Arctic Biodiversity Trends 2010

Selected indicators of change

CAFF
Conservation of Arctic Flora and Fauna

ARCTIC COUNCIL

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Permanent Participants who participated in the preparation of this report were the Arctic Athabaskan Council and the Gwich'in Council International.

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CAFF area

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"For us, so-called subsistence activity is far more than subsistence. Hunting is more than food on the table. It is a fundamental part of who we are."

Labrador Inuit Association. 1997. Presentation to Scoping Meeting, Nain, April 17.

Introduction

Janet Hohn, United States Dept. of the Interior, Fish and Wildlife Service, Anchorage, Alaska
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The Arctic plays host to a vast array of biodiversity, including many globally significant populations [1]. Included among these are more than half of the world´s shorebird species [2], 80% of the global goose populations [3], several million reindeer and caribou, and many unique mammals, such as the polar bear. During the short summer breeding season, 279 species of birds arrive from as far away as South Africa, Australia, New Zealand, and South America to take advantage of the long days and intense period of productivity. Several species of marine mammals, including grey and humpback whales, and harp and hooded seals, also migrate annually to the Arctic (Figure I).

In 2001, the Arctic Council´s Conservation of Arctic Flora and Fauna (CAFF) Working Group published the report Arctic Flora and Fauna: Status and Conservation [7], the first truly circumpolar overview of Arctic biodiversity. The report provided, "a clear understanding of the importance of the Earth´s largest ecoregion and its status in the face of a rapidly changing world". The report observed that while much of the Arctic was in its

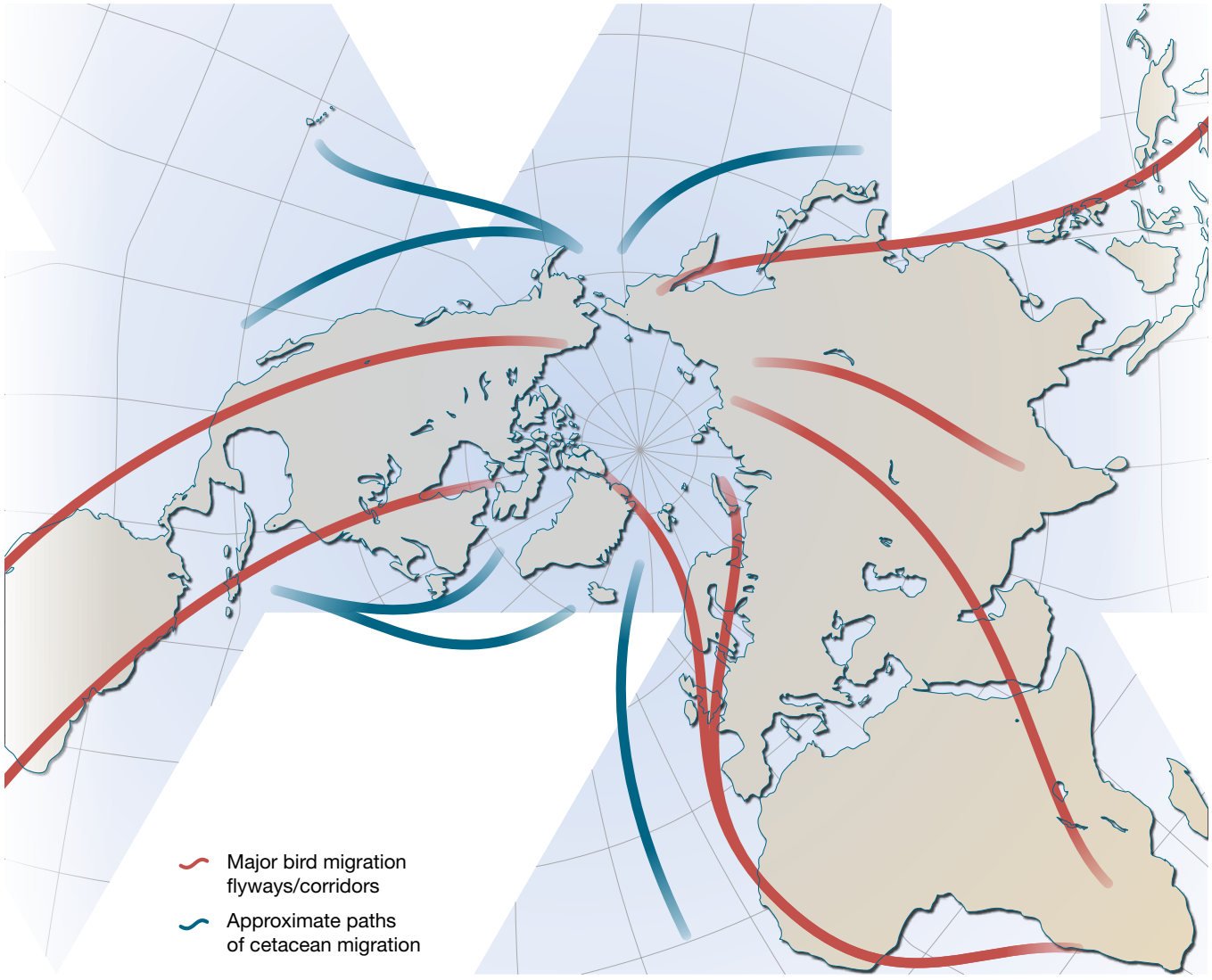


Figure I: Many species of wildlife, particularly species of birds and marine mammals, migrate annually to the Arctic from all areas of the world to breed [4–6].

natural state and that the impacts of human activity were relatively minor, individuals, species, and ecosystems throughout the Arctic faced threats from many causes, and that the long-term consequences of human impacts were unknown. It particularly noted that the information necessary to determine status and trends of Arctic fauna was fragmentary, and almost entirely non-existent for flora.

Since the publication of Arctic Flora and Fauna, the Arctic has entered into a cycle of intensive pressure and change involving a new set of challenges and stressors, with climate change at the forefront (Figure II).

In the past 100 years, average Arctic temperatures have increased at almost twice the average global rate [8]. Over the past thirty years, seasonal minimal sea ice extent in the Arctic has decreased by 45,000 km^2/year [9]. Along with earlier break-up and freeze-up, the extent of terrestrial snow cover in the Northern Hemisphere has decreased and is expected to continue to do so [9].

The magnitude of these changes will exert major influences on biological dynamics in the Arctic. Some of the most rapid ecological changes associated with warming have occurred in marine and freshwater environments. Species most affected are those with limited distributions or with specialized feeding habits that depend on ice foraging. Other predicted effects of climate change, and other stressors, such as industrial development and resource exploitation, on Arctic biodiversity include:

- changes in the distribution, geographical ranges, and abundances of species (including invasive alien species) and habitats of endemic Arctic species; and
- changes in genetic diversity; and
- changes in the behavior of migratory species.

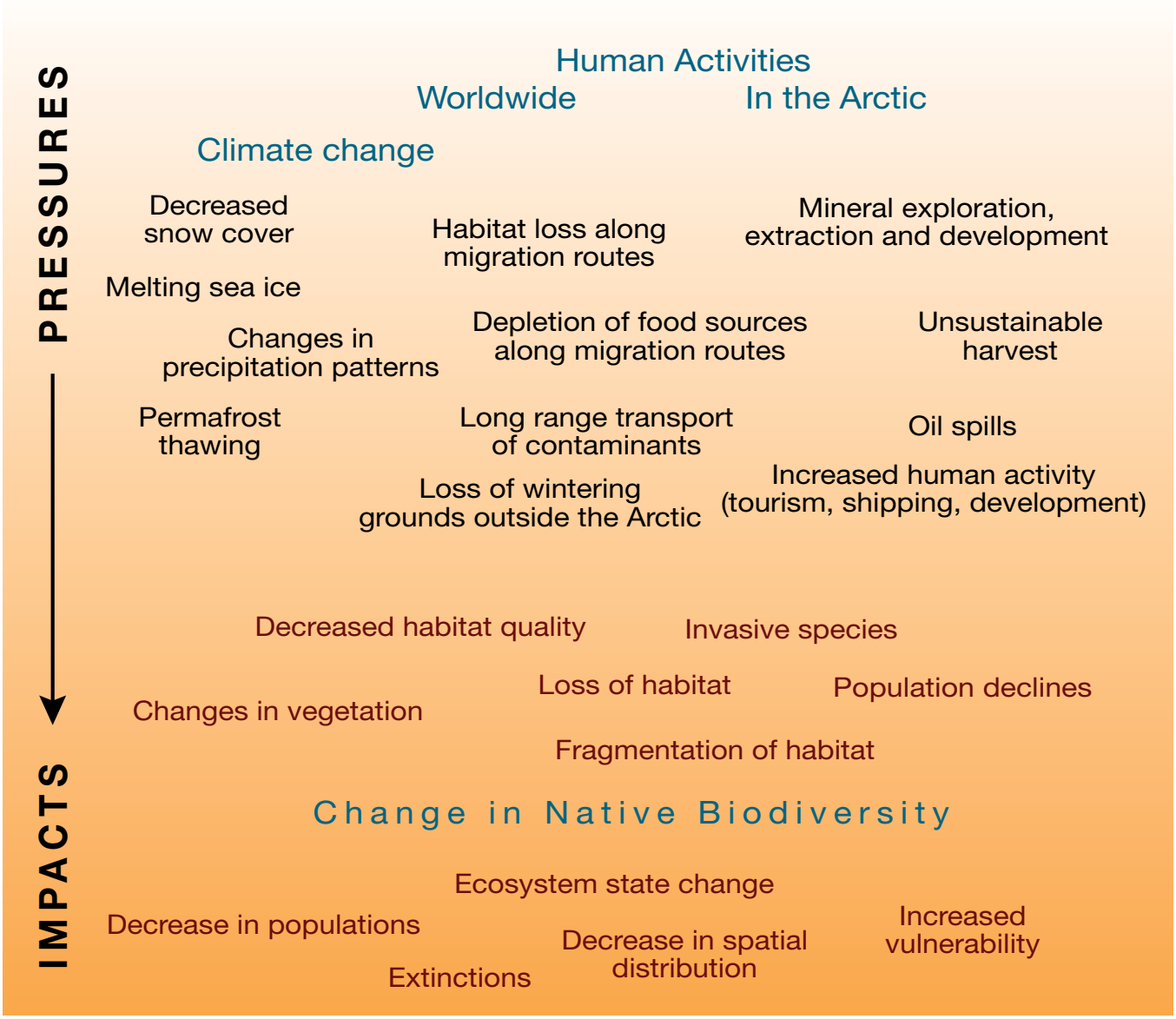


Figure II: Arctic biodiversity is being affected by numerous local and global pressures.

Thule, North Greenland Carsten Egevang/Arc-Pic.com

Arctic warming, with its many and increasing impacts on flora, fauna, and habitats, has heightened the need to identify and fill the knowledge gaps on various aspects of Arctic biodiversity and monitoring. This need was clearly identified in the 2005 Arctic Climate Impact Assessment (ACIA) which recommended that long-term Arctic biodiversity monitoring be expanded and enhanced [1]. The CAFF Working Group responded to this recommendation with the implementation of the Circumpolar Biodiversity Monitoring Program (CBMP, www.cbmp.is).

Following the establishment of the CBMP, the CAFF Working Group agreed that it was necessary to provide policy makers and conservation managers with a synthesis of the best available scientific and traditional ecological knowledge (TEK)[1] on Arctic biodiversity. This initiative, the Arctic Biodiversity Assessment (ABA, www.caff.is/aba), was endorsed by the Arctic Council in 2006. The aims of the ABA are to provide a much needed description of the current state of the Arctic's ecosystems and biodiversity, create a baseline for use in global and regional assessments of biodiversity, and provide a basis to inform and guide future Arctic Council work. In addition, it will provide up-to-date scientific and traditional ecological knowledge, identify gaps in the data record, identify key mechanisms driving change, and produce policy recommendations regarding Arctic biodiversity. The first deliverable of the ABA is the overview report, Arctic Biodiversity Trends 2010: Selected Indicators of Change which presents a preliminary assessment of status and trends in Arctic biodiversity and is based on the suite of indicators developed by the CBMP [11].

For this report, twenty-two indicators were selected to provide a snapshot of the trends being observed in Arctic biodiversity today. The indicators were selected to cover major species groups with wide distributions across Arctic ecosystems. Special consideration was given to indicators closely associated with biodiversity use by indigenous and local communities, as well as those with relevance to decision-makers. Indicators were also selected on the basis of what was achievable in terms of existing data and in the timeframe available. Each indicator chapter provides an overview of the status and trends of a given indicator, information on stressors, and concerns for the future. The geographic area covered by the ABA is shown in Figure III.

Traditional ecological knowledge is vital to form a more complete picture of the status and trends in Arctic biodiversity. TEK is actively being sought out and incorporated into the larger ABA scientific report, scheduled for 2013. The scientific report will further develop and elaborate on the findings of the Arctic Biodiversity Trends 2010 report, including different approaches to natural resource management.

The ABA is also the Arctic Council's response to global

1. Traditional ecological knowledge, or TEK has been defined as the knowledge and values which have been acquired through experience, observation, from the land or from spiritual teachings, and handed down from one generation to another. (Definition of TEK in GNWT policy statement, as quoted in [7]).

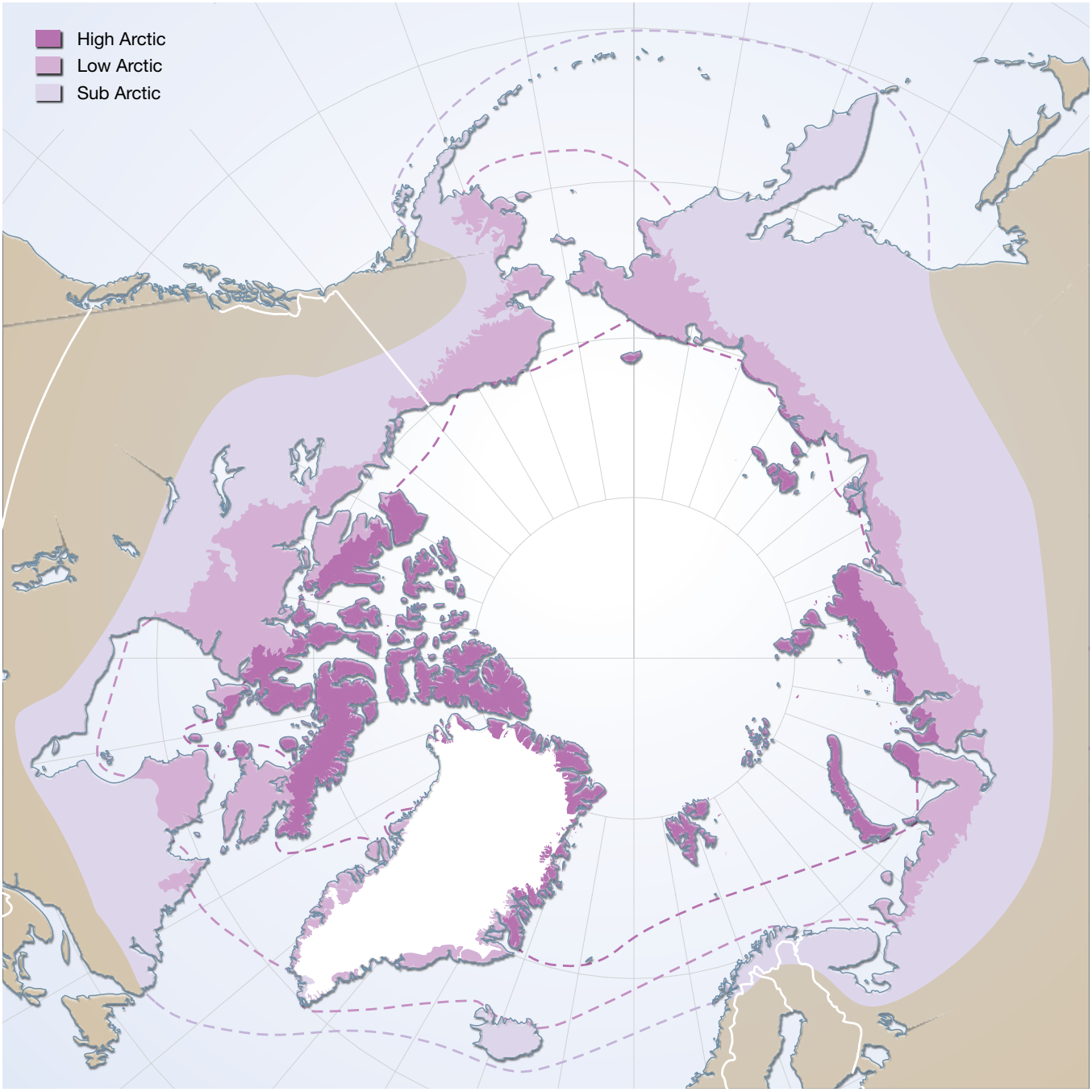


Figure III: Boundaries of the geographic area covered by the Arctic Biodiversity Assessment[2].

conservation needs. While there is a clear concern for the future of Arctic nature, this applies even more to global biodiversity. In 2002, the Conference of the Parties to the Convention on Biological Diversity (CBD) established a target, "to achieve, by 2010, a significant reduction of the current rate of biodiversity loss at the global, regional, and national levels as a contribution to poverty alleviation and to the benefit of all life on Earth". Subsequently, the 2010 Biodiversity Target was endorsed by the World Summit on Sustainable Development (2002) [13] and the United Nations General Assembly [14]. The recent Arctic Council Ministerial meeting [15] noted that the Arctic Biodiversity Trends 2010 report will be an Arctic Council contribution to the United Nations International Year of Biodiversity in 2010 and at the same time a contribution to the CBD´s 3rd Global Biodiversity Outlook to measure progress towards the 2010 Biodiversity Target.

2. For separation between the high Arctic and low Arctic, the division between subzones C and D are those defined in the Circumpolar Arctic Vegetation Map. The southern limit of the sub-Arctic is "loose", as work on the boreal vegetation map is pending. Contrary to the Arctic zones on land, the boundaries at sea are tentative. Here they just indicate a general perception of the different zones [12].

Key findings

In 2008, the United Nations Environment Programme (UNEP) passed a resolution expressing 'extreme concern' over the impacts of climate change on Arctic indigenous peoples, other communities, and biodiversity [1]. It highlighted the potentially significant consequences of changes in the Arctic. Arctic Biodiversity Trends – 2010: Selected Indicators of Change provides evidence that some of those anticipated impacts on Arctic biodiversity are already occurring. Furthermore, although climate change is a pervasive stressor, other stressors, such as long range transport of contaminants, unsustainable harvesting of wild species, and resource development are also impacting Arctic biodiversity. These key findings reflect the information in the 22 indicators presented in this report. A more complete scientific assessment of biodiversity in the Arctic will emerge from the full Arctic Biodiversity Assessment, currently in preparation.

FINDING 1

Unique Arctic habitats for flora and fauna, including sea ice, tundra, thermokarst ponds and lakes, and permafrost peatlands have been disappearing over recent decades.

Sea ice supports of vast array of life in the Arctic and represents a critical habitat for many species. Sea ice, however, is being lost at a faster rate than projected by even the most pessimistic of climate change scenarios, such as those reported by the Intergovernmental Panel on Climate Change (IPCC). Early warning signs of losses in the sea-ice food web include declines in populations of some species associated with sea ice, such as ivory gulls and polar bears.

The plant communities that make up tundra ecosystems – various species of grasses, sedges, mosses, and lichens – are, in some places, being replaced by species typical of more southern locations, such as evergreen shrubs. Trees are beginning to encroach on the tundra and some models project that by 2100 the treeline will have advanced north by as much as 500 km, resulting in a loss of 51% of the tundra habitat. Depending on the magnitude of change, the resulting ecosystems may no longer be considered "Arctic". The result may be that many of the species that thrive in the Arctic today may not be able to survive there in the future.

Thermokarst lakes[1] and ponds are the most biologically diverse aquatic ecosystems in the Arctic. While drainage and appearance of thermokarst lakes is a relatively common and natural occurrence, over the past 50 to 60 years, studies have shown a net loss of these lakes in some places such as the continuous permafrost zone of northern Alaska and northwestern Canada, and the discontinuous permafrost zone of Siberia. Meanwhile, a net gain of thermokarst lakes has been observed in the continuous permafrost zone of Siberia. The effects of these habitat shifts on local aquatic populations, migratory species, and vegetation are the subject of continuing investigations.

Permafrost peatlands represent unique ecosystem diversity, provide key habitats for some species, maintain hydrology and landscape stability, and hold an enormous stock of organic carbon. Climate change combined with other impacts is leading to a decrease in the extent and duration of permafrost in northern peatlands. Melting permafrost and peatland degradation release greenhouse gases that create a positive feedback for further climate change.

1. Thermokarst lakes and ponds are formed by the thawing of permafrost.

FINDING 2

Although the majority of Arctic species examined in this report are currently stable or increasing, some species of importance to Arctic people or species of global significance are declining.

Wild reindeer and caribou are very important to the livelihoods of Arctic peoples. Since the 1990s and early 2000s, however, herds have declined by about one-third, from 5.6 to 3.8 million. While this may be a result of naturally occurring cycles, the ability of these populations to rebound is uncertain given the multiple stressors to which they are now exposed, such as climate change and increased human activity.

Although much has been learned, information is deficient on many species and the relationship to their habitat. Even for charismatic animals such as the polar bear, trends are known for only 12 of 19 subpopulations; eight of these are declining.

Arctic shorebirds, such as the red knot, migrate long distances to breed in the Arctic. Evidence indicates that shorebird populations are declining globally. Of the six subspecies of red knot, three are declining while the other three are either suspected of being in decline or their status is unknown.

The Arctic Species Trend Index (ASTI), which provides a snapshot of vertebrate population trends over the past 34 years, shows a 10% overall decline in terrestrial vertebrate populations. The decline partially reflects declining numbers of some herbivores, such as caribou and lemmings, in the high Arctic. In the low Arctic, vertebrate populations have increased, driven by dramatically increasing populations of some goose species, which have now exceeded the carrying capacity of the environment to support them.

Populations of some very abundant seabirds, such as common eiders, are generally healthy. Some Arctic seabird populations, such as murres, may be showing divergent trends. Their populations fluctuate in relation to major climate regimes in the Northern hemisphere, while others are still affected by overharvesting.

Freshwater Arctic char populations appear to be healthy in comparison to those in more southern locations. For marine fish, there is evidence of a northward shift in the distribution of some species in both exploited and unexploited stocks. The shifts appear to be the result of climate change, in addition to other pressures, such as fishing.

FINDING 3

Climate change is emerging as the most far reaching and significant stressor on Arctic biodiversity. However, contaminants, habitat fragmentation, industrial development, and unsustainable harvest levels continue to have impacts. Complex interactions between climate change and other factors have the potential to magnify impacts on biodiversity.

The life cycles of many Arctic species are synchronized with the onset of spring and summer to take advantage of peaks in seasonal productivity. Earlier melting of ice and snow, flowering of plants, and emergence of invertebrates can cause a mismatch between the timing of reproduction and food availability. In addition, warming sea temperatures in some areas has led to a northward shift in the distribution of marine species, such as some fish species and their prey. These changes have been implicated in massive breeding failures for some seabirds, and subsequent population declines.

Arctic biodiversity is impacted by factors outside the Arctic, including the long-range transport of contaminants through air and water, habitat changes along migratory pathways, and invasive alien species. Increasing contaminant loads have been documented in some polar bear subpopulations, possibly as a result of dietary shifts due to declining sea ice. Red knots are highly dependent upon a limited number of key stopover and wintering sites making them vulnerable to habitat changes occurring outside of the Arctic.

FINDING 4

Since 1991, the extent of protected areas in the Arctic has increased, although marine areas remain poorly represented.

Between 1991 and 2010, the extent of the Arctic that has some form of protected status doubled from 5.6% to 11%. There are now 1,127 protected areas covering 3.5 million km2 of the Arctic. 40% of these areas have a coastal component but it is not possible at present to determine the extent to which they incorporate the adjacent marine environment. With rapid climate change and the emerging potential for multiple human impacts in the Arctic, there is a pressing need to assess the effectiveness of current terrestrial protected systems as a conservation tool. In the marine environment, where there are far fewer protected areas, the urgent need is for the identification and protection of biologically important marine areas.

FINDING 5

Changes in Arctic biodiversity are creating both challenges and opportunities for Arctic peoples.

Declines in Arctic biodiversity may affect the availability of traditional foods. Coupled with decreasing access to freshwater and the unpredictability of winter ice, sustaining traditional ways of life may become more difficult. On the other hand, range extensions of southern species, shifting habitats, changes in resource use, among other factors, may provide opportunities to harvest new species.

FINDING 6

Long-term observations based on the best available traditional and scientific knowledge are required to identify changes in biodiversity, assess the implications of observed changes, and develop adaptation strategies.

Significant difficulties were encountered in preparing this report because most countries do not have internal long-term biodiversity monitoring programs. Where such programs do exist, the data collected is not consistent across the circumpolar region.

In a few cases where coordinated monitoring efforts have a long history (e.g., seabirds), trend information is reliable and conservation strategies based on the results of monitoring have been successful. The 2005 Arctic Climate Impact Assessment recognized that long-term monitoring would greatly help detecting early warning signals and development of adaptation strategies.

Generations of biodiversity knowledge and its uses are contained in traditional Arctic languages, but many of these languages are facing an uncertain future. Twenty Arctic languages have become extinct since the 1800s, and ten of these extinctions have taken place after 1990 indicating that the rate of loss is increasing. Their loss represents not only a loss of culture but also a loss of historical biodiversity knowledge.

The Circumpolar Biodiversity Monitoring Program, which encompasses scientific, traditional ecological knowledge, and community-based monitoring approaches, is being implemented by the Conservation of Arctic Flora and Fauna working group of the Arctic Council, to address these urgent needs for monitoring

FINDING 7

Changes in Arctic biodiversity have global repercussions.

The importance of Arctic ecosystems for biodiversity is immense and extends well beyond the Arctic region. The Arctic, for example, supports many globally significant bird populations from as far as Australia and New Zealand, Africa, South America, and Antarctica. Declines in Arctic species, therefore, are felt in other parts of the world.

Emerging issues and

Aevar Petersen,
Icelandic Institute of Natural History, Reykjavik, Iceland

Since the publication of Arctic Flora and Fauna: Status and Conservation [1] in 2001, many changes have occurred in the Arctic environment. Most notably, the significance of climate change as an impact factor has been greatly elevated, in the Arctic as well as at a global scale. A warming climate in the Arctic is projected to set off many environmental changes including melting sea ice, increased run-off, and an eventual rise in sea level with immense coastal implications. Some of these changes are already being felt. Increasing temperatures are already showing many effects on Arctic biodiversity including the northward movement of more southern species, shrubbing and greening of the land, changing plant communities and their associated fauna, increases in migrating invasive species displacing native Arctic inhabitants, and the emergence of new diseases [2]. Additionally, changes in the timing of events (phenology) are an aspect of change which may lead to mismatches between related environmental factors [3]. As a result, some local biodiversity may be in imminent danger of extinction [4].

Although we have learned much since 2001, many questions remain unanswered. We do not know enough about the effects of climate change on biodiversity, what these changes mean to local flora and fauna, and what effects they have on natural resources, many of which are of great importance to local peoples. The Arctic Climate Impact Assessment clearly demonstrated a general lack of information on quantified effects of climate change on biodiversity [5]. It is not enough to show that climate change results in changes to the physical environment. Directly or indirectly, the peoples of the Arctic live off the biological products of land, freshwater, and sea through hunting, fishing, and agriculture. It is vital that we are able to detect changes and how they vary geographically, between species, populations, and biological communities. We need to understand the complex interactions between climate and communities of Arctic species [6]. Although this information is beginning to surface, the accumulation of data on biodiversity is still trailing climate modeling and the gathering of information on the abiotic environment.

A number of challenges are envisaged for Arctic biodiversity. With a warming climate, shipping and resource development (e.g., oil and gas exploration) are likely to increase, with a potential for increased pollution and disturbance to Arctic biodiversity. More

Prince William Sound, Alaska, USA Lars Johansson/iStockphoto

development may lead to different human settlement patterns and changes in resource use. Decreased ice cover may increase the number of areas accessible to fisheries and make new species economically available and so create both opportunities as well as challenges for sustainable use. Many Arctic species also migrate great distances throughout the world and so are subject to environmental changes during their travels, including carrying pollutants back to the north in their bodies.

