, in a process known as "positive feedback". Results could include more frequent forest and tundra fires and terrestrial and aquatic habitat loss. New evidence suggests that permafrost is thawing much faster than previously thought, with consequences not just for Arctic peoples and ecosystems, but for the planet as a whole because of feedback loops. The local effects of thawing permafrost in the Arctic range from cracked walls and uneven roads to collapsing houses and vanishing heritage (Hollesen et al., 2018). One study estimates that thawing permafrost will pose a threat to almost 4 million people and 70 per cent of current Arctic infrastructure by 2050 (Hjort et al., 2018).

The current area of permafrost in the northern hemisphere is approximately 15 million km^2. This is projected to decrease to 12 million km^2 by 2040, followed by a rapid decrease to 5 to 8 million km^2 by 2080 (AMAP, 2017a). Studies show that near-surface permafrost continues to warm and the active layer (the top layer of soil that thaws in the summer and freezes again in the fall) is deepening in most areas where permafrost is monitored (AMAP, 2017a). This change allows microbes to consume buried organic matter and release CO_2 and methane. The release of large quantities of this highly potent GHG, is particularly concerning. However, while this can accelerate climate change, the magnitude and timing of these emissions and their subsequent impact is still largely unknown (AMAP, 2015a; Schuur et al., 2015).

Studies show that when permafrost thaws below thermokarst lakes (lakes formed in the depressions left by thawing permafrost) the results may be even more severe than the thawing of near-surface permafrost. The water at the surface speeds up the thawing process of the old carbon below and the gases rise quickly through the lake into the atmosphere, effectively "flash thawing" the permafrost below (Anthony et al., 2018; Bartels, 2018). This deeper, abrupt thawing has yet to be included in current climate change models.



Thawing permafrost

Present permafrost (percentage of the surface)

- Continuous (Between 90 and 100%)
- Discontinuous (Between 50% and 90%)
- Sporadic (Between 10% and 50%)
- Isolated patches (Between 1% and 10%)
- Area where subsea permafrost is known or likely to occur
- Thermokarst

Projected permafrost extent in 2100 according to Representative Concentration Pathway (RCP) scenarios from the IPCC Fifth Assessment Report

- RCP 4.5
- RCP 8.5
- Greenland ice sheet and glaciers
- Main population centres

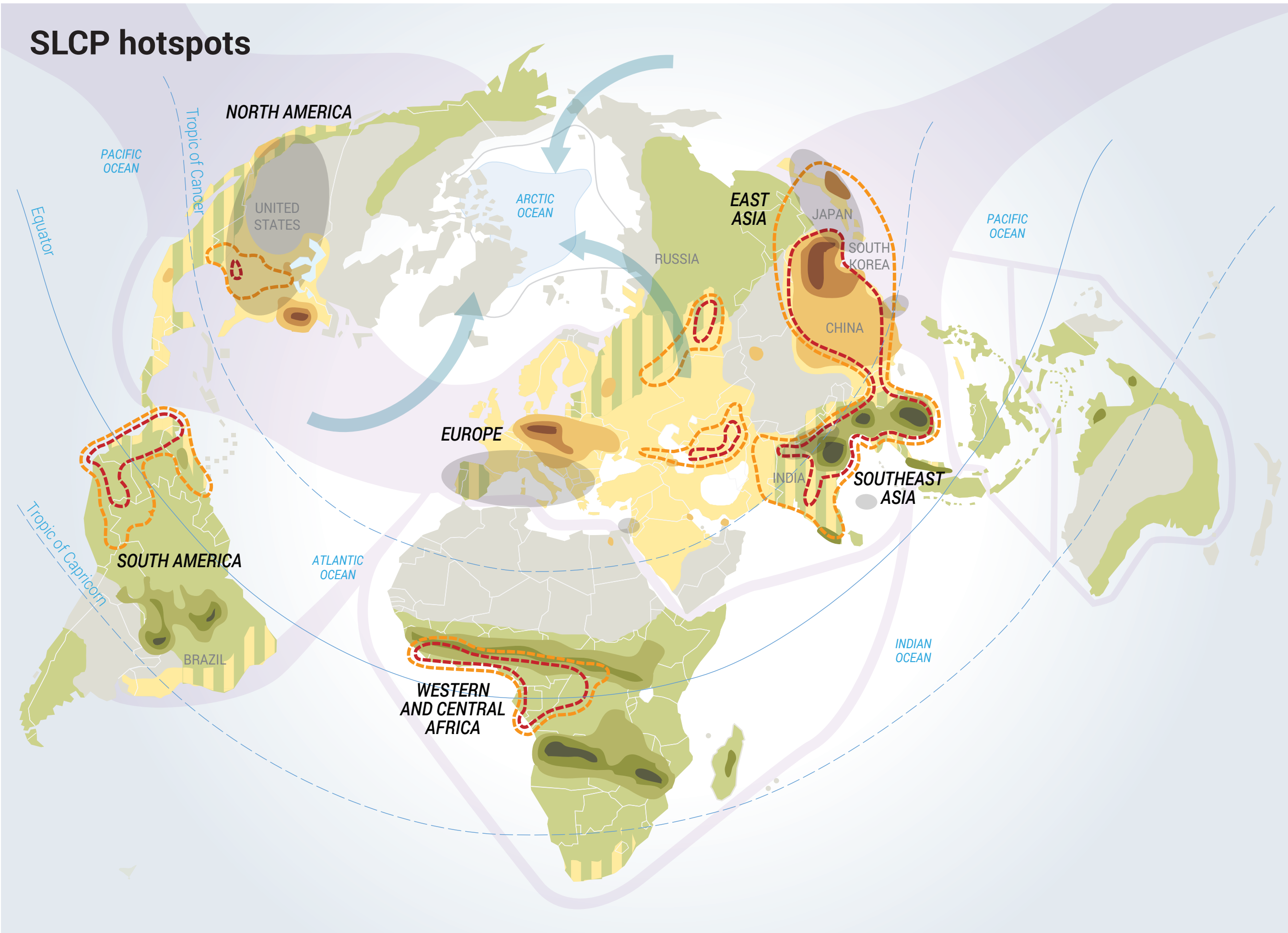
The thawing trend appears irreversible. While compliance with the existing Paris Agreement commitments would stabilize permafrost losses, the extent would still be 45 per cent below current values (AMAP, 2017a). Under a high emissions scenario, stable permafrost will likely only remain in the Canadian Arctic Archipelago, the Russian Arctic coast and the east Siberian uplands (AMAP, 2017a).

Short-lived climate pollutants: It's not just about CO_2

Short-Lived Climate Pollutants (SLCPs), also known as Short-Lived Climate Forcers (SLCFs), are gases and particles that contribute to atmospheric warming and global climate change. In addition to their warming effect, many SLCPs also pose a threat to human health and ecosystems around the globe in the form of air pollution. SLCPs are mostly produced outside the Arctic but are transported to the region through the atmosphere. Despite gaps in knowledge, current research and models indicate with high confidence that methane, tropospheric ozone and black carbon all play a significant role in Arctic climate change. Their influence is twofold: first, direct warming in the Arctic from local emissions and the airborne transport of SLCPs to the Arctic; and, second, an overall increase in global temperatures, which indirectly contributes to warming in the Arctic (AMAP, 2015c).

While CO_2 can remain in the atmosphere for centuries, SLCPs are classed as short-lived because they last from a few days to a decade. Methane persists for around nine years, is about 30 times more potent as a GHG than CO_2 and its effect on increased temperatures in the Arctic region is twice the global average (AMAP, 2015a). Methane is also a key component in the formation of tropospheric ozone, which is not emitted directly but formed through a reaction involving precursor gases and sunlight. Tropospheric ozone is likely to have contributed to direct warming in the Arctic (AMAP, 2015b). Black carbon from the burning of fossil and biogenic fuels only remains airborne for short periods, which means emission sources close to the Arctic have the greatest potential impact. When deposited on snow and ice black carbon can lower the albedo, the amount of

SLCP hotspots



Black Carbon emissions, kg/km² per year (average 2005-2015)

From industrial souces
- 0.0 to 0.3
- 0.3 to 0.5
- 0.5 to 1
- 1 to 4

From biomass burning
- 0.0 to 0.3
- 0.3 to 0.5
- 0.5 to 1
- 1 to 4

Changes in sea ice extent
- Sea ice extent 2018 in September
- Sea ice extent in September 1981
- Major polarward air transport routes from lower latitudes
- Main global shipping routes, a source for Black Carbon

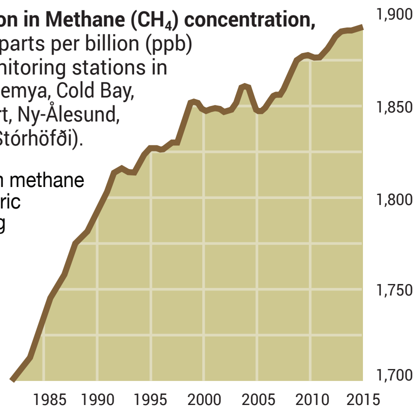
Methane concentration in the atmosphere in ppb, average 2005-2010
- 1790 - 1800 ppb
- 1800 - 1825 ppb

Ozone concentration in the atmosphere in ppb, average 2010-2014
- 40 to 65 ppb

Short-lived climate pollutants

Mean evolution in Methane (CH_4) concentration, expressed in parts per billion (ppb) for seven monitoring stations in the Arctic (Shemya, Cold Bay, Utqiagvik, Alert, Ny-Ålesund, Summit, and Stórhöfði).

Long-term methane atmospheric monitoring sites



Shipping emissions in 2015 (NO_x, CO_2, SO_2 and $PM_{2.5}$): average measured concentration per cells of 100 km² in tonnes

- More than 1
- 0.1 to 1
- 0.01 to 0.1
- Less than 0.01
- No emissions or no data

Main poleward transport routes from lower latitudes

Black Carbon emissions in 2015

Residential emissions (tonnes per year)

- 0.05 to 5
- 0.01 to 0.05

Flaring emissions (tonnes per year)

- 0.05 to 5
- 0.01 to 0.05

energy reflected back into space, and increase the absorption of sunlight, leading to accelerated melting. This in turn uncovers darker land and water surfaces that are more heat absorbent and thus contributes to a cycle of continued melting.

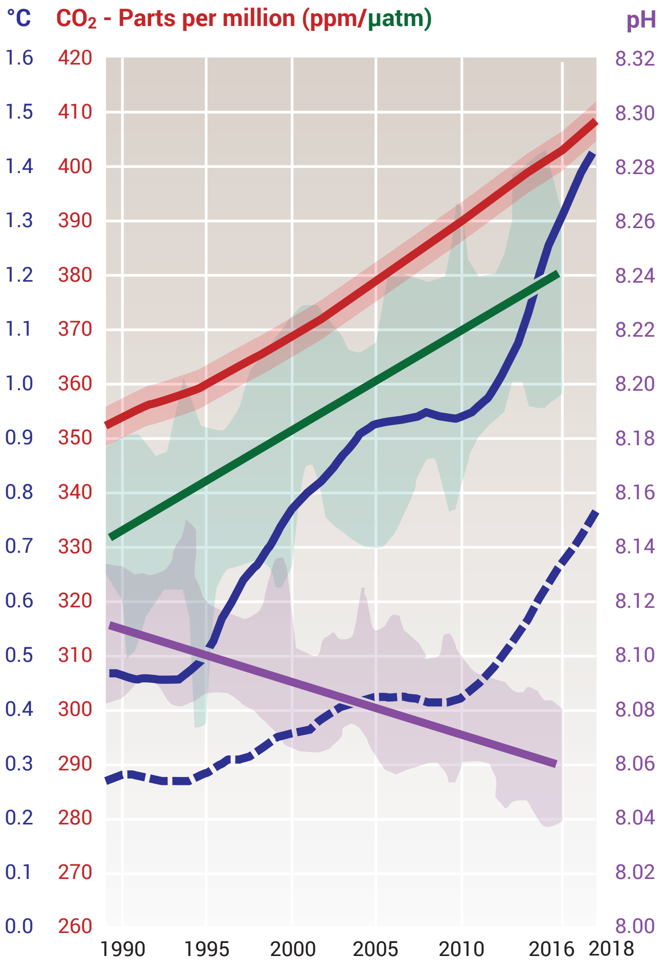
In 2017, the Arctic Council approved the shared goal of reducing black carbon emissions by 25 to 33 per cent from the 2013 levels of member countries by 2025. The Council's SCLP task force identified transport, domestic heating and burning from agriculture, forestry and wildfires as the main sources of black carbon in the region (Arctic Council, 2011). Another example of regional action is the Arctic Council's Arctic Contaminants Action Programme (ACAP) and its Black Carbon Case Studies Platform, developed "to showcase mitigation projects or policies relevant to the Arctic." The Platform is a repository of case studies produced by ACAP project partners showing how existing technologies can reduce black carbon emissions (ACAP, 2014).

The short lifetime of SLCPs provides an opportunity for rapid mitigation benefits that can slow the rate of warming through the implementation of instant measures. However, Arctic states are only responsible for 20 per cent of total anthropogenic emissions of methane and 10 per cent of total anthropogenic emissions of black carbon (AMAP, 2015b) and a significant proportion of Arctic warming can be attributed to SLCP emissions from outside the Arctic. This highlights the urgent need for global action to reduce SLCPs to compliment regional efforts to reduce emissions. One example is the Climate and Clean Air Coalition (CCAC), a voluntary partnership of more than 120 state and non-state partners working to raise awareness and reduce emissions across multiple sectors (UN Environment and CCAC, 2014).

Ocean acidification: It's all about CO_2

The world's oceans are becoming more acidic (or to be precise, less alkaline) because of CO_2 emissions from human activity. The more CO_2 is emitted into the atmosphere, the more the oceans absorb and the more "acidic" they become, i.e. the pH value of seawater is declining. The increase in ocean CO_2 has caused average ocean surface acidity to increase by 30 per cent since the beginning of the industrial revolution (AMAP, 2013; Doney et al., 2009). Lower pH levels can affect life in the ocean: for example, sea creatures like corals, molluscs, sea urchins and plankton build their shells and skeletons from aragonite, a carbonate mineral. This mineral becomes less available when pH levels of seawater fall, meaning these creatures need more energy to build their shells (Comeau et al., 2009; O'Donnell et al., 2008; Sato-Okoshi et al., 2010).

Trends in temperature, CO_2 and pH



Atmospheric CO_2 concentration (ppm) and annual variability (Mauna Loa, Hawaii)

Seawater partial pressure of CO_2 (µatm) and annual variability (Aloha, Hawaii)

Seawater pH and annual variability (Aloha, Hawaii)

Temperature anomalies relative to the mean for the period 1880-2018

Land area — Sea area (global)

There are two main reasons why the Arctic marine environment and its ecosystems are particularly vulnerable to ocean acidification: firstly, cold water can hold more dissolved CO_2 than warm water; secondly, fresh water is less resistant to changes in acidity than saltwater (known as "buffering capacity"). The increased fresh water input from rivers and melting ice is thus making the Arctic Ocean more susceptible. Therefore, ocean acidification is advancing primarily in polar areas.

The reduction of seasonal sea ice cover is also causing larger areas of the ocean surface to be exposed to and absorb CO_2 from the atmosphere for longer periods (AMAP, 2013). More recently, the influence of other factors, such as the inflow of more acidic waters from the North Pacific and the thaw of terrestrial and underwater permafrost has been highlighted (Anderson et al., 2017; Bellerby, 2017; Semiletov et al., 2016). When permafrost thaws, it contributes substantially to the organic matter load of surface fresh water delivered to the ocean, which in turn contributes to acidification through decomposition. The release of methane by thawing subsea permafrost also contributes substantially to acidification (Bellerby, 2017; Biastoch et al., 2011).

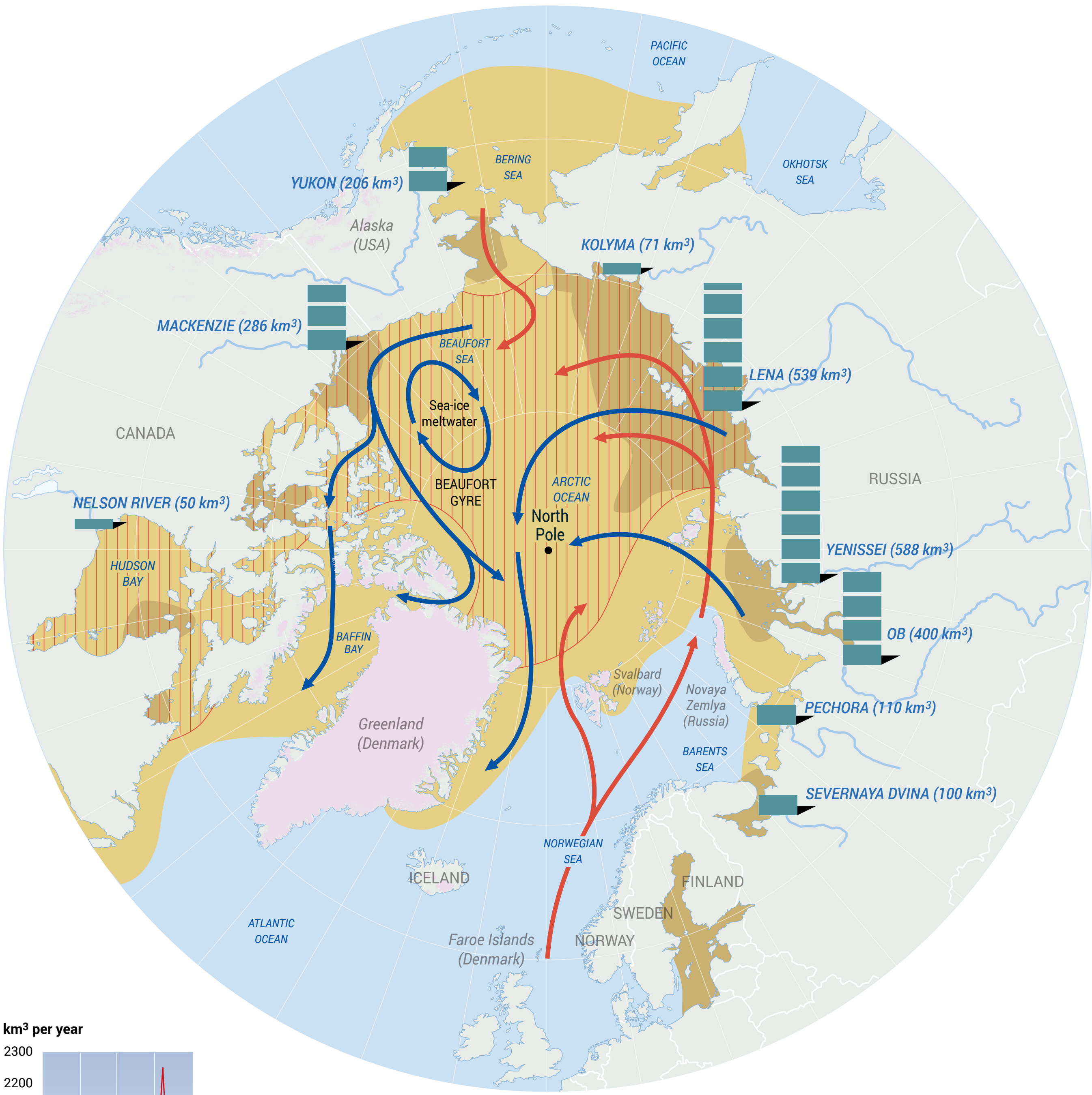
The complex set of processes in Arctic waters means that acidification and the carbonate saturation state is highly seasonal and geographical. The East Siberian Sea and shelf have been identified as areas of particular concern, where extremely low levels of aragonite, known as "aragonite undersaturation", have been observed (Semiletov et al., 2016).