Nuuk, West Greenland Carsten Egevang/Arc-Pic.com

Because they move through Arctic as well as non-Arctic territories, international cooperation beyond the Arctic is needed for their concerted and sustained conservation.

One response to greater human pressures in the Arctic is the creation of protected areas. Although improving, current protected areas are still inadequate in representation of habitats and ecosystems. For instance, it is generally recognized that marine protected areas are particularly scarce. Even a full overview of biologically sensitive areas in the Arctic marine ecosystem, including on the high seas areas beyond national jurisdictions, is lacking. However, protected areas are only one aspect of biodiversity conservation as climate change inevitably calls for greater attention to more general conservation measures due to shifts in distributions and new introductions into local flora and fauna.

Addressing the pressures facing Arctic biodiversity requires better and more coordinated information on changes in biodiversity. Through the Circumpolar Biodiversity Monitoring Program, CAFF has brought together numerous datasets that indicate changes in biodiversity. This program is an effective response to the many challenges that are envisaged in the wake of climate change in and changing human use of the Arctic regions. Much data already exists on Arctic biodiversity but the challenge is to bring these data together, to analyze and identify the gaps in circumpolar monitoring, and put them to use to facilitate better informed policy decisions. The aim of the CBMP is to cover all ecosystems at all levels, from the genetic to the ecosystem level, using the latest technologies, as well as traditional ecological knowledge of the northern peoples. The CBMP is a process that cannot be implemented all at once but is well underway with the establishment of monitoring networks, indicators and indices, and management tools such as the Circumpolar Seabird Information Network. The CBMP is a definite response to the international commitments that the Arctic countries have undertaken on halting loss of biodiversity. The results are of practical use for the many questions facing the Arctic countries and the Arctic Council in their deliberations. The current challenge is to use the data available in a better and more coordinated way, fill gaps in knowledge, and increase the geographic coverage of Arctic information for the conservation and sustainability of the environment, as well as for the benefit of decision-makers, Arctic peoples, the science, and the global community at large.

Aspects of vanishing local knowledge, such as Arctic languages and traditional ecological knowledge, need to be fully recognized and acted upon. Climate change and all the associated issues – be they of the natural environment or human-related – pose a new suite of challenges for biodiversity and peoples of the Arctic. Taking care of the environment poses major challenges for the Arctic Council and all other stakeholders interested in the north. CAFF, as the biodiversity arm of the Arctic Council, contributes towards seeking appropriate solutions to those challenges.

Indicators at a glance

Species

Indicator #01 ▸PAGE 26

Polar bears

Estimates of polar bear populations made in 2009 indicate that of the 19 recognized polar bear subpopulations, only one is currently increasing. Of the remaining subpopulations, three are stable, eight are declining, and seven have insufficient data from which to detect a trend. As polar bears are fundamentally dependent upon sea ice, increased fragmentation and loss of sea-ice habitat as a result of climate change is one of the greatest conservation concerns for this species. Pollutants entering the Arctic via long-range transport are another issue of concern for this top predator as contaminant loads are increasing in some populations.

Indicator #02 ▸PAGE 29

Wild reindeer and caribou

Wild reindeer and caribou have declined by about 33% since populations peaked in the 1990s and early 2000s. While some of the smaller populations are either stable or increasing, the majority of the large herds are in decline. The major stressors contributing to declines vary between herds but climate is an important factor for many herds. For more southern herds, increased human activity and industrial development are of particular concern. The broad spectrum of changes occurring across the tundra environment may delay or slow the recovery of some herds, and some herds may disappear altogether.

Indicator #03 ▸PAGE 32

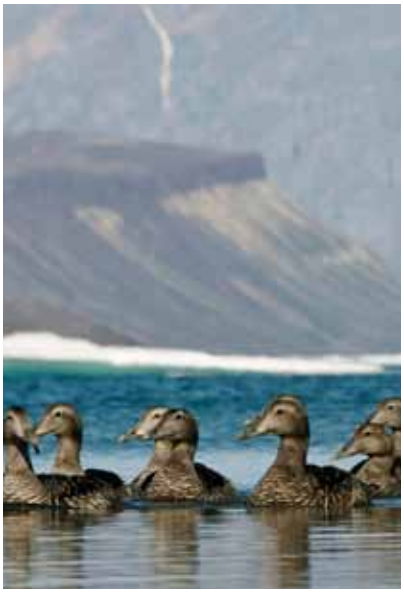
Shorebirds – red knot

Of the six subspecies of red knot, three are in decline and two appear to be declining, while the trend for the sixth subspecies is not clear. Although the red knot is not yet considered to be threatened globally, it is a long-distance migratory species dependent on a limited number of stopover and wintering sites, and is particularly vulnerable to habitat change along its migration routes. Climate change may be beneficial to this species in the short term if there is an earlier snowmelt and more food is available but ecosystem changes over the longer term may result in a loss of Arctic breeding habitat. The decline in red knots is representative of the overall declining trend in waders.

Indicator #04 ▸PAGE 35

Seabirds – murres (guillemots)

Murres are among the most abundant seabirds in the Northern Hemisphere with a population in excess of ten million adults. No obvious global trend has been identified but the majority of regional populations have shown declines over the past three decades. While they are currently abundant, climate change is projected to pose problems to murres in the future, especially for the more northern species, the thick-billed murre, which is strongly associated with sea ice. Other threats include fisheries interactions, over-exploitation, contaminants, and oil spills, the latter becoming more important if climate change expands shipping and hydrocarbon development in the Arctic.



Indicator #05 ▸PAGE 38

Seabirds – common eiders

Common eiders are important for traditional food and lifestyles, as well as being the basis of a commercial industry. The world population ranges between 1.5 and 3.0 million breeding pairs. Along with other eider species, common eiders have experienced substantial declines over several decades. Current trends vary but some populations in Alaska, Canada, and Greenland are recovering with improved harvest management. Disease outbreaks such as avian cholera can dramatically affect common eiders, while fishing by-catch in gillnets is a significant problem in some areas. Increasing oil and gas activities may put eider ducks at further risk in the future.

Indicator #06 ▸PAGE 41

Arctic char

Arctic char are widely distributed throughout the circumpolar north and are an important species culturally, socioeconomically, and scientifically. Populations of char in the Arctic are generally healthy in comparison to more southern populations. There are, however, many examples of stressed populations, especially near communities where over-fishing, sometimes combined with habitat change, has led to population collapses. The effects of climate change on Arctic char may be both positive and negative within different populations, and may impact the fish directly or indirectly through habitat and ecosystem changes.

Indicator #07 ▸PAGE 45

Invasive species (human-induced)

Across the globe, invasive species have caused extensive economic and ecological damage and are a significant factor in the endangerment and extinction of native species. As native species are lost so too are the potential cultural, subsistence, and other human uses of that biodiversity. Although biological invasions are less studied in the Arctic, invasive species have been reported in both aquatic and terrestrial environments. Arctic lands and waters have thus far remained largely intact and less invaded than more temperate environs, but are increasingly at risk of invasion. In terrestrial ecosystems, many invasive plants have been recorded along limited road systems and other altered habitats. There is less information on marine ecosystems but they are believed to be at increasing risk from shipping and offshore development activity. As climate change alters Arctic ecosystems and allows more human access and activity, the number of invasive species and the extent of their impacts in this region are likely to increase.

Indicator #08 ▸PAGE 49

The Arctic Species Trend Index

The Arctic Species Trend Index (ASTI) was developed to provide a pan-Arctic perspective on trends in Arctic vertebrates. Tracking this index will help reveal patterns in the response of Arctic wildlife to growing pressures and thereby facilitate the prediction of trends in Arctic ecosystems. A total of 965 populations of 306 species were used to generate the ASTI. Overall, the average population of Arctic species rose by 16% between 1970 and 2004, although this trend is not consistent across biomes, regions, or groups of species. The terrestrial index shows an overall decline of 10%, largely a reflection of declines (-28%) in terrestrial high Arctic populations such are caribou, lemmings, and the high Arctic brent goose. Declines in terrestrial high Arctic populations may be partly due to the northward movement of southern species in combination with increasing severe weather events in the high Arctic and changing tundra vegetation. Although both freshwater and marine indices show increases, the data behind the freshwater index is currently too sparse in terms of species and populations, while the marine index is not spatially robust.

Indicator #09 ▸PAGE 53

Arctic genetic diversity

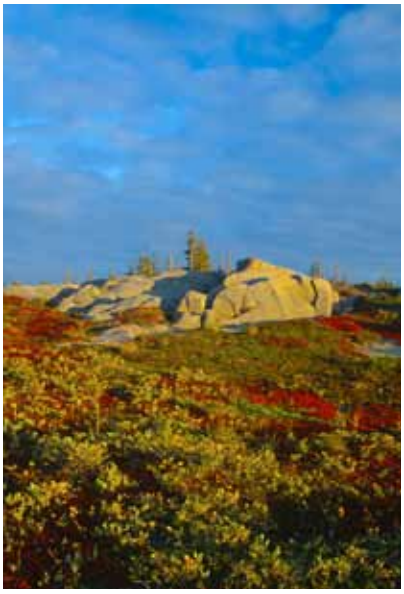
Understanding genetic variation in Arctic species is critical to their conservation and effective management in this time of rapid environmental change. Genetic analyses can be used for a variety of purposes, from determining the history of species dispersal and diversification to evaluating the conservation status of a species of concern. As the range and abundance of species declines, the genetic variability needed to respond to novel challenges will also be reduced. A significant increase in our efforts to build temporally-deep and spatially-extensive specimen archives is needed. These specimens will provide a baseline of environmental conditions and, when combined with mapping of genetic structure, will be crucial for both effective recovery efforts for declining species and for predicting species response in the face of climate change and other human impacts in the Arctic.

Ecosystems

Indicator #10 ▸PAGE 58

Arctic sea-ice ecosystem

Arctic sea ice is a unique ecosystem providing habitat to many ice-associated species, including micro-organisms, fish, birds, and marine mammals. Although Arctic sea ice has decreased substantially in extent and thickness in recent years, the response of individual species to changes in sea ice depends on its ability to adapt and its natural history, as well as the scale of environmental change. Information to assess the status and trends of ice-associated species is very limited, and in some cases the relationship between sea ice and species is not entirely understood. Continued sea ice loss due to climate change is expected to lead to changes in the sea-ice ecosystem towards a pelagic, sub-Arctic ecosystem over a larger area. Increased production in open water may increase prey concentrations for some species, such as bowhead whales; however, with less ice there will be less ice algae, affecting bottom-feeding marine species. Continued warming and continued reductions in sea ice will likely result in the northward expansion of sub-Arctic species, with the associated potential for increase in disease, predation, and competition for food.



Indicator #11 ▸PAGE 62

Greening of the Arctic

Climate change is impacting terrestrial Arctic ecosystems, with evidence showing that Arctic vegetation has undergone significant shifts in recent decades. There is an increase in productivity over much of the Arctic, as well as an increase in the length of the growing season. The northward movement of the treeline is encroaching on the southern margin of the tundra and could result in significant losses of tundra habitat by 2100. Climate warming is also likely to change the composition of plant communities. While the number of plant species inhabiting the Arctic may actually increase over the long term, the diversity of plants unique to the Arctic will probably decrease in abundance.

Indicator #12 ▸PAGE 65

Reproductive phenology in terrestrial ecosystems

Changes in the timing of reproduction in plants and animals have been reported from the Arctic. There is some evidence indicating that the timing of reproduction – including the flowering of plants, emergence of insects, and egg-laying in birds – is occurring earlier in response to warming conditions and earlier snowmelt. Longer growing seasons may be an advantage to some species in terms of reproduction and growth. There is, however, a serious risk of disruptions in food webs when there is a "trophic mismatch", where the breeding of some species (e.g., caribou or birds) no longer matches up with the timing of the most abundant and nutritious food (e.g., new plant growth or insects).

Indicator #13 ▸PAGE 68

Appearing and disappearing lakes and their impacts on biodiversity

Thermokarst lakes and ponds, formed by the thawing of permafrost, are the most abundant and productive aquatic ecosystems in the Arctic. They are areas of high biodiversity with abundant microbes, benthic communities, aquatic plants, plankton, and birds. While the disappearance and appearance of thermokarst lakes is a relatively common occurrence, there are concerns about their future in the face of climate warming. There has been a net decrease in the number of thermokarst lakes over the past fifty years in the western Canadian Arctic, Siberia, and Alaska. Trends in other Arctic regions are unknown. The appearance and disappearance of thermokarst lakes is projected to be more common with climate change and will likely lead to more aquatic habitat becoming available in higher latitudes over time. The effects of these habitat shifts on local aquatic populations, migratory species, and vegetation is the subject of further investigation.

Indicator #14 ▸PAGE 71

Arctic peatlands

Wetlands cover about 70% of the Arctic with the most extensive wetland types being non-forested and forested peatlands. Peatland species comprise 20–30% of the Arctic and sub-Arctic flora. Arctic peatlands also support biodiversity worldwide through bird migration routes. Seventy-five percent of the more than 60 bird species with conservation priority in the European part of the Arctic are strongly associated with tundra and mire habitats. Peatlands also provide crucial ecosystem services such as habitat maintenance, permafrost protection, and water regulation. Over recent years, the southern limit of permafrost in northern peatlands has retreated by 39 km on average and by as much as 200 km in some parts of Arctic Canada, with some of this attributed to climate change. The northward movement of the treeline will affect not only Arctic biodiversity through shifting habitats and species, but also reduce albedo (surface reflectivity), further enhancing warming of the atmosphere.

Indicator #15 ▸PAGE 75

Effects of decreased freshwater ice cover duration on biodiversity

Ice cover is an important component of northern freshwater ecosystems, influencing many physical, chemical, and biological processes. The duration of freshwater ice cover has decreased by an average of almost two weeks over the last 150 years, with earlier break-ups and later freeze-ups. As the climate warms, longer open-water conditions will prevail. Depending on the type and location of a water body, decreases in the duration of lake ice can be expected to have a range of ecological impacts from increased productivity and increased habitat availability with less ice to changing distributions and reduced habitat availability for some cold-water species of fish.

Indicator #16 ▸PAGE 78

Changing distribution of marine fish

There is evidence of changes occurring in the distribution of some fish species, specifically a northward shift of both bottom-dwelling and pelagic marine species, and in both exploited and unexploited fish stocks. Climate change is likely one of the reasons for the shifts, along with other factors such as fishing pressure. Temperature changes in the oceans can affect fish populations directly (e.g., shifting to areas with preferred temperatures) and indirectly (e.g., by impacting food supply or the occurrence of predators). Computer modeling using current climate change scenarios indicates that the distribution and abundance of Arctic fin, an important prey species, may be greatly reduced over the next 30 years. The implications of such changes on both marine ecosystems and the human societies dependent upon them are a cause for concern.

Indicator #17 ▸PAGE 81

Impacts of human activities on benthic habitat

Cold-water coral reefs, coral gardens, and sponge grounds are areas of high biodiversity in the Arctic and have been identified as Vulnerable Marine Ecosystems (VMEs). Damage to these ecosystems may reduce local biodiversity. Also, because corals and sponges grow so slowly, recovery of these habitats may range from decades to centuries. These habitats are particularly vulnerable to human activities such as fishing and oil and gas exploration. Increasing sea temperatures, ocean acidification, and pollution present further threats to corals and sponges.

Ecosystem services

Indicator #18 ▸PAGE 86

Reindeer herding

The most productive semi-domestic reindeer herds occur in northern Fennoscandia and northwest Russia. Herd sizes here have been increasing since World War II and are currently at or near historic highs. While many rangelands across northern Eurasia are in poor condition because of high reindeer densities, it is unclear whether this is affecting herd performance. The relationship between reindeer herding and local biodiversity is similarly complex, where grazing by reindeer may either increase or decrease the variety of plant species in a given area, and in some regions may even be an important factor in regional biodiversity. In addition to climate change, reindeer herding in Fennoscandia is threatened by increased resource development, and in Russia, hydrocarbon development is actually considered a greater threat to the most productive herding areas than climate change.

Indicator #19 ▸PAGE 89

Seabird harvest

Seabirds have been harvested by humans in the circumpolar Arctic for centuries for their meat, eggs, skins, and down. Harvesting is a significant factor in the population size of many species, and there are examples of overharvesting causing substantial losses in some populations, as well as rapid recovery following major changes to harvest regulations. Currently, harvest levels in the Arctic are tending to decline due to factors such as stricter hunting regulations, declining seabird populations, fewer or less active hunters, or a combination of these. In some areas, harvests for several species have declined by 50% or more. The number of birds harvested varies considerably between countries, from less than 5,000 in Norway to 250,000 in each of Canada, Greenland, and Iceland. For some species, climate change can be a serious threat to the sustainable use of seabird populations in the future, especially if the availability of important food sources is affected. The migratory nature of seabirds means international cooperation is vital for their conservation.

Indicator #20 ▸PAGE 92

Changes in harvest

Harvesting natural resources continues to be a key feature of traditional lifestyles and economies across the Arctic. In Alaska, subsistence harvest accounts for a small proportion (about 2–3%) of the total fish and wildlife harvest, compared with 97% taken by commercial fisheries. While no systematic statewide survey of the status of subsistence harvests has been conducted, there are indications that subsistence harvests by rural Alaskans are declining across space and time. Development impacts, environmental and ecological changes, socio-economic changes, changing tastes, in- and out-migration, and harvests by competing user groups likely all adversely affect subsistence harvests. In Canada, up to 60% of residents in small communities in the Northwest Territories rely on traditional/country food for the majority of their meat and fish. This percentage has remained largely unchanged over the last ten years. By comparison, subsistence harvesting in the Russian Arctic has been affected by the widespread socio-economic changes following the collapse of the Soviet Union. The overall area where natural resources are harvested has been reduced, although subsistence consumption around indigenous communities has increased. Illegal harvesting and trade in valuable species also increased as law enforcement declined, leading to localized depletion of some resources.

Indicator #21 ▸PAGE 96

Changes in protected areas

Protected areas are a key element for maintaining and conserving both Arctic and global biodiversity, protecting important habitat for resident and migratory species. The first protected areas in the Arctic were established at the beginning of the 20th century although the area under protection remained low until the 1970s. The extent of the Arctic which is under some form of protected status doubled between 1991 and 2010, from 5.6% to 11%. There are now 1,127 protected areas covering 3.5 million km^2 of the Arctic. Climate change is a significant challenge to protected areas as a conservation tool because the features protected today may be altered or lost in the future. Implementing sound environmental conservation measures both within and beyond the boundaries of protected areas will be important to biodiversity conservation. This is particularly important in marine ecosystems where the level of protection is lower in comparison to terrestrial ecosystems.

Indicator #22 ▸PAGE 99

Linguistic diversity

Much important traditional knowledge of biodiversity and its uses is embedded within indigenous languages, yet Arctic languages face an uncertain future. Twenty languages have become extinct since the 1800s, with ten of these extinctions taking place after 1990. Of these extinctions, one was in Finland, one in Canada, one in Alaska, and seventeen in the Russian Arctic. The remaining Arctic indigenous languages are decreasing in vitality as the number of speakers decreases. Only four out of 44 languages surveyed displayed either no change or an increase in absolute number of speakers and proportion of speakers. The increasing rate of language extinction emphasizes the need to increase our understanding of the cultures and traditions contained within these languages, and to increase efforts aimed at revitalizing them.

Species

INDICATORS #01–09

Alexey Nikolayevich Kemlil, a Chukchi reindeer herder from the Turvaurgin community reports that:

"All of the tundra is on the move now. Many forest animals are coming to tundra now. Even the elk have moved to tundra"

Mustonen, T. 2007. Report on the Biodiversity Observations of the Indigenous Communities of the ECORA Model Area Lower Kolyma River, Sakha-Yakutia, Russia. Conference Speech in Snowchange 2007: Traditions of the North, April 2007, Neriungri and Iengra, Sakha-Yakutia, Russia. Available from the Snowchange Cooperative, Finland

INDICATOR #01

Polar bears

Nick Lunn, Environment Canada, Edmonton, Alberta, Canada.
Dag Vongraven, Norwegian Polar Institute, Tromsø, Norway.
Scott Schliebe, US Fish and Wildlife Service, Anchorage, Alaska, USA.
Stanislav Belikov, All-Russian Research Institute for Nature Protection, Moscow, Russian Federation.

Svalbard, Norway Pauline Mills/iStockphoto

Polar bears, Ursus maritimus, are distributed throughout the ice-covered waters of the circumpolar Arctic. This top-level predator is of interest because it is an iconic species of the Arctic and one that is particularly vulnerable to changes in sea ice. They are fundamentally dependent upon sea ice as a platform for hunting seals, travelling, finding mates, and breeding. Changes in the distribution, duration, and extent of sea-ice cover and in the patterns of freeze-up and break-up have the potential to significantly influence the population ecology of polar bears [1, 2].

As a species highly specialized for and dependent on the sea ice habitat, polar bears are particularly sensitive and vulnerable to changes in their environment [3]. Over the past several decades there have been a number of studies that have documented significant reductions in sea-ice cover in parts of the Arctic, thinning of multiyear ice in the polar basin and seasonal ice in Hudson Bay, and changes in the dates of break-up and freeze-up of the sea ice that are a consequence of climate warming [e.g.4, 5–11]. If climate warming in the Arctic continues as projected by the Intergovernmental Panel on Climate Change [12], diminished ice cover and extended ice-free seasons will have profound negative effects on the ability of polar bear subpopulations to sustain themselves, particularly those at the southern parts of their range [1, 2, 13].

Population/ecosystem status and trends

Polar bears occur in 19 relatively discrete subpopulations with an estimated worldwide abundance of 20,000–25,000 animals [14]. Our knowledge of the status and trend of each subpopulation varies due to availability, reliability, and age of data. Furthermore, for many subpopulations, there is limited or no data collected over a sufficient period of time to examine trends. Based on a 2009 review of the worldwide status of polar bears [14], one of 19 subpopulations appears to be increasing, three are stable, and eight are declining. For the remaining seven subpopulations, there is insufficient or no data to provide an assessment of status (Figure 1.1). In particular, there is a lack of data for the Russian subpopulations.

For six of the eight subpopulations in decline (Baffin Bay, Chukchi Sea, Davis Strait, Kane Basin, Lancaster Sound, and Norwegian Bay), harvesting appears to be the primary factor although in some, climate-induced effects are also suspected to play a role. Harvesting can be addressed through appropriate management actions. Four of these subpopulations are co-managed by two nations, creating special management challenges. In some cases, inter-jurisdictional agreements are in place or are under negotiation.

Figure 1.1: Distribution and current trend of polar bear subpopulations throughout the circumpolar Arctic [14].

For the Western Hudson Bay subpopulation, the decline is linked to the impacts of climate warming and loss of sea-ice habitat on body condition and demographic rates of polar bears [9, 13, 15].

Declines in the extent of summer sea ice in the Beaufort Sea have resulted in loss of optimal polar bear habitat [16]. Negative trends in body size and survival of certain age and sex classes of polar bears of the Southern Beaufort Sea subpopulation are associated with changes in habitat [17–19]. Although the previous [20] and current [17] point estimates, 1800 and 1526, respectively, suggest a decline in the abundance of the Southern Beaufort Sea subpopulation, it is not statistically significant because there has either been no change in numbers or insufficient precision in the estimates to detect a change [17].


Svalbard, Norway Bessemann

Concerns for the future

The increased fragmentation and loss of sea ice habitat, as a consequence of climate change, is the single most critical conservation concern for polar bears. Global warming has been amplified at high latitudes in the Northern Hemisphere [21, 22] and a number of studies have documented significant reductions in extent, duration, thickness, and age of sea ice [e.g., 4, 5, 9, 23, 24]. Recent predictions of continued climate warming [12] will result in unidirectional, negative changes to sea ice, although the timing and rate of change will not be uniform across the circumpolar Arctic. However, because of their dependence on sea-ice habitat, the impacts of continued climate change will increase the vulnerability and risk to the welfare of all polar bear subpopulations. Population and habitat modeling have projected substantial future declines in the distribution and abundance of polar bears [16, 25, 26]. A changing environment also increases the need for more frequent inventories because previous assumptions about the relative constancy of sea ice are no longer valid.

Pollutants that enter the Arctic via long-range transport on air and ocean currents, river systems, and runoff [27, 28] are also a cause for concern. Many persistent organic pollutants reach high levels in polar bears due to their high fat diet and high trophic position [29]. The effects of pollutants on polar bears at the individual and subpopulation levels are largely unknown. However, recent studies suggest that pollutants impact the endocrine system [30], immune system [31], and subsequent reproductive success of polar bears [32]. In addition, new pollutants in polar bear tissues have been documented [33–38]. Finally, McKinney et al. [38] documented increasing contaminant burdens in Western Hudson Bay polar bears as a consequence of dietary shifts due to climate-induced changes in sea ice.

Lastly, reductions in sea-ice extent, duration, and thickness will likely increase human presence and activities in the Arctic [39, 40]. Longer ice free seasons and reduced ice coverage could increase shipping activity and increase resource exploration, development, and production in areas used by polar bears. Potential effects of shipping on polar bears include pollution, noise, physical disturbance related to ice-breaking, and waste. The number and range of cruise ships moving further north into areas used by polar bears may also increase. Potential effects of increased tourism include pollution, disturbance, and increased risk of defense kills.

INDICATOR
#02 Wild reindeer and caribou

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Girdwood, Alaska, USA Serdar Uckun/iStockphoto

Wild reindeer and caribou, Rangifer tarandus, are widely distributed around the circumpolar Arctic (Figure 2.1) where they play a key role in the environment, culture, and economy of the region. Their migrations often involve several hundred thousand individuals. Being sometimes so abundant, these medium-sized herbivores support a diversity of large- (grizzly bears, Ursus arctos horribilis) and medium-sized predators (wolves, Canis lupus, and wolverines, Gulo gulo), as well as scavengers. They are also an important part of the nutrient cycle in the Arctic. Terrestrial Arctic habitats are mostly nutrient-limited and reindeer and caribou [1], through their forage intake and output (i.e., fecal pellets [2]), could have complex and cascading effects [3, 4].

Caribou and wild reindeer have also been fundamental to the diversity and strength of aboriginal peoples. Many aboriginal people across the circumpolar regions have evolved with reindeer or caribou, and these animals have become part of their spiritual values, as well as their subsistence or commercial economies [6, 7].

Global warming is anticipated to have complex and interacting effects on caribou and wild reindeer. Climate and weather have a direct impact on most aspects of wild Rangifer ecology through influences on forage quality, quantity, and availability, as well as influences on vulnerability to their predation and parasites. Other indicators of global warming, such as the timing of green-up, as well as lake or sea freeze-up and break-up, will impact the timing and routes for seasonal migrations and distribution. This, in turn, influences the availability of caribou and wild reindeer to harvesters. There are no simple answers as to how global warming will affect the persistence of wild Rangifer herds given regional diversity and herd histories.

Population/ecosystem status and trends

Currently wild reindeer and caribou have declined by about 33% since populations (herds) peaked in the 1990s and early 2000s (3.8 million compared to 5.6 million) which followed almost universal increases in the 1970s and 1980s. The declines are likely natural cycles, driven by continental and perhaps global atmospheric changes in combination with changing harvest practices and industrial developments [9]. Regionally, there is a tendency for herds to show a measure of synchrony in their phases of increase and decrease. For example, currently all seven of the major migratory tundra herds in Canada's Northwest Territories and Nunavut are declining from highs in the late 1980s/early 1990s, with four of these herds having decreased by 75% or more in 2009 than in the 1990s. In neighboring Alaska, the two larger herds are declining including the well-known Porcupine herd, while two smaller coastal herds are still increasing from the 1970s.

More is known about the status of caribou in Alaska than elsewhere as monitoring is more frequent. Of Alaska's 24 southern and interior herds where trends are known, 16 are declining, six are stable, and two are increasing. In Nunavut, the status of the several smaller herds on the northeast mainland and Baffin Island is unknown as the

Figure 2.1: Distribution and observed trends of wild Rangifer populations throughout the circumpolar Arctic (from The CircumArctic Rangifer Monitoring and Assessment Network, CARMA [5]). Note: Wild boreal forest reindeer have not been mapped by CARMA and thus are not represented here.

herds are not monitored. East of Hudson Bay, close to one million caribou in two herds occupy the Ungava Peninsula. As of the last population estimate, conducted in 2001, the George River Herd has declined while the Leaf River Herd has increased [10].

Canada is the only range for high Arctic Peary caribou, whose overall numbers have declined since 1961, including the loss of one large subpopulation [11]. The rate of decline has varied over time and between the different island populations, with few reversals in decline. Consequently, the Peary caribou is considered endangered in Canada.

One of the two major wild reindeer populations in west Greenland has declined from about 45,000 to 35,000 between 2001 and 2005, while the trend for the second major herd is uncertain. From a management and biological perspective, however, it may be desirable to reduce the size of this population due to a potential risk for overgrazing at the present population level. Neighboring Iceland's introduced wild reindeer have been increasing since 2000 with currently over 6,500 animals. Further east in Norway, mountain reindeer totaled about 25,000 animals in 2003 and the trend for the two largest herds is stable since then. In Finland, the numbers and ranges of wild boreal forest reindeer have been decreasing since 2000 after initial increases in previous decades. In Northern Russia, four of five major wild reindeer herds are declining while one herd, Lena-Olenyk increased as of a 2009 population estimate (Figure 2.2).

The major stressors contributing to recent declines vary between individual herds. Generally, Rangifer in the far north, notably the Peary caribou in Canada and the Arctic island reindeer in Russia, have been impacted by severity of local weather, primarily fall to spring icing [12]. For the migratory mainland herds, continental climate trends are implicated, with current climatic changes likely exacerbating natural cycles and forcing lower

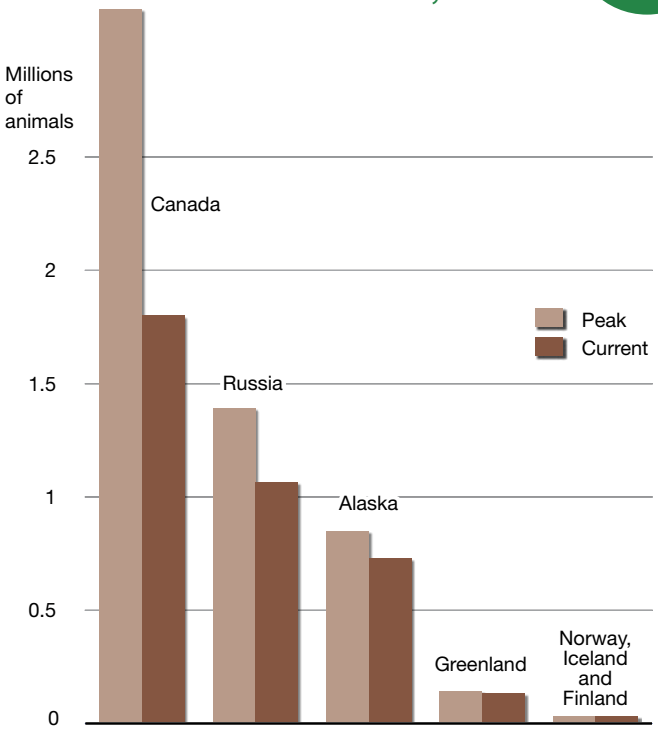

Figure 2.2: Wild Rangifer populations: population peak compared to today (millions of animals) [5].

population troughs and/or slowing the recovery period for some herds [9]. Increased human activity and industrial development are also implicated in the declines of many herds, particularly in the more southern ones [7]. The small mountain herds in Norway, for example, are affected by habitat fragmentation resulting from hydroelectric projects, roads, and recreational activities [13]. In Russia and western Alaska, the overlap between wild and domestic reindeer, with the subsequent loss of domestic stock, undoubtedly complicates or masks normal wild reindeer or caribou trends [7]. For of all these herds, as population numbers decline, the impact of harvesting increases and in many cases may promote further declines and delay recovery.

Concerns for the future

The sheer numbers of wild caribou and reindeer, numbering in the millions, coupled with their historical resiliency, contributes to complacency about their future. However, given the changes taking place across the tundra, the recovery of most herds is not assured: recovery may be delayed or very slow, and some herds may disappear altogether. Habitat changes include a reduction in the size of tundra ranges through the expansion of roads, oilfields, and mining areas. At the same time, current and future climate-related changes occurring on the tundra will have interacting implications for the abundance of caribou and wild reindeer. These include the encroachment of the treeline and shrubs into the tundra and corresponding loss of grasses, lichens, and mosses; increases in plant biomass and declines in plant nitrogen levels; increases in the length of the summer coupled with other changes, e.g., warmer summers; and changes in the timing of mushroom fruiting (an important fall food for caribou and wild reindeer).

There is also a need to integrate changes in predation from environmental changes (e.g., changing snow conditions), or changes in predation as alternate prey, such as moose and deer, move north. Those environmental trends set the context for the changing pattern of harvesting as technology and the socio-economic situation of northern people evolve as well.

INDICATOR #03

Shorebirds – red knot

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Larry Hennessy/iStockphoto

Shorebirds are the most diverse group of Arctic breeding birds and one of the most abundant. From the Arctic, they migrate to their non-breeding grounds along well-defined flyways that circle the world. As a group, however, their recent conservation status has been unfavorable. Trend data are only available for 65 of the 112 breeding shorebird populations that are wholly or largely confined to the Arctic. Of these, 35 populations (54%) are in decline, 29 are stable, and only one is increasing (Figure 3.1) [1].

The red knot, Calidris canutus, is an example of a long-distance migratory shorebird. It has been the subject of extensive research worldwide including studies on its breeding cycle, winter ecology, and stopover sites. It is a typical representative of high Arctic shorebirds and is, therefore, a good indicator species for the whole group. As one of nature's most prodigious travelers, it excites the interest of wildlife enthusiasts, scientists, and conservationists worldwide. For this reason its migration system is among the best known of all shorebirds, although many mysteries still remain.

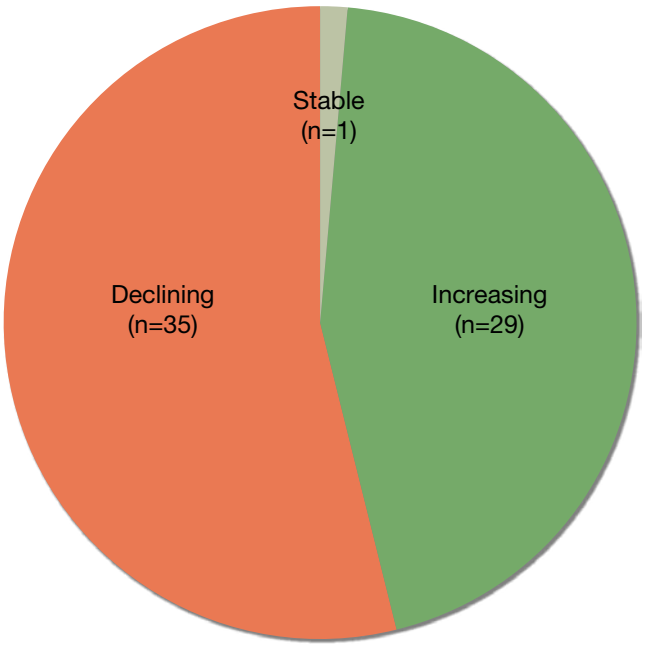

Figure 3.1: Trends in 65 breeding shorebird populations that are wholly or largely confined to the Arctic [1].

Together, the six red knot subspecies have a circumpolar Arctic breeding distribution although each breeds in a discrete area and mainly winters separately. Non-breeding sites range as far south as New Zealand, South Africa, and Tierra del Fuego (Figure 7.2). In many of these places numbers are counted annually, but several important populations, including those of whole subspecies, are not yet adequately monitored.

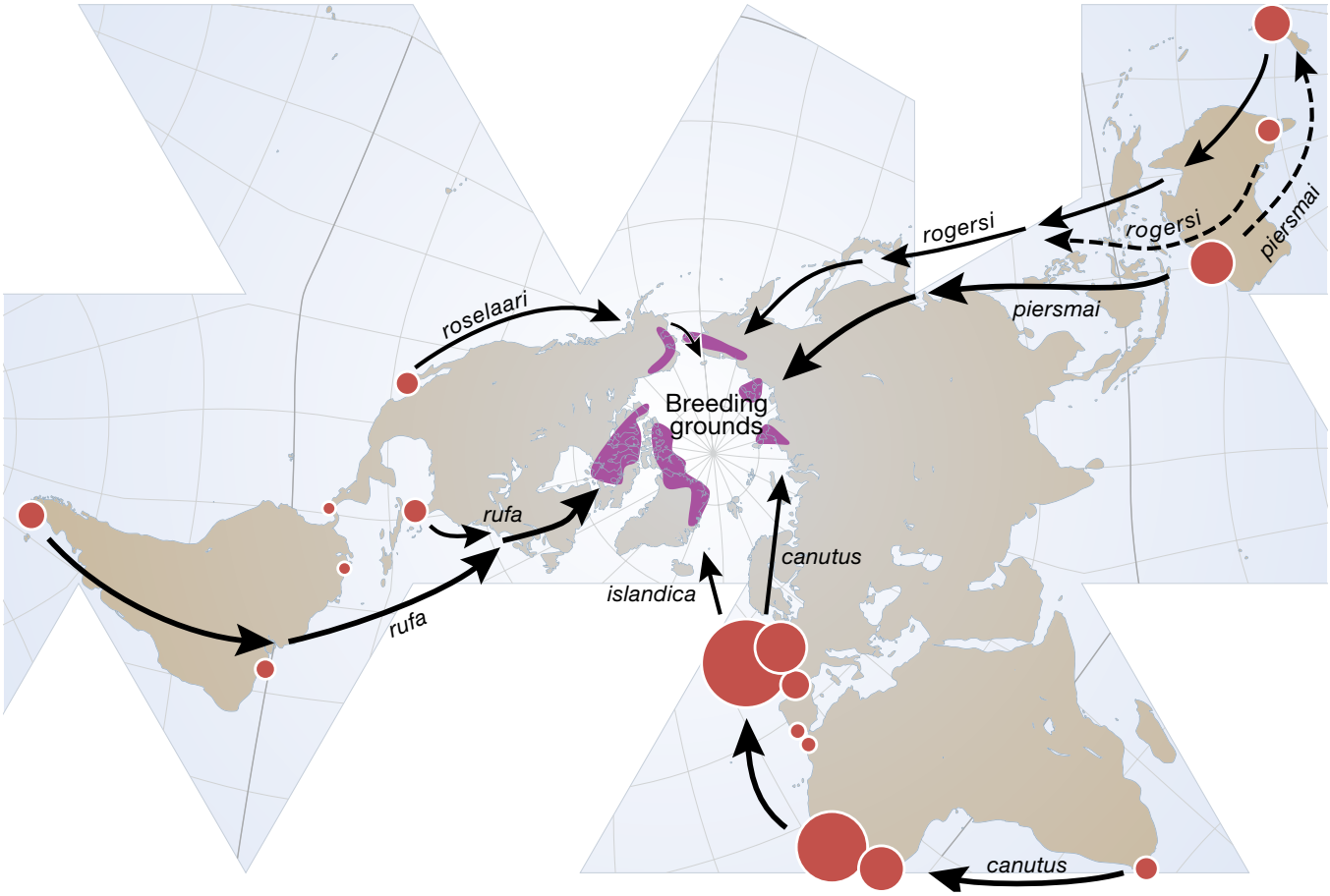

Figure 3.2: Worldwide distribution of the six recognized subspecies of the red knot [2]. All breeding areas (dark purple shading) are on high Arctic tundra where adults spend June–July. After their long-distance migrations, they spend the non-breeding season (August–May) mainly in intertidal, soft-sediment habitats (red dots, which are scaled according to population size).

Population/ecosystem status and trends

Of the six subspecies of red knot, by far the largest populations are those of C. c. canutus and C. c. islandica (Figure 3.3). C. c. canutus winters mainly in West Africa and has its breeding grounds centered on the Taimyr Peninsula of northern Russia. C. c. islandica winters in northwest Europe, and breeds in Greenland and northeast Canada. Large numbers of both populations, however, are highly dependent on one very large site: the Wadden Sea. There, mechanical shellfish harvesting has so severely depleted the food supply that both populations are thought to have suffered population declines, especially that of C. c. canutus. Mechanical shellfish harvesting was stopped in 2006 but it is too early to know whether it has had a beneficial effect on either population [3].

There is insufficient evidence to determine the population trends of the two red knot subspecies of the East Asian – Australasian Flyway, C. c. rogersi and C. c. piersmai, but both are thought to be declining with several sites recording lower non-breeding numbers in recent years [4]. Their relative status is also confused because although most C. c. piersmai are found in northwest Australia and most C. c. rogersi are found in east Australia and New Zealand, there appears to be some overlap. The migration route of both subspecies takes them through the coastal regions of Southeast Asia, especially along the shores of the Yellow Sea. These regions are currently undergoing extensive development with whole estuaries being filled in and converted to human use. It is quite likely that it is habitat loss in this region that is having a detrimental impact on both populations but this has yet to be proved.

The populations of both Western Hemisphere subspecies, C. c. rufa and C. c. roselaari, appear to be vulnerable. The population of C. c. rufa was thought to be as high as 170,000 as recently as 2001[5] but is now down to 30,000 [6]. Undoubtedly, the most significant factor has been the depletion of the food supply at the final northbound stopover in Delaware Bay, USA. There, knots and other shorebirds time their migration to coincide with the mass spawning of horseshoe crabs, Limulus polyphemus, and in the past they made rapid mass gains to fuel their onward migration by feeding on surplus crab eggs. Since the mid-1990s, the horseshoe crab population has been over-harvested for use as shellfish bait and the supply of eggs has been greatly reduced [6]. Studies have shown that red knots which fail to gain sufficient mass in Delaware Bay have lower survival rates [7].

The status of C. c. roselaari, which breeds in Alaska and on Wrangel Island and winters along the American Pacific coast, is unclear. In May 1980, there was an extraordinary and well-documented count of 110,000 C. c. roselaari at a stopover site in western Alaska but nothing approaching such numbers has been recorded before or since. Now, stopover numbers in Alaska suggest a population not exceeding about 35,000. Further south, however, in the United States and Mexico where it is thought that all C. c. roselaari winter, numbers recorded have never exceeded 10,000.

The subspecies of red knots have a disjointed Arctic breeding distribution ranging from just south of the Arctic Circle at 63°N (C. c. rufa and C. c. rogersi) to 83°N, nearly the most northerly land in the world (C. c. islandica) (Figure 3.2). They nest in areas of sparse vegetation, often close to a damp area where the chicks can feed. They arrive


Taimyr Peninsula, Russia Peter Prokosch

on the breeding grounds in late May to early June and the eggs hatch in early July whereupon the females depart from the nesting area leaving the chicks in the care of the males. The males leave in early August and the young soon after.

Breeding success can be very variable depending mostly on weather conditions and the abundance of predators. If there is a late snowmelt, or if the weather is cold leading to a reduction in invertebrate food for the young, and/or if there is an abundance of egg or chick predators such as Arctic foxes Alopex lagopus and jaegers, Stercorarius spp., breeding success can be almost negligible. But in years when such factors have the least impact, as many as half the birds seen on the non-breeding grounds may be juveniles. Year-to-year variation in breeding success arising from random changes in Arctic weather and the often cyclic abundance of predators are natural phenomena which usually lead to only minor changes in otherwise stable shorebird populations.

Concerns for the future

With a total world population of a little over one million (Figure 3.3), the red knot is not yet threatened as a species but there are good reasons to be concerned for its future. Like most long-distance migratory shorebirds, red knots are highly dependent on a limited number of key stopover and wintering sites, making them particularly vulnerable to habitat change. Among the most vital sites are the last major stopovers before the final flight to their Arctic breeding grounds. These are of key importance because in those places the birds require sufficient food resources not only to sustain their long flight but also to ensure their survival during the early part of the breeding cycle when Arctic food resources can be scarce. Other sites may be of equal importance when they form part of a chain of "stepping stones" in which each link is indispensible.

Subspecies	Estimated population size	Trend	Source
C. c. islandica	450,000	Decline	[1]
C. c. canutus	400,000	Decline	[1]
C. c. rogersi	90,000	Probable decline	[4]
C. c. piersmai	50,000	Probable decline	[4]
C. c. roselaari	35,000	Not clear	[6]
C. c. rufa	30,000	Major decline	[6]

Figure 3.3: Population estimates of the six subspecies of the red knot.

Another concern for the future is the possible impact of climate change. In the short term, it may be beneficial if it leads to earlier snowmelt and a greater abundance of invertebrate food. In the longer term, however, red knot breeding habitat may be lost as the tundra zone is pushed northwards towards the Arctic Ocean.

INDICATOR
04

Seabirds – murres (guillemots)

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Acknowledgements: Thanks to Freydig Vigfúsdóttir and members of the CBird – Circumpolar Seabird Group of CAFF for information and

Newfoundland, Canada Liz Leyden/iStockphoto

The two species of murres (known as guillemots in Europe), the thick-billed murre, Uria lomvia, and common murre, Uria aalge, both have circumpolar distributions, breeding in Arctic, sub-Arctic, and temperate seas from California and northern Spain to northern Greenland, high Arctic Canada, Svalbard, and Novaya Zemlya. The thick-billed murre occurs mostly in Arctic waters, while the common murre, although overlapping extensively with the thick-billed murre, is more characteristic of sub-Arctic and temperate waters. They are among the most abundant seabirds in the Northern Hemisphere with both species exceeding 10 million adults [1].

Murres feed from coastal to pelagic waters, mostly over the continental shelf and slope, taking a wide range of small fish (<50 g) and invertebrates, including annelids; pteropod and cephalopod molluscs; and mysid, euphausiid, amphipod, and decapod crustaceans. Common murres generally are greater fish eaters than thick-billed murres [1]. Adults of both species weigh about 1 kg, can remain under water for up to 4 minutes, and dive regularly to depths greater than 100 m, reaching a maximum depth of approximately 150 m. Their diving capacity, allied to their typical foraging radius of up to 100 km from the colony, means that murres sample a relatively large volume of the marine environment around their colonies [2, 3].

Murres breed in very large colonies of up to one million birds on mainland cliffs or offshore islands (Figure 4.1). In most places, they lay their eggs in the open, making them easy to count. Consequently, their population trends are relatively easy to assess and this, allied to their abundance and widespread distribution, makes them ideal subjects

Population/ecosystem status and trends

Both species have shown regional population changes over the past three decades and although no obvious global trend has been identified, the majority of populations have shown declines [7]. The sensitivity of murre populations to changes in environmental conditions has been demonstrated on a hemispheric scale by recent studies by the Circumpolar Seabird Group of CAFF. By combining population trend data from around the Arctic with information on sea surface temperature (SST) and decadal-scale oscillations, it has been shown that both species tended to show negative population trends where there was a large change in SST [7]. Colony growth was most often positive where conditions remained relatively stable (Figure 4.2).

In contrast, the northern species, the thick-billed murre, exhibited highest population growth where conditions warmed moderately, whereas the common murre showed highest rates of increase where conditions cooled moderately. In the context of global warming, this result suggests that not only the direction but the magnitude of change may be important in determining outcomes and that species, even those closely related, may not necessarily react in the same way to a given temperature change.

Other major problems facing murres include gillnet and oil spill mortality and in some parts of their range, hunting (especially of the thick-billed murre in Greenland). Populations in several countries have declined due to drowning in fishing nets. In addition, they are highly susceptible to oiling and are often the most numerous species killed by oil spills.

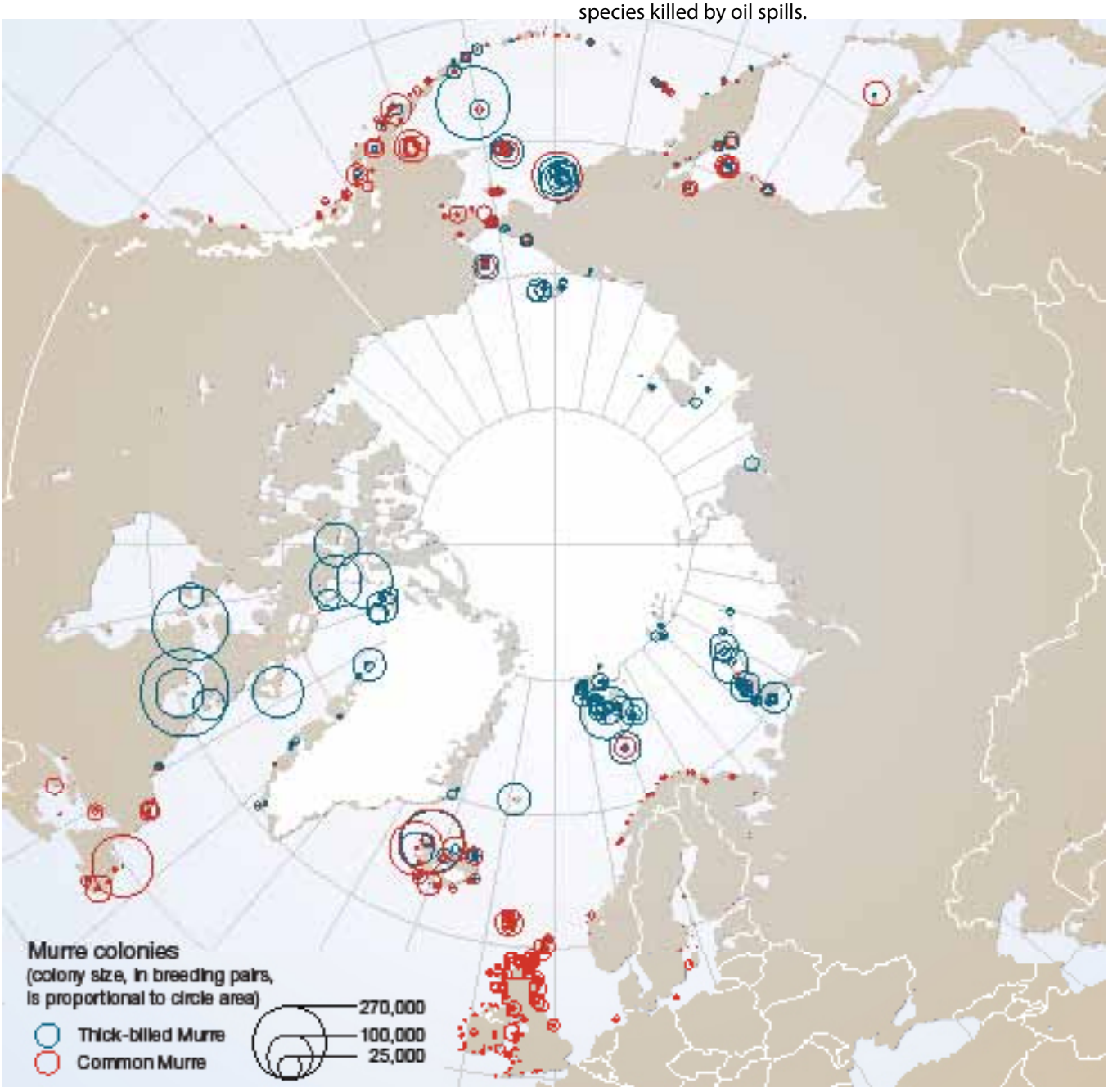

Figure 4.1: The distribution of thick-billed and common murre colonies in the North [4–6].

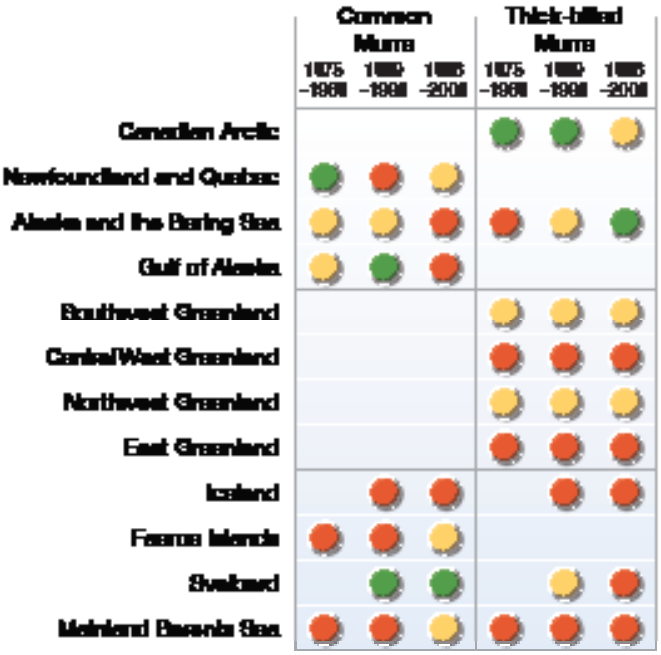

Figure 4.2: Changes in murre populations since 1975 by region and 'decade' (as defined by regime shifts in the Pacific Decadal Oscillation; see [7]). Green indicates positive population trends, yellow indicates stable populations, and red indicates negative population trends. (Data from [4, 7–12]).

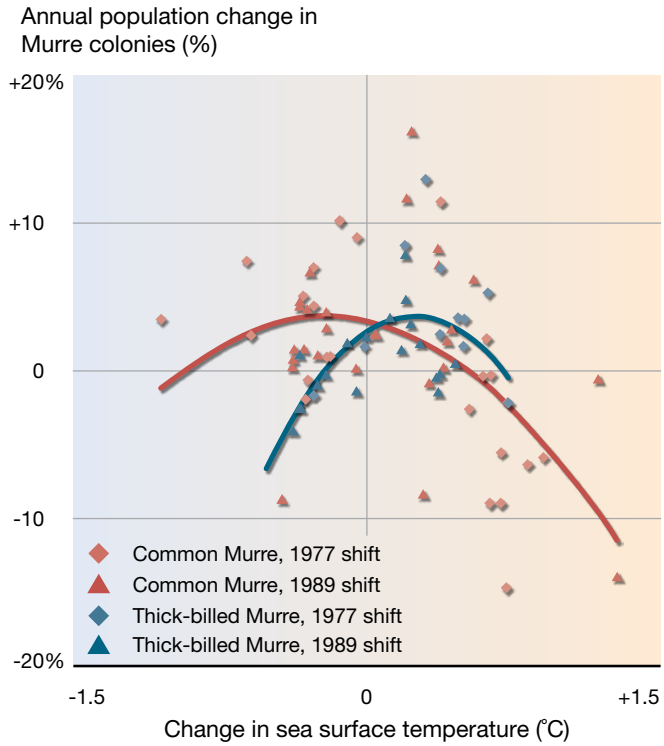

Figure 4.3: Annual rates of population change of individual murre colonies during 12 years after the 1977 climatic regime shift in the North Pacific and during 9 years after the 1989 shift, in relation to changes in sea surface temperatures around the colonies from one decadal regime to the next. Population data are from 32 U. aalge and 21 U. lomvia colonies, encompassing the entire circumpolar region. Ten sites supported both species, so 43 different study areas were represented. (Reprinted from [7]).

Concerns for the future

For the thick-billed murre, changes in the extent and timing of sea-ice cover over the past several decades [13] are leading to changes in phenology and reproduction with adverse consequences for nestling growth [14]. These changes seem likely to intensify. Aside from climate change, problems facing murres include fisheries interactions, contaminants, and oil spills [15] and, in some parts of their range, hunting (especially of thick-billed murres). Levels of some contaminants, especially mercury, have increased in murre eggs in the North American Arctic since the 1970s, although they remain at sub-lethal levels [16]. If climate change leads to increased shipping and oil and gas exploitation in Arctic waters, the increased risk of spills would also pose a potential hazard for murres, which are extremely susceptible to mortality from oil pollution [17].

Although both species of murre are currently abundant, many populations have been declining for several decades (Figure 4.2). In the long term, the decrease in range of thick-billed murres in response to the retreat of Arctic sea ice appears likely. Eventually it may be replaced by the common murre and other more southern auks.


Sweden David Thyberg/iStockphoto

INDICATOR
#05 Seabirds – common eiders

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Young Sund, Northeast Greenland Carsten Egevang/Arc-Pic.com

The common eider, Somateria mollissima, has a circumpolar distribution breeding mainly on small islands in Arctic and boreal marine areas in Alaska (Bering Sea region), Canada, Greenland, Iceland, western Europe, and the Barents Sea region. In Russia, there is a gap in distribution along the mainland coast from the Yugorski Peninsula (Kara Sea) to Chaunskaya Bay in east Siberia (Figure 5.1). Important wintering areas include the Gulf of Alaska/Bering Sea/Aleutian region, southeast Canada, southwest Greenland, Iceland, Western Europe, along the Russian coast of Barents Sea, and in the White Sea. Six or seven subspecies are recognized, of which four occur in North America [1, 2].