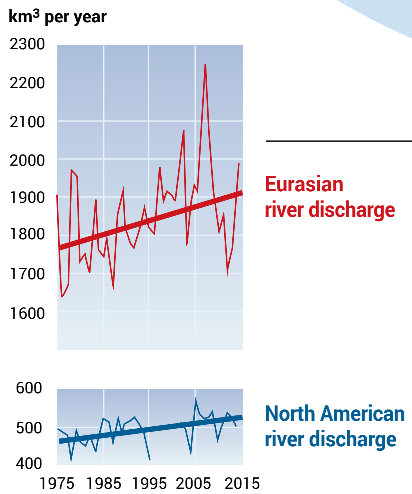
Future projections suggest continuing changes in ocean chemistry over the coming decades. By the late twenty-first century (2066–2085) all Arctic surface waters, with the exception of the Norwegian Sea and the Barents Sea, are projected to reach aragonite undersaturation, largely due to increased fresh water input from melting sea ice and the expected increase in precipitation and freshwater run-off (Steiner et al., 2014).

However, while global climate change is driving Arctic Ocean acidification, the impact is not limited to the Arctic. The connections between the Arctic Ocean and the North Atlantic lead to the spread of the corrosive impacts of aragonite-undersaturated water from the Arctic into neighbouring regions (Anderson et al., 2017).

Research on the Arctic and elsewhere indicates that ocean acidification has the potential to drive changes in the Arctic marine environment from the organism to the ecosystem level, including direct impacts on individual species and groups and indirect effects through trophic interactions (AMAP, 2013). Despite the varying responses of organisms, with some positively influenced and others more adversely affected, current research suggests that future ocean acidification is likely to drive changes in Arctic organisms and ecosystems on a scale that will pose risks to fisheries and other ecosystem services in the region, affecting the associated human societies (AMAP, 2018a).

Ocean acidification





Aragonite undersaturated sea area ($CaCO_3$)
according to the RCP8.5 scenario (MPI-ESM-LR) of the IPCC

- Estimate for the period 1986-2005
- Projection for the period 2066-2085

Sea water acidity estimate (pH)

- Area where the pH is expected to significantly decrease between the period 1986-2005 and 2066-2085

Main deep seawater currents

- Warm
- Cold

River discharge

- One rectangle represents 100 km³/y

- Glaciers and Greenland ice sheet

Despite a growing sense of urgency and increasing scientific interest, public awareness of ocean acidification is generally low (Mossler et al., 2017). The risk that ocean acidification will affect marine ecosystems is ranked with high confidence in the IPCC Fifth Assessment Report (IPCC, 2014). However, it is not recognized by the Paris Agreement on climate change (United Nations, 2015a).

Pollution prevention

Pollution takes many forms, including chemical substances, sewage, wastewater and run-off, litter and different types of energy (light, heat and noise). UN Environment (2017) identifies seven main sources of pollution: food production and harvest, energy production, industry, manufacturing, the service sector, transport and improper management of waste.

While the biggest impact of pollution on people and environments is often near their source, other pollutants are transported over long distances by air, rivers and ocean currents. The geographical characteristics and the cold climate of the Arctic mean that the region functions as a sink for contaminants from around the globe and that many pollutants remain in the Arctic for long periods (AMAP, 2009). These pollutants are present in the air, water, snow, ice, soil and living organisms. Some can even accumulate throughout the food chain, posing a serious threat to the health of humans and animals.

The issue of pollution is complex. The harmful effects of many pollutants and their breakdown products and the impacts of multiple stressors on local communities and human and environmental health are widely recognized (AMAP, 2015d; AMAP, 2017b; AMAP, 2018b). Climate change may also affect the release of certain pollutants: more frequent forest fires, for example, will increase air pollution. In addition, climate change may modify the current routes by which pollution is transported to the Arctic, which could alter the degree of human exposure to contaminants (AMAP, 2015d).

Pollution is not a new phenomenon and a number of international conventions (for example, the Stockholm Convention on Persistent Organic Pollutants, the Minamata Convention on Mercury, and the Montreal Protocol on Substances that Deplete the Ozone Layer) and national laws have been negotiated and established to address the chemicals known to be most harmful to the environment. This includes the ongoing repair of the ozone layer and the phasing out of numerous banned pesticides and chemicals (UN Environment, 2017). This effort is strengthened by a number of the SDGs: target 3.9 aims to substantially reduce the adverse impact on human health from hazardous chemicals and air, water and soil pollution; target 6.3 aims to improve water quality by reducing pollution and the release of hazardous chemicals and materials; and target 14.1 works towards significantly reducing and preventing all kinds of marine pollution (United Nations, 2015b).

Contaminants: Bad chemistry

Persistent Organic Pollutants (POPs) include numerous pesticides and industrial chemicals and their by-products that are known to adversely affect ecosystems, animals and humans. While there has been little direct use of POPs in the Arctic, they are transported to the region from southern latitudes by wind, rivers and ocean currents (AMAP 2018b). The Arctic functions as a sink for these contaminants and the problems associated with POPs have been on the agenda for a long time and are well documented by the extensive work of AMAP. Global efforts to regulate these substances include the Stockholm Convention and the UNECE Convention on Long-range Transboundary Air Pollution.

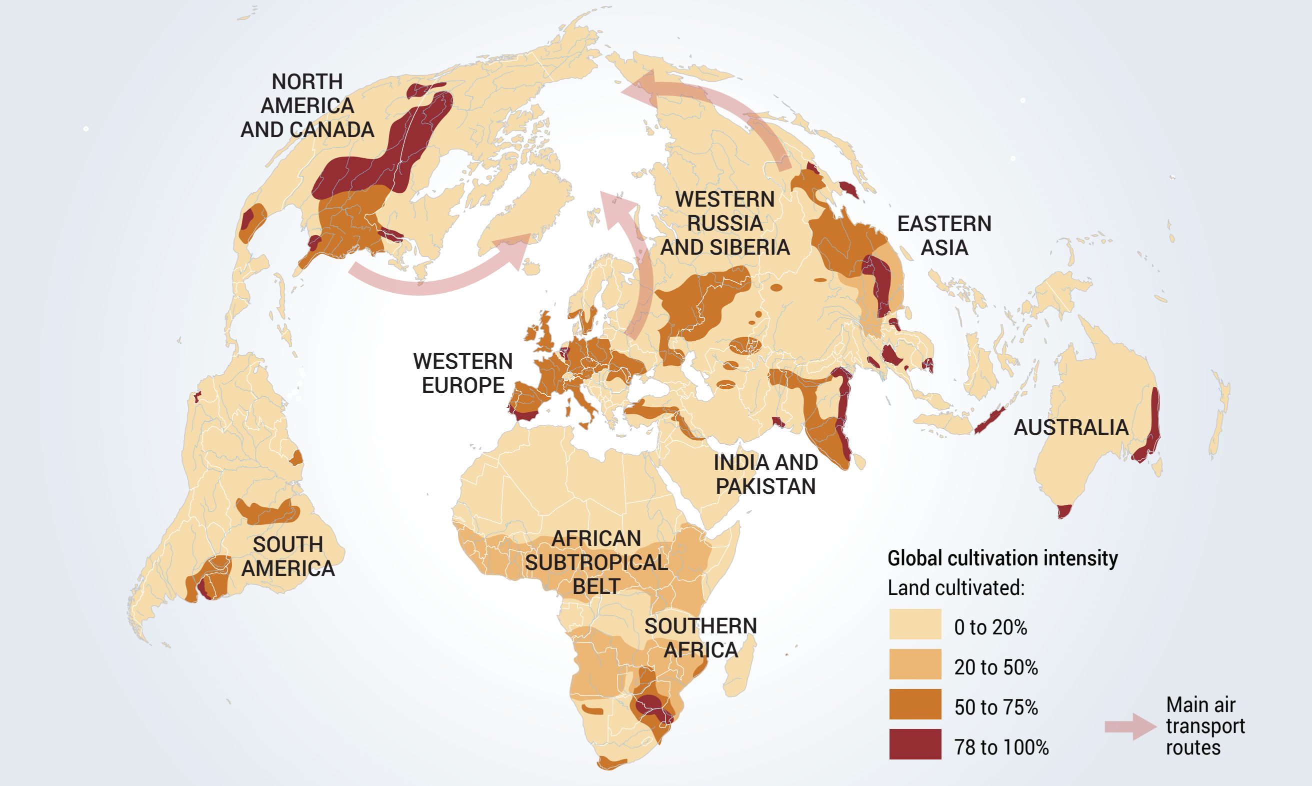
Contaminant levels and concentrations in the Arctic have been monitored in humans and animals for decades. This monitoring is important to understand past and current trends. Research shows that human exposure to POPs and mercury is falling in many parts of the Arctic. However, it remains high in certain communities, where levels of mercury and other chemicals exceed blood guidance levels (AMAP, 2015d).

The decline in the concentrations of some contaminants highlights the importance of international cooperation and control measures to limit the emission of harmful chemicals like POPs. As new chemical contaminants find their way to the Arctic, the need to strengthen existing international mechanisms becomes even more pressing. However, while international instruments like the Stockholm Convention continue to add to the list of restricted chemicals, an assessment by AMAP highlights the limitations of their scope. The large number of chemicals in common use can limit their effectiveness to address all emerging Arctic pollutants: there are around 150,000 chemical substances in use around the world and fewer than 1,000 are regularly monitored (AMAP, 2016). Limited knowledge and monitoring means there is often insufficient information on the toxicity and effects chemicals can have on ecosystems and humans.

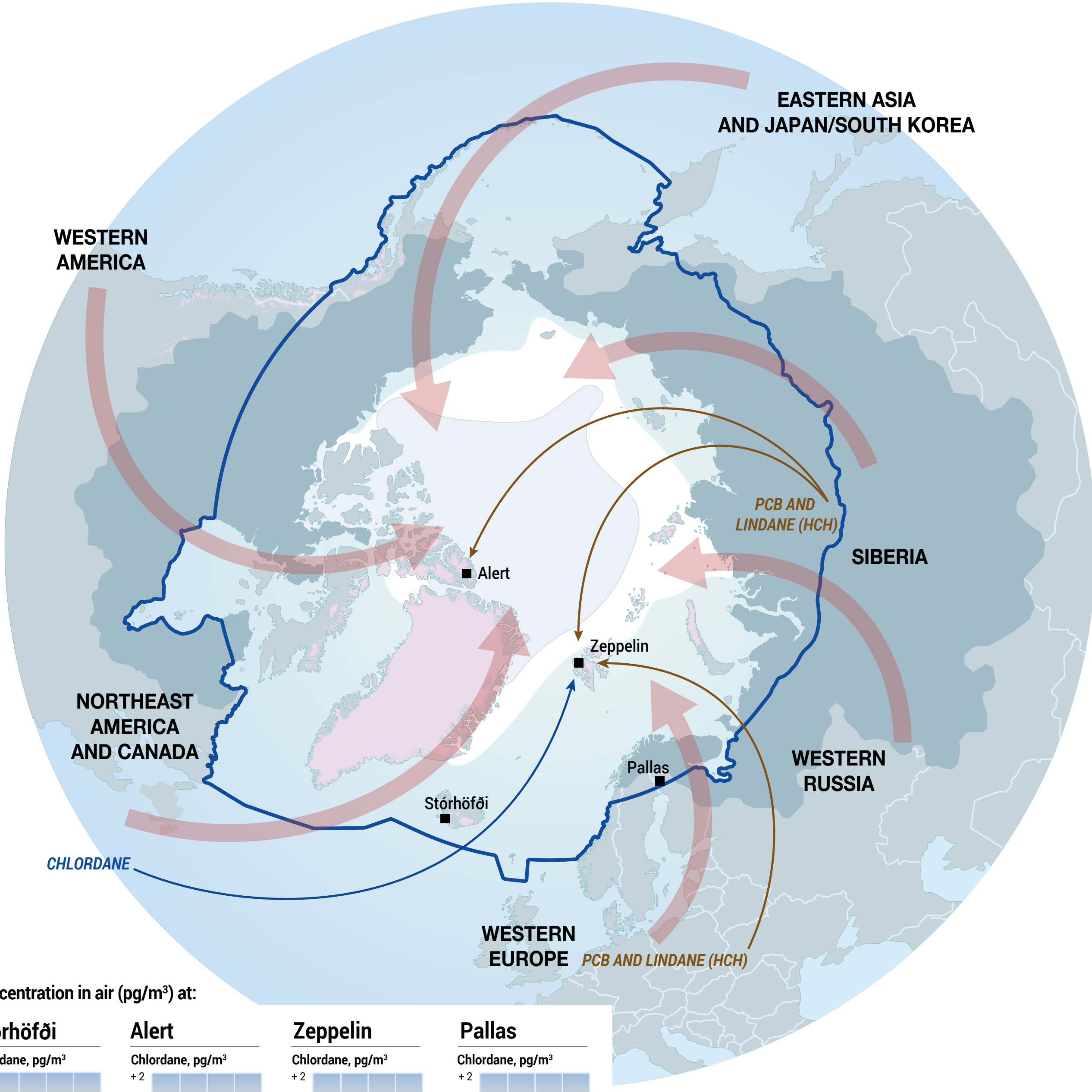
One class of contaminants with similarities to POPs in terms of potential harmful effects, persistence and mobility, are microplastics and nanoplastics. These small particles made up of organic polymers are increasingly present in the world's oceans, either broken down from larger plastics or deliberately manufactured. Microplastics can also act as a source of chemical contaminants, either by leaching additives as they age or by absorbing and transporting chemicals in marine waters (AMAP, 2017b; Royer et al., 2018).

The problem of emerging chemicals is highly complex and we have yet to fully understand the magnitude of the issue or how unmonitored chemicals may affect humans, animals and ecosystems. As we phase out different types of chemical contaminant, we must ensure replacements do not create new problems. Chemicals recently detected in the Arctic may have been present in the environment for years or decades and there is a substantial time lag between detecting harmful chemicals and the establishment of international agreements to ban or restrict their use. Moreover, the persistence of many pollutants mean they continue to affect nature and humans long after the period for which restrictions are applied.

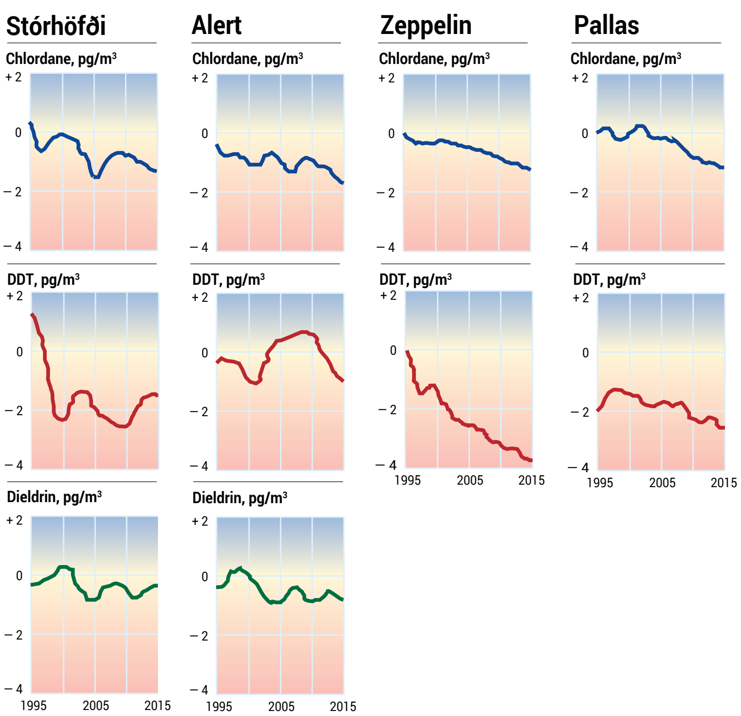
Global cultivation intensity as a proxy for POPs



Persistent organic pollutants



Concentration in air (pg/m³) at:



- ■ Active air monitoring
- Main air transport route of pollutants
- Catchment area of rivers flowing into the Arctic Ocean
- Origin of pollutants measured at selected monitoring stations

Changes in sea ice extent

- Sea ice extent in September 2018
- Sea ice extent in September 1981
- AMAP boundary
- Main glaciers and Greenland ice sheet

Plastic pollution: Going with the flow

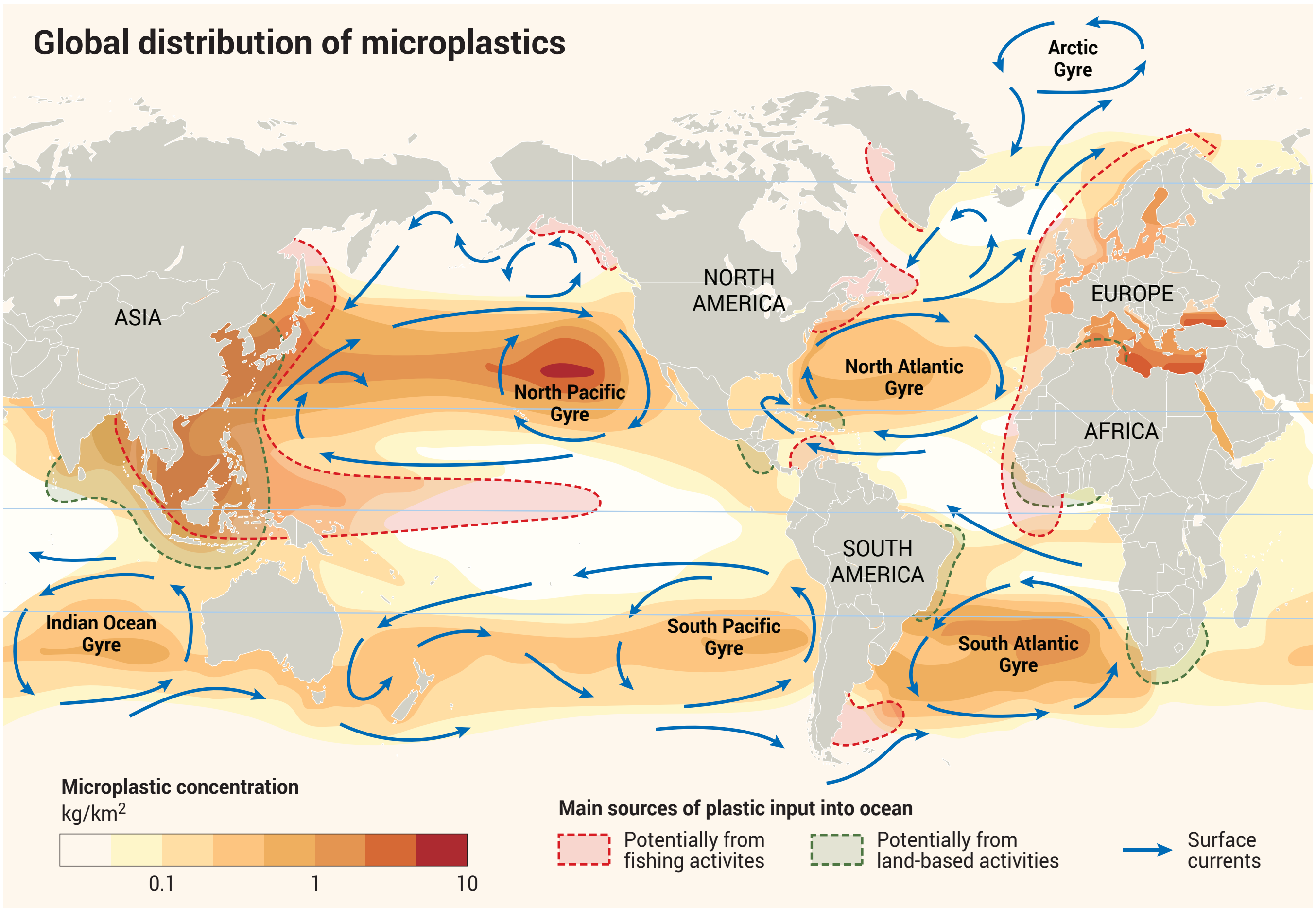
Plastic makes up approximately three quarters of the litter in the world's oceans (Bergmann et al., 2017a) and is one of the most widespread transboundary pollution problems affecting marine and coastal environments throughout the world. The presence of plastic debris in the marine environment has adverse socioeconomic impacts, both in terms of its presence (for example, debris on beaches or entangled in boat propellers and fishing gear) and its interaction with organisms (for example, ingestion and entanglement). The resulting impacts range from the individual to the ecosystem level (UN Environment and GRID-Arendal, 2016) and the Arctic is not immune to this threat (Hallanger and Gabrielsen, 2018).

It is widely accepted that activities on land are responsible for the largest share of plastic in the oceans (UN Environment and GRID-Arendal, 2016). Plastic debris travels from population centres into the ocean via rivers, wind or direct dumping. It is estimated that more than 150 million tons of plastics have accumulated in the world's oceans, between 4.6 and 12.7 million tons added every year due to mismanaged plastic waste from coastal regions (Jambeck et al., 2015; UN Environment and GRID-Arendal, 2016).

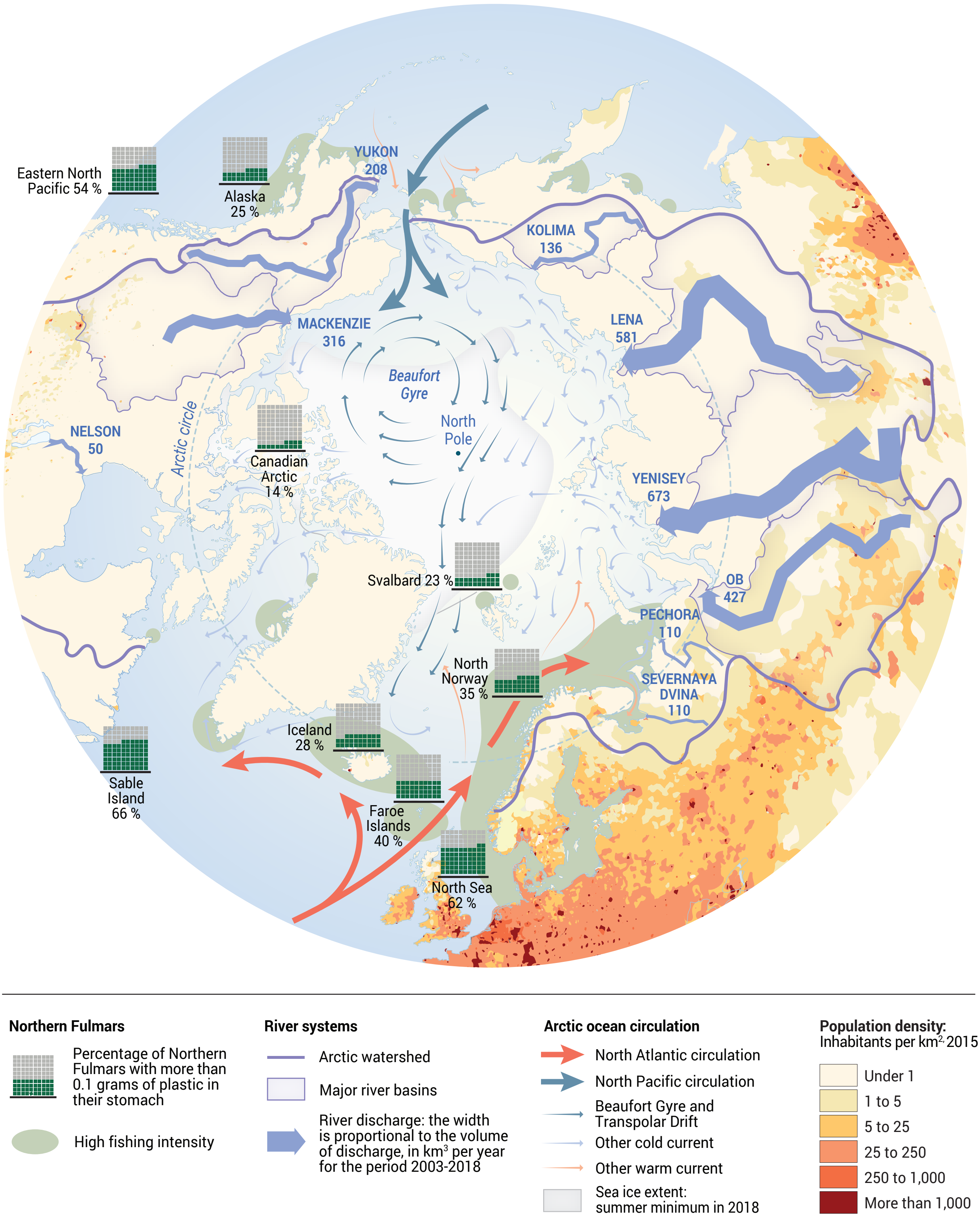
Poor waste management in Arctic coastal communities has been highlighted as a potential local source of plastic debris (Strand, 2018). However, Arctic sea floor and shoreline studies have found that in the Arctic, in contrast to more urbanized regions, plastic originating in the sea is more prevalent that plastic originating on land. This is shown by the predominance of plastic debris associated with fishing activities (Bergmann et al., 2017b; Buhl-Mortensen and Buhl-Mortensen, 2017; Grøsvik et al., 2018; Nashoug, 2017).

Like other parts of the world's oceans, marine plastic pollution in the Arctic is not only the result of activities within the Arctic seas or its coastal areas. It is also linked to debris arriving from other parts of the globe and the large Arctic watershed. The Arctic Ocean receives enormous amounts of surface fresh water from rivers and run-off, which strongly influences the chemistry and dynamics of surface ocean water (Holmes et al., 2011). Furthermore, 79 per cent of water in the Arctic Ocean flows from the Atlantic and 19 per cent from the Pacific (Murray et al., 1998). The potential transfer of plastic pollution from relatively more populated parts of the Arctic watershed, such as the headwater areas of the basins of the Ob and Yenisei rivers in Russia, has yet to be investigated. However, the inflow of polluted water from the Atlantic, connected to the global thermohaline circulation[2] (Cózar et al., 2017; van Sebille et al., 2012) and melting sea ice drifting from the inner central and coastal Arctic (Bergmann et al., 2017d; Fang et al., 2018) have been proposed as transfer mechanisms that contribute to higher concentrations of plastic in surface waters and sediments in the Fram Strait and the Barents and Chukchi seas. The higher level of plastic pollution in the Barents Sea is also reflected by the comparatively high incidence of

2. Thermohaline circulation is the large-scale density-driven circulation in the ocean, caused by differences in temperature and salinity.



Plastic input into the Arctic Ocean



plastic ingestion by seabirds like northern fulmars compared to other Arctic locations at a similar latitude (Provencher at al., 2017).

The Arctic Council has recognized the potential effects of marine plastic litter on the Arctic environment and is assessing the current state of knowledge and how to monitor trends and impacts on ecosystems. An action plan for the protection of the Arctic Ocean from marine litter and microplastics is also being discussed and CAFF is undertaking work to address the impacts of plastics on seabirds.

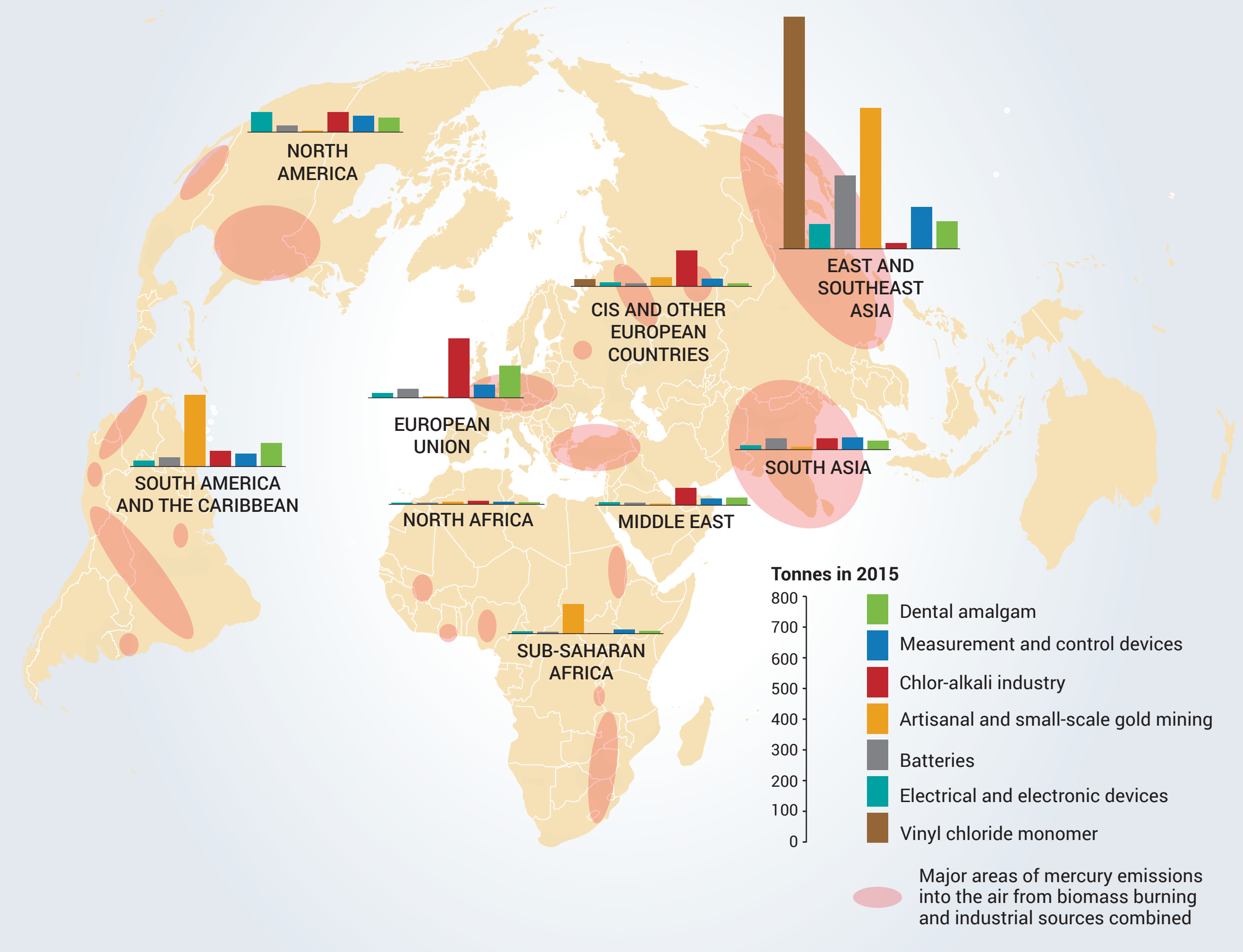
Mercury rising

Although mercury (commonly known as quicksilver) is a naturally occurring element, human activity has resulted in increased concentrations in aquatic and land ecosystems around the globe (Driscoll et al., 2013; Streets et al., 2018). Anthropogenic mercury emissions come from a variety of sources, the largest of which are artisanal and small-scale gold mining and coal combustion (AMAP, 2011). While improved regulation in Europe has produced a small decline in atmospheric mercury in high northern latitudes, emissions in the tropics, especially Southeast Asia, are still increasing (Horowitz et al., 2014). Even though the Arctic only makes up a small proportion of global anthropogenic mercury, gaseous mercury from other parts of the globe is transported over large distances, meaning some of it eventually ends up in the Arctic. Mercury contamination in the Arctic remains a concern due to its documented uptake and accumulation in Arctic biota, especially marine mammals and terrestrial predators (AMAP, 2011).

Tracking the movement of mercury into the Arctic environment is complex, due to the different forms of mercury and the many possible transformations and mechanisms that concentrate or remobilize this element. Sunlight in spring, for example, causes atmospheric mercury to react with oxygen, causing it to solidify. This solidified mercury is then deposited on land, sea ice and water surfaces. A large portion is quickly re-emitted to the atmosphere as gaseous mercury (Steffen et al., 2008). However, studies show that this process is largely confined to coastal areas and the quantity of mercury deposited is not sufficient to explain the increasing concentrations in Arctic ecosystems. Recent monitoring indicates that tundra vegetation could be the missing part of the equation, since a significant amount of circulating anthropogenic gaseous mercury finds its way into tundra soil via uptake from the atmosphere by tundra vegetation (Obrist et al., 2017). The amount of mercury found in tundra soil also makes it one of the most important global sinks for gaseous mercury circulating in the atmosphere. Research has found that northern hemisphere permafrost soils contain an enormous amount of stored mercury, nearly twice as much as all other soils, the ocean, and the atmosphere combined (Schuster et al., 2018).

The impact of climate change on mercury distribution and availability is likely to be complex. In the Arctic, thawing permafrost will increase soil erosion, potentially releasing old stores of mercury and leading to an increase in the amount

Global use of mercury



Mercury in Arctic soil

Mercury in the soil from 0 to 300 cm
mg Hg/m^2

5 to 20 | 20 to 80 | 80 to 150 | More than 150

Projected permafrost extent in 2100 according to Representative Concentration Pathway (RCP) scenarios from the IPCC Fifth Assessment Report

RCP 4.5 | RCP 8.5 | Current extent of permafrost entering the ocean from drainage and river flows. Tundra soils are a major global mercury sink and the erosion of these soils appears to be the dominant source of mercury entering the Arctic Ocean (Obrist et al., 2018).

Sea ice generally acts as a buffer to exchange between the air and the sea and mercury concentrations are higher under ice than in open waters. The loss of sea ice is likely to result in lower concentrations of mercury in some surface waters as more mercury is released into the atmosphere (DiMento et al., 2019). Increased atmospheric and ocean temperatures may also result in higher microbial activity and increased formation of methylmercury, an organic and highly poisonous type of mercury formed when bacteria react with mercury in water, soil and plants (Angot et al., 2016). However, understanding the impact of climate change on an element as mobile as mercury is very difficult. There are many uncertainties and extensive research is required to understand the implications of predicted climatic changes on the environmental distribution of mercury.

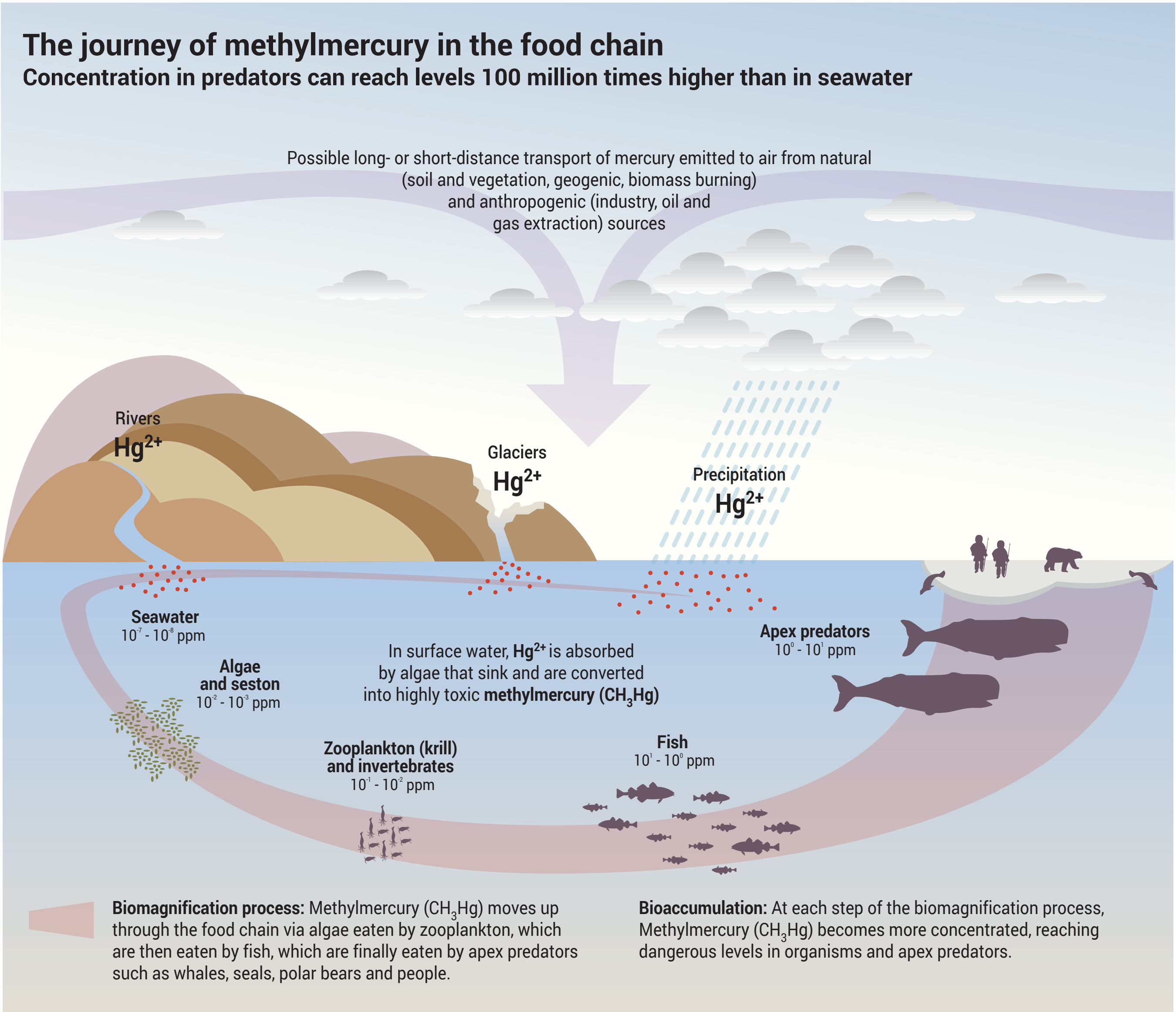
The Minamata Convention, together with national climate policies to reduce the use of coal, is expected to cut global mercury emissions (Maas and Grennfelt, 2016). However, any gains may be offset by the release of legacy mercury stored in tundra soils and permafrost. If this mercury is released and enters the food web, it could result in dangerous contamination levels in the main sources of protein for humans, with devastating effects on food security in the Arctic.

Pollution and health: The invisible threat

While the previous three sections have focused on sources of pollution in the Arctic, this section considers its health implications for people, wildlife and ecosystems. The spread of chemical contaminants and heavy metals from around the world, in addition to local emissions, are increasingly linked to a number of diseases and adverse effects on health (AMAP, 2015d). Despite falling concentrations of some contaminants, new and possibly harmful chemicals are emerging in large numbers and contaminants in Arctic apex predators are increasing (AMAP, 2017b, 2018b).