The common eider is a highly valued living resource in the Arctic. The birds or their products are harvested throughout most of the circumpolar region. As the largest duck in the Northern Hemisphere, it is important for traditional food and lifestyle not only in many Arctic communities, but also in southeast Canada and the Baltic region [3]. In some countries, especially Iceland, down feather collection constitutes a significant commercial industry [4].

The often close connection between eiders and human societies makes it very feasible to apply traditional knowledge in monitoring and research of common eiders and examples of this already exist [e.g.,5].

The common eider is dependent on benthic organisms in shallow marine waters for food throughout the year, making them a potential indicator of the health of marine coastal environments. This is similar to situations in which fish-eating seabirds can indicate changes in the pelagic marine ecosystem. Year-round movements have been studied intensively over the past 10–15 years by satellite telemetry [e.g., 6, 7] and this provides a good foundation for monitoring change in the future.

Figure 5.1: Breeding and wintering range of common eiders in the circumpolar region (not all southern breeding areas included) [8].

Population/ecosystem status and trends

The world population of common eiders probably ranges from 1.5 to 3.0 million breeding pairs [1]. Around the early 1990s, it was clear that common eiders in the Arctic, along with other eider species, had generally suffered large declines over the past two to five decades, and the need to stabilize and manage eider populations was increasingly recognized. As part of the Arctic Environmental Protection Strategy, signed in 1991, the Circumpolar Seabird Working Group of CAFF (1997) developed a Circumpolar Eider Conservation Strategy and Action Plan [9].

The factors behind several eider population declines reported in the 1980s and 1990s (including populations in Alaska, Canada, Greenland, and Russia) were often unknown, but in some cases involved human disturbances, excessive harvest, and severe climatic events [10–12]. The current trend of common eider populations varies but at least some populations in Alaska, Canada, and Greenland are now recovering with improved harvest management as a likely contributing factor [2, 13, 14]. Breeding populations in the Barents Sea region appear reasonably stable or locally increasing [1, 15]. In the more southern distribution range, the eider population in the Baltic region increased up until the early 1990s but is now decreasing [16]. Low rates of recruitment due to viral infections of ducklings, higher predation on breeding females and deteriorating foraging conditions on wintering grounds seem to be contributing to the decline [17–19].

Iceland Alari Kivisaar/iStockphoto

Concerns for the future

Along with other gregarious bird species common eiders are sometimes affected dramatically by diseases. A recent outbreak (2005–present) of avian cholera in the Hudson Strait of eastern Canada abruptly reversed a population increase and reduced the population of a large colony there by 30% in just three years [20]. The cholera outbreaks appear to be occurring with increasing frequency in the north and may have significant conservation implications. By-catch in fisheries gillnets (mainly for cod, Gadus spp., and lumpsucker, Family Cyclopteridae) is known to occur in most Arctic countries [21], however, the magnitude of the problem is often not clear. Recent concern has been expressed for Greenland, Norway, and the Baltic region [22–24]. The search for oil and gas reserves in the Arctic is increasing and may put eider ducks at further risk in the future. The direct response of eiders to climate change is currently under investigation in several countries. In Iceland, local weather conditions appear to affect nesting dates and clutch sizes, although not consistently between colonies [25]. The North Atlantic Oscillation Index was found to have no effect on the survival of eider females in Finland [26]. The management of human harvest of eiders or their products, and the management of introduced predators such as foxes, Vulpes spp., and mink, Mustela vison, will remain important issues in the conservation of common eider populations.

Svalbard, Norway Laila Røberg/iStockphoto

INDICATOR
#06 Arctic char

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Vebjørn Karlsen/iStockphoto

Chars are salmonid fishes of the genus Salvelinus and are widely distributed throughout the circumpolar north from northernmost land areas to temperate regions in the south, i.e., from 84°N south to ~40°N [1]. The distribution of the Arctic char species complex, sensu stricto, is shown in Figure 6.1. They occur across a broad range of environments and habitats, and are prominent components of northern aquatic ecosystems including freshwater, estuarine, and nearshore marine habitats. Chars are usually the only fish species present in the relatively simple freshwater ecosystems in Arctic areas north of ~75°N latitude [2].

Chars exhibit wide species diversity but this is poorly understood and unresolved at several taxonomic levels. Firstly, between seven and twenty two (or more) formal species are recognized, although taxonomists disagree on exact boundaries between them [3]. Two major taxonomic groups occur in the Arctic: Arctic char, Salvelinus alpinus (L.) (Figure 6.2a), which has a Holarctic distribution and is primarily associated with lake-dominated river systems, and Dolly Varden, Salvelinus malma (Walbaum) (Figure 6.2b), which has a north Pacific distribution and is primarily associated with Arctic rivers [1, 4, 5]. Second, both groups exhibit diversity in life history type and migratory patterns below the 'species' level being either anadromous (sea-run or migratory), freshwater resident (non-migratory; co-occur with anadromous type) [5, 6], or isolated (lack access to the sea). Lastly, multiple ecophenotypes (i.e., visible physical characteristics that result from environmental conditions) of chars co-occur as adults in the same water body but differ in morphology (e.g., size, color, body form), ecological associations and habitat use (e.g., littoral, benthic, or pelagic), position in food webs, and growth variations. For example, three forms of Arctic char occur in Lake Hazen, northern Ellesmere Island, Canada (Figure 6.2c–e).

Chars are also important to northern communities, both culturally and as a source of consistently available local food. In Nunavut, northern Canada, for example, char constitute 45% by number of the top 15 species harvested as traditional/country food by the local Inuit population [8]. Chars are also fished commercially in many areas of the Arctic, contribute to local economies through sport fisheries, and are cultured in areas where conditions permit (e.g., Norwegian fjords and some areas of Canada).

Chars are of significant importance from a scientific perspective due to their wide and northern distribution in fresh waters, high and unique forms of diversity, high endemism (i.e., local diversity found only in one area) of many taxa, and the wide range of evolutionary patterns observed.

As a direct consequence of their local diversity and their occupancy of many habitats, and their wide functional, cultural, socio-economic, and scientific importance, chars are not only an essential component of Arctic aquatic biodiversity, but are also fundamentally well-suited as indicator species of both the specific circumstances and the general health of northern freshwater ecosystems.

Figure 6.1: The distribution of Arctic char species complex, sensu stricto, and the location of introduced populations [7].

Population/ecosystem status and trends

Although studies of the status of char populations in Arctic regions are generally lacking, some assessments exist for non-Arctic nations and their findings may be applied to Arctic populations. Unlike their southern counterparts, char populations in the Arctic generally appear to be mostly healthy, although this in part may simply be due to greater numbers being present and/or inadequate information. For example, in the Arctic regions of nations with natural populations of Arctic char, it is likely that no populations have gone extinct (information interpolated from Table 1, p. 114 in [9]). However, significant extinctions have occurred in more southerly regions (e.g., 12 of 258 known populations in Scotland and 30% of the known populations in Ireland have gone extinct [10]), despite these being in more remote areas of these countries. This is not to say that Arctic populations are unstressed. Rather, several examples of stressed char populations are known for the Arctic particularly near to communities (e.g., for the Canadian Arctic: Dolly Varden, Big Fish River [11]; Arctic char, Hornaday River [12]), especially where over-fishing perhaps combined with habitat changes has resulted in local population collapse.

Assessments of trends for chars tend to be population specific, episodic, and of short duration. Widespread geographic comparisons and assessments of status are therefore difficult to synthesize. Furthermore, the focus

Figure 6.2: (A) Arctic char, Salvelinus alpinus (L.) (B) Dolly Varden, Salvelinus malma (Walbaum) (C) Lake Hazen dwarf benthic form Arctic char (D) Lake Hazen small form Arctic char (E) Lake Hazen large form Arctic char.


Kanektok River, Alaska, USA Sandy Lockleer/iStockphoto

of most data is in the context of fisheries management and thus is generally inadequate from a biodiversity perspective.

Catch records for the last century for the commercial fishery of non-migratory Arctic char in Mývatn, northeastern Iceland indicate that average annual catches remained relatively stable until 1970, after which they declined due to the combined effects of exploitation and industrially induced environmental change [13]. Other studies, however, show that at least some anadromous populations of Arctic char appear to be resilient to heavy exploitation to some degree [14]. Typical shifts expected from commercial fishing (e.g., age and length distributions) were relatively stable over time, and populations have returned to earlier conditions with reduced intensity of exploitation and environmental amelioration [14]. Thus, sustainable fisheries on the anadromous form, at least in sub-Arctic situations, are possible [14].

Diversity in chars, particularly in life history, increases the exposure of populations to effects of different natural drivers and anthropogenic stressors. These range in scope from global, pervasive stressors affecting all populations in some fashion (e.g., climate variability and change), to local stressors affecting single populations (e.g., exploitation).

Climate variability and change will differentially affect char populations principally through latitudinal and regional effects acting directly upon the fish (e.g., thermal regimes enhancing growth) or indirectly through ecosystem or habitat pathways (e.g., shifts in competitors, predators, prey, or parasites and diseases) [15–17]. Thus, climate change effects on chars may range from positive (e.g., enhanced growth) to negative (e.g., shift in balance among or loss of life history types). An additional significant effect from climate change is alteration of habitat quantity (see [18]) and quality [19, 20]. Other pervasive stressors include long-lived contaminants particularly those which biomagnify and accumulate at higher levels of food chains (e.g., mercury, PCBs).

Locally acting stressors particularly important in the Arctic include exploitation as commercial, subsistence, and/or recreational fisheries; industrial development; eutrophication; habitat change; contamination; species introduction and colonization; translocations of chars; and barriers to migration ([10], references therein). In addition to being the direct result of a particular local stressor, effects observed on local char populations may also result from the pervasive stressors noted above (e.g., habitat and hydrological shifts from climate change). While it may be difficult to distinguish the ultimate cause for a specific effect, the potential for significant synergistic cumulative effects resulting from the suite of stressors may be very high in particular populations.

Concerns for the future

Chars generally, and Arctic char in particular, represent the unique diversity present in northern aquatic ecosystems. This diversity, however, is very poorly known, as are the mechanisms which maintain and generate it.

It is in this context that significant anthropogenic stressors are presently affecting char and are likely to continue to do so in the future. We are possibly altering char biodiversity without documenting it and understanding its relevance. Concerted pan-Arctic biodiversity assessments, sustained research, and coordinated monitoring of chars are required to outline the scope of diversity present and its significance, and the mechanisms responsible for maintaining it and documenting changes.

INDICATOR
07

Invasive species (human-induced)

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Spitsbergen, Svalbard, Norway Michel de Nijs/iStockphoto

As humans and their goods and services have become increasingly mobile, so too have the intended and unintended movements of species. In many cases, the intended benefits of species movement (food, fiber, recreation) have been realized. In other cases, both unintentional and intentional introductions have had harmful results [1]. The term "invasive species" is used here to reflect this latter situation and refers to species that are not native to a given ecosystem (i.e., when a species is present due to an intentional or unintentional escape, release, dissemination, or placement into that ecosystem as a result of human activity) and which may cause economic or environmental harm (including harm to subsistence species and activities) or which may cause harm to human health. It should be noted that some non-native species considered to pose no invasive threat may exhibit explosive population growth long after their initial establishment in a new environment [2], leading to invasive impacts, despite initially being considered benign.

Biological invasion is now widely recognized as second only to habitat alteration as a factor in the endangerment and extinction of native species [3, 4], and is arguably the less reversible of the two. Indeed, many consider invasive species, together with climate change, to be among the most important ecological challenges facing global ecosystems today. The impacts of invasive species are not limited to ecological harm. The annual economic impact of invasive species has been estimated at between $13 and $34 billion CAD for a subset of invasive species in Canada

[5] and considerably more in the United States where estimates of economic impacts are in excess of $138 billion USD per year [6].

Impacts on cultural systems are harder to define, but two things are clear: 1) as native biodiversity is lost, so too are the potential human uses of that biodiversity, and 2) climate change will increase the likelihood of biological invasions in the Arctic. The combination of these two factors, plus the existence of many vibrant subsistence cultures in the Arctic which rely on native flora and fauna, suggest this is a timely opportunity for additional study.

Population/ecosystem status and trends

Biological invasions are known from around the globe but are relatively less known or studied in the Arctic. In their analysis of coastal marine invasions, de Rivera et al. [7] noted a pattern of decreasing diversity and abundance of non-native species with increasing latitude. This does not mean the Arctic is not susceptible. In fact, a subsequent study estimated that a suite of marine invasive species, including the European green crab, Carcinus maenas, had the potential to expand to sub-Arctic and Arctic waters even under moderate climate change scenarios [8]. Similarly, Ruiz and Hewitt [9] concluded that "environmental changes may greatly increase invasion opportunity at high northern latitudes due to shipping, mineral exploration, shoreline development, and other human responses."

This secondary migration of invasives complicates ecological interactions as naturally occurring species from areas adjacent to the Arctic are also expanding their ranges northward [10]. Another study found that the rate of marine invasion is increasing; that most reported invasions are by crustaceans and molluscs; and, importantly, that most invasions have resulted from shipping [11]. Given the findings of the recent analysis of current Arctic shipping (Figure 7.1) and the potential for climate change to expand such shipping [12], this has potentially very high relevance for future marine invasive risks to Arctic waters. In fact, in August 2009, two German vessels moving Korean goods from Vladivostok to the Netherlands along the Northern Sea Route became the first legal commercial ship crossings of the Arctic without icebreaker assistance [13]. Studies of polar shipping operations have demonstrated that the external hull and ballast tanks of vessels operating in ice-covered waters can support a wide variety of non-native marine organisms [14, 15].

To date, there are many fewer invasive terrestrial plants known from the Arctic than in the more highly altered and invaded ecosystems of lower latitudes. However, even Arctic ecosystems are susceptible to invasion. Over a dozen invasive plant species are already known from the ecozones of the Canadian Arctic and many more have reached ecozones to their immediate south [16]. In the Alaskan Arctic, 39 taxa of introduced plants (or roughly 7% of the total Arctic flora) have been reported, including a suite of highly invasive grasses and clovers [17]. Another highly invasive plant, white sweet clover, Melilotus alba, has now spread up the Dalton Highway to above the Arctic Circle in Alaska. This nitrogen fixing invader has the potential to alter soil chemistry, with unknown consequences for native plant species that have evolved in low nitrogen systems. Invasive plants are even known in the high Arctic, with 15% of the flora from a survey in Svalbard reported to be non-native species [18].

Concerns for the future

As climate change alters Arctic ecosystems and enables greater human activity, biological invasions are likely to increase in the Arctic. To some extent, Arctic terrestrial ecosystems may be predisposed to invasion because many invasive plants are adapted to open disturbed areas. If fire frequency and intensity increase with climate change, this may further enhance invasion susceptibility. Sites of human disturbance and those located along pathways of human activity (e.g., shipping, including port facilities, and road corridors) are the most likely focal points of invasion into Arctic habitats. One study, for example, noted the susceptibility of gravel-rich river corridors to invasion by Melilotus, a type of clover, from bridge crossings [19].

The ability for climate change to directly enhance invasion has been demonstrated for marine tunicates [20] and the spread of invasive marine tunicates to the Arctic could present a significant risk to benthic-feeding marine mammals that are already at risk (e.g., several whale and pinniped species). Benthic communities in northern Norway and the Kola Peninsula in Russia are already facing significant disturbance from the introduced red king crab, Paralithodes camtschaticus [21], and further introductions may contribute to accelerated and synergistic impacts (e.g. [22]). Range map scenarios developed for 16 highly invasive plants either occurring in or at risk of invading Alaska [23] also paint a sobering

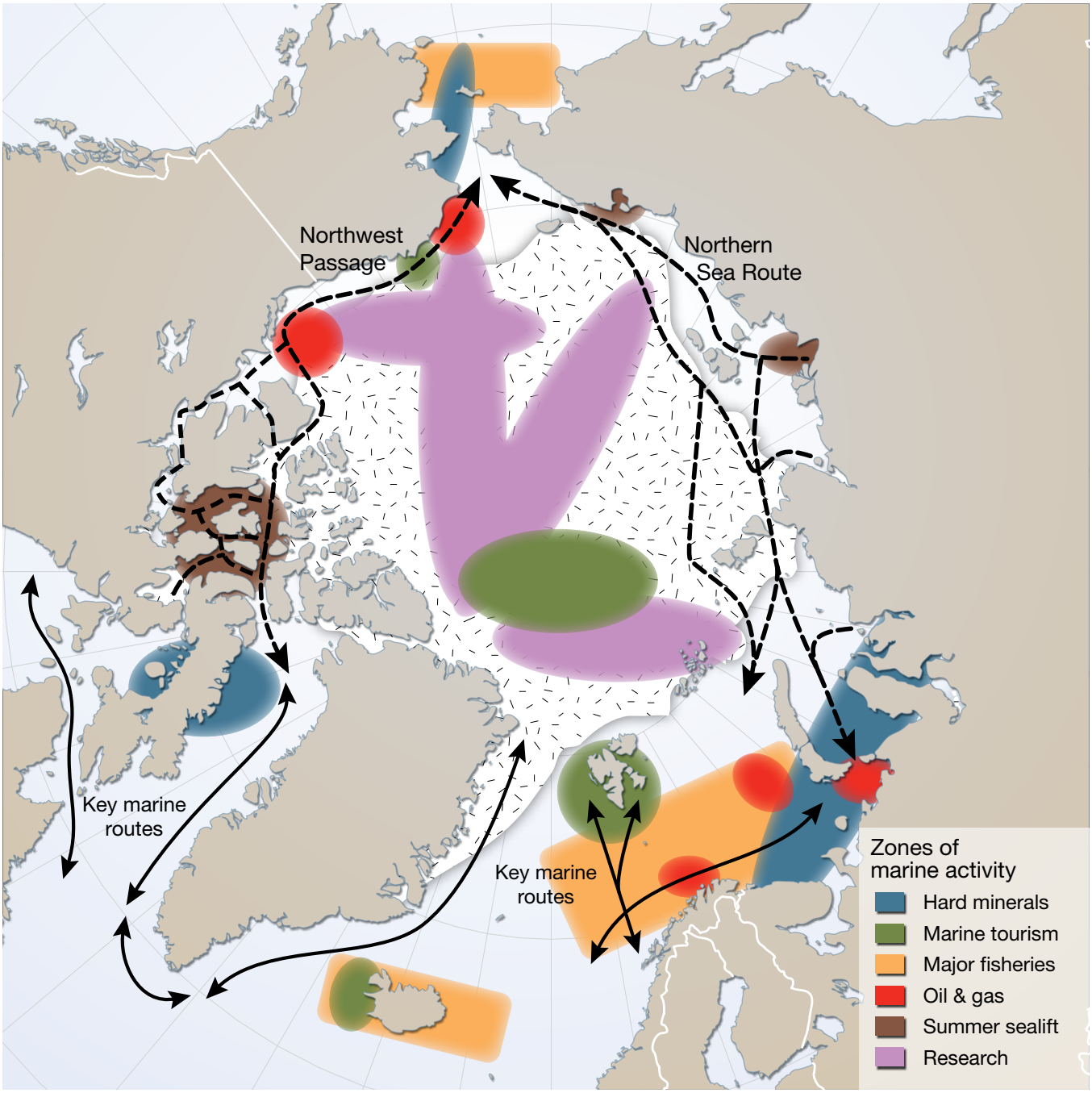

Figure 7.1: Current marine shipping uses in the Arctic [12].

outlook for the future. Figure 7.2 depicts the potential expansion of one invasive aquatic plant, Hydrilla veticillata, well up into Arctic Alaska ecosystems and even into far eastern Russian aquatic systems. Another recent study examining global distribution trends associated with climate change predicted that marine communities in the Arctic and Antarctic will be the most at risk from climate induced invasions [10].

Because future change will be best understood when measured against a credible baseline, much more work similar to that of Ruiz et al. [24] will be needed. Due to the distribution of resources in the Arctic, the development of cost-effective early detection monitoring networks will be a challenge. Special attention should be given to monitoring around key points of introduction via the unloading of goods, such as ports and airports, or in areas likely to see increased ship deballasting or at higher risk of shipwrecks. Engaging a network of citizen scientists might present a viable alternative to traditional monitoring approaches. Such networks could represent an excellent opportunity to employ the traditional ecological knowledge of northern residents. After all, who knows better when something "different" appears in an ecosystem than those who have used the native species of that ecosystem for millennia?

In addition to valid baselines, there will need to be increased and targeted prevention efforts to limit the influx on non-native species (e.g., ballast water treatment, inspection and treatment of containers and packaging material, and the effective cleaning and treatment of ship hulls and drilling rigs brought in from other marine ecosystems). Such measures should be complemented with targeted management plans for activities known to present a high risk of introduction. For example, petroleum drilling rigs have been identified as a significant risk for modern marine introductions, and the increase of petroleum extraction in the Arctic should be accompanied by stringent cleaning and monitoring requirements [25].

Finally, two additional future Arctic risks that may accompany climate change: 1) much like climate change, invasive species can decrease stability and increase uncertainty in ecosystem function and the evolutionary trajectories of its component species; and 2) as more southern ecosystems feel the effects of these climate-induced uncertainties, there may be a push to resort to using Arctic ecosystems as refugia at the receiving end of well-intended but risky efforts to "assist" species in the colonization of new habitats [26]. Since ability of species to successfully invade will vary with their mobility and physiological capacities, much work is also needed on basic biology and life history traits of potential Arctic invaders in order to effectively assess Arctic vulnerabilities and risks.

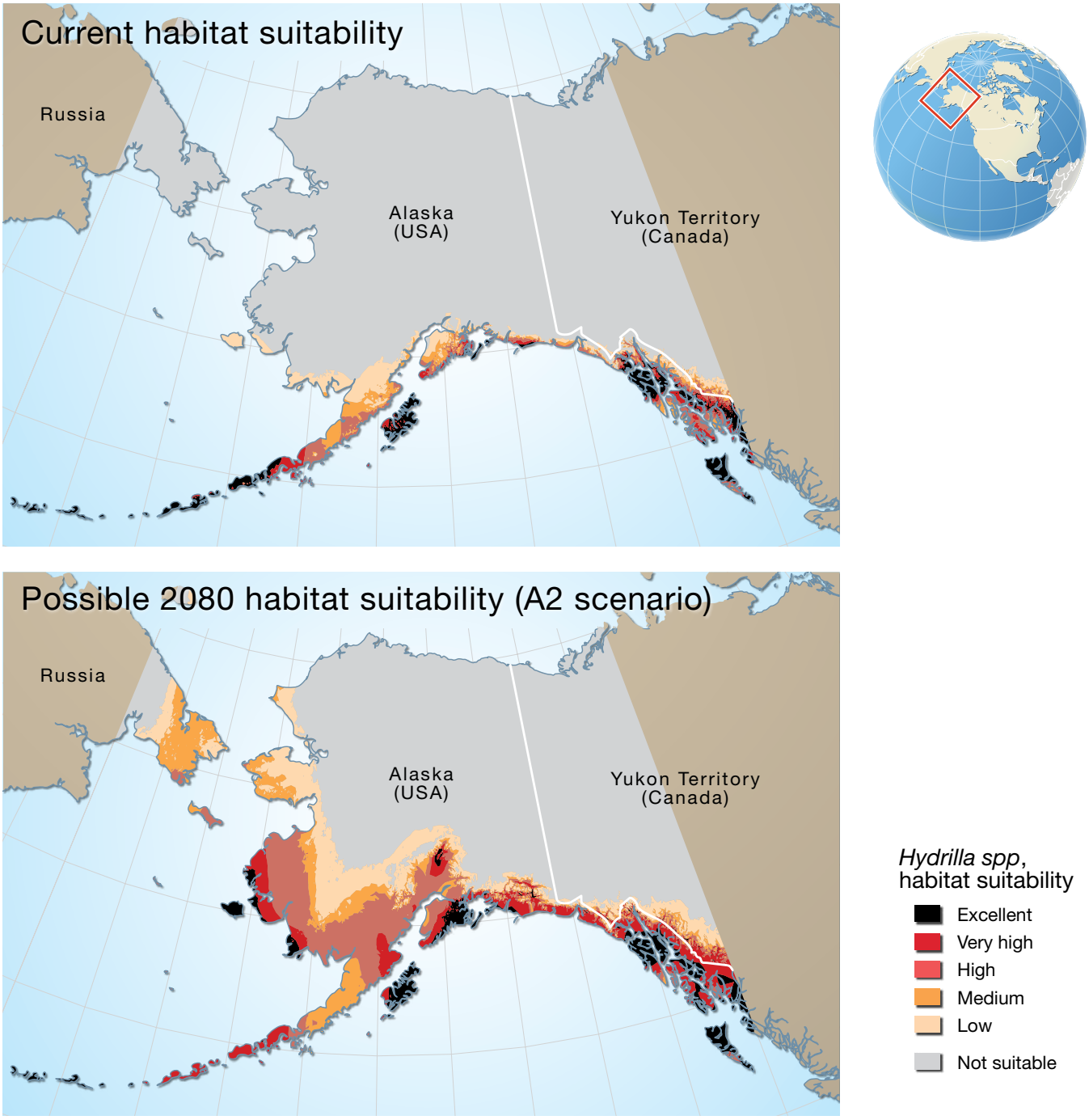

Figure 7.2: Current potential range of Hydrilla verticillata in Alaska and projected potential range with climate warming (adapted from [23]).

INDICATOR
08

The Arctic Species Trend Index

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Kangerlussuaq, West Greenland Carsten Evegand/Arc-Pic.com

Dramatic changes, such as sea ice loss, are projected to occur in Arctic ecosystems over the next century [1]. Understanding how the Arctic's living resources, including its vertebrate species, are responding to these changes is essential in order to develop effective conservation and adaptation strategies. Arctic species that are adapted to these extreme environments are expected to be displaced, in part, by the encroachment of more southerly species and ecosystems [2]. Limited functional redundancy in Arctic ecosystems poses a particular risk as the loss of a single species could have dramatic and cascading effects on an ecosystem's state and function [2]. Our current, mostly single species approach to monitoring with a bias towards charismatic species over functional species, limits our ability to detect and understand critical changes in the Arctic's ecosystems. A broader and more integrated approach is needed to facilitate a better understanding of how Arctic biodiversity is responding to a changing Arctic and how these changes might reflect or counter global biodiversity trends.

For the first time, an index that provides a pan-Arctic perspective on trends in Arctic vertebrates is available. The Arctic Species Trend Index (ASTI)[1], like the global Living Planet Index (LPI), illustrates overall vertebrate population trends by integrating vertebrate population trend data of an appropriate standard [3] from across the Arctic and over the last 34 years (with 1970 as the baseline[2]). This index not only gives a composite measure of the overall trend of Arctic vertebrate populations, but can also be disaggregated to display and investigate trends based on taxonomy, biome, region, period, and other categories. These disaggregations will ease the identification of potential drivers of these trends. Over time, tracking this index will help reveal patterns in the response of Arctic wildlife to growing pressures, thereby facilitating the prediction of trends in Arctic species.

1. Technical Note on the ASTI: The population data used to calculate the index are gathered from a variety of sources and must meet the appropriate standard [3] before being included. All data used are time series of either population size, density, abundance, or a proxy of abundance. The period covered by the data runs from 1950 to 2004. Annual data points were interpolated for time series with six or more data points using a generalized additive modelling framework or by assuming a constant annual rate of change for time series with less than six data points [3, 4]. The average rate of change in each year across all species was calculated. The average annual rates of change in successive years were chained together to make an index, with the index value in 1970 set to 1. A boot-strap resampling technique was used to generate confidence limits around the index values; these are not shown to avoid over-complicating the figures.

2. 1970 was used as the baseline as pre-1970 data in the ASTI was limited making trend results uncertain for years preceding 1970.