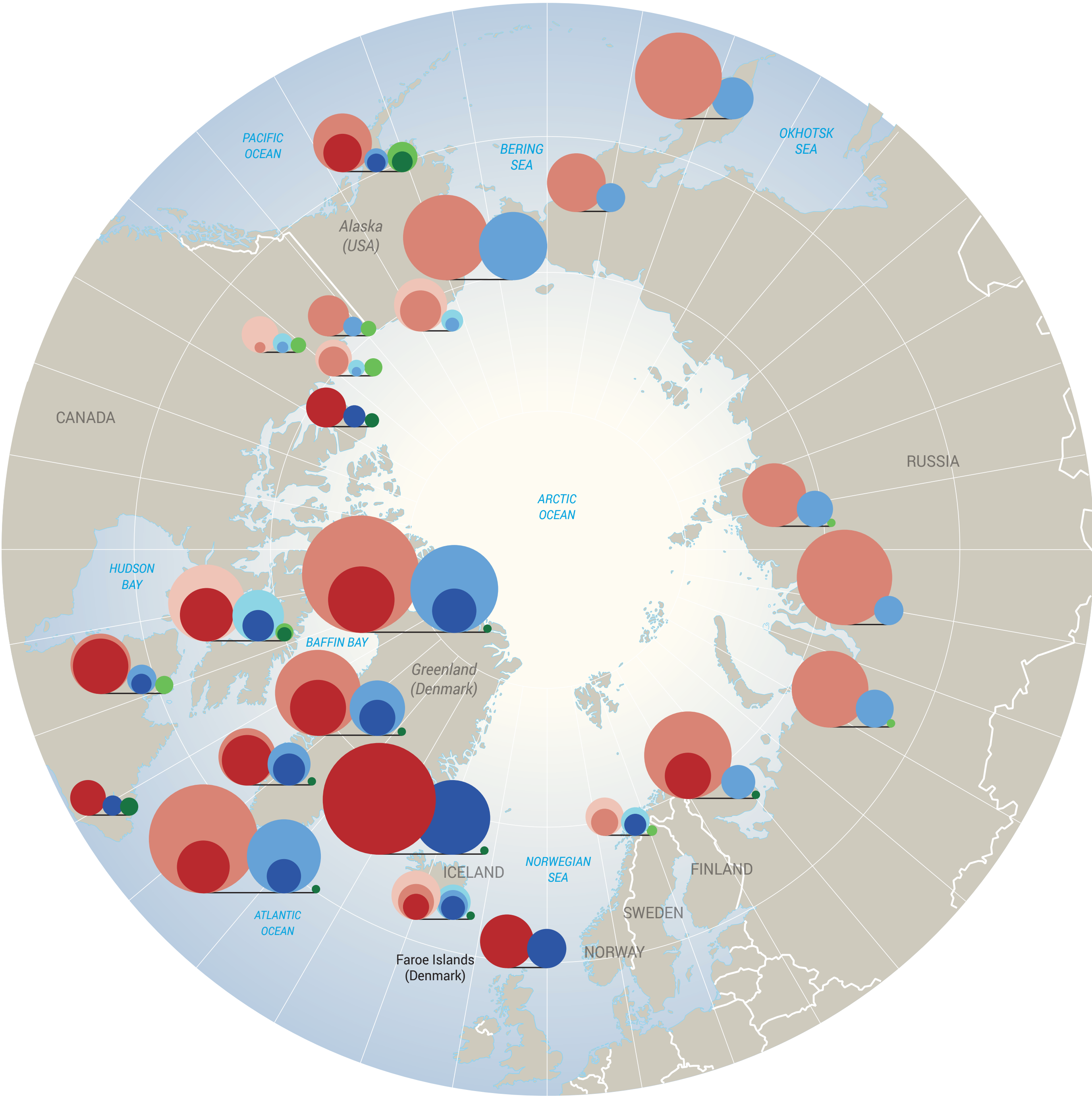
Heavy metals, such as mercury, together with POPs, accumulate and magnify throughout the food chain, resulting in much higher concentrations in organisms higher up the food chain than in primary producers or low order consumers. Fish, for example, are a major source of contaminants for humans and marine mammals. Studies on upper trophic levels in the Arctic have shown that POPs and heavy metals may affect the hormone and immune systems, reproduction and behaviour of wildlife (AMAP, 2018b). For example, polychlorinated biphenyls (PCBs) and mercury are associated with weakened immune function in marine mammals, especially in polar bears in the central Canadian High Arctic and Alaska and pilot whales in the Faroe Islands (AMAP, 2018b). Several POPs have been shown to affect hormone production in Arctic mammals and seabirds. One example is thyroid hormone balance, which adversely affects reproductive capacity, growth, the immune system and the body's ability to regulate temperature. However, there is still a lack of direct evidence of this cause–effect relationship, despite behavioural and morphological effects of POPs being consistent with hormone disruption (AMAP, 2018b).

Small and remote Arctic communities are often highly dependent on local sources of food and sensitive to environmental changes that can have adverse consequences for traditional ways of life and food security. Limiting mercury intake is especially important for pregnant women and small children as the element is a powerful neurotoxin and can affect foetal and childhood development (AMAP, 2015d; Ha et al., 2017; Karagas et al., 2012). However, providing dietary advice can be complex due to



Pollution and human health

Level of pollutants in blood or breast milk of women in childbearing age



DDE
p,p'-Dichlorodiphenyldi-chloroethylene (a breakdown product of the insecticide, DDT)

- 1990-1999
- 2000-2007
- 2007-2014

PCB-153
2,2',4,4',5,5'-Hexachlorobiphenyl (previously used as coolant fluids in electrical equipment)

- 1990-1999
- 2000-2007
- 2007-2014

PBDEs
Polybrominated diphenyl ethers (used as flame retardant)

- 2005-2007
- 2007-2013

µg/kg plasma lipid

700
600
400
200
100

Note: No circle reflects lack of data, not that the pollutant level is zero.

varying contamination levels in different foods and areas of the Arctic. Consumption of most traditional foods is recommended as a healthy choice, prioritizing foods lower down the food chain with lower concentrations of contaminants. (AMAP, 2015d). High concentrations of chemicals and heavy metals in humans have also been linked to cancer, cardiovascular diseases and negative effects on the nervous system. Although the general trend in the Arctic has been a decline in human exposure to most metals and POPs, Inuit communities in Canada and Greenland are exceptions (AMAP, 2015d).

The emergence of new chemical contaminants is a continuous threat in the Arctic and around the globe. Our knowledge of their effects on humans and wildlife remains limited, highlighting the need for research on the cumulative effects of exposure to different stressors and the interrelated effects of different chemicals (AMAP, 2018b). Our understanding of contaminants must also take climate change into account, as it is projected to change transportation routes, flows in the food web and the level of ecosystem exposure (AMAP, 2015d, 2018b). Hormone-disrupting chemicals and climate change are regarded as one of the most serious anthropogenic threats to biodiversity and ecosystems in the Arctic AMAP (2018b) and international cooperation and treaties to regulate the use of harmful chemicals play an important role in addressing this threat.

Biodiversity conservation

The Arctic is home to over 21,000 species of plants, fungi, mammals, birds, fish, insects and invertebrates. The region is home to one third of the world's shorebirds and two thirds of the global goose population which breed in the Arctic and sub-Arctic (CAFF, 2013). Many Arctic species are migratory and spend some of the year in other parts of the world. Others live only in the Arctic and thrive in its harsh climate. The ecosystems and biodiversity of the Arctic have also long provided the basis for livelihoods and cultural diversity (CAFF, 2013; CBD, 2011). Changes in Arctic biodiversity will first be felt by the people who directly rely on them but will also have effects far beyond the polar region.

The global loss of biodiversity is one of the major human-induced environmental changes of the modern era. Its drivers include overexploitation, pollution, climate change, habitat loss and degradation, invasive species and diseases (Dirzo et al., 2014; WWF, 2016). Between 1970 and 2012, the WWF Living Planet Index reported an overall decline of 58 per cent in the world's species, with the greatest losses in freshwater environments (WWF, 2016). While there are some variations across regions and species groups, habitat degradation and loss is reported as the greatest threat to biodiversity globally.

The story in the Arctic region is different. The Arctic Species Trend Index (ASTI) showed a general increase of 16 per cent in the abundance of Arctic species between 1970 and 2004 (McRae et al., 2010). ASTI tracks trends in over 300 Arctic vertebrate species, encompassing 35 per cent of all known vertebrates found in the region. While nonetheless present, pressures from habitat loss, pollution, exploitation and invasive species are relatively lower in the Arctic, largely due to a lack of intensive human encroachment compared to other parts of the world (CAFF, 2013). However, this trend is not consistent across the Arctic and varies across biomes, regions and groups of species. For example, while Low Arctic species populations – largely dominated by marine species – have increased by an average of 46 per cent, the figure for High Arctic species has decreased by an average of 26 per cent.[3] The reported increase for some species can be partly attributed to the recovery of some vertebrate populations that had historically suffered from overharvesting, such as marine mammals. Non-migrant bird species have also increased, although the population sizes of migratory birds have fallen slightly (McRae et al., 2010). Migratory birds may be affected by conditions at any stage along their migration routes and these often occur outside of the Arctic, which shows how these species closely link the Arctic to the rest of the world.

Until recently, the negative impacts of anthropogenic stressors on Arctic biodiversity were relatively small. However, this is now changing as the Arctic region faces changes and new challenges, including increased human activity and pressure on resources. The most serious threat to Arctic biodiversity is now climate change: the increasing pressures and rates of change, including ocean acidification and the spread of invasive species, are expected to alter the Arctic ecosystem and displace species that are adapted to the extreme Arctic environments (McRae et al., 2010; CAFF, 2013).

The Arctic Council is working to mitigate threats to biodiversity, including through its Conservation of Arctic Flora and Fauna (CAFF) working group, which cooperates closely with international conventions including the World Heritage Convention, the Convention on Biological Diversity, the Ramsar Convention on Wetlands and the Convention on the Conservation of Migratory Species of Wild Animals (Convention on Migratory Species). The CAFF Circumpolar Biodiversity Monitoring Programme (CBMP) also coordinates circumpolar efforts to monitor and report on the state of Arctic biodiversity.

3. "Sub-Arctic", "Low Arctic" and "High Arctic" are terms used to describe the Arctic according to the amount of woody vegetation present.

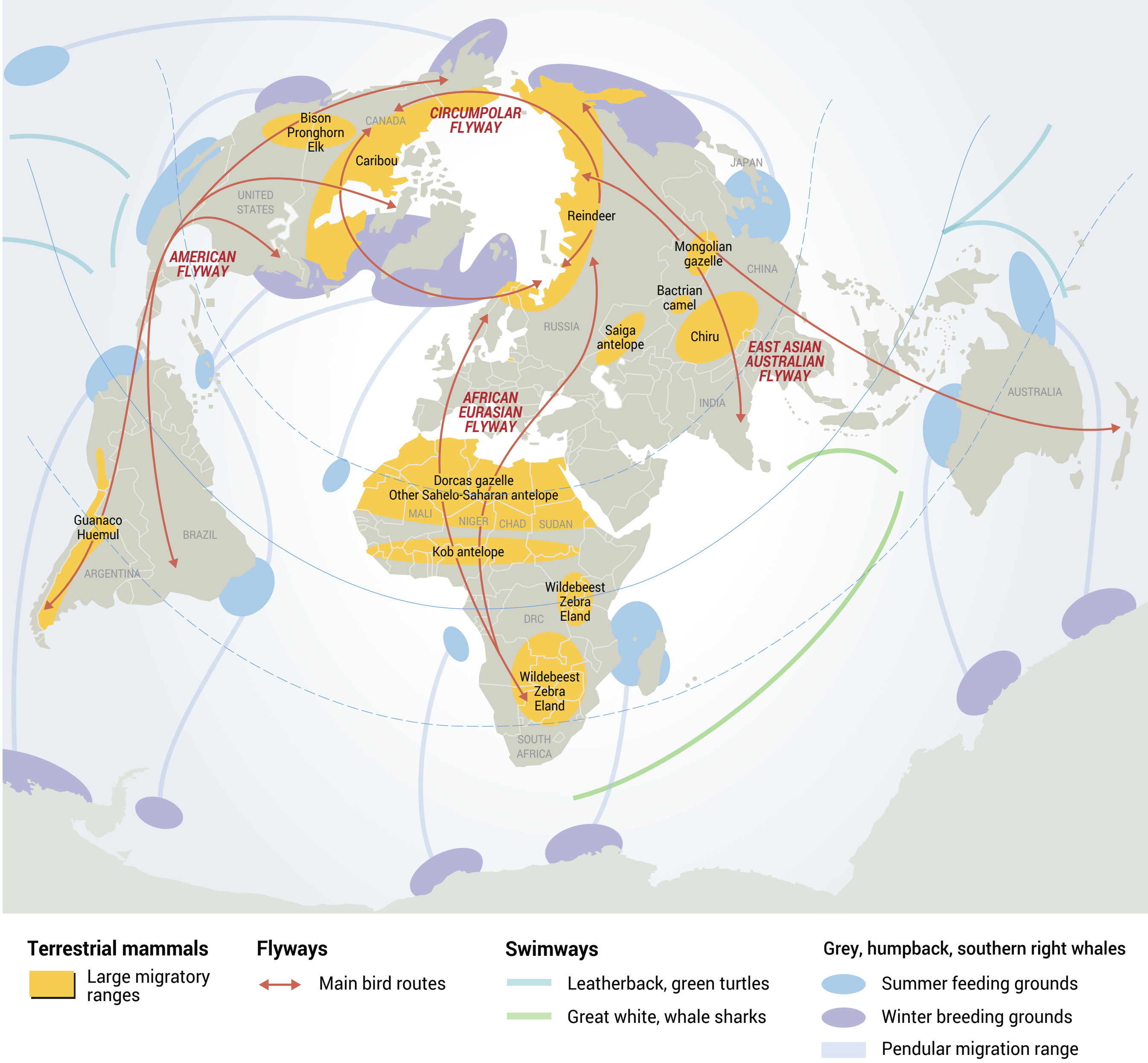
Migratory species: Frequent travellers

Many Arctic species have adapted to the challenges of extreme weather conditions and scarce resources by migrating between the north and south or between marine and freshwater habitats, either annually or at different stages in the lives of individuals (Binder et al., 2011; Gauthreaux, 1982). As a result, several species living in the Arctic are migratory, including reindeer, marine mammals (including cetaceans and pinnipeds) many freshwater and diadromous fish (which spend parts of their lives in both fresh and saltwater environments) and numerous bird species. Inhabiting at least two different geographical areas, means migratory species can be affected by stressors both inside and outside the Arctic.

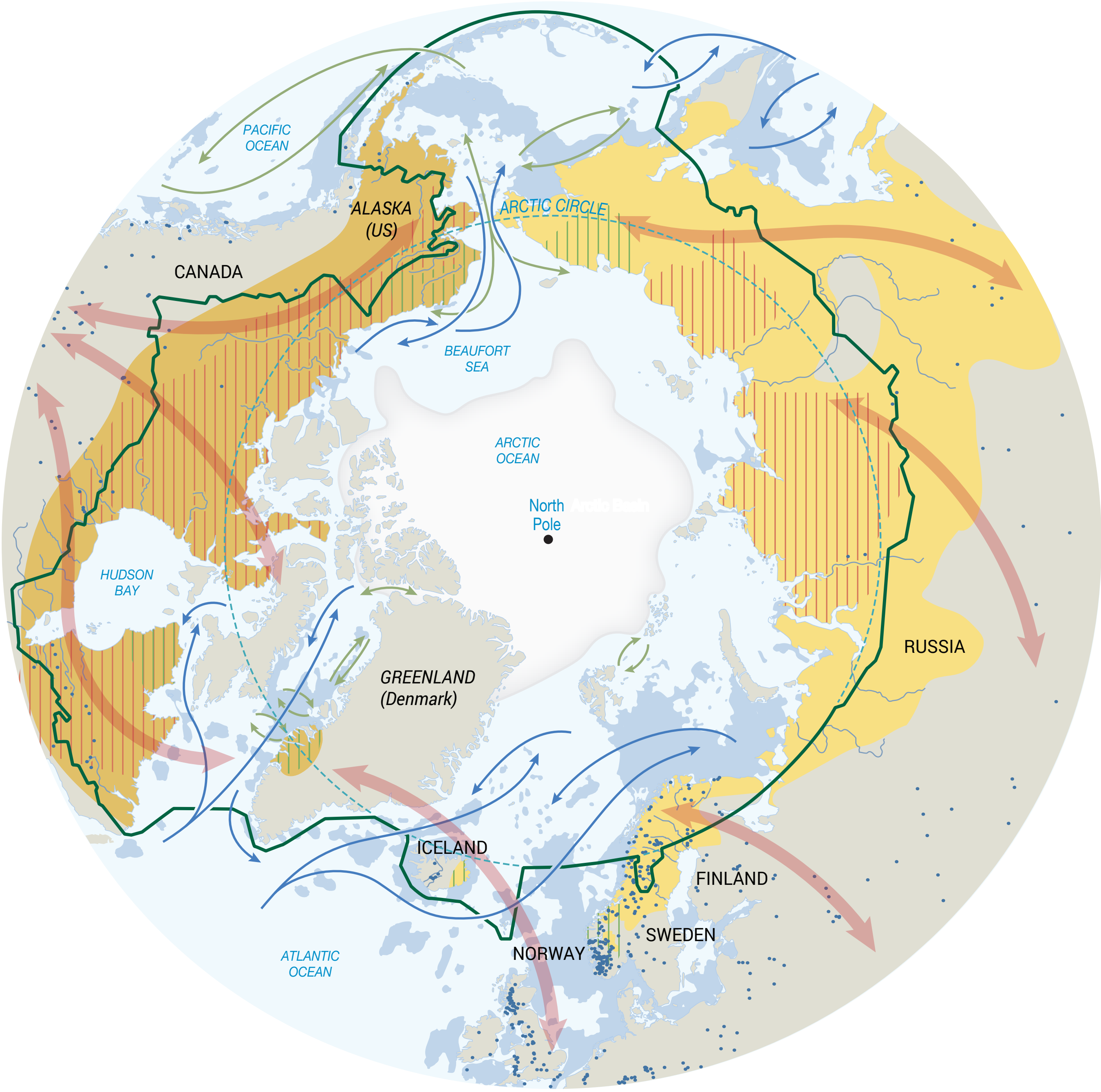
The fact that a large proportion of Arctic biodiversity is migratory means that changes in populations, distributions and migratory pathways can have a significant effect across entire Arctic ecosystems and the people who rely on them (CAFF, 2013). The challenges facing these species include overharvesting, habitat degradation and low population densities inside and outside the Arctic. Their populations and migratory patterns can also be affected by pollution, invasive species and the northern expansion of species from the south.

Subsistence hunting and fishing continue to be important for many communities in the Arctic (Council of Canadian Academies, 2014; Nakhshina, 2016). This means changes in wildlife populations can pose a serious threat to the food security of Arctic peoples who depend on them (CAFF, 2013; Laidre et al., 2015; Troell et al., 2017). Migratory species also provide opportunities for economic development through wildlife tourism, recreational hunting and fishing, which can all play an important role in local economies.