Population/ecosystem status and trends

A total of 965 populations of 306 species (representing 35% of all known Arctic vertebrate species) were used to generate the ASTI. In contrast to the global LPI [4], whose overall decline is largely driven by declines in tropical vertebrate populations, the average population of Arctic species rose by 16% between 1970 and 2004. This pattern is very similar to the temperate LPI [4] and is consistent in both the North American and Eurasian Arctic. The overall increasing trend in the Arctic is thought to be partly driven by the recovery of some vertebrate populations (e.g., marine mammals) from historical over-harvesting [5] as well as from recent changes in environmental conditions both inside (e.g. Bering sea pollock, Boreogadus saida [6]) and outside of the Arctic (e.g., lesser snow geese, Chen. c. Caerulescens [7]) resulting in dramatic increases in some species' populations. This increasing trend, however, is not consistent across biomes, regions, or groups of species.

Populations in the high, low, and sub-Arctic boundaries (Figure 8.1), for instance, show markedly different trends. High Arctic vertebrate abundance has experienced an average decline of 26%. Despite an initial growth period until the mid-1980s, sub-Arctic populations (mostly terrestrial and freshwater populations) have, on average, remained relatively stable (–3% decline) whereas low Arctic populations, largely dominated by marine species, show an increasing trend (+46%). This pattern may reflect, to some extent, varying and predicted responses [1, 2] to changing pressures such as climate change and harvest patterns, but may also reflect natural, cyclic patterns for some species and populations. However, caution is needed in interpreting these results.

The high Arctic has experienced the greatest increases in temperature to date and even greater temperature increases are expected resulting in further loss of sea ice extent and range contraction of high Arctic ecosystems and species [1, 8]. However, 34 years is too limited a time series to attribute these changes to declining trends in high Arctic vertebrates. For example, wild barren-ground caribou and reindeer herds are known to naturally cycle over long time periods and recent, largely synchronous declines across the Arctic are thought to be natural and, in part, responsible for the declining high Arctic index. Declines in other species populations, such as lemmings, Dicrostonyx groenlandicus, in Greenland, Russia, and Canada, however, may be, in part, the beginning of a negative response to a dramatically changing system. In contrast, increasing trends in low Arctic populations are biased by dramatically increasing fish populations in response to changing marine conditions [6] and recovering marine mammal populations [5] in the eastern Bering Sea. More data is needed in other Arctic marine systems before an accurate picture regarding Arctic marine vertebrate population trends can be developed.

Divergent patterns are also observed between the different biomes (marine, freshwater, terrestrial). Whereas the freshwater and marine indices increase over the time period (52% and 53% respectively), the terrestrial index shows an overall decline of 10% despite increasing in the late 1970s to the mid-1980s. The data behind the freshwater index is currently too sparse (51 species, 132 populations) to fully reflect the circumpolar freshwater situation, and although the marine index is robust in terms of species and populations (107 species, 390 populations), it is not spatially robust being largely driven by an overweighting of population data from the eastern Bering Sea. The moderate decline in the terrestrial index (–10%) is largely a reflection of declines (–28%) in terrestrial high Arctic populations (mostly herbivores, such as caribou, lemmings, and the High Arctic brent goose, Branta bernicla) (Figure 8.2). Terrestrial low Arctic population increases (+7%) are driven, in part, by dramatically increasing goose populations, but may also reflect an ecological response to climatic changes whereby species with more southerly

Figure 8.1: Location of datasets in the Arctic Species Trend Index.

distributions are responding favorably to these climatic changes [2]. This northward movement of southern species (e.g., red fox, Vulpes vulpes [9]) coupled with increasing incidence of severe weather events in the high Arctic [2, 10] and changing tundra vegetation [11–13] may explain, in part, the declines in terrestrial high Arctic populations and the possible negative impact on herbivorous species.

The major Arctic taxa (birds, mammals, and fish) also exhibit divergent trends. Birds, which comprise 52% of the ASTI populations are revealing a very flat trend overall (–2%), whereas mammal populations increased fairly steadily (+33%) over the same time period. The fish index experienced the greatest increase (+96%), however the data behind the fish index is not currently representative enough to provide meaningful results. Within the bird taxa, freshwater birds have increased dramatically (+43%), largely a reflection of increases in some waterbird populations, and likely in response to stricter hunting regulations and land-use changes on their wintering grounds [14]. The terrestrial bird index, despite a doubling in the numbers of geese, has experienced a slight decline (–10%) over the past 34 years, whereas marine birds, although fluctuating, have remained steady (–4%). An analysis of migrant versus non-migrant birds showed an increasing trend for non-migrants (+20%) and a flat trend (–6%) for migrants although there was no significant differences between the two groups. However, the slight decline in migrant birds would have likely become a more significant decline if the increasing geese populations were not included and we were able to include shorebird population trend data derived from non-Arctic survey sources[3]. Declines in migrant shorebirds to

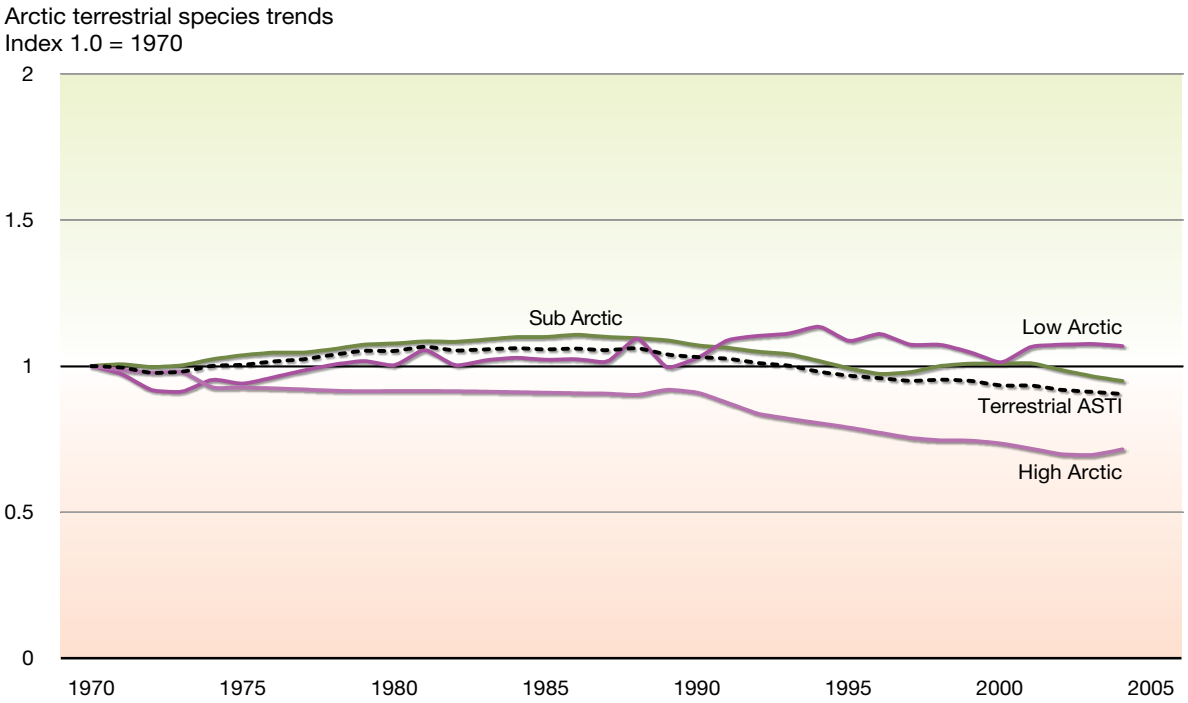

Figure 8.2: Index of terrestrial species disaggregated by Arctic boundary for the period 1970–2004 (high Arctic, n=25 species, 73 populations; low Arctic, n=66 species, 166 populations; sub-Arctic, n=102 species, 204 populations).

date are mostly regarded as a response to pressures (land-use changes, etc.) found on wintering and stop-over sites [15–17], but expected changes to Arctic breeding habitat as a response to climate change may also become a factor in the long-term as most high Arctic species and populations would be at risk [2, 18].

While the ASTI offers some initial insight into recent trends in Arctic vertebrate populations, and notwithstanding the over-representative sample of Arctic vertebrate species, careful interpretation of the ASTI is required as it does not yet adequately represent all populations, taxa, biomes, and regions. While rapid, human-induced changes in Arctic ecosystems are already likely resulting in winners and losers among Arctic species and populations [2], more data coverage and longer-time series are needed to give an accurate, unbiased picture. Despite the limited time series for the index, the large and diverse collection of data in the index, representing a multitude of taxa across regions, biomes and longitudes does provide some insight into potential responses to human-induced pressures, outside of natural variation. This index will improve with the scale, number and breadth of contributions and future analyses will be more robust in their results.

3. Population trend data derived from non-Arctic surveys were not included in the analyses.

Concerns for the future

A number of pressures, many global in nature, are acting cumulatively to exert growing pressure on Arctic biodiversity [2]. Climate change is of paramount concern and recent evidence suggests that our current projections are too conservative, with much higher rates of change already being experienced [19, 20]. These increasing pressures and rates of change are expected to fundamentally change Arctic ecosystems [1, 2]. With changing extent and quality of Arctic habitats, potential ecological bottlenecks emerging due to extreme events and other pressures, limited functional redundancy, and increasing competition from northward shifting species, in conjunction with either natural downward trends or other human-induced pressures such as development or contaminants, loss of some Arctic species and ecosystems is expected [2]. In particular, high Arctic and marine ecosystems and the species they currently support are expected to undergo the greatest changes [1] reducing the potential for these species and ecosystems to persist.

These expected rapid changes will challenge both Arctic residents directly dependent on the Arctic's ecosystems and the global community as a changing Arctic is expected to upset the Earth's physical, chemical, and biological balance. Enhanced, integrated, and coordinated research, monitoring, conservation, and adaptation efforts are needed to meet these growing challenges.

INDICATOR
09 Arctic genetic diversity

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David Marchal/iStockphoto

The concept of biodiversity encompasses aspects of biology ranging from large-scale ecosystems down to the molecular level, where genetic variability is used to characterize diversity within and among populations of species. The genetic component of biodiversity is often not distributed evenly across the geographic range of species, but instead is spatially structured. The primary cause for such structure in the Arctic may be due to evolutionary history and processes related to geography, variable climate, and strong ties to seasonally available resources [e.g., 1]. Exceptions to this generalized pattern of geographic structure may include migratory species such as some birds [2, 3], but intensive research into this key aspect of biodiversity needs to be completed across a wide range of marine and terrestrial Arctic organisms.

In the Arctic, historical events have left distinctive signatures on the gene pools of individual species and these signatures must be understood if we hope to predict the impact of future changes on the genetic component of Arctic biodiversity. The Pleistocene glacial – interglacial periods (roughly 20 events every 100,000 years) during the last 2 million years played a primary role in structuring genetic variation in Arctic organisms. An understanding of genetic variability sets the stage for enlightened management of high latitude organisms in light of rapid environmental change. Molecular genetic approaches are now used in a wide range of applications from tracing the history of species dispersal and diversification across the Holarctic to evaluating the conservation status of high latitude species of concern so that wildlife populations can be sustained. Documenting the prior response of the Arctic biota provides a framework for interpreting the influence of different life history traits (e.g., migratory vs. sedentary) on genetic diversity and ultimately, will allow us to more effectively respond to future impacts on biodiversity under various climate warming scenarios.

Population/ecosystem status and trends

Pleistocene climatic change had two main effects on genetic diversity of existing species. First, glacial advances created geographic barriers, leading to genetic divergence within species. Second, species responded to climatic change by adapting, moving, or suffering local extirpation or eradication. These episodic contractions and expansions of Arctic species altered their effective population size, evolutionary processes, and ultimately the geographic distribution of genetic diversity. Paleoecology and fossil records show that, in contrast to temperate species, cold-adapted Arctic species persisted in the north and expanded their ranges thousands of kilometers southward during glacial periods in Eurasia [4] and North America [5]. Ranges of many Arctic species subsequently retracted during warming phases, such as that currently under way, and retraction likely led to reduced genetic variability. Arctic-adapted populations now at the southern extreme of the species range may be isolated and most vulnerable to loss of genetic diversity. Loss of genetic variability may have important consequences for individual fitness and long-term persistence of species.

The concept of glacial refugia (i.e., areas isolated by glaciers) is appropriate for Arctic species only in the high latitude regions where development of ice sheets prevented persistence of biota during glacial periods. However, recent paleogeographical data show limited extent of the Pleistocene ice sheets in the Eurasian Arctic [6]. In contrast to Eurasia, the North American Arctic was extensively glaciated [7] with the Laurentide ice sheet covering much of Canada. These formerly glaciated Arctic regions were colonized from ice-free areas, so that understanding the nature of these colonization events provides key insight into the current distribution of genetic diversity.

Strong correspondence between evolutionary relationships and geographic distribution of genes (i.e., phylogeographic structure) has been found in the Arctic that reflects substantial endemism in many terrestrial free living and parasitic animals that have been sampled at continental and circumpolar scales [8–12]. The geographic locations of major evolutionary splits are largely similar across different species and coincide around mountain ranges that were formerly glaciated such as the Ural, Verhoyanskiy, Anuiskiy, and Richardson Mountains. In addition, cryptic northern refugia were identified [13–15] and recently supported by palaeoecological lines of

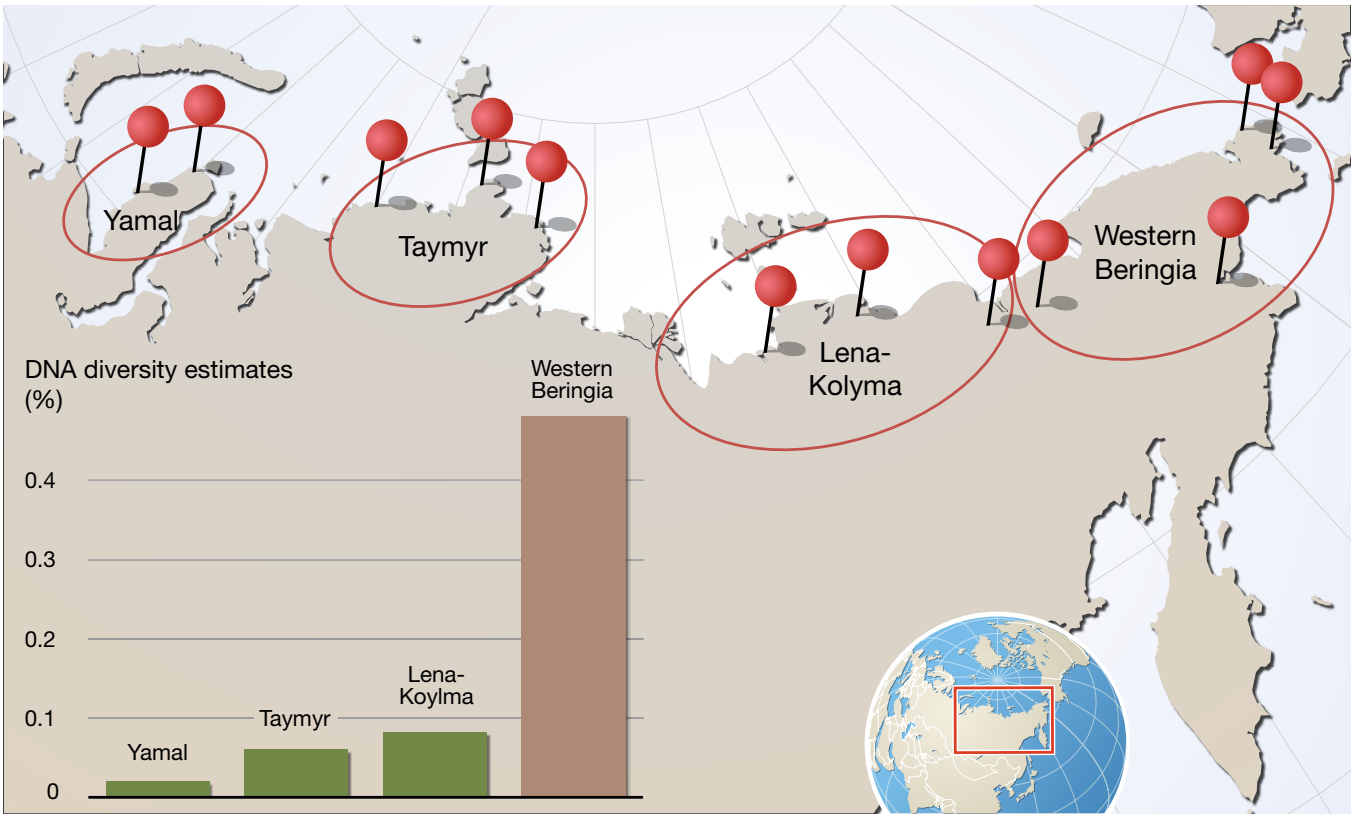

Figure 9.1: Nucleotide diversity estimates based on the complete sequences of mitochondrial genome in the collared lemming [19] indicate how past climate has structured the genetic component of biodiversity. Lower diversity in regions (green) affected by the northward forest expansion during the Holocene warm climatic events [20] compared to Western Beringia, where there was no forest expansion, suggests a reduction of effective size due to regional range contractions during warming events in the Holocene [18].

evidence [16, 17]. These refugia were important sources for colonization of formerly glaciated Arctic regions in Scandinavia and Canada. Genetic diversity of cold-adapted Arctic species also was influenced by warm climatic events during interglacials and the Holocene (the last 11 thousand years). Arctic specialists, such as the collared lemming, Dicrostonyx torquatus, experienced a reduction in effective population size due to range contraction (Figures 9.1 and 9.2) during warming events that expanded forest cover [18].

From a circumpolar perspective, an important historical event for the Arctic terrestrial and marine biota was the existence of the Bering Land Bridge connecting Eurasia and North America. Lowered sea levels during the glacial periods exposed the continental shelf and formed a single ice-free land mass, Beringia, that extended from the Kolyma River in north-eastern Siberia to the Mackenzie River in northwestern Canada. Apart from its importance for the transcontinental migration of plants and animals, Beringia is traditionally considered the main source for multiple recolonizations of deglaciated regions in the Arctic [21]; however, preliminary genetic analyses are equivocal on this point. Beringia represents an area of endemism (i.e., divergent DNA lineages are specific to only this region [9]). Separation of Eurasia and North America by the Bering Strait generally is not reflected in genetic analyses, which suggests that this recurring barrier to terrestrial species dispersal (most recently formed 11,000 years ago) has had a minor influence on genetic structure or divergence within many free-living and perhaps parasitic organisms [22]. In Arctic terrestrial species that are ecologically associated with dry environments, however, this barrier delineates significant genetic breaks [12, 18]. These findings are consistent with paleoecological evidence suggesting that the Bering Land Bridge represented a moisture barrier to the dispersal of steppe-tundra biota indicative of arid environments [23]. For marine organisms, the Bering Land Bridge was a barrier to exchange between populations in the Arctic Ocean and those in the North Pacific. Hence major historical events such as formation of the Bering Land Bridge significantly altered the distribution of genetic diversity within Arctic species and ultimately the composition of biotic communities in marine and terrestrial ecosystems [24].

Figure 9.2: The collared lemming is an Arctic mammal that is providing insight into the location of refugial areas or areas that tend to support the highest levels of genetic diversity in Arctic species versus areas of recent expansion of species (generally lower genetic diversity).

Concerns for the future

Far too little is known about the distribution of genetic variability in natural populations across the Arctic. In part, past political subdivisions have hampered international collaborative efforts and there have been few coordinated efforts to survey biotic systems (and archive genetic specimens) that would allow us to assess spatial and temporal changes. Prediction of responses of individual organisms, biotic communities, or entire ecosystems to future events relies on an understanding of past responses to environmental change. Molecular genetic analyses can provide key insights into future responses because these data can be used to model the impact of various climate scenarios on population structure and ultimately species viability [1]. The contemporary distribution of genetic diversity in the Arctic points to potential areas of long-term persistence and diversification or areas that served as corridors for colonization following environmental change. These areas should be protected [25], but studies of Arctic genetic diversity are based on far too few regions and organisms. Genetic data are beginning to reveal the dynamics of how biotic communities are assembled and whether communities remained intact or, instead, species responded idiosyncratically to environmental change. Molecular genetic approaches will help identify areas where distinct biotic communities may come into contact, mix and potentially exchange pathogens and these contact zones need to be carefully monitored [26]. Fine-scale sampling of wild populations in these zones is needed to rigorously track these events, so that we can respond quickly to emerging pathogens.

The Arctic is an exceptional system for examining the influence of climatic events on the patterns and processes of both genetic differentiation as well as loss of genetic variability [27]. These details are essential to determining the prospects for long-term persistence of a diverse set of organisms adapted to Arctic terrestrial and marine environments. Loss of individual populations that harbor novel genetic variability decreases the overall adaptive potential of a species that will be necessary to respond to novel challenges. Ultimately loss of variability within species becomes a significant contributor to the extinction process and loss of species diversity contributes to ecosystem collapse. A detailed map of genetic structure is a crucial first step for conservation efforts that should be followed by renewed emphasis on identification and conservation of regions of high evolutionary potential. In extreme cases, this blueprint can be used for rescue efforts for declining species in the face of changing climate and increasing anthropogenic impacts in the Arctic.

Ecosystems

INDICATORS #10–17

In the Lower Kolyma area of Sakha-Yakutia, the local Chukchi and Yukaghir reindeer herders have reported that the permafrost is melting and this is causing, among other things, the disappearance of whole lakes as well as changes to the water system. Alexey Nikolajevich Kemlil, a Chukchi reindeer herder of the community Turvaurgin, describes this process on the western side of the Kolyma River:

"There have been changes to the permafrost. In the past ten years, several lakes have disappeared both from the taiga and tundra area where we have our reindeer migration. Lakes have become rivers and drained out. You can see this in the tundra, but even more on the forest zone. This impacts on the fishing for sure. One of the lakes disappeared, but the fish got stuck in the bottom and died of course. Wetlands and marshes are as well more, how to say, deeper or not so solid. Close to the rivers like Chukatsha there are depression faults and holes on the ground. The marshlands cannot be used

Mustonen, T. 2009. Karhun väen ajast-aikojen avartuva avara. Tutkimus kolmen euraasialaisen luontaistalousyhteisön paikallisesta tiedosta pohjoisen ilmastonmuutoksen kehyksessä. University of Joensuu Press. pp. 246.

INDICATOR
10 Arctic sea-ice ecosystems

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Thule, North Greenland Lars Witting/Arc-Pic.com

Sea ice represents a unique ecosystem in the Arctic, providing habitat to specialized ice-associated species that include microorganisms, fish, birds, and marine mammals. Individual species use sea ice in different ways depending on their biological needs. Ice algae form the base of the food web (Figure 10.1) [1]. Some algae stay attached to the bottom of the ice, some fall into the water column, and some fall to the bottom of the sea, and so provide food for species that feed at different depths. Protists (single-celled organisms) and zooplankton eat the algae which are then eaten by, for instance, Arctic cod, Boreogadus saida [2] and sea birds (e.g. dovekie, Alle alle), which in turn act as the major link to other fish and birds, seals, and whales [e.g.,3]. Polar bears, Ursus maritimus, prey upon seals from the ice and walrus, Odobenus rosmarus, forage on clams from drifting pack ice.

Arctic sea ice has changed in recent years, decreasing substantially in extent and thickness, with thin first-year ice replacing thicker multi-year ice [4]. These changes are happening faster than models predict and a nearly ice-free Arctic Ocean in late summer is likely within this century and possibly before mid-century [5]. The response of an individual ice-associated species to changes in sea ice depends on its ability to adapt, its natural history, and the scale of environmental changes. While these species are experiencing a variety of impacts as the sea ice changes, it is not clear exactly what will happen as the summer sea ice continues to disappear.

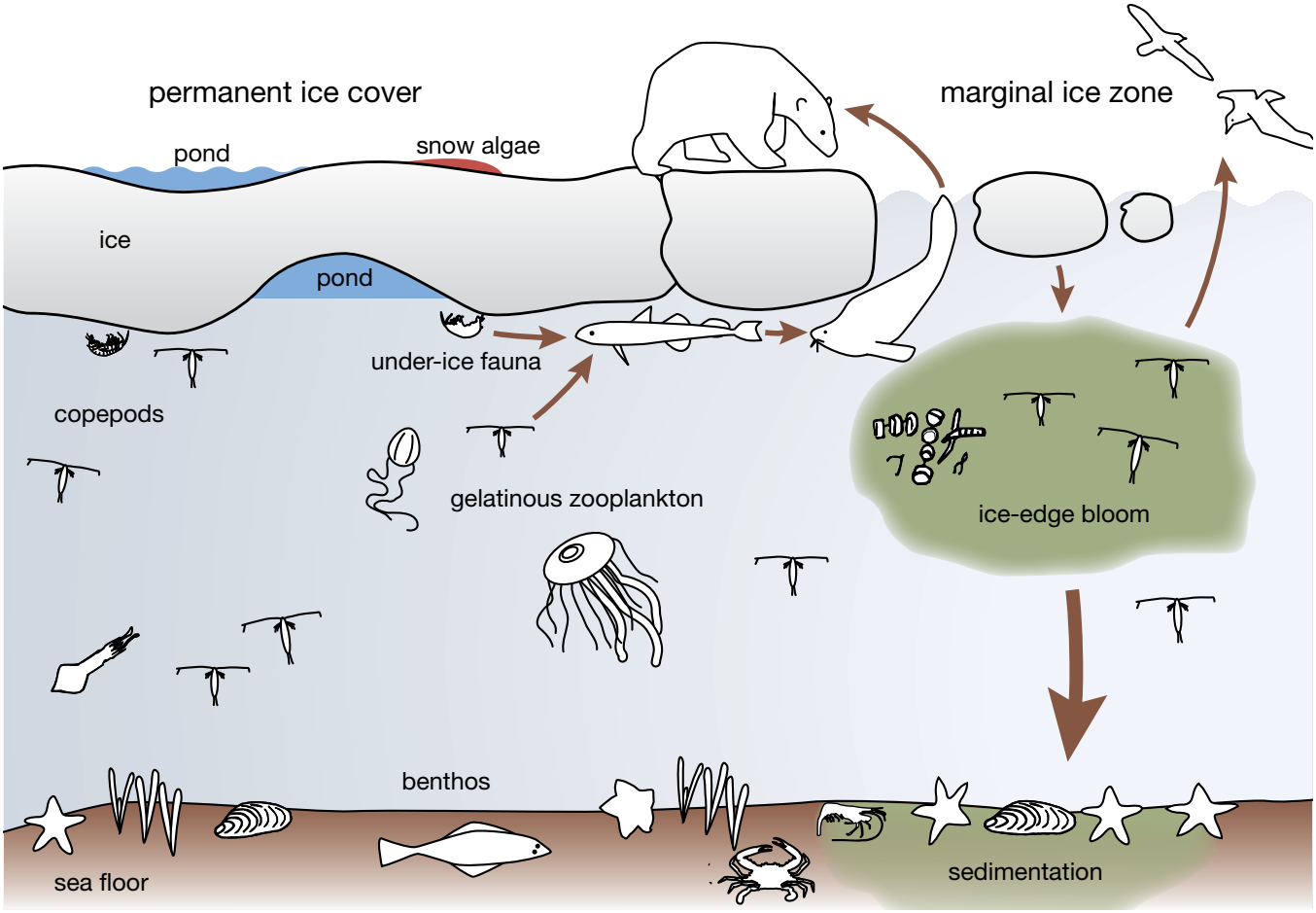

Figure 10.1: Schematic representation of the Arctic marine ecosystem and its interactions [1].

Population/ecosystem status and trends

A complete understanding of the sea-ice ecosystem does not yet exist. Comprehensive data regarding population and trends of ice-associated species are limited due to the difficulty in surveying them in an extreme and remote environment. The information below does not represent a comprehensive listing of ice associated species. Following are some examples of ice-associated species from different trophic levels with indications of their status and trends.

Ice algae

During spring, when light becomes available for photosynthesis, and throughout the summer, a large biomass of ice algae develops within the lowermost sections of the ice [1, 6–8]. These algae occasionally form long filaments that can extend several meters into the water. Previous studies have provided a glimpse of the seasonal and regional abundances of ice-associated biota. However, the biodiversity of these communities is virtually unknown for most groups and many taxa are likely still undiscovered [1].