Migratory species worldwide



Migratory pathways in the Arctic



Wild and domesticated rangifer populations

- Caribou
- Reindeer

Trend in caribou and reindeer populations

- Increasing
- Decreasing

- Sea ice extent in September 2018
- CAFF boundary
- Main existing dams
- Commercial fishing activity in summer and autumn
- Main migratory routes for birds
- Rivers where fish migrate between seawater and freshwater

Main migratory routes for marine mammals

- **Cetaceans:** Beluga, narwhal, humpback, bowhead and grey whale
- **Pinnipeds:** Walrus, northern fur seal and bearded seal

Migratory species are an important ecological link between the Arctic and the rest of the world (CAFF, 2013; Deinet et al., 2015). In the tropics, the proportion of migratory bird species is often less than half of the total number of species, whereas in most areas of the Arctic over 80 per cent of bird species migrate (Somveille et al., 2013). Many migratory birds breeding in the Arctic face overharvesting and habitat degradation in their wintering areas south of the Arctic from the drainage of wetlands, urbanizing coastlines and riverbanks and the release of toxic chemicals into the environment. Of all Arctic migratory bird species, waterfowl and shorebirds suffer the most from habitat loss outside the Arctic (CAFF, 2013). Migratory fish are vulnerable to habitat alteration and overharvesting because they typically concentrate in particular locations and at predictable times of the year (CAFF, 2013). In addition to freshwater habitat changes, migratory fish travelling to the sea face similar pressures from commercial fishing as marine fish stocks. Fishing is likely to increase in the Arctic as the retreating sea ice makes marine areas more accessible (Zeller et al., 2011).

International coordination is key to successful conservation because migratory species face threats across their whole migratory range. The Convention on Migratory Species is the only global convention addressing the conservation of migratory species, their habitats and migration routes (CMS, 2018). In addition, the United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks entered into force in 2001 (United Nations, 2016).

Furthermore, CAFF has established the Arctic Migratory Birds Initiative (AMBI), which engages Arctic and non-Arctic states in efforts to conserve breeding, staging and overwintering areas of Arctic migratory bird species (Provencher et al., 2018). In 2017 the five Arctic coastal states, together with Japan, China, South Korea and the European Union, also adopted an agreement to ban commercial fishing in the central Arctic Ocean for the next 16 years to protect the high seas area from unregulated fishing (IISD, 2017).

Invasive species: Hitching a ride

For thousands of years, as humans have migrated over land and explored the oceans, they have helped to move species from one part of the world to another, both intentionally and unintentionally. These organisms introduced outside of their past or present distributional ranges by humans are invasive species. While the intentional relocation of some non-native species such as crops and livestock has led to the spread of agriculture, human population growth and economic benefits, many of these species can have unforeseen effects on the environment, economic activity and humans.

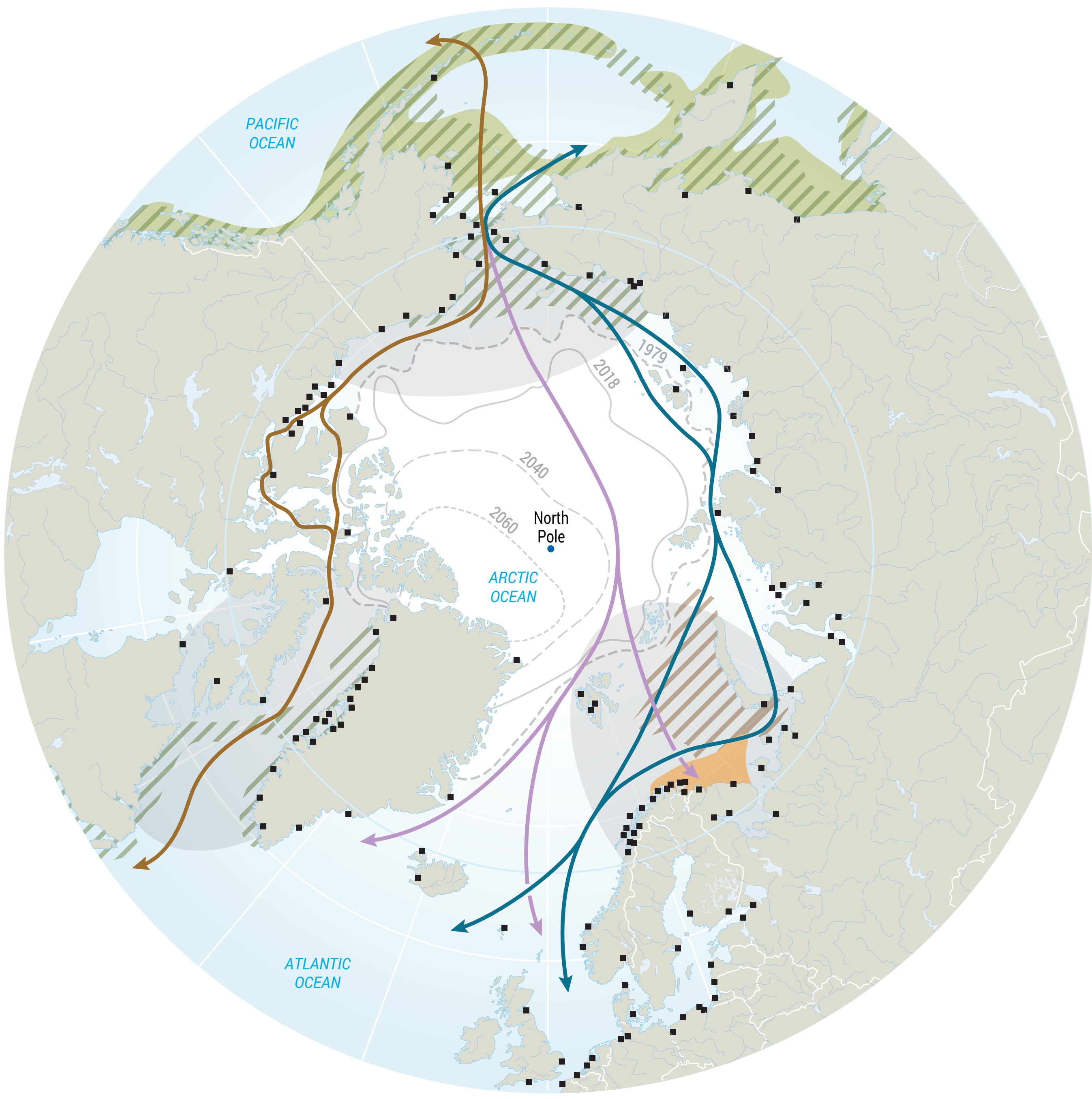
Around 480,000 invasive species are estimated to have been introduced around the world by humans (Pimentel et al., 2001). Introduced species, such as the introduction of rats on islands where local species evolved without mammalian predators, often have severe effects on local biodiversity and can even cause extinctions, (Harper and Bunbury, 2015). However, not all introduced species may cause harm: 15 per cent of the more than 10,000 species introduced in Europe are currently known to have a negative ecological or economic impact (EEA, 2012).

Globally, invasive species are the second threat to biodiversity after habitat destruction (Bellard et al., 2016). Invasive species are introduced through unintentional transport of insects, algae and crustaceans as "stowaways" in airfreight, in shipping containers, on the hulls of ships and in ballast water. As trade volumes increase and countries become more and more connected, the likelihood of an increase in the number of invasive species rises (Seebens et al., 2017).

So far, the limited monitoring that has been conducted has found that the Arctic region has fewer recorded terrestrial and marine invasive species than areas further south (CAFF, 2013). Some of the best-known invasive species include the American mink (Mustela vison), which was introduced to Iceland and northern Scandinavia for fur farming, and the Pacific red king crab (Paralithodes camtschaticus), which was brought to the

Invasive globetrotters

Marine invasive pathways in the Arctic



Infrastructure

Open now

- Northern Sea Route
- Northwest Passage

Due to open in a few decades

- Transpolar Sea Route
- Main harbours

Sea ice extent in summer

- 2018
- 1979

Forecast for summer

- 2040
- 2060

Human activities favouring the introduction of invasive species (marine tourism, mining, oil and gas extraction, major fisheries, ballast water)

Crabs in the Barents Sea

1. Native range

- Red king crab
- Snow crab

2. Invaded area

- Red king crab
- Snow crab

Barents Sea. While still considered invasive, harvesting red king crab has become a profitable industry for Norway and Russia (Lorentzen et al., 2018). Conversely, Arctic species have also been introduced in other parts of the world, for example the Atlantic salmon (Salmo salar), which has been introduced to Chile, Tasmania and the Pacific coast of the United States for commercial farming (Jones, 2004).

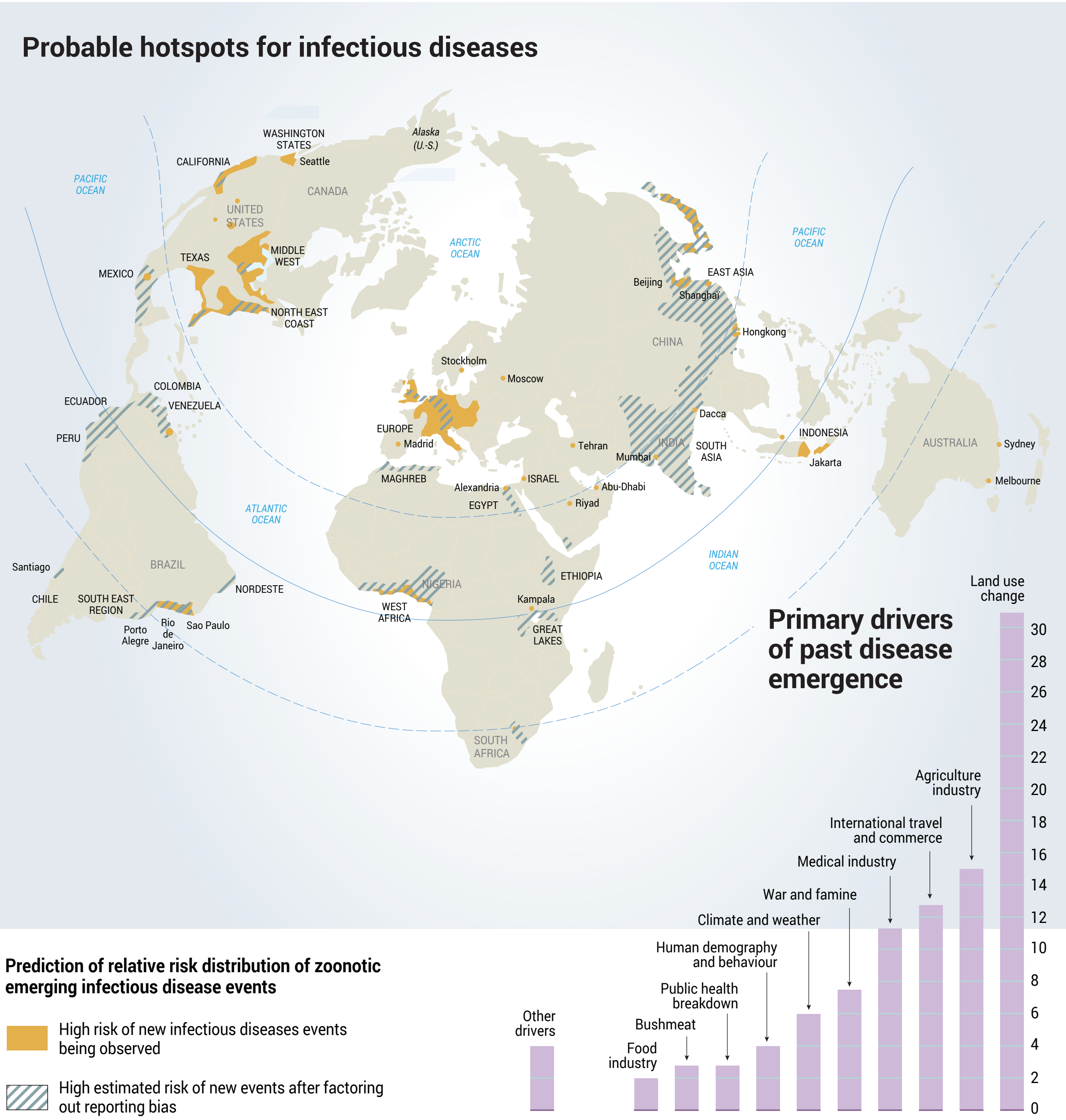
The ballast waters and hulls of commercial ships are the main means by which marine invasive species are transported and introduced to new coastal areas. One of the biggest concerns is the expected increase in shipping in and across the Arctic, since an ice-free Northern Sea Route offers major advantages for ships sailing between Europe and Asia compared to the Suez or Panama canals. Although the volume of trans-Arctic shipping is currently low, it is projected to rise over the coming decades (Melia et al., 2016; Smith and Stephenson, 2013). This development is significant because it will likely bring a wave of new marine species into the Arctic and northern hemisphere, creating new opportunities for their transfer between the Atlantic and Pacific Oceans (Miller and Ruiz, 2014).

By acting now, countries have a unique opportunity to limit the spread of invasive species. Recent measures, such as the International Convention for the Control and Management of Ships' Ballast Water and Sediments and its enforcement in Arctic waters through the International Code for Ships Operating in Polar Waters are designed to help to prevent the spread of marine invasive species in the Arctic. Furthermore, the Protection of the Arctic Marine Environment (PAME) and CAFF working groups of the Arctic Council have developed the Arctic Invasive Alien Species Strategy and Action Plan setting out a circumpolar strategy based on the principles of prevention, early detection, rapid response, eradication and control.

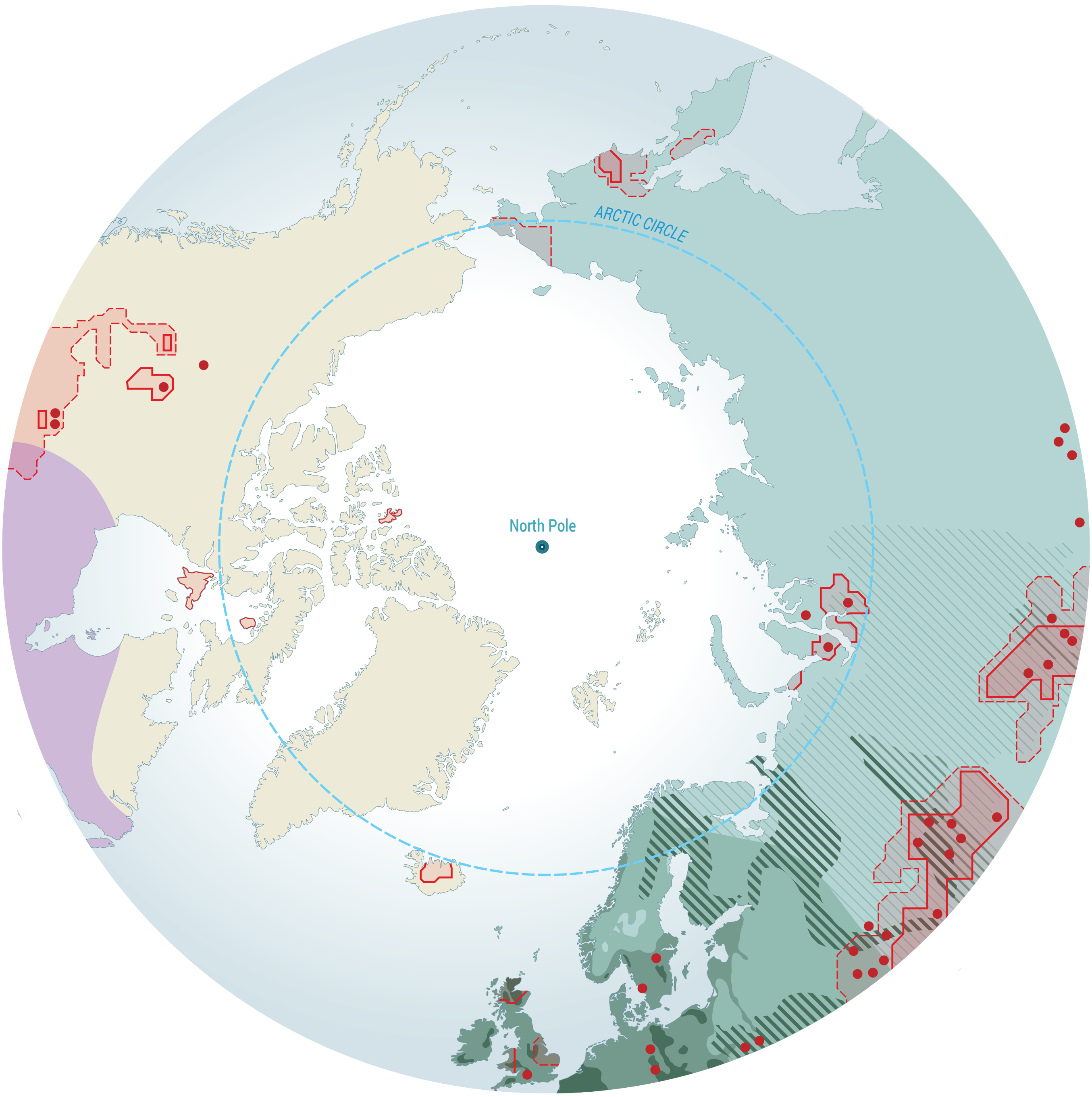
Zoonoses: From animals to humans

Global pandemics occur when a new disease suddenly appears against which humans have no immunity. They are often caused by a virus or other pathogens "jumping" from animals to humans. These transfers from animals to humans are called zoonoses and include infections or infectious diseases caused by viruses, bacteria, parasites, fungi and prions (proteins linked to several fatal neurodegenerative diseases). Zoonoses are transmitted through a variety of pathways, including through direct contact between animals and humans, biting insects, ingesting food and water contaminated with parasites and through the air. The Spanish flu of 1918, caused by the Influenza A virus found naturally in wild aquatic birds, claimed between 30 and 50 million lives (Taubenberger and Morens, 2006) and is perhaps the best-known – and deadliest – example. The rabies virus and recent emerging diseases, such as the Ebola and Zika viruses, are other examples.

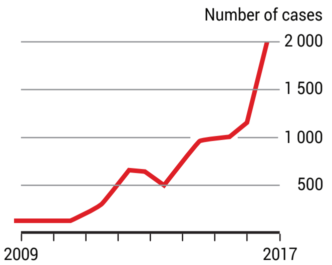
The greatest risk of emerging zoonotic diseases is thought to occur in tropical regions, where wildlife biodiversity and land-use change is highest (Allen et al., 2017). However, given the high rate of warming in the Arctic, animal hosts or insect vectors may expand northward and survive, bringing them, together with their pathogens, into contact with human populations. A warmer climate could allow infected host species to



The northward spread of infectious disease



Lyme disease cases in Canada



Geographic distribution of climatic suitability for tick *Ixodes ricinus* responsible for Lyme disease in Eurasia

Situation in 2013

- Very low suitability
- Low suitability
- Medium suitability
- High suitability

Projection for 2080 according to the B2 scenario of the IPCC 4th assessment report

- Low suitability
- Medium suitability
- High suitability

The IPCC B2 scenario describes a world with an emphasis on local solutions to economic, social and environmental sustainability rather than the global approach (scenario B1).

Presence of the tick *Ixodes Scapularis* Lyme disease vector for the period 2040-2080 according to the RCP 8.5 scenario of the IPCC

Main anthrax outbreaks as documented by the World Organisation for Animal Health (OIE) and Pro-MED between 2005 and 2016.