Arctic cod, Boreogadus saida

Arctic cod, also known as polar cod, are frequently observed in close association with ice year-round, from their larval stage through to their juvenile stages [9]. The Arctic cod is a pivotal species in the Arctic marine food web and no other prey items compare in terms of abundance and energetic value [10]. Arctic cod use sea ice for protection from predators, as feeding habitat, and as a place to spawn in winter [11]. This species has not been extensively surveyed and trend data are not available. Summer surveys in 2008 in the Alaskan Chukchi and Beaufort Seas estimate Arctic cod biomass at 27,122 metric tons (mt) and 15,217 mt respectively, totaling 42,339 mt [12]. In northern Hudson Bay, researchers correlated reduced consumption of Arctic cod by thick-billed murres, Uria lomvia, from 1981–2002 with reduced ice cover and concluded there were decreases in fish abundance [13].

Ivory Gull, Pagophila eburnea

The ivory gull is a seabird which spends the entire year in the Arctic. The global breeding population is found in Canada, Greenland, Svalbard, and Russia where they rarely range far from sea ice [14]. They are often found along the ice edge and leads in pack ice, where they feed on small fish, including juvenile Arctic cod, squid, invertebrates, and macro-zooplankton [14–16]. They also scavenge carrion on the ice and forage on marine mammal feces and placenta

[14]. The global estimate of ivory gulls is 8,900–13,500 pairs [17, 18]. Studies indicate that Canadian populations are declining, the populations in Greenland and Svalbard are either declining or uncertain, and Russian populations are largely fluctuating with no trend data available [17, 18].

Ivory gulls forage around sea ice year-round, relying on visual prey detection. Thus, if winter sea ice retreats to the north where the days are shorter, the ivory gull will have less time available to forage each day. However, no data exists to establish a causative relationship between sea ice changes and ivory gull declines and further studies are required [17].

Spectacled Eider, Somateria fischeri, and King Eider, Somateria spectabilis

Spectacled eiders and king eiders are large sea ducks that live and breed in the Arctic. Both species associate with offshore dense pack ice in the winter to feed in openings in the ice. Roosting on sea ice uses less energy than being immersed in cold water such as when eiders dive for food [19, 20]. The ice pack may also dampen the effects of winter storms [21], allowing birds to feed in calmer conditions within the ice pack [19, 20].

The spectacled eider breeds in three locations, two in Alaska and one in Russia [22]. In winter, these three populations concentrate within a 50 km diameter circle in small openings in the sea ice in the central Bering Sea [19, 23]. The entire wintering population, and perhaps the worldwide population is estimated conservatively at 374,792 birds [23]. The population trend for the nesting population of the Yukon-Kuskokwim Delta in Alaska can be characterized as stable to slightly increasing from 1991–2001. The breeding population of the North Slope in Alaska does not show a significant decline throughout most of the 1990s but did show a downward trend of 2.6% per year [23].

From surveys done off Point Barrow, Alaska in the Beaufort Sea, the king eider population appeared to remain stable between 1953 and 1976 but declined by 56%, from approximately 802,556 birds in 1976 to about 350,835 in 1996 [24]. Reasons for the declines are unknown. Surveys of molting areas in West Greenland show 50% declines over the last 40 years [25, 26] and the Rasmussen Lowlands breeding area in Canada [27] indicate a decreasing population size [20].

Thick-billed murre, Uria lomvia

The thick-billed murre is an Arctic seabird that is associated with areas of seasonal and sometimes extensive sea-ice cover [28] and occurs mostly in Arctic waters in the winter [29]. The thick-billed murre seems to be dependent on plankton blooms stabilized by predictable sea ice break-up [30]. For population status and trends, please see Indicator #4 Seabirds – Murres (guillemots).

Marine Mammals

Several marine mammal species associate with sea ice [31]. These include polar bear, walrus, and ice seals bearded, Erignathus barbatus; ringed, Phoca hispida; hooded, Cystophora cristata; harp, Pagophilus groenlandicus; ribbon, Histriophoca fasciata; and spotted seal, Phoca largha). Three whale species also occupy Arctic waters year-round – narwhal, Monodon monoceros; beluga whale, Delphinapterus leucas; and bowhead whale, Balaena mysticetus [31]. Each species uses sea ice in different ways [32]. Abundance estimates are not available for one or more populations of most species, and trends are unknown for even more populations. Further, some of the available estimates are outdated. Those species for which sufficient data exist exhibit mixed population trends, with some populations of each species increasing while others are stable or declining. The available data are not sufficient for an analysis of trends by region. Below are brief summaries of the four marine mammal species considered most associated with sea ice [31, 33, 34]. Additional details about these and other ice-associated species are being developed by CAFF.

Polar bear, Ursus maritimus

For details on polar bear status and trends, please see Indicator #1 Polar Bears.

Walrus, Odobenus rosmarus

The population of Pacific walrus is estimated at 129,000 based on 2006 joint Russian-American surveys [35]. Abundance trends will be examined in more detail once all aspects of the analysis of the 2006 survey data have been completed [35].

The current total abundance of Atlantic walrus is very poorly known, but the most recent information suggests a population size of perhaps 18,000–20,000 [36–38]. Modeling indicates that the walrus populations in West Greenland and the North Water Polynya of Baffin Bay have been in steady decline, while the population in East Greenland has been increasing [39]. Walrus numbers at Svalbard have increased slowly during 1993–2006 [40]. The current global population trend is unknown [36].

Ringed seal, Phoca hispida

Of the five sub-species of circumpolar ringed seals, there is very little trend data [32]. The Lake Saimaa subspecies in Finland is increasing based on 2005 surveys [41], while trends in the Baltic Sea subspecies are mixed based on surveys from the 1990s [42].

Bearded seal, Erignathus barbatus

No recent information about population status and trends is available for bearded seals in their circumpolar range.

Jökulsárlón Lagoon, Iceland Daniel Sambraus/iStockphoto

Concerns for the future

The ongoing trend of declining sea ice [43] is likely to lead to changes in the sea-ice ecosystem shifting toward a pelagic, sub-Arctic ecosystem [44] over a larger area [45, 46]. Phytoplankton and zooplankton productivity is predicted to increase, with sub-Arctic species expanding their range and competing with existing Arctic species [45, 47, 48]. The increased production in open water will increase the prey concentrations for bowhead whales [46]. However, with less ice, there may be less ice algae which fall to the bottom, leaving less food for bottom-feeding marine species. Marine mammal species that are capable of using both pelagic and benthic prey may be less affected by the expected changes in the food web structure [46].

There may be mismatches with the life histories of ice-associated organisms if the timing of life functions shifts due to reduction of sea ice [45]. If one or more of the links between increased light penetration, higher production by ice algae, increased activity and breeding of zooplankton grazers and predators, and production and feeding of larval and juvenile Arctic cod fail, then effects may flow-through the sea-ice ecosystem on to top predators, such as ringed seals and birds and possibly polar bears [45].

More information on mismatches in life histories can be found in Indicator #12 (Reproductive Phenology in Terrestrial Ecosystems).

It is unclear how the reduction in sea ice is affecting Arctic cod. It is likely that a generalist species will replace Arctic cod as the main forage fish as sea ice decreases [11]. According to modeling, with warming temperatures and a retreat of the ice edge of 5 km per year, Arctic cod may be extirpated from most of its range in 30 years [49]. More information on the Arctic cod can be found in Indicator #16 (Changing distribution of marine fish).

Arctic marine mammal ranges are generally expected to shift northward to inhabit areas within their preferred metabolic temperature tolerances because conditions at the southern limits of their previous distribution will no longer meet their ecological needs [33]. Interannual changes in the onset and severity of seasonal sea ice may also affect the length of feeding seasons, timing of migrations, fecundity, and survivorship of marine mammal species [50]. Marine mammals will likely compete with one another on some level despite their different specializations [51]. If the climate continues to warm, a continued reduction in sea ice will follow and likely result in the northward expansion of some presently sub-Arctic species, with potential for increases in disease, predation, and competition for food [31, 33].

For the bird species discussed in this indicator, their relationship with sea ice is not entirely understood, nor

INDICATOR
#11 Greening of the Arctic

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Arctic Canada Trevor Bauer/iStockphoto

Arctic vegetation has undergone enormous change in the past, most notably in response to the glacial and interglacial periods of the Quaternary [1, 2]. Data from many sources and at several scales suggest that recent climate change is already affecting terrestrial Arctic ecosystems. Comparisons of historical and contemporary aerial photographs provide evidence that Arctic vegetation has already undergone significant shifts in recent decades, foreshadowing changes that are likely to come. Increased shrub cover has been confirmed in two repeat photography studies in northern Alaska [3, 4] and in a recent study in the Mackenzie Delta region of Canada [5].

Data from ground-based studies offer a more detailed view of vegetation changes. When plots established in the 1970s in Alaska were resampled, the results were consistent with a warming and drying trend, in which moist and wet community types tended to be replaced by dry community types over time [6]. At Toolik Lake, Alaska, Shaver et al. [7] found that graminoids (grasses and sedges), mosses, and lichens decreased and evergreen shrubs increased in abundance over a 13-year period; a subsequent study nearby [8] found that shrubs and litter had increased in abundance over eight years at the expense of lichens and total diversity. At a high Arctic site on Ellesmere Island, significant increases in biomass over the past 25 years were found in wet sedge tundra [9] and in a dwarf-shrub community [10].

Although many published data are limited to studies conducted in Alaska, unpublished reports and observations from Arctic indigenous people suggest similar changes are occurring elsewhere in the Arctic. Satellite monitoring provides a broad-scale, repeatable measure of these changes. The Normalized Difference Vegetation Index (NDVI) is a remotely sensed index of productivity, allowing spatial and temporal trends to be examined and related to changes observed on the ground.

Population/ecosystem status and trends

The area covered by Tundra Climate, as defined by the Köppen climate classification system, has been reduced by about 20% since 1980, which corresponds to a change in NDVI signatures from tundra to forest-tundra [11]. NDVI has been changing steadily since the 1980s over much of the Arctic reflecting an increase in productivity related to the increases in shrub cover (Figure 11.1) [11–13]. In addition to overall increases in productivity, NDVI data also indicate that the length of the growing season is increasing [13].


Spitsbergen, Svalbard, Norway Michel de Nijs/iStockphoto

Spatial variation in NDVI increases corresponds well to land

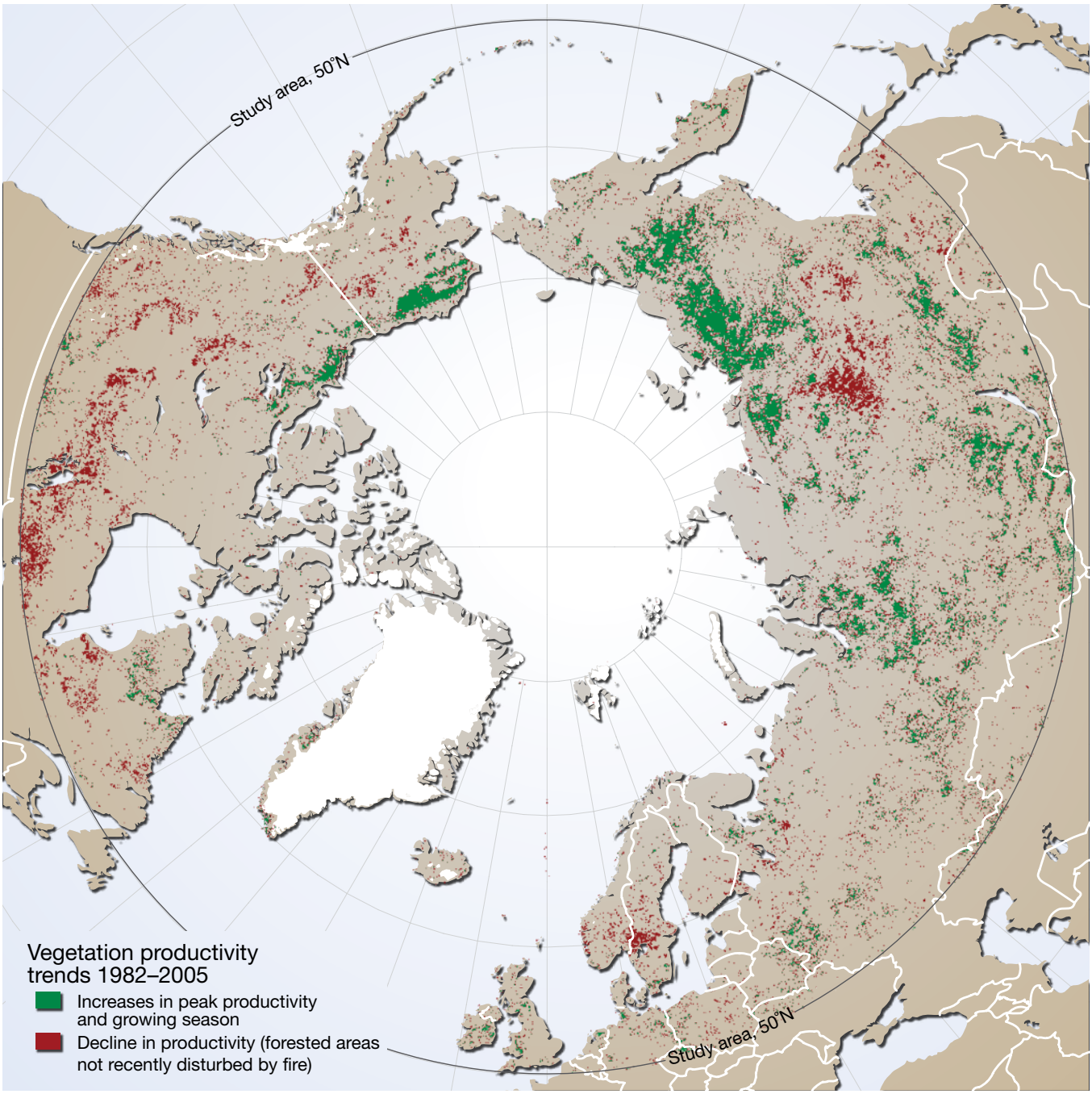

Figure 11.1: Trends in productivity derived from a 1982–2005 time series of GIMMS-G AVHRR vegetation indices (NDVI). Significant positive trends, showing as green, indicate an increase in both peak productivity and growing season. Negative trends, showing as red, represent forested areas not recently disturbed by fire that declined in productivity (Source: [15]).

surface temperature changes, with the greatest changes in NDVI occurring in Arctic areas that have experienced the most climate warming [11, 13]. Productivity levels are tightly correlated to maximum summer temperatures in tundra regions [14]. Together, these data provide strong evidence that tundra productivity is increasing regionally as a direct result of recent climate warming.

In a repeated measurement study conducted on Ellesmere Island, Nunavut, Canada, over a period of 13 years, the plant community became more productive over time, suggesting that the ecosystem is in transition (Figure 11.2) [10]. Abundance of bryophytes (mosses and liverworts) and evergreen shrubs increased, while deciduous shrub, forb, graminoid, and lichen cover did not change. The increased productivity was attributed to regional warming over the past 30–50 years.

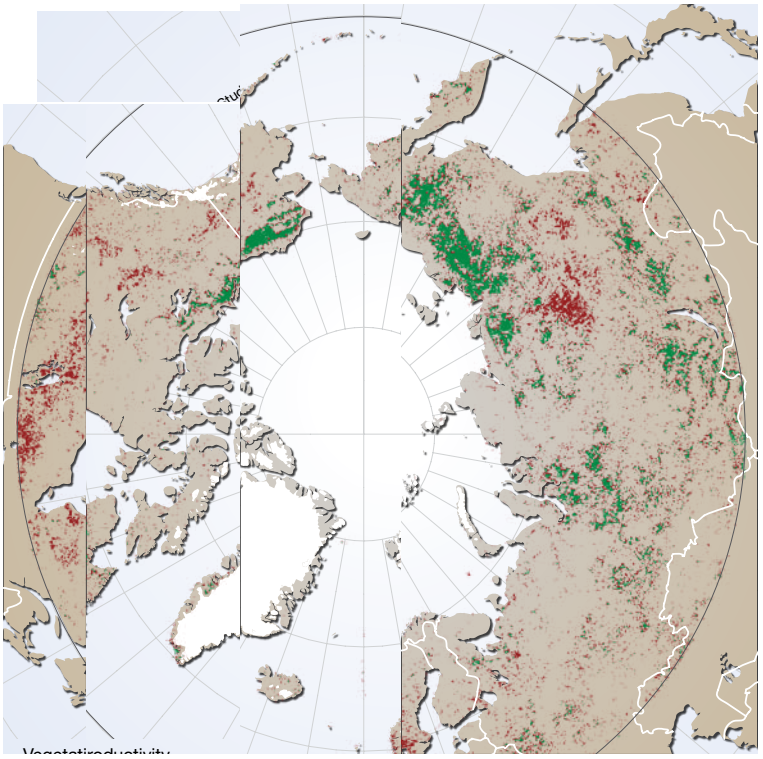

Figure 11.2: Total live vegetation, bryophytes, and evergreen shrubs increased significantly from 1995–2007 [10].

Concerns for the future

Treeline encroachment threatens the tundra at its southern margins. Some models predict that by 2100 treelines will have advanced northward by as much as 500 km, resulting in a loss of 51% of tundra habitat [16]. Expansion of white spruce forests into areas previously occupied by tundra have been documented in numerous locations in Alaska [17, 18]. Rates of treeline expansion may lag in some areas due to, for example, seed availability, disturbance frequency, permafrost changes, moisture constraints [18] and reindeer grazing activity [19].

A number of experimental warming studies conducted in the Arctic can be used in conjunction with observations and paleo-data to predict how future climate warming will affect tundra ecosystems. An analysis of warming studies found that warming generally increased productivity [20], consistent with the NDVI results. A more detailed analysis concentrating solely on Arctic sites, however, suggested increases in productivity may be transitory – warming in Arctic systems tends to lead to an initial increase in vegetative growth, followed by a boost in reproductive effort in subsequent years [21]. In addition, initial increases in growth may be greatest in herbaceous species [21] but shrub species show a greater increase in cover and biomass over the medium term [22].

Warming experiments and paleo-ecological studies also indicate that increasing temperatures are likely to change plant species composition. Research suggests that climate warming leads to rapid increases in deciduous shrubs and graminoids and decreases in mosses and lichens [22, 23]. Since more than half of all northern species are non-vascular [24], the fate of many mosses and lichens under future climate scenarios is of particular concern for biodiversity conservation. Just 1–3°C of warming can cause significant decreases in plot-level diversity within 2 years [22]. Over longer time scales, diversity throughout the Arctic may actually increase, as historically non-Arctic species migrate northwards [16]. However, the loss of endemic Arctic species and landscapes will result in an overall loss of biodiversity at the global scale.

Even within a single location, short-term responses can be poor predictors of longer-term changes in vegetation composition [25]. Vegetation changes in response to warming will also differ among sites, and at least one study indicates that long-term warming impacts may be more variable among sites than are the shorter-term responses [26]. These uncertainties emphasize the need for more long-term experiments and observational studies in a variety of locations in order to clarify tundra responses to climate warming on the greater spatial and temporal scales as measured through NDVI.

INDICATOR
12

Reproductive phenology in terrestrial ecosystems

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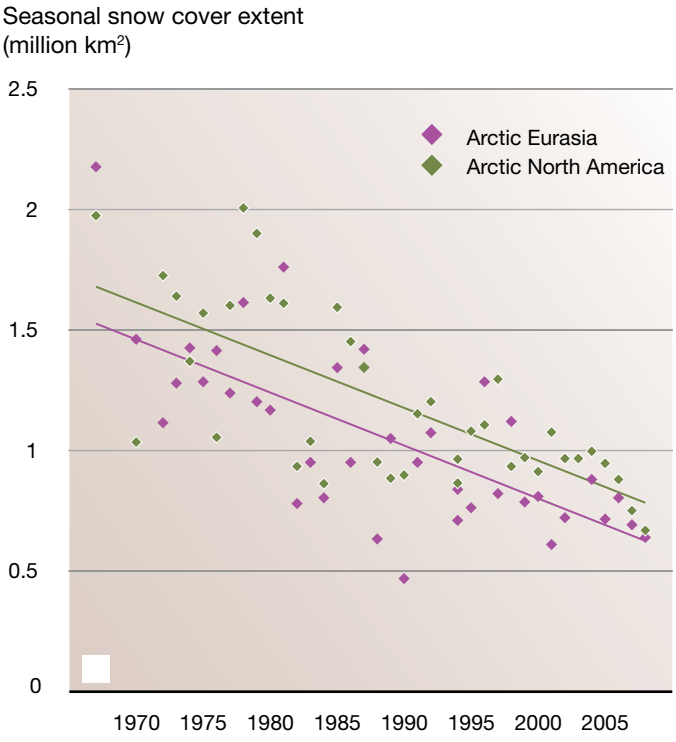
The timing of reproduction in plants and animals, also termed 'reproductive phenology', is probably the most frequently reported indicator of a species response to climate change and possibly one of the most sensitive. Along with the growing awareness of climate change, shifts in species phenology have been reported from the Arctic [1] and most other biomes globally [2]. Most Arctic species breed during the short summer, and they face the double challenge of avoiding severe weather during spring while ensuring sufficient time for offspring growth and development. Different reproductive strategies explain why, for instance, musk oxen, Ovibos moschatus, give birth long before the spring thaw, while the hatching of eggs of migratory birds like the ruddy turnstone, Arenaria interpres, takes place during the peak of summer. Musk oxen are able to provide their young with milk during late winter even with limited access to forage, while migratory shorebirds need to build up body reserves for egg formation after their arrival on Arctic breeding grounds. Yet, the short Arctic summer poses a constraint on successful breeding in most species, and changes to the duration of the breeding season can be expected to have profound consequences for the production of offspring and survival.

Population/ecosystem status and trends

Despite the current focus on global climate change, the number of studies on trends in Arctic reproductive phenology is very limited. This was evident in a recent analysis where very few relevant studies were identified north of 60°N [3]. There are some examples of phenological recordings that have been made over extended time periods but there are no explicit attempts to quantify the rates of change [4, 5]. Logistical challenges and funding constraints associated with maintaining long-term monitoring in the Arctic have no doubt contributed to the scarcity of data sets.

It is clear from lower latitudes that phenological trends are linked to temperature changes [6] and experimental warming also results in earlier plant phenology [7]. Yet, in Arctic and alpine ecosystems, the melting of the winter snow pack rather than temperature per se determines the onset of biological activity like the timing of flowering in plants and emergence in invertebrates [8–10]. As such, the phenology of these groups of organisms, or taxa, could be advancing considerably in response to earlier snowmelt. In fact, in a study covering a range of taxa carried out at Zackenberg Research Station in Northeast Greenland,



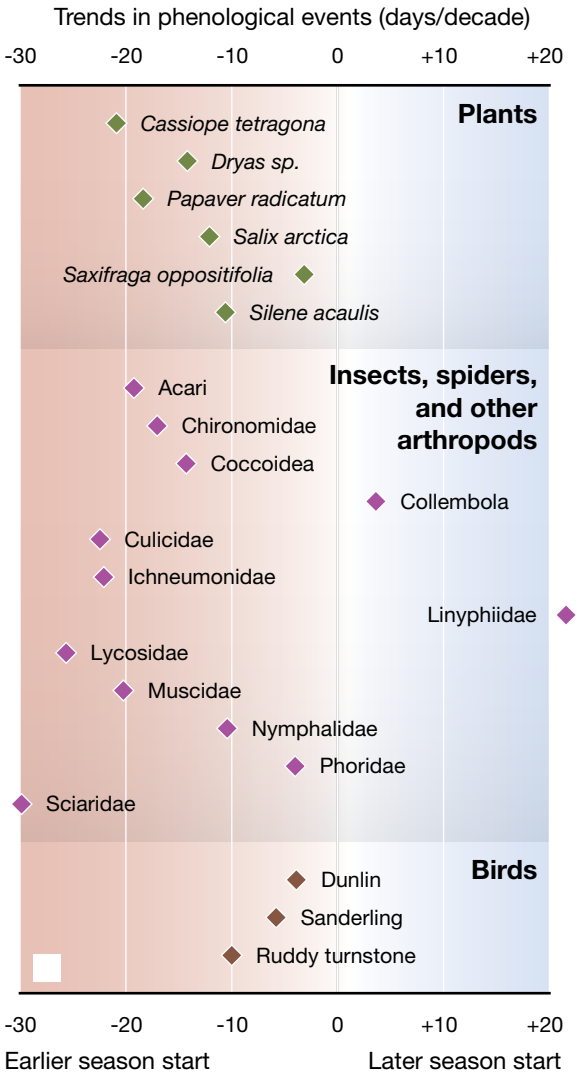


Figure 12.1: (A) The average snow cover extent during June, July and August across the Arctic (north of the polar circle) section of Eurasia and North America has decreased by 22,000 km²/year during 1968–2008 (data kindly provided by the Global Snow Lab, Rutgers University, New Jersey). (B) During the last decade this has resulted in rapid advancement of the reproductive phenology of plants and animals at Zackenberg, Northeast Greenland (adapted from [11]). The species in the photos are: (C) Arctic fritillary, Boloria chariclea, (D) eggs of ruddy turnstone, Arenaria interpres, and (E) purple saxifrage, Saxifraga oppositifolia.

it was found that not only is reproductive phenology showing stronger trends in the Arctic than elsewhere, trends were also stronger the later, on average, that an event (e.g., flowering in plants, emergence in arthropods, and egg-laying in birds) took place during the season [11] (Figure 12.1). There are clearly limits to such phenological flexibility. In a situation with extreme changes to the physical environment, the timing of reproductive phenology may be more influenced by other cues like day length.

The timing of reproductive phenology in birds and mammals may respond to changes in food availability as well as to changes in the abiotic environment [12, 13]. Calf production in muskox populations in West and East Greenland benefit from earlier plant phenology when accounting for variation in winter harshness [14]. In migratory species like the ruddy turnstone, however, the timing of producing offspring at breeding areas is dependent upon the timing of migration away from wintering areas, which is likely triggered by day length and so may not be a good predictor of conditions at breeding areas [15, 16]. This can have consequences for reproductive success and predation rates in situations where predators are also migrating [17].

It appears that Arctic species of plants and invertebrates exhibit considerable flexibility in their reproductive phenology. Individual plants can change their date of flowering by several weeks between years. This


Taimyr Peninsula, Russia Peter Prokosch

is particularly evident in species inhabiting areas with extensive snow cover. In mountain avens, Dryas octopetala, for instance, late-flowering individuals (i.e., those in late snow-free microhabitats) show more year-to-year variation in timing of flowering than early-flowering individuals (i.e., those in early snow-free microhabitats) of the same species [9]. Although the evidence is sparse, there are indications that Arctic birds and mammals are less responsive in their reproductive phenology, and their migration and breeding strategies may explain why this is the case [11].

Concerns for the future

As stated above, variation in the timing of snowmelt in time and space has a strong influence on variation in phenological events of plants and insects in the Arctic. At Zackenberg, warmer temperatures have resulted in markedly earlier snowmelt despite no trend across years in the thickness of the end-of-winter snowpack. Across the entire Northern Hemisphere, the extent of snow cover during spring and summer is rapidly declining suggesting that a strong shift in the reproductive phenology of these taxa is a circum-Arctic phenomenon [1]. The reproductive phenology of birds and mammals appears to be less responsive to changes in the physical environment but a conclusive comparison among taxa is hampered by the scarcity of data. Importantly, responsiveness can be either advantageous or disadvantageous and lack of responsiveness should not be confused with lack of flexibility.

The effect of climate change on the population dynamics of plants and animals can be both beneficial and detrimental. Longer growing seasons may allow more southern species to invade Arctic ecosystems, but could also be advantageous in terms of growth and reproduction for Arctic species. One of the serious risks, however, is the disruption of food webs due to differing phenological responses among trophic levels resulting in a so-called trophic mismatch. The timing of calving in caribou in West Greenland, for example, varies little among years despite pronounced advancements of the plant growing season there. In years where calving is mistimed to the emergence of plant forage, calf production and survival are lower [15]. Indications of a similar trophic mismatch has been reported for greater snow geese, Chen caerulescens atlantica, in the Canadian Arctic, suggesting that this could be a geographically and taxonomically widespread phenomenon [18]. Our ability to understand whether trophic mismatch or other effects of changes to reproductive phenology will put species and populations at risk, hinges upon a continued effort to gather long-term data from the rapidly changing Arctic.

INDICATOR
13

Appearing and disappearing lakes in the Arctic and their impacts on biodiversity

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K. Brown, Water and Climate Impacts Research Centre, University of Victoria, British Columbia, Canada.

Arctic Canada Oksana Perkins/iStockphoto

The Arctic contains a variety of types of lakes but overall, it is thermokarst lakes and ponds that are the most abundant and productive aquatic ecosystems in the Arctic [1]. They are found extensively in the lowland regions of western and northern Alaska [2], Canada [3, 4] and Siberia. These (i.e., thaw) lakes are most commonly formed by the thaw of ice-rich permafrost, which leads to the collapse of ground levels and ponding of surface water in the depression [e.g., 4, 5]. Continued thawing of the permafrost can lead to the drainage and eventual disappearance of these lakes, as can erosion and lake coalescence [e.g., 4, 6].

Thermokarst lakes act as "hot spots" of biological activity in northern regions, with abundant microbes, benthic communities, aquatic plants, plankton, fish, and birds [1]. Such biologically productive systems are also of direct importance to Arctic peoples for supporting traditional indigenous lifestyles providing water for rural/urban communities and development, especially where groundwater resources are unavailable [7].

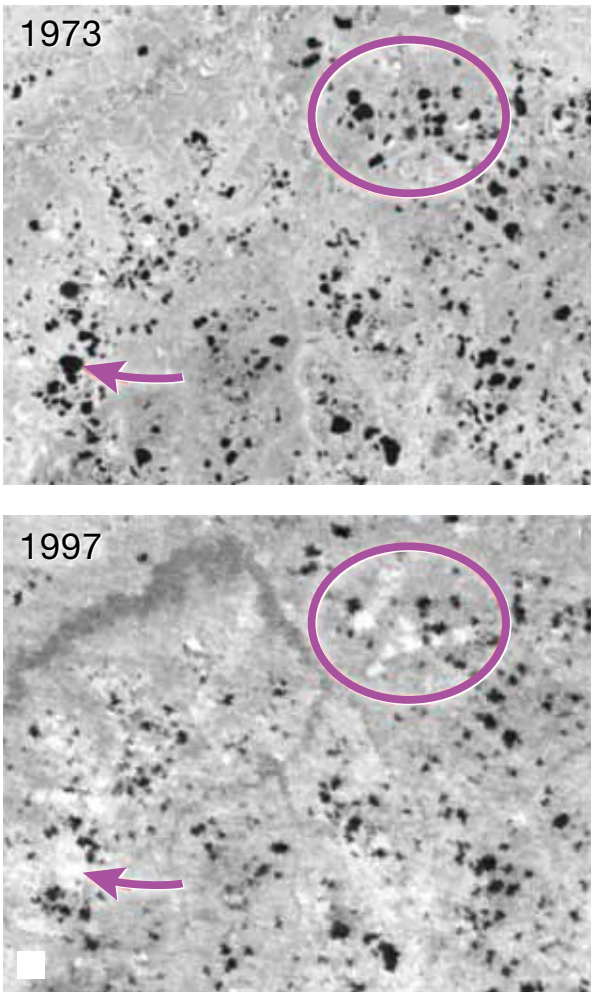
Thermokarst lakes are also important because of greenhouse gases emitted at scales large enough to create significant feedbacks to the global climate system. When draining, organic matter decomposes and releases carbon dioxide to the atmosphere [e.g., 8, 9], while their growth can result in methane emissions through higher lake productivity [e.g., 10]. Thermokarst lake formation or drainage can also cause changes in vegetation through radiative feedbacks [e.g., 11, 12, 13], and such changes in vegetation are important to the "greenness" of the Arctic [e.g., 14, 15] (see also Indicator #11 – Greening of the Arctic).

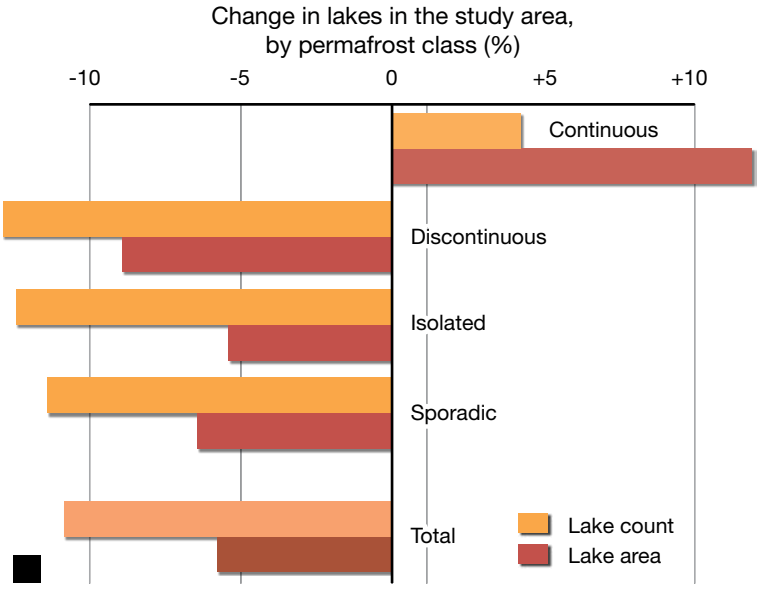
While having an effect on climate, the behavior of thermokarst lakes is also strongly controlled by climate. Due to their wide Arctic distribution, thermokarst lakes have the potential to be a useful indicator of climatic changes that are occurring in high-latitude regions.

Population/ecosystem status and trends

Drainage and appearance of thermokarst lakes is a relatively common occurrence as described by the "thaw lake cycle" [5]. Research is now trying to determine whether the warming air temperatures observed in northern regions are affecting patterns of lake disappearance and appearance, as well as affecting changes in lake area. Whilst the direction of some of the trends remains unclear, there seems to be general agreement of a net decrease in the number of thermokarst lakes over the last fifty years, although not for all regions.

Historical observations of thermokarst lakes in different regions, primarily conducted over the last five to six decades, show both increases and decreases in lake area and number. On northern Alaska's Barrow Peninsula, for example, there has been a slight decrease in total lake area and number over the last 25 years of the 20th century in the continuous permafrost of the Arctic Coastal Plain [6]. Many of the lakes drained completely but for reasons which were unknown in many cases, although the role of intentional or inadvertent modification by human activity was also noted to be a significant factor. In the discontinuous permafrost of the Alaskan boreal forest, there have been reductions in lake area and decreases in lake numbers for the period 1950–2002 [16]. In Siberia, there has been an overall net decrease in lake area and number since the 1970's [17], although increases were observed within the northern continuous permafrost, and decreases only





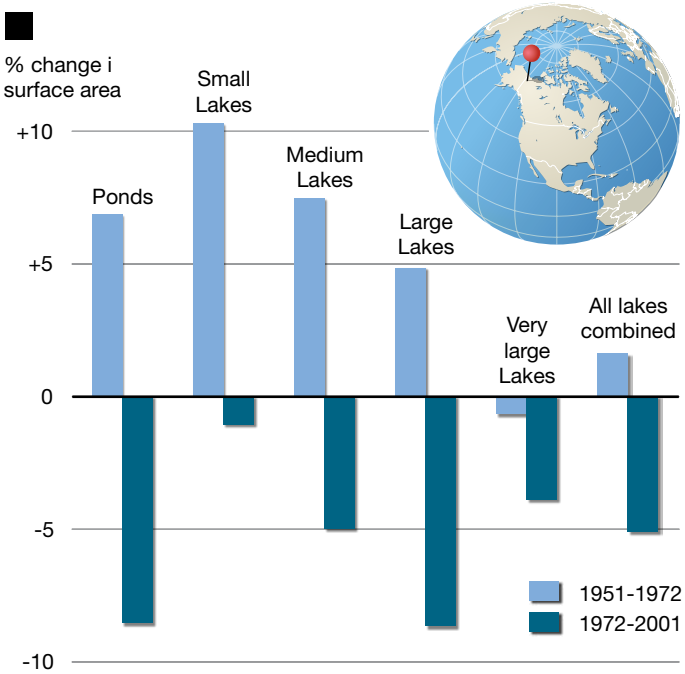


Figure 13.1: (A) Total lake abundance and inundation area have declined since 1973 including permanent drainage and revegetation of former lakebeds (the arrow and oval show representative areas). (B) Net increases in lake abundance and area have occurred in continuous permafrost, suggesting an initial but transitory increase in surface ponding [17]. (C) Percentage change in surface water area for ponds and lakes, 1951–1972 and 1972–2001 in Old Crow Basin, Canada [20].

seen in the more southerly discontinuous, sporadic, and isolated permafrost zones (Figure 13.1.A and B). Increases are believed to be due to the effects of surface permafrost thawing whereas the decreases are due to drainage, possibly related to taliks, areas of unfrozen ground in permafrost, completely penetrating the permafrost into the underlying groundwater system.

In northwest Canada, where ground ice content is high, thawing and erosion of drainage channels has resulted in a catastrophic drainage of lakes [18, 19]. In the Old Crow Flats, Yukon, the overall surface area of water decreased 1300 ha (3.5%) from 1951 to 2001 (Figure 13.1.C) [20]. Most large lakes decreased in extent over this 50-year period while small ponds increased. The changes were due to a number of effects that include sudden lake drainage through the collapse of permafrost, and an overall drying trend from hotter summers in recent years.

There is also concern about the rates of change, particularly during the most recent period of Arctic warming that has caused some abrupt increases in permafrost degradation [e.g., 21]. However, such information is sparse and what is available is not spatially consistent.


Barrow Point, Alaska, USA George Burba/iStockphoto


Yamal Peninsula, Russia Peter Prokosch

Concerns for the future

Given the ecological importance and role in climate-feedbacks of thermokarst lakes, significant concern has been raised about their future in a changing climate [22–24]. Thermokarst development has been linked to changes in climatic variables – particularly air temperature (summer and annual) and winter snow depth, both of which are likely to see further, significant increases at high northern latitudes [e.g., 25]. As a result, appearance of thermokarst lakes in continuous permafrost regions and disappearance in the discontinuous permafrost zone is likely to become a more common occurrence given future climate-change scenarios. The situation could be exacerbated in coastal plains where rising sea levels and related erosion could enhance thermokarst lake drainage [e.g., 26].

Such habitat shifts will affect local aquatic populations, as well as having other wide-ranging effects on transient species such as waterfowl. Although these are expected to flourish with the formation of new thermokarst lakes in the continuous zone [e.g., 27], the effect of large-scale regional changes in lake availability on their migratory patterns is unknown. The water quality of growing or newly formed lakes is also likely to be increasingly affected by changes in the adjacent permafrost landscape as it progressively thaws and degrades [e.g., 28–31]. Complex changes in vegetation regimes are also likely to result from the appearance/disappearance of thermokarst lakes; the suite of changes further complicated by the northward movement of vegetation types that will accompany climate change [e.g., 32]. Lake appearance and drainage may increasingly affect the traditional practices of the indigenous peoples in the region as well, particularly where they are used for subsistence fisheries or small mammal harvesting [33–35].

In general, the appearance and disappearance of thermokarst lakes could be used as an indicator of climate warming and the associated effects on permafrost in northern regions. However, more research about the processes controlling their formation and loss in different permafrost regimes is still required to be able to make robust links to changes in climate. Furthermore, more studies need to be conducted at broader regional scales that span permafrost zones and at finer temporal resolution to be able to accurately define spatial patterns and rates of changes.

INDICATOR
14 Arctic peatlands

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Wetlands are widely distributed in the Arctic, covering about 70% of the region. Of the six Ramsar[1] wetland types represented, the most extensive are forested and non-forested peatlands (Figure 14.1). Peatlands are wetlands where organic matter (peat) derived from dead and decaying plant material has accumulated and remains stored under conditions of permanent water saturation. Those which still have peat-forming vegetation are known as mires, and can be divided into fens (minerotrophic) and bogs (ombrotrophic) on the basis of nutrient status, which is closely related to the quality of the water supply. Freeze-thaw processes play a key role in the development and maintenance of these peatlands by shaping the surface of the landscape, and the types that are exclusive to the Arctic – most notably polygon mires and palsa mires – are associated with permafrost.

Polygon mires are characterized by regular surface depressions surrounded by low ridges ("bolsters"), each with a central crack, and all three of these landscape elements have different characteristic vegetation (Figure 14.2). They occur mostly at the northern edge of North America and in the eastern part of the Eurasian Arctic, and account for 5.6% of the peatland area within the Russian Federation [1].

Palsa mires are complexes of flat, very wet minerotrophic mire and frozen peat mounds with mineral cores and ombrotrophic vegetation (Figure 14.3). They account for 14.6% of the peatland area of Russia [1], where they are also known as "bugristaya" or mounded/patchy tundra; in Canada and Alaska, they are called "pingos". In Siberia, palsa mires occur well south (to 55° N) of the modern permafrost limit, their ice cores having persisted through warm paleoclimatic periods because they are thermally insulated by layers of dry peat.

1. The Ramsar Convention on Wetlands' defininition of wetlands includes ecosystems typical of the Arctic: shallow lakes, rivers and deltas, coastal marshes, shallow sea waters, and non-forested and forested peatlands.

Other Arctic peatland types are the so-called "alases", which are thermokarst lakes undergoing terrestrialization, most typically in eastern Siberia; and various combinations of sedge and forested fens in valleys and on floodplains. Finally, a range of ecosystem types is combined under the name "shallow peat tundra".

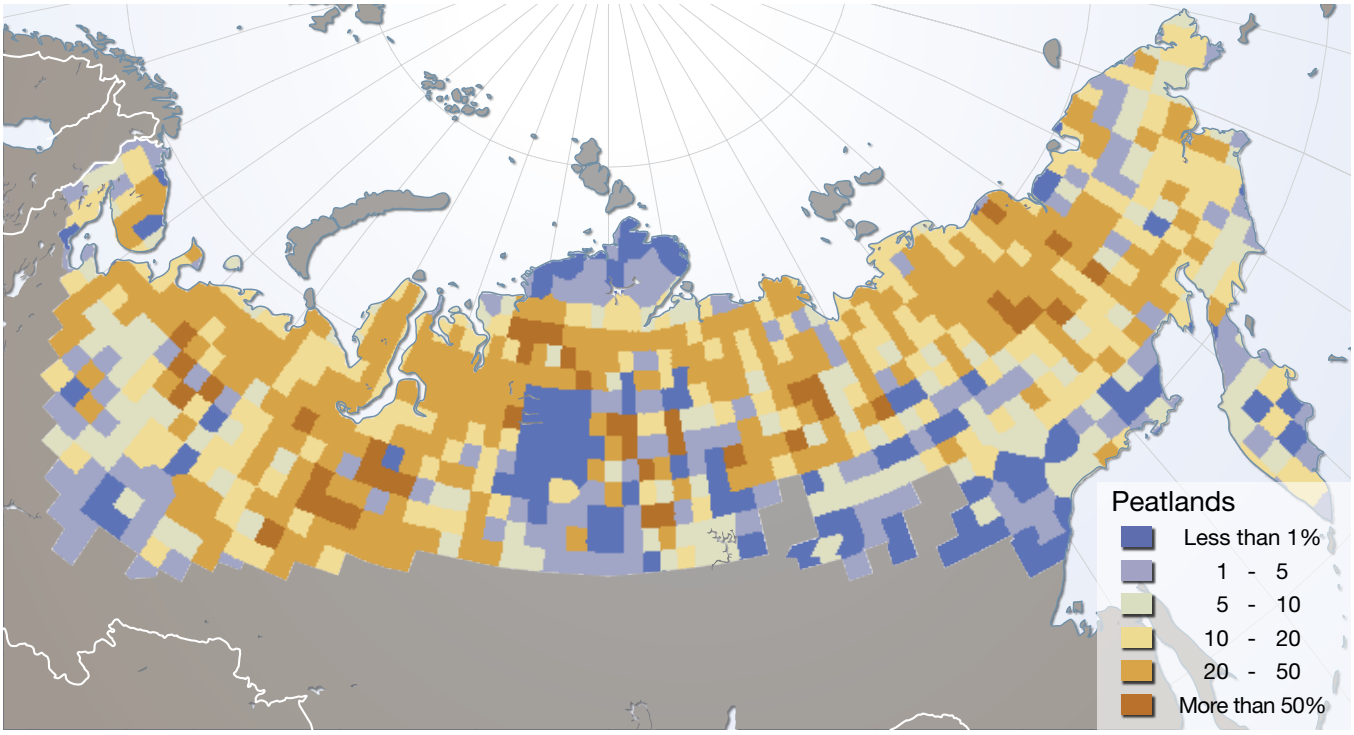

Figure 14.1: The proportion (%) of peatland within Arctic Russia, after [1].

Figure 14.2: Polygon mire photographed from the air (A) and from ground level (B) (Yakutia).

Population/ecosystem status and trends

Peatlands are significant for the floristic diversity of the Arctic because peatland species comprise 20–30% of the Arctic (e.g., Yamal Peninsula) and sub-Arctic (eg., Komi) flora [2]. Moreover, of the more than 60 bird species with conservation priority in the European Arctic, 75% are strongly associated with tundra and mire habitats. Indeed, Arctic peatlands – often referred to as 'the source of all flyways' – support biodiversity worldwide through bird migration routes. They also provide crucial ecosystem services such as habitat maintenance, permafrost protection, water regulation, greenhouse gas exchange, primary production, and accumulation of biomass.

Arctic peatlands are highly-integrated ecosystems which are extremely vulnerable to both natural and human-induced perturbations. Although their status has not yet been described comprehensively in the scientific literature, certain trends are clearly evident [2–4]. These are dominated by direct and indirect effects of climate change arising from global warming, which has multiple and sometimes subtle implications for Arctic peatlands.

Over recent years, the southern limit of permafrost in northern peatlands has retreated by 39 km on average and by as much as 200 km in some parts of Arctic Canada. Although regional warming by 1.32°C has accelerated permafrost thaw in northern Manitoba, Canada, these changes are not exclusively linked to temperature rise. The loss of permafrost in Quebec has been attributed to the insulating effect of increased snowfall since the late 1950s rather than to temperature, which did not rise until

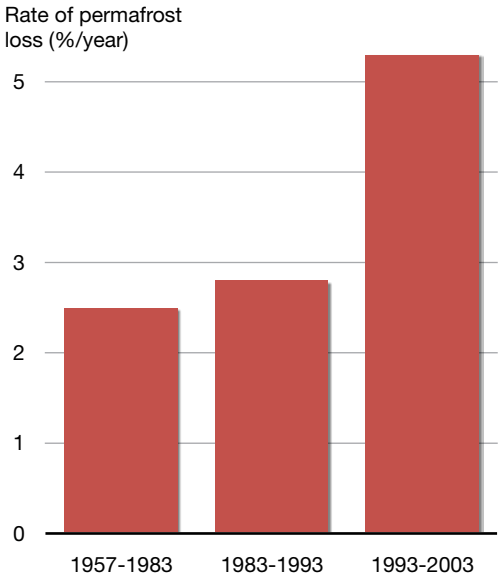

Figure 14.4: Permafrost decay rates for frozen peatlands in northern Quebec [5].

Figure 14.3: Palsa mire photographed from the air (A) and from ground level (B) (West Siberia).

the late 1990s, and has been accompanied by new peat accumulation on thawed areas (paludification) and in thermokarst ponds (terrestrialization) (Figure 14.4). Thus, small changes in weather conditions can cause abrupt changes in the direction of peatland system development. The distinctive polygonal patterns and palsa mounds of permafrost peatlands can exist only where the ground is permanently frozen. The thicker snow cover of the progressively milder Arctic winters (with increased precipitation) already threatens the persistence of these remarkable peatland systems. Moreover, it is anticipated that trees and other boreal species will colonize Arctic peatlands as the northern treeline migrates to higher latitudes in response to rising summer temperatures [3, 4]. This will not only affect biodiversity but also reduce albedo (surface reflectivity), further enhancing warming of the atmosphere. In locations such as the high Arctic, where low temperatures currently limit primary production and thus peat growth, non-frozen peatlands are likely to expand in topographically suitable locations as temperature rises. Peatlands in floodplains and lake basins are particularly susceptible to the increasingly dynamic river flow regimes that are expected as the intensity of rainfall and droughts continues to increase. The biota of surface water bodies are in turn vulnerable to changes in the load of dissolved and/or particulate organic matter (DOC, POC) in drainage water from any peatlands within their catchments that are degrading, regardless of the cause.

Concerns for the future

Although the Ramsar Convention and the Convention on Biological Diversity have acknowledged that special action to conserve peatlands is urgently required [2, 6–8], they are still under-represented in conservation strategies and seldom recognized as specific targets for management.

The vast undisturbed peatlands of the Arctic and sub-Arctic zones are amongst the last remaining wilderness and natural resource areas of the world. Development in such areas often ignores the special hydrological and ecological characteristics that are central to the productivity of these areas.

Traditional uses of Arctic peatlands, such as grazing, hunting, and berry-picking were sustainable for many years, and even in the recent past were still largely within natural ecosystem capacity. Now, new technologies have provided the means to overcome the challenges presented by the harsh Arctic environment, leading to renewed development of the oil and gas industry and a supporting infrastructure for transport which significantly fragments the landscape and disrupts its hydrology. Even traditional land uses such as reindeer herding are being industrialized, and the increased human presence means that wild mammals and birds are increasingly threatened by recreational hunting [9]. Thus, there is a need to promote sustainable practices.

These impacts are superimposed on those of climate change, which alone is expected to transform Arctic peatlands through loss of permafrost. This will in turn reduce their ecosystem diversity and thus their biodiversity value, and create a positive feedback for climate change by releasing the greenhouse gas methane [2]. The resulting changes in peatland status will in turn restrict use of the land by the indigenous people who have traditionally depended on peatlands for food including herded reindeer, game, and fish.

Arctic ecosystems are characterized by low species diversity, and typical species are highly specialized and intimately linked to their habitats. The short growing season limits annual production and the ecological niche capacity of these species, so that communities have low resistance to disturbance and extremely limited potential for natural recovery. Thus, there is already a need for the development of restoration technologies for Arctic peatlands which, in order to be effective, must be designed specifically for permafrost systems.

INDICATOR
15

Effects of decreased freshwater ice cover duration on biodiversity

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Lapland Lars Lindholm/iStockphoto

Ice cover is an important component of northern freshwater ecosystems influencing numerous physical, chemical, and biological processes in standing-water (lentic) and running-water (lotic) systems [1]. The duration of Arctic lake and river ice is determined by the dates of autumn freeze-up and spring break-up, the timing of which is strongly controlled by climate [e.g., 2, 3]. The broad extent of lakes and rivers throughout the northern high-latitudes provides good spatial coverage necessary to make the timing of lake and river ice freeze-up and break-up an effective indicator of climate change, and how such change might be affecting these important aquatic ecosystems.

Population/ecosystem status and trends

Records of lake and river ice duration are available for the Arctic from a variety of sources covering different time periods, from remote sensing and direct ice-observing programs to historical archives and sediment cores. Changes in the taxa buried in lake and pond sediments have been used by many researchers to identify warming trends and the historical presence/absence of ice cover on northern lakes [e.g., 4–9]. In general, such evidence points towards warming temperatures and shorter ice durations since the end of the Little Ice Age around 1850, with greater changes observed in northernmost areas when compared to more temperate locations [8]. Ground-based observation and remote sensing are being used to quantify shorter-term trends. These studies are revealing a number of key temporal trends in Arctic lake and river ice cover.


Esben Emborg/iStockphoto

Over the last 150 years lake and river freeze-up dates in the northern hemisphere have become later at an average rate of 5.8 days per century and break-up dates have become earlier at a rate of 6.5 days per century (Figure 15.1) [10]. Overall, this is an average reduction in ice-cover duration of almost two weeks per century. Further reductions have been observed in ice cover duration from a small number of records that began as early as the 16th century, although rates of change increased after approximately 1850 [10].

In many trend analyses, there have been various attempts to link changes in the timing of freeze-up and break-up with climatic variables. Although ice events result from a complex set of variables, particularly in the case of river ice [e.g., 11], the primary focus has been on simple air temperature. Specifically, air temperatures one to three months preceding the events have been most strongly correlated with their timing [e.g., 1, 10, 12, 13]. Strong correlations have been shown between the timing of freeze-up and break-up events, and that of spring and autumn 0° isotherm dates over Canada for various lake and river ice processes in the last century [14].

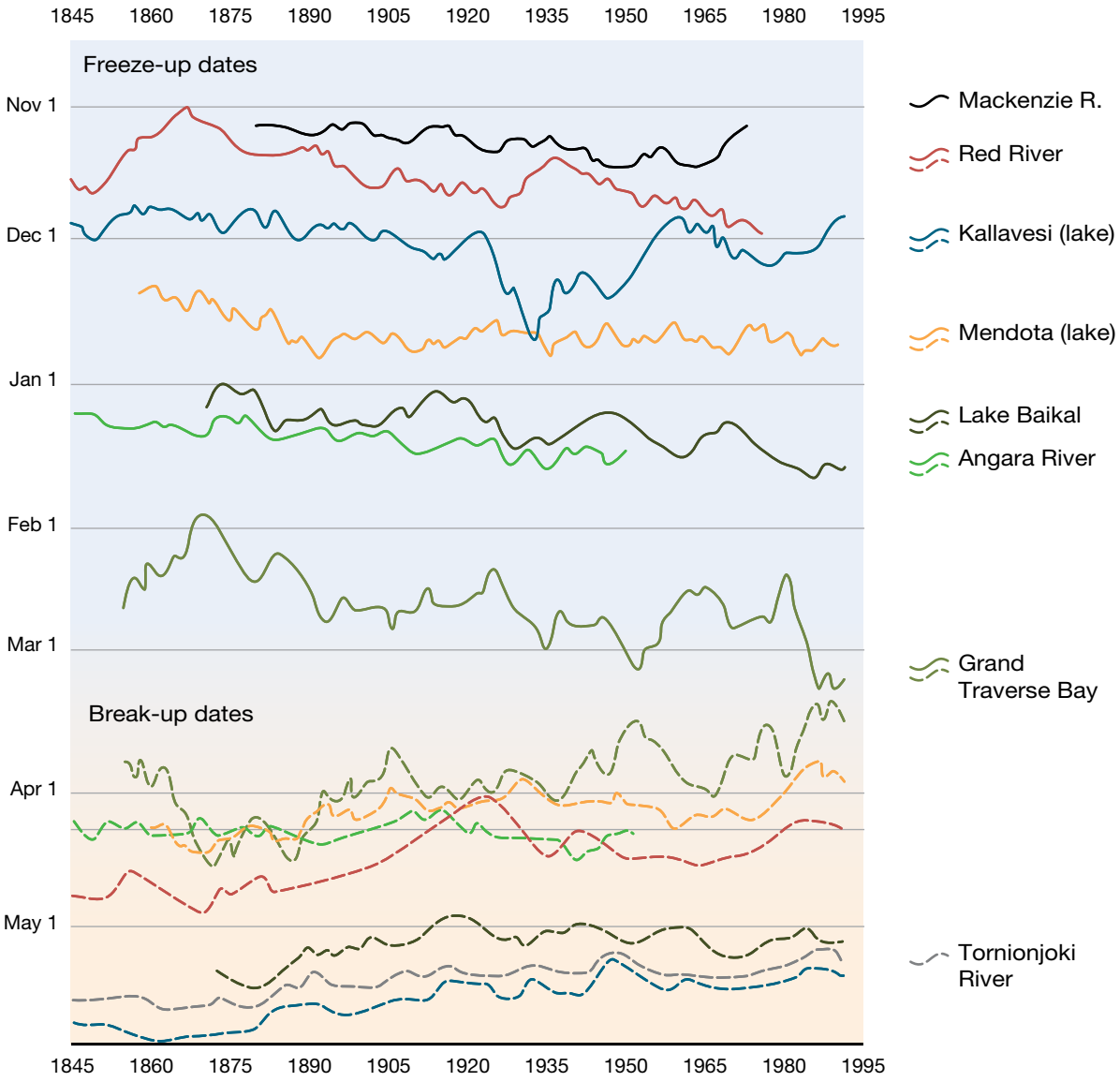

Figure 15.1: Time series of freeze-up and break-up dates from northern hemisphere rivers and lakes, 1846–1995. Data were smoothed with a 10-year moving average [10].