Anthrax climatic suitability

- Current situation
- Forecast for 2050 based on projected warming anomalies using a concentration pathway of 4.5 W per m^2 radiative forcing.

survive winters in larger numbers and expand their range. Hunting, gathering and certain forms of food preparation and preservation methods may increase the risk of zoonotic infections (Hueffer et al., 2013).

The frequency of contagious diseases in Arctic species has increased, for example, avian cholera outbreaks in marine birds in the northern Bering Sea and Arctic Archipelago, and mortalities in seals and walruses in the US Arctic (CAFF, 2017). Thawing permafrost on land also has the potential to release previously immobile spores of anthrax, as shown by the outbreak in Yamal in the Russian Arctic in 2016, which was widely covered in the media and resulted in the death of a 12-year-old boy, the hospitalization of around 100 people and the death of 2,300 reindeer (Goudarzi, 2016). However, even if the risk of anthrax outbreaks is linked to a warming climate and the Arctic has the right conditions for them, outbreaks have been much more common further south and this situation is predicted to continue (Walsh et al., 2018).

Insects like mosquitoes and ticks have the potential to connect the Arctic and tropics (Evengård and Sauerborn, 2009) and there is already evidence of the northward spread of zoonotic diseases across Canada, Russia and Europe. For example, the number of reported cases of Lyme disease in Canada, which is transmitted by the black-legged tick, has been steadily rising in the last 10 years and has doubled between 2016 and 2017 (Government of Canada, 2018). Climate warming is expected to support further expansion northwards, with the increase in the number of days over 0°C being the most important determinant for the establishment of ticks (Leighton et al., 2012). Migratory birds also have the potential to transmit ticks over long distances.

Further research is needed to better understand the distribution and spread of climate-sensitive infectious diseases in Arctic ecosystems and societies to develop early warning systems and preventive measures.

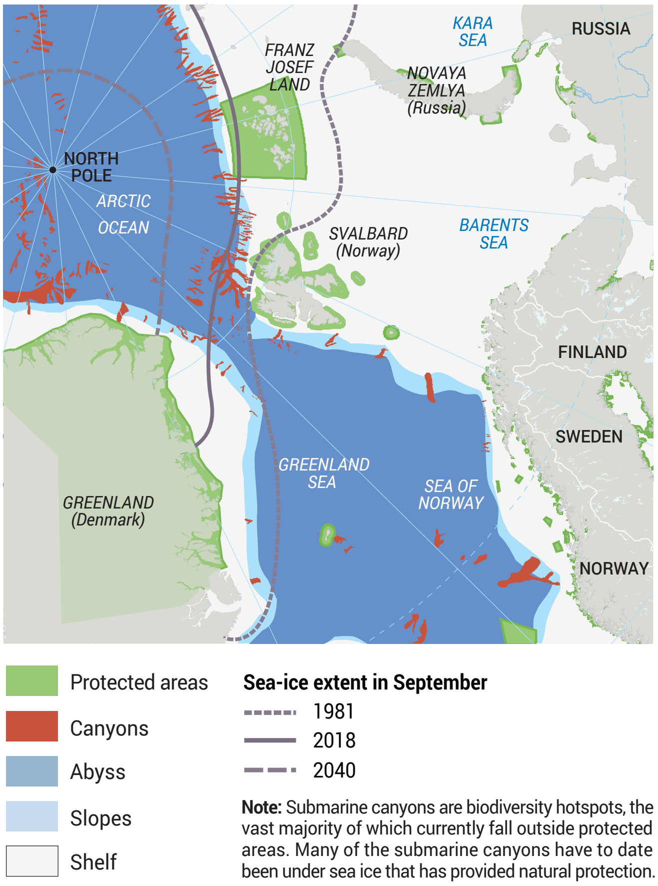
Protected areas: Filling the gaps

A shifting tree line, thawing permafrost and melting sea ice, coupled with rising temperatures and invasive species, are challenging and changing sensitive Arctic ecosystems and the people who depend on them. To address this new reality, Aichi Biodiversity Target 11 aims for at least 17 per cent of terrestrial and inland water and 10 per cent of coastal and marine areas to be under conservation, specifying the use of "effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes" (CBD, 2011).

While this target has not yet been achieved internationally and the biological representativeness of protected areas remains low (UN Environment WCMC and IUCN, 2016), in the Arctic the target has been met and exceeded for terrestrial and inland water areas, with 2.8 million km^2 (20.2 per cent) under protection (CAFF and PAME, 2017). However, there remain gaps in representation and connectivity that need to be addressed.

The story is different for the Arctic marine environment. A significant number of the world's ecologically or biologically significant marine areas (EBSAs) are in the Arctic (CBD, 2009). However, fewer than 1 per cent are in protected areas (CAFF and PAME, 2017). On its own, EBSA status offers no protection of any kind and while the number of marine protected areas has increased considerably in recent decades, only 4.7 per cent of the Arctic marine area (860,000 km^2) is under some form of protection. The majority of these existing protected areas cover coastal and continental shelf areas, providing little or no protection of many habitats and deep-sea floor features of the Arctic Ocean (Harris et al., 2017). In light of concerns that retreating sea ice will cause the expansion of offshore industry into new areas, there is an urgent need to expand the current protected areas network to include these pristine environments. Adapting existing protected areas (both on land and at sea), including accommodating for shifts in species distributions as a result of climate change, will also play an important role in effectively protecting species and ecosystems in the coming decades.

Submarine canyons without protection



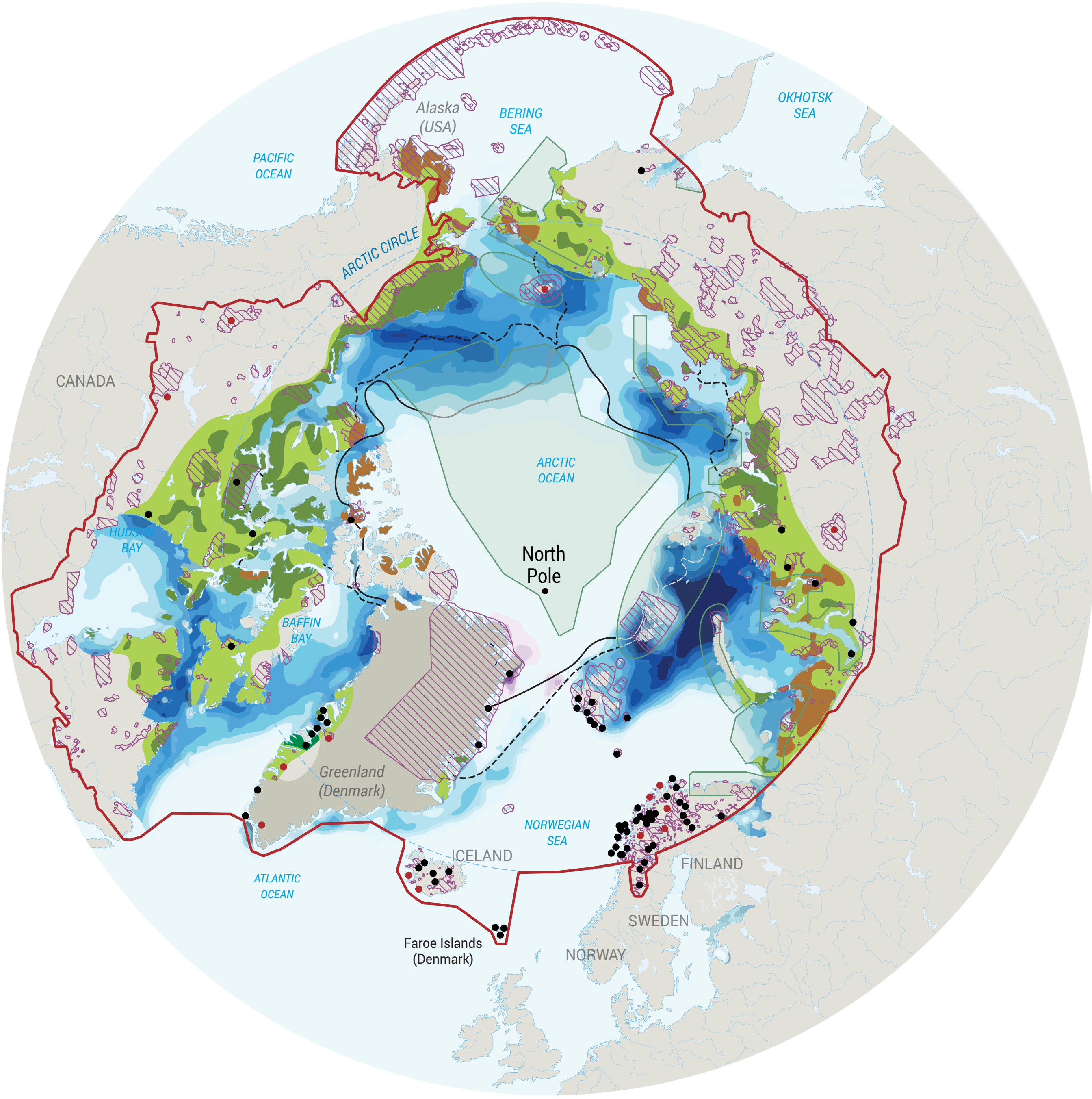
Note: Submarine canyons are biodiversity hotspots, the vast majority of which currently fall outside protected areas. Many of the submarine canyons have to date been under sea ice that has provided natural protection.

Aichi target 11 also recognizes that safeguarding biodiversity needs the support of local populations. The Fourth Global Biodiversity Outlook (GBO-4) specified that further progress on this target could be made through the involvement of Indigenous Peoples and local communities in the "creation, control, governance and management of protected areas" (CBD, 2014). The Edéhzhíe Protected Area in the Northwest Territories of Canada and the Laponia area in northern Sweden, are two examples of the co-management of resources and governance of protected areas in the Arctic.

Sacred natural sites are also being recognized for their importance in the conservation of both biological and cultural diversity and "as a tool for the preservation of fragile northern social-ecological systems" (Heinämäki and Herrmann, 2017). However, there is often little or no legal protection for such sites in the Arctic. Moreover, GBO-4 noted that greater progress towards meeting the Aichi targets requires "promoting initiatives that support traditional and local knowledge of biodiversity and promote customary sustainable use, including traditional health care initiatives, strengthening opportunities to learn and speak indigenous languages, research projects and data-collection using community-based methodologies, and involving local and indigenous communities in the creation, control, governance and management of protected areas" (CBD, 2014).

While traditional protected areas will continue to play a significant role in meeting current challenges, for example by providing carbon storage and essential habitat refugia, more effort is needed to address conservation beyond their borders. Both international cooperation and the involvement of Arctic peoples who are dependent upon these ecosystems and know them best will both be vital.

Protected areas in a changing environment



Normalized difference vegetation index (NDVI)
Percent change 1982-2012

- - 40% to 0
- 0 to + 25%
- 25 to 50%
- Ecologically or biologically significant marine areas

Regulated areas

- Protected areas
- CAFF boundary
- Ramsar sites
- UNESCO heritage sites

Summer open water
Magnitude change 1982-2012

- 40% - 20% 0 20% 40%

Changes in sea ice extent

- Sea ice extent in September 1981
- Sea ice extent in September 2018

Conclusion and key messages

The Arctic is facing multiple pressures and drivers of change from both inside and outside the region. These changes affect ecosystems, climate and human society in different and interconnected ways. The consequences have knock-on effects both at local, regional and global levels and the pace and extent of the changes mean that the Arctic and the rest of the world will be a very different place in the decades to come. Adapting to the changes presents a major challenge for people in the Arctic and beyond. Challenges can no longer be managed in isolation: a holistic, ecosystem-based approach that considers multiple drivers and cumulative pressures is needed.

The Arctic region has a significant impact on the global climate and there are strong feedback mechanisms between the Arctic and the rest of the world. Global emissions drive the melting of ice caps and glaciers, significantly contributing to rising sea levels, which will affect coastal and island communities throughout the world. Rising temperatures in the Arctic – twice the global average – thaw permafrost and melt snow and sea and land ice, which exacerbates the albedo effect. While climate change may create new economic opportunities, it is important that these are developed, managed and governed sustainably to ensure they do not cause more emissions and pollution or increase the risk of accidents that could damage ecosystems and people.

The geographical characteristics and cold climate of the Arctic make the region a sink for contaminants from around the globe and many pollutants remain there for long periods. While local sources of pollution exist, most pollutants come from lower latitudes. The good news is that international cooperation has been established. There are now a number of conventions, such as the Minamata Convention to reduce global mercury emissions, to address the chemicals known to be most harmful to the environment. However, there is no room for complacency: more than 150,000 chemical substances are in use around the world, fewer than 1,000 of which are regularly monitored. While there is still much we do not know, including the impacts of climate change and the role of plastic pollution in redistributing pollutants, we do know that POPs and heavy metals accumulate throughout the food chain and pose a serious threat to the health of both humans and wildlife.

The slightest change in temperature can have a substantial effect on ecosystems. This makes climate change the most serious threat to biodiversity in the Arctic. Moreover, it exacerbates all other threats, including overharvesting, habitat degradation, pollution, the spread of invasive species and disease. The graphics in this report explore some of the key Arctic–global linkages for biodiversity, focusing on the impact of rising global CO_2 levels and ocean acidification in the Arctic on marine ecosystems and the impact of climate change and related socioeconomic changes (including increased shipping) on the likely spread of invasive species into the Arctic. Arctic migratory species are also linked to the rest of the world: habitat degradation and loss, beside overharvesting along migratory flyways and waterways outside the Arctic, have a direct impact on these species. The spread of climate-sensitive zoonotic diseases into the Arctic from the south is also closely linked to global climate change.

Key messages

Climate change

- Many changes are already "locked-in" for the Arctic. In the years and decades to come, adaptation that integrates and respects local knowledge and Indigenous knowledge will be vital to help Arctic societies address the coming challenges.

- Global action is also needed to reduce CO_2 emissions to avoid tipping points. These include the thawing of permafrost, which could release large amounts of carbon into the atmosphere and derail efforts to meet the long-term goal of the Paris Agreement on climate change. Other possible tipping points are related to increased fresh water input or ocean acidification, with direct impacts on ocean circulation and ecosystems.

- Longer-term efforts to transition to low-carbon economies, both in the Arctic and globally, must be complemented by instant measures to reduce SLCPs, including methane, tropospheric ozone and black carbon. Immediately controlling SLCPs across the world could cut the rate of warming in the Arctic by up to two-thirds by mid-century.

- Concerted efforts are also needed to ensure that governments around the world understand the very real implications of Arctic climate change for their own countries and act appropriately.

Pollution

- As new chemical contaminants find their way to the Arctic, the need to strengthen international mechanisms becomes even more pressing. This includes an improved global approval system for new chemicals and exploring alternative control actions for chemicals not covered by existing conventions.

- Many pollutants remain in the Arctic for long periods. Some accumulate and build-up in the food chain, posing a health risk to people, animals and ecosystems.

- Tackling pollution both in the Arctic and globally has clear benefits for human health.

- The Arctic acts as a sink for chemicals and heavy metals and emerging evidence shows that the Arctic Ocean, its coastline and sea floor also act as a sink for plastics from around the world as well as from Arctic sources. Concerted regional and global action, with the participation of Arctic countries and stakeholders, is needed to manage the problem of plastic pollution.

- Increased understanding of the global effects of environmental change in the Arctic and the ways these changes affect ecosystems and the people who depend on them creates an opportunity for the harmonization and rationalization of multi-contaminant monitoring programmes.

Biodiversity

- International coordination and action outside the Arctic, including through the Convention on Migratory Species, to limit or stop overharvesting and habitat degradation in critical staging or wintering grounds is crucial for the conservation of Arctic migratory species.

- Future ocean acidification will likely mean changes in Arctic organisms and ecosystems reach a scale that will affect human societies.

- Early warning and further research and understanding is needed to adequately prepare for and prevent the spread of new, climate-sensitive zoonotic diseases in the Arctic.

- The risk of new invasive species both on land and at sea is also likely to rise in the future. This will require coordinated national and international action, including the measures outlined in documents such as the Arctic Invasive Alien Species Strategy and Action Plan.

- Arctic marine conservation is not always well prepared for all environmental changes as protected areas do not always cover biodiversity and ecological hotspots.

- To adapt to the coming changes, Arctic protected areas and networks on land and at sea will need to be flexible and adaptable to remain effective at conserving biodiversity. An example of this is being able to accommodate changes in species and ecosystem ranges as a result of climate change. Indigenous Peoples and other local communities must be involved in the creation, control and governance of protected and conserved areas to ensure fair and sustainable management of ecosystems and resilient local livelihoods, as outlined in Aichi Biodiversity Target 11.

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In the years and decades to come, adaptation that integrates and respects local knowledge and Indigenous knowledge will be vital to help Arctic societies address the coming challenges.

References for graphics

Arctic population and development
US Census Bureau and US Department of Commerce; Statistics Canada; Statistics Greenland; Statistics Faroe Islands; Statistics Iceland; Statistics Norway; Statistics Sweden; Statistics Finland; Russian Federal State Statistics Service; United States Geological Survey (USGS); Arctic Monitoring and Assessment Programme (AMAP); Conservation of Arctic Flora and Fauna (CAFF); US Energy Information Administration (EIA); International Energy Agency (IEA); Barents Euro–Arctic Council (BEAC); Comité professionnel du pétrole (CPDP); Institut français du pétrole (IFP); OpenStreetMap; United Nations Population Information Network (POPIN); Petroleum Economist.

Indigenous Peoples
W. K. Dallmann, Norwegian Polar Institute (NPI); Natural Earth; Russian Association of Indigenous Peoples of the North (RAIPON); Conservation of Arctic Flora and Fauna (CAFF); Inuit Circumpolar Council, 2017; Indigenous Peoples' Secretariat, Arctic Council. Based on a map by L. Westerveld, Grid-Arendal, 2016.

Arctic climate change
Snow, Water, Ice and Permafrost in the Arctic (SWIPA), Arctic Monitoring and Assessment Programme (AMAP), 2017 (based on the data and graphic compiled by G.M. Flato, of the Canadian Centre for Climate Modelling and Analysis - CCCma); IPCC Fourth Assessment Report, 2007, Chapter 15, Polar Regions; IPCC Fifth Assessment Report, 2014, Chapter 28, Polar Regions.

Sea level rise and ocean currents
National Oceanic and Atmospheric Administration (NOAA), National Ocean Service (NOS); Intergovernmental Panel on Climate Change (IPCC); Millennium Ecosystem Assessment; World Resources Institute (WRI); United Nations Environment Programme (UNEP); The World Bank; World Meteorological Organization (WMO); R.J. Nicholls and A. Cazenave, Sea-Level Rise and Its Impact on Coastal Zones, Science, 2010, 328(5985): 1517–1520.

The melting cryosphere
National Snow and Ice Data Center (NSIDAC); J. Richter-Menge, et al. (eds.), 2017 Arctic Report Card 2017, Arctic Programme, National Oceanic and Atmospheric Administration (NOAA); The Arctic Environment European Perspectives on a Changing Arctic, European Environment Agency, 2017; Assessment 2018: Arctic Ocean Acidification, Arctic Monitoring and Assessment Programme (AMAP); Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017, AMAP.

Permafrost and climate change
Adapted from Riccardo Pravettoni; AWI.

Thawing permafrost
International Permafrost Association (IPA), 2018; National Snow and Ice Data Center (NSIDC); C. Voigt., et al., "Increased nitrous oxide emissions from Arctic peatlands after permafrost thaw", PNAS, 114 (24) 6238-62432017 2017; Intergovernmental Panel on Climate Change (IPCC); A.G. Slater and D. Lawrence, Diagnosing Present and Future Permafrost from Climate Models, Journal of Climate, 2013.

SLCP hotspots
D. Koch and J. Hansen, "Distant origins of Arctic black carbon: A Goddard Institute for Space Studies Model experiment", Journal of Geophysical Research, 2005; Measures to reduce emissions of Short-Lived Climate Pollutants (SLCP) in the Nordic countries, Nordic Council of Ministers, 2018; Mitigation of Arctic warming by controlling European black carbon emissions (MACEB), 2013; European Space Agency Anthropogenic Greenhouse Gases Climate Change Initiative (ESA GHC CCI) Climate Research Data Package (CRDP); O. Cooper et al., Tropospheric ozone and its precursors from the urban to the global scale from air quality to short-lived climate forcer, 2015; International Chamber of Shipping (ICS); IHS Global Insight; World Shipping Council.

Short-Lived Climate Pollutants
AMAP Assessment 2015: Methane as an Arctic climate forcer, 2015; Summary for Policy-makers: Arctic Climate Issues 2015, Short-lived Climate Pollutants, AMAP; AMAP Assessment 2015: Black carbon and ozone as Arctic climate forcers; International Council on Clean Transportation (ICCT), Prevalence of heavy fuel oil and black carbon in Arctic shipping, 2015 to 2025, 2017; National Oceanic & Atmospheric Administration (NOAA), Earth System Research Laboratory (ESRL); S. Shankman, These Climate Pollutants Don't Last Long, But They're Wreaking Havoc on the Arctic, Inside Climate News, 2018; A. Stohl et al., Black carbon in the Arctic: the underestimated role of gas flaring and residential combustion emissions, Atmospheric Chemistry and Physics, 2013.

Trends in temperature, CO_2 and pH
National Aeronautics and Space Administration (NASA), Goddard Institute for Space Studies (GISS); National Oceanic and Atmospheric Administration (NOAA), Pacific Marine Environmental Laboratory (PMEL), Carbon Group; NASA, Global Climate Change: Vital Signs of the Planet; World Meteorological Organization (WMO).

Ocean acidification
Assessments of Arctic Ocean acidification for 2013 and 2018, Arctic Monitoring and Assessment Programme (AMAP); N.S. Steiner, et al., Future ocean acidification in the Canada Basin and surrounding Arctic Ocean from CMIP5 earth system models, Journal of Geophysical Research-Oceans, 2014, 119(1): 332–347; M. Yamamoto-Kawai, et al., Aragonite Undersaturation in the Arctic Ocean: Effects of Ocean Acidification and Sea Ice Melt, Science, 2009, 326(5956): 1098–1100; Arctic Report Card 2015, Arctic Programme, National Oceanic and Atmospheric Administration (NOAA).

Global cultivation intensity as a proxy for POPs
Food and Agriculture Organization of the United Nations, FAOSTATS; S. Siebert, et al., Global Patterns of Cropland Use Intensity, Remote Sensing, 2010, 2(7): 1625–1643; W. Wenbin, et al., Global Cropping Intensity Gaps: Increasing Food Production without Cropland Expansion, Land use Policy, 2018, 76(July): 515–525; Goddard Institute for Space Studies (GISS), National Aeronautics and Space Administration (NASA), Global Land Cover Datasets; E. Matthews, Global Vegetation and Land Use: New High-resolution Data Bases for Climate Studies, Journal of Applied Meteorology and Climatology, 1983, 22: 474–487.

Persistent organic pollutants
EBAS database, European Monitoring and Evaluation Programme (EMEP), Arctic Monitoring and Assessment Programme (AMAP), Norwegian Institute for Air Research (NILU); K. Tørseth et al., Introduction to the European Monitoring and Evaluation Programme (EMEP) and observed atmospheric composition change during 1972–2009, Atmospheric Chemistry and Physics, June 2012; AMAP Assessment 2015: Temporal Trends in Persistent Organic Pollutants in the Arctic; Arctic Pollution Issues 2015, Persistent Organic Pollutants; Radioactivity in the Arctic, Human Health in the Arctic, Summary for Policy-makers; AMAP Assessment 2016: Chemicals of Emerging Arctic Concern.

Global distribution of microplastics
E. van Sebille et al., A global inventory of small floating plastic debris, IOP Publishing, 2015; Cooperative Institute for Meteorological Satellite Studies; K. Lavender Law, Plastics in the Marine Environment, Annual Review of Marine Science, 2016; H. Ritchie and M. Roser, Plastic Pollution, Our World in Data, 2018; J. R. Jambeck et al., Plastic waste inputs from land into the ocean, Science, 2015; R. Geyer et al., Production, use, and fate of all plastics ever made, Science, 217; L. Lebreton, River plastic emissions to the world's oceans, Nature Communications, 2017; The Ocean Cleanup; K. Martini, Where is the best place to put your ocean cleanup device? Not where currently proposed, Deep Sea News, 2016. Based on two maps from R. Pravettoni, Grid-Arendal, 2016.

Plastic input into the Arctic Ocean
U.S. Global Change Research Program; Arctic Great Rivers Observatory, Woods Hole Research Center; Center for International Earth Science Information Network (CIESIN), 2017; A. Cózar et al., The Arctic Ocean as a dead end for floating plastics in the North Atlantic branch of the Thermohaline Circulation, American Association for the Advancement of Science, 2017; Laurent Lebreton, The Ocean Cleanup; J. F. Provencher, Quantifying ingested debris in marine megafauna: a review and recommendations for standardization, Analytical Methods, Royal Society of Chemistry, 2017; Convention on Biological Diversity.

Global use of mercury
Mercury: Acting Now!, UNEP Chemicals Branch, UNEP, 2013; Technical Background Report for the Global Mercury Assessment, Arctic Monitoring and Assessment Programme (AMAP), 2013; Global Mercury Assessment 2013: Sources, Emissions, Releases and Environmental Transport, UNEP; Global Mercury Supply, Trade and Demand, UNEP, 2017.

Mercury in Arctic soil
P.F. Schuster. et al., Permafrost Stores a Globally Significant Amount of Mercury, Geophysical Research Letters, 2018, 45(3): 1463–1471; National Snow and Ice Data Center (NSIDC), January 2018; Assessment 2011: Mercury in the Arctic, Arctic Monitoring and Assessment Programme (AMAP); Global Mercury Modelling: Update of Modelling Results in the Global Mercury Assessment 2013, AMAP; UNEP Chemicals Branch, 2015; Mercury: Acting Now!, UNEP Chemicals Branch, UNEP, 2013; Technical Background Report for the Global Mercury Assessment, AMAP, 2013; A.G. Slater and D. Lawrence, Diagnosing Present and Future Permafrost from Climate Models, Journal of Climate, 2013.

The journey of methylmercury in the food chain
Technical Background Report for the Global Mercury Assessment, Arctic Monitoring and Assessment Programme (AMAP), 2013; I. Lehnherr, 2014. Methylmercury Biogeochemistry: A Review with Special Reference to Arctic Aquatic Ecosystems, Environmental Reviews, 2014, 22(3): 229–243; J.L. Kirk, 2006. Potential Sources of Monomethyl Mercury in Arctic and Subarctic Seawater, Arctic, 2006, 56(1): 108–111.

Pollution and human health
AMAP Assessment 2015, Human Health in the Arctic; AMAP Assessment 2018, Biological Effects of Contaminants on Arctic Wildlife and Fish.

Migratory species worldwide
Adapted from G. Harris, et al., Global Decline in Aggregated Migrations of Large Terrestrial Mammals, Endangered Species Research, 7: 55–76, 2009; Milner-Gulland, E.J. et al., Animal Migration A Synthesis, Oxford University Press, 2011; Billions of Birds Migrate: Where Do They Go?, National Geographic, March 2018; Living Planet: Connected Planet, GRID-Arendal, 2012; B. Hoare, Animal Migration Remarkable Journeys by Air, Land and Sea, London Natural History Museum, 2009; L. Medrano González and J. Urbán Ramírez, La ballena jorobada en la Norma Oficial Mexicana [The humpback whale in the Official Mexican Standard], Universidad Nacional Autónoma de México, Faculty of Sciences, SNIB-CONABIO, Mexico, 2002; Conservation of Arctic Flora and Fauna (CAFF); Arctic Migratory Birds Initiative (AMBI); S. Nebel, Animal Migration. Nature Education Knowledge, 2010, 3(10): 77; Migratory Birds and Flyways, Birdlife Flyways Programme, Birdlife International.

Migratory pathways in the Arctic
Oceans North, 2018; P. Boveng, et al., Seasonal Migration of Bearded Seals Between Intensive Foraging Patches, National Oceanic and Atmospheric Administration (NOAA); Global Fishing Watch, 2018; B. Lehner, et al., High-Resolution Mapping of the World's Reservoirs and Dams for Sustainable River-Flow Management, Frontiers in Ecology and the Environment, 2011, 9(9): 494–502; Environment and Natural Resources (ENR), Government of the Northwest Territories (GNWT), Barren-ground Caribou; Circum Arctic Rangifer Monitoring and Assessment Network (CARMA); WWF Arctic Geographical Information System; G.B. Stenson, et al., The Impact of Changing Climate and Abundance on Reproduction in an Ice-dependent Species, the Northwest Atlantic Harp Seal, Pagophilus groenlandicus, ICES Journal of Marine Science, 2015, 73(2): 250–262; P.E. Jorde, et al., Detecting Genetic Structure in Migrating Bowhead Whales off the Coast of Barrow, Alaska, Molecular Ecology, 2007, 16(10): 1993–2004; D. W. Hauser, Seasonal Sea Ice and Arctic Migrations of the Beluga Whale, Alaska Park Science, 2018, 17(1); Kuznetsova et al., 2016; WWF, 2018; US Global Change Research Programme, 2018; National Oceanic and Atmospheric Administration (NOAA) Ocean Media Center and National Marine Fisheries Service (NMFS) Alaska Fisheries Science Center, 2010; Arctic Portal, 2018; CAFF, 2017.

Invasive globetrotters
J.L. Molnar, et al., Assessing the Global Threat of Invasive Species to Marine Biodiversity, Frontiers in Ecology and the Environment, 2008, 6(9): 485–492; H. Seebens, et al., Predicting the Spread of Marine Species Introduced by Global Shipping, Proceedings of the National Academy of Sciences of the United States of America, 2016, 113(20): 5646–5651; R. Early, et al., Global Threats from Invasive Alien Species in the Twenty-first Century and National Response Capacities, Nature, 2016, 7: 12485; International Maritime Organization (IMO); P. Rekacewicz, et al., UNOSAT Global Report on Maritime Piracy – A Geospatial Analysis 1995–2013, 2014.

Marine invasive pathways in the Arctic
N. Vestergaard, et al., Arctic Marine Resource Governance and Development, Springer, 2018; J.L. Molnar, et al., Assessing the Global Threat of Invasive Species to Marine Biodiversity, Frontiers in Ecology and the Environment, 2008, 6(9): 485–492; State of the Arctic Marine Biodiversity Key Findings and Advice for Monitoring, Conservation of Arctic Flora and Fauna (CAFF), 2017; G. Lorentzen, et al., Current Status of the Red King Crab (Paralithodes camtchaticus) and Snow Crab (Chionoecetes opilio) Industries in Norway, Reviews in Fisheries Science & Aquaculture, 2018, 26(1): 42–54; Food and Agriculture Organization of the United Nations (FAO), Fisheries and Aquaculture, Aquatic Species Distribution; E. Regan, et al., Global Threats from Invasive Alien species in the Twenty-first Century and National Response Capacities, Nature Communications, 2016, 7: 12485; Protection of the Arctic Marine Environment (PAME), 2018; L. Fernandez et al. (eds.), Marine invasive species in the Arctic, Norden, 2014; CAFF, Arctic Biodiversity Assessment (ABA), 2018; K.L. Laidre, et al., Quantifying the Sensitivity of Arctic Marine Mammals to Climate- induced Habitat Change, Ecological Applications, 2008, 18(2 special): S97–S125.

Probable hotspots for infectious diseases
T. Allen et al., Global hotspots and correlates of emerging zoonotic diseases, Nature Communications, 2017; UNEP Frontiers 2016 Report: Emerging Issues of Environmental Concern; Global animal disease intelligence report, Food and Agriculture Organization of the United Nations (FAO), 2017.

The northward spread of infectious disease
D. Porretta et al., Effects of global changes on the climatic niche of the tick Ixodes ricinus inferred by species distribution modelling, Parasites and Vectors, 2013; M. G. Walsh et al., Climatic influence on anthrax suitability in warming northern latitudes, Scientific Reports, Nature, 2018; M. McPherson et al., Expansion of the Lyme Disease Vector Ixodes Scapularis in Canada Inferred from CMIP5 Climate Projections, Environmental Health Perspectives, 2017.

Submarine canyons without protection
P.T. Harris, Arctic Marine Conservation Is Not Prepared for the Coming Melt, ICES Journal of Marine Science, 2018, 75(1): 61–71. Based on a map by M. Macmillan-Lawler, personal communication, 2019.

Protected areas in a changing environment
US Global Change Research Program, Arctic Area Ice Extent, 2018; Conservation of Arctic Flora and Fauna (CAFF), 2016 and 2017; T. Barry, et al., Arctic Protected Areas in 2017: Status and Trends, Biodiversity, 2017, 18(4): 186-195.

References

ACAP (2014) Reduction of Black Carbon Emissions from Residential Wood Combustion in the Arctic – Black Carbon Inventory, Abatement Instruments and Measures. Arctic Contaminants Action Program (ACAP).

ACIA (2004) Impacts of a Warming Arctic: Arctic Climate Impact Assessment (ACIA). Cambridge University Press.

Allen, T., Murray, K.A., Zambrana-Torrelio, C., Morse, S.S., Rondinini C., et al. (2017) Global hotspots and correlates of emerging infectious zoonotic diseases. Nature Communications, 8: 1124.

AMAP (2009) Arctic Pollution 2009. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP (2011) Assessment 2011: Mercury in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP (2013) AMAP Assessment 2013: Arctic Ocean Acidification. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP (2015a) AMAP Assessment 2015: Methane as an Arctic climate forcer. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP (2015b) AMAP Assessment 2015: Black carbon and ozone as Arctic climate forcers. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP (2015c) Summary for Policy-makers: Arctic Climate Issues 2015. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP (2015d) Assessment 2015: Human Health in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP (2016) AMAP Assessment 2016: Chemicals of Emerging Arctic Concern. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP (2017a) Snow, Water, Ice and Permafrost in the Arctic (SWIPA). Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP (2017b) Chemicals of Emerging Arctic Concern. Summary for Policy-makers. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP (2018) Adaptation Actions for a Changing Arctic (AACA) – all assessment three “perspectives” reports. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.

AMAP (2018a). AMAP Assessment 2018: Arctic Ocean Acidification. Arctic Monitoring and Assessment Programme (AMAP), Tromsø, Norway.

AMAP (2018b) AMAP Assessment 2018: Biological Effects of Contaminants on Arctic Wildlife and Fish. Arctic Monitoring and Assessment Programme (AMAP), Tromsø, Norway.

Anderson, L. G., Ek, J., Ericson, Y., Humborg, C., Semilentov, I. Sundbom, M. and Ulfsbo, A. (2017) Export of Calcium Carbonate Corrosive Waters from the East Siberian Sea’. Biogeosciences, 14(7): 1811–1823.

Angot, H., Magand, O., Helmig, D., Ricaud, P., Quennehen, B., Gallée, H., Del Guasta, M., Sprovieri, F., Pirrone, N., Savarino, J. and Dommergue, A. (2016) New insights into the atmospheric mercury cycling in central Antarctica and implications on a continental scale. Atmospheric Chemistry and Physics, 16(13): 8249–8264.

Anthony, K.W., von Deimling, T. S., Nitze, I., Frolking, S., Emond, A., Daanen, R, et al. (2018) 21st-century modeled permafrost carbon emissions accelerated by abrupt thaw beneath lakes. Nature Communications, 9: 3262.

Arctic Council (2011) Arctic Council Task Force on Short-Lived Climate Forcers: An Assessment of Emissions and Mitigation Options for Black Carbon for the Arctic Council.

Arctic Council (2017) Fairbanks Declaration.

Bamber, J. L., Westaway, R., Marzeion M. B. and Wouters B. (2018) The land ice contribution to sea level during the satellite era. Environmental Research Letters, 13: 063008.

Bartels, M. (2018) Melting Permafrost Below Arctic Lakes Is Even More Dangerous to the Climate, NASA Warns. Space.com, 18 August 2018.

Bellard C., Cassey P. and Blackburn T. M. (2016) Alien species as a driver of recent extinctions. Biology Letters, 12: 20150623.

Bellerby, R.G.J. (2017) Ocean acidification without borders. Nature Climate Change, 7: 241–242.

Bergmann, M., Tekman M. B. and Gutow L. (2017a) Sea change for plastic pollution. Nature, 544: 297.

Bergmann, M., Lutz, B., Tekman M. B. and Gutow L. (2017b) Citizen scientists reveal: Marine litter pollutes Arctic beaches and affects wild life. Marine Pollution Bulletin, 125(1–2): 535–540.

Bergmann, M., Wirzberger, V., Krumpen, T., Lorenz, C., Primpke, S., Tekman, M. B. and Gerdts, G. (2017d) High Quantities of Microplastic in Arctic Deep-Sea Sediments from the HAUSGARTEN Observatory. Environmental Science & Technology, 51(19): 11000–11010.

Biastoch, A., Treude, T., Rupke, L. H., Riebesell, U., Roth, C., Burwicz, E. B., et al. (2011) Rising Arctic Ocean temperatures cause gas hydrate destabilization and ocean acidification. Geophysical Research Letters, 38(8): L08602.

Binder, T. R., Cooke, S. J. and Hinch S. G. (2011) The Biology of Fish Migration. (Farrell A. P., ed.) Encyclopedia of Fish Physiology: From Genome to Environment 3, San Diego, California: Academic Press, pp. 1921–1927.

Bokhorst S., Pedersen S. H., Brucker L., et al. (2016) Changing Arctic snow cover: A review of recent developments and assessment of future needs for observations, modelling, and impacts. Ambio, 45(5): 516–537.

Buhl-Mortensen, L. and Buhl-Mortensen P. (2017) Marine litter in the Nordic Seas: Distribution composition and abundance. Marine Pollution Bulletin, 125(1–2): 260–270.

CAFF (2013) Arctic Biodiversity Assessment: Report for Policy Makers. Conservation of Arctic Flora and Fauna (CAFF), Akureyri, Iceland.

CAFF (2017) State of the Arctic Marine Biodiversity Report. Conservation of Arctic Flora and Fauna (CAFF), Akureyri, Iceland.

CAFF and PAME (2017) Arctic Protected Areas: Indicator Report, 2017: Conservation of Arctic Flora and Fauna (CAFF) and Protection of the Arctic Marine Environment (PAME), Akureyri, Iceland.

CBD (2009) Ecologically or Biologically Significant Marine Areas. Secretariat of the Convention on Biological Diversity (CBD).

CBD (2011) Strategic plan for biodiversity 2011-2020. Further information related to the technical rationale for the Aichi Biodiversity Targets, including potential indicators and milestones. Conference Of The Parties To The Convention On Biological Diversity (CBD). Tenth meeting, Nagoya, Japan, 18–29 October 2010. UNEP/CBD/COP/10/INF/12/Rev.1.

CBD (2014) An Updated Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity (S. Hennige, J.M. Roberts and P. Williamson, eds.). Secretariat of the Convention on Biological Diversity (CBD), Montreal, Technical Series No. 75.

Collins, M., Knutti, R. Arblaster, J. Dufresne, J.-L. Fichefet, T. Friedlingstein, P., et al., 2013: Long-term Climate Change: Projections, Commitments and Irreversibility. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., et al. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Comeau, S., Gorsky, G., Jeffree, R., Teyssié, J. L. and Gattuso, J. P. (2009) Impact of ocean acidification on a key Arctic pelagic mollusc (Limacina helicina). Biogeosciences, 6(9): 1877–1882,

CMS (2018) Convention on the Conservation of Migratory Species of Wild Animals (CMS).

Council of Canadian Academies (2014) Aboriginal Food Security in Northern Canada: An Assessment of the State of Knowledge. The Expert Panel on the State of Knowledge of Food Security in Northern Canada, Council of Canadian Academies, Ottawa, ON.

Cózar, A., Martí, E., Duarte, C. M., García de Lomas, J., Van Sebille, E., Ballatore, T. J, et al. (2017) The Arctic Ocean as a dead end for floating plastics in the North Atlantic branch of the Thermohaline Circulation. Science Advances, 3(4): e1600582.

Dai, A., Lua, D., Song, M. and Liu, J. (2019) Arctic amplification is caused by sea-ice loss under increasing CO2. Nature Communications, 10: 121.

Deinet, S., Zöckler, C., Jacoby, D., Tresize, E., Marconi, V., McRae, L., Svobods, M. and Barry, T. (2015) The Arctic Species Trend Index: Migratory Birds Index. Conservation of Arctic Flora and Fauna, Akureyri, Iceland.

DiMento, B. P., Mason, R. P., Brooks, S. and Moore, C. (2019) The impact of sea ice on the air-sea exchange of mercury in the Arctic Ocean. Deep Sea Research Part I: Oceanographic Research Papers, 144: 28–38.

Dirzo, R., Young, H. S., Galetti, M., Ceballos, G., Isaac, N. J. and Collen, B. (2014) Defaunation in the Anthropocene. Science, 345: 401–406.

Doney, S. C., Fabry, V. J., Feely, R. A. and Kleypas, J. (2009) Ocean Acidification: The Other CO2 Problem. Annual Review of Marine Science, 1: 169–192.

Driscoll, C. T., Mason, R. P., Chan, H. M., Jacob, D. J. and Pirrone, N. (2013) Mercury as a global pollutant: sources, pathways, and effects. Environmental Science & Technology, 47(10): 4967–4983.

EEA. (2012) The Impacts of Invasive Alien Species in Europe. EEA Technical Report. European Environment Agency (EEA), Copenhagen.

Evengård B. and Sauerborn R. (2009) Climate change influences infectious diseases both in the Arctic and the tropics: joining the dots. Global Health Action.

Fang, C., Zheng, R., Zhang, Y. Hong, F., Mu, J., Chen, M., Song, P., Lin, L., Lin, H., Le F., and Bo J. (2018) Microplastic contamination in benthic organisms from the Arctic and sub-Arctic regions. Chemosphere, 209: 298–306.

Gauthreaux, S. A. (1982) The ecology and evolution of avian migration systems. Avian Biology, pp. 93–68.

Glomsrød, S., Duhaime G. and Aslaksen, I. (2017) The Economy of the North 2015. Statistics Norway, Oslo and Kongsvinger.

Government of Canada (2018) Surveillance of Lyme Disease.

Goudarzi, S. (2016) What Lies Beneath. Scientific American, 315(5): 11–12.

Grøsvik, B. E., T. Prokhorova, E. Eriksen, P. Krivosheya, P. A. Horneland and D. Prozorkevich (2018) Assessment of Marine Litter in the Barents Sea, a Part of the Joint Norwegian–Russian Ecosystem Survey. Frontiers Marine Science, 5: 72.

Ha, E., Basu, N., Bose-O'Reilly, S., Dórea, J.G., McSorley, E., Sakamoto, M. and Chan, H.M. (2017) Current progress on understanding the impact of mercury on human health. Environmental Research, 152: 419–433.

Hallanger I. G. and Gabrielsen, G. W. (2018) Plastic in the European Arctic. Brief Report no. 045. Norwegian Polar Institute, Tromsø, Norway.

Harper, G.A. and Bunbury, N. (2015) Invasive rats on tropical islands: Their population biology and impacts on native species. Global Ecology and Conservation, 3: 607–627.

Harris, P.T., Macmillan-Lawler, M., Kullerud, L. and Rice, J.C. (2017) Arctic marine conservation is not prepared for the coming melt. ICES Journal of Marine Science, 75(1): 61–71.

Heinämäki, L. and Herrmann, T. M. (2017) Experiencing and Protecting Sacred Natural Sites of Sámi and other Indigenous Peoples. Springer International.

Hjort, J., Karjalainen, O., Aalto, J., Westermann, S., Romanovsky, V. E., Nelson, F. E., Etzelmüller, B. and Luoto, M., (2018) Degrading permafrost puts Arctic infrastructure at risk by mid-century. Nature Communications, 9: 5147.

Hollesen, J., Callanan, M., Dawson, T., Fenger-Nielsen, R., Friesen, T., Jensen, A., . . . Rockman, M. (2018) Climate change and the deteriorating archaeological and environmental archives of the Arctic. Antiquity, 92(363), 573-586.

Holmes, R. M., J. W. McClelland, B. J. Peterson, S. E. Tank, E. Bulygina, T. I. Eglinton, V. V. Gordeev, T. Y. Gurtovaya, P. A. Raymond, D. J. Repeta, R. Staples, R. G. Striegl, A. V. Zhulidov and S. A. Zimov (2011) Seasonal and Annual Fluxes of Nutrients and Organic Matter from Large Rivers to the Arctic Ocean and Surrounding Seas. Estuaries and Coasts, 35(2): 369–382.

Horowitz, H. M., D. J. Jacob, H. M. Amos, D. G. Streets and E. M. Sunderland (2014) Historical mercury releases from commercial products: Global environmental implications. Environmental Science and Technology, 48: 10242–10250.

Hovelsrud, G. K., B. Poppel, B. van Oort and J. D. Reist (2011) Arctic Societies, Cultures, and Peoples in a Changing Cryosphere. Ambio, 40(1): 100–110.

Hueffer, K., Parkinson, A.J., Gerlach, R., and Berner, J. (2013) Zoonotic infections in Alaska: disease prevalence, potential impact of climate change and recommended actions for earlier disease detection, research, prevention and control. International Journal of Circumpolar Health, 72: 19562.

IISD (2017) Countries Agree to Prevent Unregulated Fishing in Central Arctic Ocean. International Institute for Sustainable Development (IISD).

IPCC (2014) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team, R.K. Pachauri and L.A. Meyer eds.). Intergovernmental Panel on Climate Change (IPCC), Geneva, Switzerland, pp. 117–130.

IPCC, 2018. Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., et al. (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp.

Jahn, A., Kay, J. E., Holland, M.M. and Hall, D. M. (2016) How predictable is the timing of a summer ice-free Arctic? Geophysical Research Letters, 43(17): 9113–9120.

Jambeck, J. R., R. Geyer, C. Wilcox, T. R. Siegler, M. Perryman, A. Andrady, R. Narayan and K. L. Law (2015) Marine pollution. Plastic waste inputs from land into the ocean. Science, 347(6223): 768–771.

Jones, M. (2004) Salmo salar. Cultured Aquatic Species Information Programme. FAO Fisheries and Aquaculture Department. Rome.

Karagas, M.R., Choi, A.L., Oken, E., Horvat, M., Schoeny, R., Kamai, E., et al. (2012) Evidence on the human health effects of low-level methylmercury exposure. Environmental health perspectives, 120(6): 799–806.

Laidre, K. L., Stern, H., Kovacs, K. M., Lowry, L., Moore, S. E., Regehr, E. V., et al. (2015) Arctic marine mammal population status, sea ice habitat loss, and conservation recommendations for the 21st century. Conservation Biology, 29(3): 724–737.

Larsen J. N. and Fondahl G. (2015, eds.) Arctic Human Development Report Regional Processes and Global Linkages. Nordic Council of Ministers, Denmark.

Leighton, P.A., Koffi, J.K., Pelcat , Y., Lindsay, L.R. and Ogden. N.H. (2012) Predicting the speed of tick invasion: an empirical model of range expansion for the Lyme disease vector Ixodes scapularis in Canada. Journal of Applied Ecology, 49(2): 457–464.

Lorentzen G., Voldnes, G., Whitaker, R.D., Kvalvik, I., Vang, B., Solstad, R.G., Thomassen, M.R. and Siikavuopio S.I. (2018) Current Status of the Red King Crab (Paralithodes camtchaticus) and Snow Crab (Chionoecetes opilio) Industries in Norway. Reviews in Fisheries Science & Aquaculture, 26(1): 42–54

Maas, R. and Grennfelt, P. (2016) Towards cleaner air. Arctic Monitoring and Assessment Programme.

McRae, L., Zöckler, C., Gill, M., Loh, J., Latham, J., Harrison, N., Martin, J. and Collen, B. (2010) Arctic Species Trend Index 2010: Tracking Trends in Arctic Wildlife. CAFF CBMP Report No. 20, CAFF International Secretariat, Akureyri, Iceland.

Miller, A.W. and Ruiz, G.M. (2014) Arctic shipping and marine invaders. Nature Climate Change, 4: 413–416.

Melia, N., K. Haines and E. Hawkins (2016) Sea ice decline and 21st century trans-Arctic shipping routes, Geophysical Research Letters banner, 43(18): 9720–9728.

Mossler, M. V., Bostrom, A., Kelly, R. P., Crosman, K. M. and Moy, P. (2017) How does framing affect policy support for emissions mitigation? Testing the effects of ocean acidification and other carbon emissions frames, Global Environmental Change, 45: 63–78.

Murray J. L., H., L., Gregor, D. J., Loeng, H. (1998) Physical/Geographical Characteristics of the Arctic. AMAP Assessment Report: Arctic Pollution Issues. Oslo, Norway.

Nashoug, B. F. (2017) Sources of Marine Litter: Workshop Report, Svalbard 4–6 September 2016. SALT report no. 1017.

Nakhshina, M. (2016) Constraints on community participation in salmon fisheries management in Northwest Russia. Marine Policy, 74: 309–315.

Noël, B., van de Berg, W. J., Lhermitte, S., Wouters, B., Machguth, H., Howat I., et al. (2017) A tipping point in refreezing accelerates mass loss of Greenland's glaciers and ice caps. Nature Communications, 8: 14730.

NSIDC (2018) Circum-Arctic Map of Permafrost and Ground-Ice Conditions, Version 2. National Snow and Ice Data Center (NSIDC). Online. Accessed 28 August 2018.

NSIDC (2019) Arctic sea ice maximum ties for seventh lowest in satellite record. National Snow and Ice Data Center (NSIDC). http://nsidc.org/arcticseaicenews/ - accessed 21 March 2019

Obrist, D., Agnan, Y., Jiskra, M., Olson, C. L., Colegrove, D. P., Hueber, J., et al. (2017) Tundra uptake of atmospheric elemental mercury drives Arctic mercury pollution. Nature, 547(7662): 201–204.

Obrist, D., Kirk, J.L., Zhang, L., Sunderland, E.M., Jiskra, M. and Selin, N.E. (2018) A review of global environmental mercury processes in response to human and natural perturbations: Changes of emissions, climate, and land use. Ambio, 47(2): 116–140.

O'Donnell, M., Hammond, L., M. and Hofmann, G. (2008) Predicted impact of ocean acidification on a marine invertebrate: elevated CO. Marine Biology, 156: 439–446.

Overland, J., Dunlea, E., Box, J.E., Corell, R., Forsius, M., Kattsov, V., Olsen, Morten.Skovgå., Pawlak, J., Reiersen, L.-O. and Wang, M. (2018) The urgency of Arctic change, Polar Science, in press.

Parkinson, C. L. and N. E. DiGirolamo (2016) New visualizations highlight new information on the contrasting Arctic and Antarctic sea-ice trends since the late 1970s. Remote Sensing of Environment, 183: 198–204.

Pimentel, D., Mcnair, S., Janecka, J., Wrightman, J., Simmonds, C., O'Connell, C., and Wong, E. (2001) Economic and environmental threats of alien plant, animal, and microbe invasions. Agriculture, Ecosystems and Environment, 84: 1–20.

Provencher, J. F., Bond, A. L., Avery-Gomm, S., Borrelle, S. B., Bravo Rebolledo, E. L., Hammer, S., et al. (2017) Quantifying ingested debris in marine megafauna: a review and recommendations for standardization. Analytical Methods, 9(9): 1454–1469.

Provencher, J. V. Johnston, E. Syroechkovskiy, N. Crockford, R.B. Lanctot, S. Millington, R., et al. (2018). Arctic Migratory Birds Initiative (AMBI): Revised Workplan 2015–2019. CAFF Strategies Series No. 6. Conservation of Arctic Flora and Fauna, Akureyri, Iceland.

Royer S.J., Ferrón S, Wilson S.T. and Karl, D.M. (2018) Production of methane and ethylene from plastic in the environment. PLoS ONE, 13(8): e0200574.

Samenow, J. (2018) This Summer Has Been Brutal: Show These 7 Images to Anyone Who Says It's Normal. Science Alert, 18 August 2018. https://www.sciencealert.com/this-summer-has-been-brutal-and-these-7-unsettling-charts-show-why-you-should-be-concerned - accessed March 2018.

Sato-Okoshi, W., Okoshi, K., Sasaki, H. and Akiha F. (2010) Shell structure of two polar pelagic molluscs, Arctic Limacina helicina and Antarctic Limacina helicina antarctica forma antarctica. Polar Biology, 33: 1577–1583.

Schiermeier, Q. (2018) Droughts, heatwaves and floods: How to tell when climate change is to blame. Nature: International Journal of Science, 30 July 2018. https://www.nature.com/articles/d41586-018-05849-9 - accessed March 2018.

Schuster, P.F., Schaefer K. M., Aiken G. R., Antweiler R. C., Dewild J. F., Gryziec J. D., et al. (2018) Permafrost Stores a Globally Significant Amount of Mercury. Geophysical Research Letters, 45(3): 1463–1471.

Schuur, E.A.G., Bockheim, J., Canadell, J.G., Euskirchen, E., Field, C.B., Goryachkin, S.V., et al. (2008) Vulnerability of Permafrost Carbon to Climate Change: Implications for the Global Carbon Cycle. BioScience, 58(8): 701–714

Schuur, E.A.G., A. D. McGuire, C. Schädel, G. Grosse, J. W. Harden, D. J. Hayes, et al. (2015) Climate change and the permafrost carbon feedback. Nature, 520: 171–179.

Seebens, H., Blackburn, T., … and Essl, F. (2017) No saturation in the accumulation of alien species worldwide. Nature Communications, 8: 14435.

Semiletov, I., Pipko, I., Gustafsson, Ö., Anderson L. G., Sergienko, V., Pugach, S., et al. (2016) Acidification of East Siberian Arctic Shelf waters through addition of freshwater and terrestrial carbon. Nature Geoscience, 9: 361–365.

Smith, L. and Stephenson, S. (2013). New Trans-Arctic shipping routes navigable by mid-century. Proceedings of the National Academy of Sciences of the United States of America, 110(13): 4871–4872.

Somveille, M., Manica, A., Butchart, S. H. M. and Rodrigues, A. S. L. (2013). Mapping Global Diversity Patterns for Migratory Birds. PLoS ONE, 8(8): e70907.

Steffen, A., Douglas, T., Amyot, M., Ariya, P., Aspmo, K., Berg, et al. (2008) A synthesis of atmospheric mercury depletion event chemistry in the atmosphere and snow, Atmospheric Chemistry and Physics, 8: 1445–1482.

Steiner, N. S., Christian, J. R., Six, K. D., Yamamoto, A. and Yamamoto-Kawai, M. (2014) Future ocean acidification in the Canada Basin and surrounding Arctic Ocean from CMIP5 earth system models, Journal of Geophysical Research: Oceans, 119(1): 332–347.

Strand, J. (2018) Amounts, compositions, and sources to marine litter in Danish waters, North Atlantic and Arctic. ArkVet Mini-seminar, Copenhagen.

Streets, D. G., Lu, Z., Levin, L., Ter Schure, A. F.H. and Sunderland, E. M. (2018) Historical releases of mercury to air, land, and water from coal combustion. Science of The Total Environment, 615: 131–140.

Taubenberger J. K. and Morens D. M. (2006) 1918 influenza: the mother of all pandemics. Emerging Infectious Diseases, 12: 15–22.

Troell, M., Eide, A., Isaksen, J., Hermansen, Ø. and Crépin, A.S. (2017) Seafood from a changing Arctic. Ambio, 46(suppl. 3): 368–386.

UN Environment (2018) The Emissions Gap Report 2018. United Nations Environment Programme, Nairobi

UN Environment and CCAC (2014) Time to Act to reduce short lived climate pollutants. Paris (second edition).

UN Environment and GRID-Arendal (2016) Marine Litter Vital Graphics. Nairobi and Arendal, UN Environment and GRID Arendal.

UN Environment (2017) Towards a Pollution-Free Planet Background Report. Nairobi: United Nations Environment Programme.

UN Environment – WCMC and IUCN (2016) Protected Planet Report 2016. UN Environment – World Conservation Monitoring Centre (WCMC) and International Union for Conservation of Nature (ICUN), Cambridge UK and Gland, Switzerland.

United Nations (2015a) Paris Agreement.

United Nations (2015b) Resolution adopted by the General Assembly on 25 September 2015. 70/1. Transforming our world: the 2030 Agenda for Sustainable Development.

United Nations (2016) The United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (in force as from 11 December 2001) Overview, 2 September.

van Sebille, E., England, M. H. and Froyland, G. (2012) Origin, dynamics and evolution of ocean garbage patches from observed surface drifters. Environmental Research Letters, 7(4): 044040.

Walsh, M. G., de Smalen, A. W. and Mor, A.M. (2018) Climatic influence on anthrax suitability in warming northern latitudes. Nature - Scientific Reports, 8: 9269.

WWF (2016) Living Planet Report 2016. Risk and resilience in a new era. World Wide Fund for Nature (WWF), Gland, Switzerland

Zeller, D., Booth, S., Pakhomov, E., Swartz, W. and Pauly, D. (2011) Arctic fisheries catches in Russia, USA, and Canada: baselines for neglected ecosystems. Polar Biology, 34(7): 955–973.

The Arctic region is changing. It is dealing with multiple pressures and drivers of change from both inside and outside the region that are affecting ecosystems, climate and human society. The consequences have knock-on effects at the local, regional and global levels. The pace and extent of change means that the Arctic and the rest of the world will be a very different place in the decades to come. Adapting to the changes is a major challenge for people in the Arctic and beyond.

Global Linkages: A graphic look at the changing Arctic examines three interlinked topics: climate change, pollution and biodiversity. It provides visual representations of some of the most prominent changes in the region and how they are linked to the rest of the world. The publication highlights why these challenges can no longer be managed in isolation. It also calls for a holistic, ecosystem-based approach to promote a sustainable future for the Arctic that will also benefit the rest of the world.

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