Concerns for the future

Given the strong association of lake and river ice freeze-up and break-up timing, as well as winter duration, significant concern has been raised about future changes that might occur in ice-covered systems [15–17]. It is generally accepted that as climate warms, earlier break-up dates will be seen in northern areas and longer open-water conditions will prevail [18]. Such changes will affect sensitive northern ecosystems, as well as human activities. It will, for instance, directly affect traditional and subsistence lifestyles of northern peoples that have relied on lake and river ice covers, such as in the case of fisheries [19–21].

In addition to simply affecting access to fisheries, ice-induced changes in primary production are expected to affect all trophic levels, the effect on Arctic fish populations being one example. Increased temperature and light availability, from reduced ice duration or changes in ice composition, will favor productivity [e.g., 16, 22, 23]. Other related changes may, however, produce negative effects. For example, the increased abundance of food available for fish in river systems, and the increased habitat availability with less ice (e.g., lack of freezing to the lakebed), may cause otherwise migratory species to remain in rivers year round. Feeding at sea has been linked to larger sizes in fish and larger populations, thus the increased productivity may ultimately lead to decreased fish yields [20].

The increased ultraviolet radiation that will reach aquatic ecosystems as a result of changing snow and ice cover may also cause pigmentation changes in both plankton and fish, and may render some food sources inedible or less nutritious and may possibly affect their immune systems [16]. For Arctic lakes that have been perennially ice and snow covered, orders-of-magnitude increases in ultraviolet exposure are projected to occur – increases greater than those due to moderate stratospheric ozone depletion [23, 24].

Some changes in ice cover may reduce the available habitat for cold-water organisms, forcing some fish to seek refuge in deeper areas [20]. Planktonic species, on the other hand, will benefit from the increased light availability and warm temperatures in the upper layer associated with lake stratification [22]. One of the more obvious effects of warming on fish populations is the fact that certain species are very close to their tolerance limits. Some fish living in sub-Arctic environments may move northwards resulting in competition for native species while for other fish the temperature stresses may prove fatal [20].

Changes in the duration of river ice is also reason for concern, particularly as it relates to the dynamics of hydrologic events, such as spring break-up floods. These events are of special importance to the ecosystem health of riparian ecosystems, especially to the major Arctic river deltas and their associated vast array of lakes [17]. Reduced ice-cover duration will be accompanied by thinner ice covers, ice thickness being one of the major physical controls on the frequency and severity of ice-jam flooding [e.g., 25, 26]. In particular, if accompanied by other climate-induced changes such as sea-level rise or reduced snowmelt runoff, reduced ice cover is likely to seriously impair the aquatic function of these critical Arctic ecosystems [e.g., 27, 28]. Moreover, such changes will also affect the traditional practices of the indigenous peoples that rely on such delta ecosystems for subsistence fisheries or harvesting of aquatic mammals [20, 21, 29].

Kola Peninsula, Russia Dmitry ND/iStockphoto

INDICATOR
16

Changing distribution of marine fish

Are Dommasnes, Institute of Marine Research, Bergen, Norway.

Disko Bay, West Greenland Carsten Egevang/Arc-Pic.com

Different species of fish, both marine and freshwater, are important resources for human populations in the Arctic. Fish are also prey for many species of birds and mammals, and form an essential link in Arctic food chains. Changes in the distribution and abundance of fish populations will, therefore, have consequences for the different species of prey which the fish feed on, for the predators of the fish, and for humans who depend on these fish or their predators. As an example, in times when the Barents Sea capelin, Mallotus villosus, stock is very low, concentrations of its zooplankton prey are higher, while the seabirds and harp seals, Pagophilus groenlandicus that prey on the capelin show increased mortality and recruitment failure. During these periods, the Barents Sea cod, Gadus morhua which also feeds on capelin and which supports an important commercial fishery, shows reduced growth and delayed maturation, and cannibalism within the stock increases [1].

Population/ecosystem status and trends

Arctic marine ecosystems have a large number of fish species, and many of them have several populations that are isolated from each other in some way. Only a few of the species have very large populations, and most of those are heavily exploited by marine fisheries.

In the northern Bering Sea, a change from ice-dominated Arctic conditions to sub-Arctic conditions with more open water tends to favor pelagic species like pollock, Theragra chalcogramma, over benthic and bottom-feeding species. With the recent shift to a cold period, the pollock population in 2009 is in collapse [2, 3].

In the Barents Sea/Norwegian Sea ecosystem, there is clear evidence that the biomass of another pelagic species, the Norwegian spring spawning herring, Clupea harengus, fluctuates with temperature [4]. The distribution of this herring stock also changes over time [5], with temperature change as one of the probable underlying causes. In the Barents Sea, capelin, Mallotus villosus, and cod, Gadus morhua, also display large variations in both biomass and distribution, with temperature change an important driving force [1, 6].

When changes in distribution occur, the causes are often complex and may be difficult to understand. In the northeast Atlantic, for example, there is ample evidence for changes in the distribution and abundance of fish populations [7]. The changes are consistent with a northward shift, or increase in abundance, in the northern part of their ranges and a decrease in southern parts. These changes are observed in both bottom-dwelling and pelagic species, and in exploited and unexploited species. It is highly likely that climate effects are part of the reason for the shifts. Other factors, however, in particular fishing, may also be important [7].

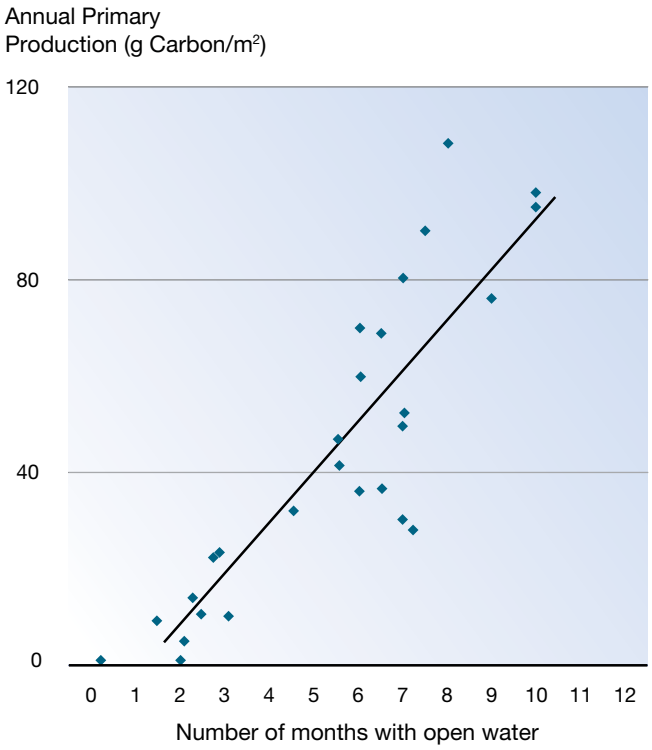

Figure 16.1: The relationship between annual primary production and the ice-free period based on measurements from several sites in the Arctic [9].


Vebjørn Karlsen/iStockphoto

Temperature changes may influence fish populations both directly, through shifts to areas with preferred temperature, and indirectly through the food supply and the occurrence of predators. The length of the ice-free period in the Arctic, for example, affects annual primary production, which is the basis of the food chain supporting populations of fish, sea mammals, and seabirds (Figure 16.1). As the amount of ice in the Arctic has considerably reduced since the 1970s, and projections indicate that the reduction will continue [8], it seems likely that primary production in the Arctic will increase during this century.

Marine fish have complex life histories with eggs, larvae, juveniles, and adults of the same species often occurring in different geographic locations and at different depths, and temperature changes may have different effects for the different life stages of a species. Free-floating eggs and hatched larvae drift with currents from the spawning areas to nursery areas where the young may grow and develop for several years until they near maturity. When maturation starts, adults return to the spawning areas to complete the cycle. If a change in temperature causes a species to shift its spawning areas, its continued success will depend on factors such as whether current systems in the new area take the eggs and larvae to suitable nursery areas, and whether the nursery areas are adequate in terms of temperature, food supply, depth, etc. Changes in spawning and nursery areas caused by climatic changes may, therefore, also lead to changes in population or species abundance.

In addition to climate changes, there is also increasing concern about ocean acidification due to increased carbon dioxide in the atmosphere [10]. More acidic oceans will directly influence organisms with calcareous structures, among them many species of phytoplankton and zooplankton which form part of the food chains for fish and other marine animals. Increased levels of carbon dioxide in the sea will also influence fish directly, with possible short-term effects being disturbance of respiration, blood circulation, and nervous activities, while possible long-term effects include reduced growth rate, reproduction, and calcification [11]. Predicting changes in distribution and abundance of fish stocks due to climate change or acidification will, however, be difficult until we have a more complete understanding of the mechanisms through which the stocks are influenced.

Concerns for the future

There is uncertainty about the impacts of global warming already underway, and still more uncertainty about the effects it will have on Arctic ecosystems. Some of the effects which may occur can be shown through computer modeling. An example is given in Figure 16.2 which shows simulated changes in the distribution of Arctic cod[1], Boreogadus saida, during the next 30 years, given reasonable assumptions about ocean warming. Arctic cod is a small, pelagic gadoid fish (less than 20 cm) which lives in the Arctic seas. It feeds on zooplankton and is not itself a target for large fisheries, but it is an important prey species for larger fish and marine mammals. The modeling results indicate that both distribution and abundance of Arctic cod may be dramatically reduced. This gives rise to many concerns. If the Arctic cod disappears, what will replace it? Will its predators also disappear? Will there still be fish and marine mammals to sustain human societies dependent on them? Clearly, a reduction in distribution for Arctic cod will affect both its predators and the human societies that have based their economies on them. Arctic cod is just one of the species which might be affected by the global warming; changes can be expected in other species as well.

1. Arctic cod is also called "polar cod".

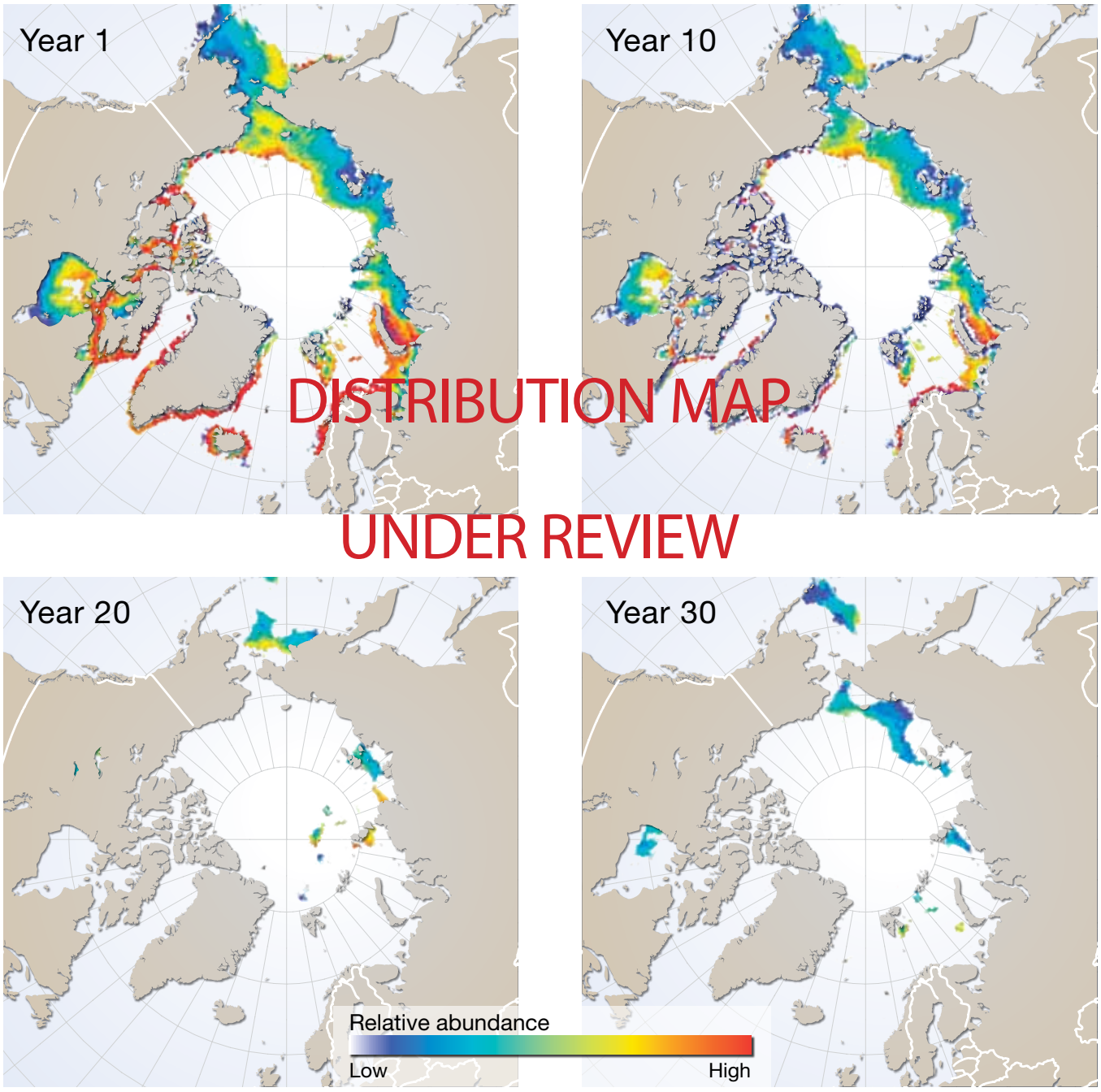

Figure 16.2: Simulated changes in distribution of polar cod after 1 year (upper left), 10 years (upper right), 20 years (lower left) and 30 years (lower right) under hypothetical scenarios of ocean warming and retreating sea ice edge at a rate of 5 km per year. Polar cod is extirpated from most of its range in 30 years [from 12].

INDICATOR
17

Impacts of human activities on benthic habitat

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Troms County, Norway Lars Johansson/iStockphoto

Cold-water coral reefs, coral gardens, and sponge aggregations provide a habitat for a variety of fish and invertebrates and thus represent biodiversity hotspots in the Arctic seas [1–3]. These habitats are vulnerable to fisheries and other human activities such as oil and gas exploration [4, 5] and are as such examples of Vulnerable Marine Ecosystems (VMEs). Impact or damage may lower the local biodiversity and diminish the possibility for many species to find shelter and feeding grounds. Because corals and sponges grow very slowly [3, 6], the recovery of these habitats may take from decades to centuries, and in some cases, may not recover at all. Political awareness about this issue is reflected in The United Nations General Assembly Resolution 61/105 towards long-term sustainable use of deep-sea fisheries resources and prevention of significant adverse impacts on vulnerable marine ecosystems.

Population/ecosystem status and trends

Cold-water coral reefs

Reef-building corals are characterized by a calcareous skeleton and are called stony corals. A reef is formed when dead coral skeletons accumulate over thousands of years. Lophelia pertusa is a reef-building species (Figure 17.1A) and is common in the waters around the south coast of Iceland, the Faroe Islands, and Norway north to about 71 °N [3].

Coral gardens

Coral gardens are important ecosystems in the Aleutian Islands and the eastern Bering Sea. These gardens are often structurally complex environments dominated by gorgonians (sea fans), stylasterid corals (lace corals), sponges, and other sedentary animals. Gorgonians have a largely upright, plant like growth form (Figure 17.1A) and a skeleton of a horny organic material. They reach their highest diversity in the Arctic in the Aleutian Islands. To date, 101 coral species have been indentified of which 50 could be endemic to the region [5]. The Bering Sea has dense aggregations of soft corals and sea pens on the shelf and slope, respectively. This region is relatively poor in stony corals, which occur as solitary cups and do not form true reefs as Lophelia does in the Norwegian and Barents Seas. The diversity of non-reef building corals, including Octocorallia and Scleractinia, is also high in these seas. In Norway, a total of 40 species are documented, of which the gorgonians are the most conspicuous [7].

Sponge grounds

Sponge grounds refer to areas where large sponges are strikingly common, i.e., those areas where more than 90% of the biomass in a trawl haul, excluding benthic fish, is sponges (Figure 17.1D). There have been so few studies on these types of environments that it is still necessary to define sponge grounds by the percentage biomass in trawl hauls. They have been found in the waters of East Greenland, Iceland, the Faroe Islands, northern Norway, the Barents Sea, Svalbard, and the Aleutian Islands [3, 5, 8].

Stressors and protection

Most of the Arctic Ocean, notably the deep basins, ridge systems and parts of the continental shelf, is largely unexplored and not impacted by human activities due to the limitations imposed by the annual ice-cover. These activities are thus limited to seasonally ice-free areas such as some shelf seas (e.g., Chukchi Sea, Bering Sea, and Barents Sea) that sustain important commercial fisheries and offshore regions where oil and gas exploration takes place. The on-going decrease in the ice-cover around the Arctic means that previously pristine areas are becoming accessible to fisheries and an expanding oil and gas industry.

Bottom trawling has the greatest potential to disturb benthic habitats. Because it involves towing a trawl, or fishing net, along the sea floor, it has a detrimental effect on the VMEs [1, 4]. Bottom trawls are widely used in the Bering Sea, around the Aleutian Islands, and in the Barents Sea.

Few studies have evaluated the impacts of trawl disturbance on Arctic benthic ecosystems. Preliminary estimates, however, show that 30–50 % of the reefs in the Norwegian Exclusive Economic Zone (EEZ) have been impacted or damaged by bottom trawling [4] (Figure 17.1B–C). Reefs damaged by trawling have been documented also in the Faroe Islands and Iceland. All three countries have closed some coral areas against trawling.

In the Aleutian Islands corals and sponges are common by-catch [9] and one study showed that about 40% of the surveyed sea floor was disturbed by trawling [1]. In 2006, the Aleutian Islands Coral Habitat Conservation Area was established prohibiting bottom trawling in a 950,000 km^2 area around the island chain and closed six coral gardens to all bottom tending fishing gear [5].

There is little quantitative information on the impact of trawling on sponge communities in the Arctic (Figure 17.1E–F). However, studies from other areas indicate that lumpy, non-flexible species are the most vulnerable. Trawling not only causes physical damage to the organisms but also turns over the substrate and causes re-suspension of sediments [10]. This is crucial because the water immediately above the seabed contains a naturally high concentration of particles with dead organic matter that sponges, as well as corals, feed upon. Re-suspension of sediments due to trawling causes organic matter to mix with mineral particles from the sediments. The result is lower food quality for suspension feeders and a high concentration of mineral particles in suspension that can clog up the filtering mechanism of sponges.

Drilling for oil and gas can impact VMEs through anchoring operations and discharge of drill mud and cuttings to the seafloor. During production, additional impacts may result from the discharge of produced water if it is not injected back into the geological structures. Handling of pipelines and cables may directly interfere with benthic communities, as can anchor operations by the vessels.

For most of the Arctic, there is no quantitative information on the impact of human activities on VMEs making it difficult to evaluate trends. In several countries, however, (e.g., Iceland, Norway, and the US) restrictions on trawling have been imposed on coral reefs and coral gardens through the establishment of coral Marine Protected Areas (MPAs). It is expected that human impacts have ceased within the MPAs, and in Norway satellite tracking shows that the restrictions are respected. In areas with no such protection it is likely that human activities still have a negative impact on corals. There are no restrictions specificly aimed at sponges in the Arctic. The lack of information about distribution makes it very difficult to evaluate trends, but large sponges are easily caught as by-catch in trawls and thus there may be an ongoing negative trend.

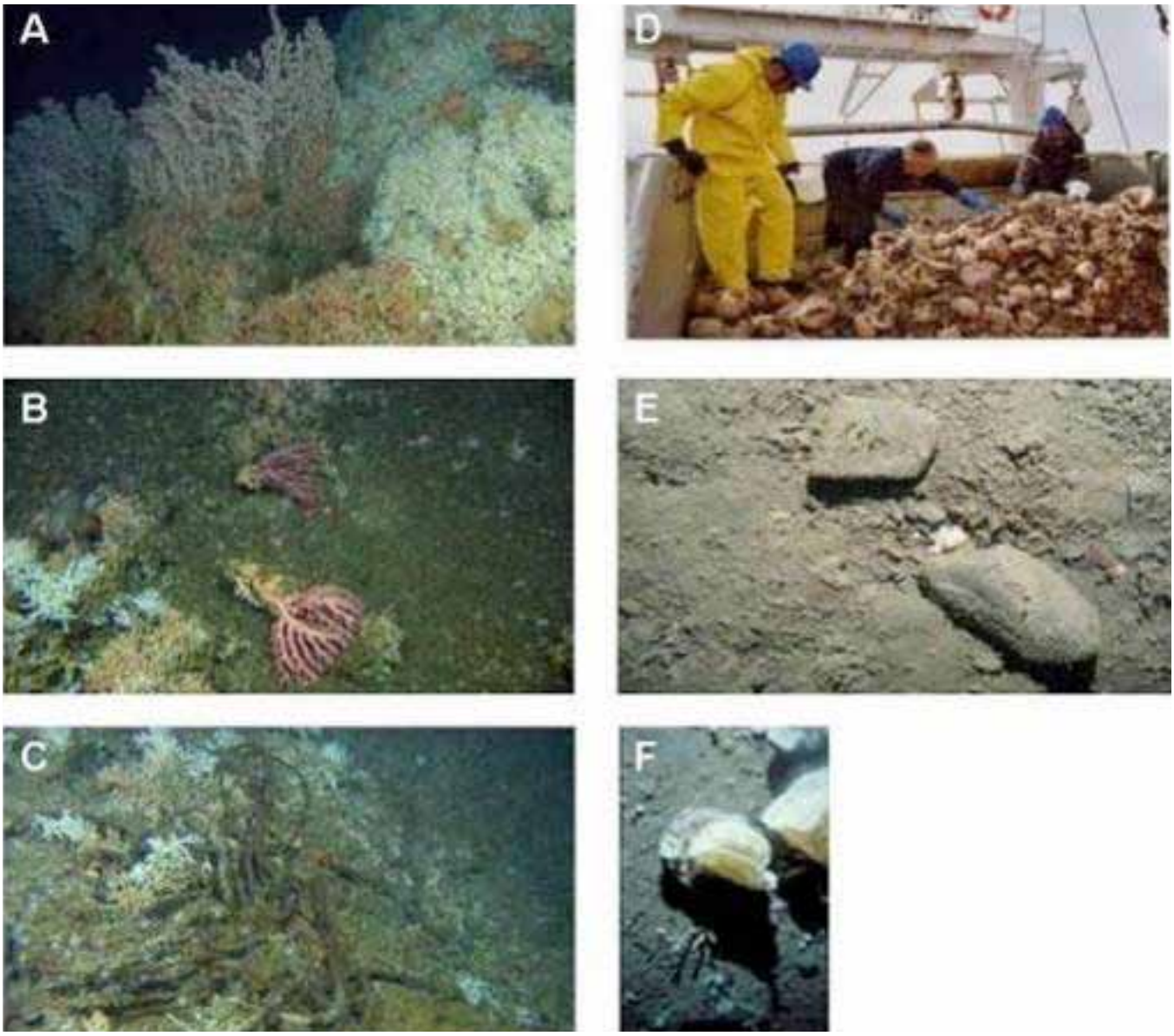

Figure 17.1: (A) Typical Lophelia pertusa reef at 160 m depth in Lopphavet, Finnmark county, northern Norway. Other species on the photo are the gorgonian coral Paragorgia arborea ("bushes" upper left), redfish Sebastes sp. and Mycale sponges (lower left and right). (B) Korallen, the northernmost coral reef in the world at about 71 °N. Smashed Lophelia skeletons and slain down gorgonian corals (red). (C) A dumped or lost wire at Korallen. (D) Agassiz trawl sample from a sponge ground off Iceland. Demonstrates how sponges are prone to be caught in large numbers by bottom trawls. (E) Axinellid sponges found in Langanes fisheries closure north of Iceland. The field was closed in 1993 and the photo is from 2005. (F) Typical bottom from a trawled area close to the Langanes closure in Iceland. Large sponges are rare in the trawled area.

Concerns for the future

Large areas of the Arctic are not mapped and the full distribution and condition of the VMEs are not assessed. Thus, there is an urgent need to map and evaluate the condition of the hitherto defined VMEs and to use new knowledge to define additional VMEs if necessary.

Increasing sea temperature will most likely induce changes in the distribution of species and the structure of benthic communities. Ocean acidification and changes in salinity are additional stressors with as yet unpredictable consequences. When ice melts, new and pristine areas may become more accessible to fishing, oil and gas exploration, and seafloor mining. Maritime transport is expected to increase considerably, which will add to the pollution load of the region. Finally, the distribution of fish stocks is expected to change and with it the location of fishing, perhaps bringing more fishing activity into VMEs [11].

Ecosystem services

INDICATORS #18–22

The Nutendli herders attribute the expansion of the willow to the tundra to the warming and melting of permafrost which they have observed. Elders of the Kolymskaya village reported in 2006 that willow are moving to tundra and to river banks. They said:

"It tells of the changes which are under way. You should graze cows and horses, not reindeer on these spots.
All of the tundra is covered with willows and bushes.

Mustonen,T. 2007. Report on the Biodiversity Observations of the Indigenous Communities of the ECORA Model Area Lower Kolyma River, Sakha-Yakutia, Russia. Conference Speech in Snowchange 2007: Traditions of the North, April 2007, Neriungri and Iengra, Sakha-Yakutia, Russia. Available from the Snowchange Cooperative, Finland.

INDICATOR
18 Reindeer herding

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Kautokeino, Norway Lawrence Hislop

Reindeer, Rangifer tarandus L., is an animal with a circumpolar distribution that has been a key component of Eurasian high latitude ecosystems for at least two million years. Interactions with humans date from the late Pleistocene onward, and both wild and semi-domestic animals continue to be highly valued by aboriginal and non-native peoples for a diversity of purposes [1–3]. The most productive semi-domestic herds occur in the Sápmi homeland of northern Fennoscandia and the Nenets regions of northwest Russia straddling the Ural Mountains.

As a widespread and dominant ungulate across many tundra and taiga regions, reindeer have a number of effects on ecosystem structure and function. Herded animals move seasonally between summer, winter, and transitional spring/autumn pastures. Their effects on vegetation and soils vary greatly in space and time depending on factors such as altitude/exposure, snow depth, substrate, moisture, prevailing vegetation type, and most importantly, animal density. Given the diverse suite of factors involved, changes in vegetation associated with grazing and trampling can be remarkably varied spatially yet remain to a large extent predictable. Potential threats facing reindeer populations of Eurasia, and reindeer herding as a livelihood, include rapid land use change, excessive predation, climate change, and ongoing institutional conflicts.

Population/ecosystem status and trends

In Fennoscandia and Russia, carrying capacity models are generally used by the respective nations to manage semi-domestic animals in relation to state-sponsored scientific assessments of range conditions [2, 4–8]. Animal populations have generally increased in the Nenets and Nordic regions since World War II and are at or near historic highs, although limits have been set in Fennoscandia. This trend has occurred in the Nordic countries in concert with the high-tech modernization of husbandry practices, such as motorized transport for herders and intensive veterinary

care. There are currently approximately 230,000 reindeer in Sweden, 165,000 in Norway, and 195,000 in Finland. In the Yamal-Nenets Autonomous Okrug of Russia, the number of reindeer has increased steadily since World War II from approximately 300,000 to around 610,000 animals today, despite the conspicuous absence of mechanized transport [9, 10]. In Finland, in particular, the negative effects of climate change, such as increasing frequency of rain-on-snow events which makes natural food sources less accessible, are offset via supplemental feeding of animals from January to April. In the Nenets Autonomous Okrug of Russia, there have been recent instances of extensive ice crusts on snow in which many animals died, yet herders have not expressed serious concern regarding weather or climate [11].

Strongly linked to carrying capacity is the concept of 'overgrazing' and that due to the high animal densities sustained over several decades, many rangelands across northern Eurasia are considered to be in poor condition [4, 12]. For herders, the concept of 'overgrazing' does not exist and, therefore, it is not recognized by them [13]. Lately some scientists have also asserted that it is extremely difficult to make a link between grazing impacts and animal performance [14, 15]. A recent study from Sweden also found no negative relationship between animal condition and either animal density or herd growth [16].

With regard to biodiversity, the evidence for the influence of reindeer is complicated and the results mixed. This is due to the fact that grazing may either increase or decrease vascular and/or non-vascular plant species richness, depending on factors such as grazing intensity and nutrient availability [15, 17–19]. There should be some caution against focusing too much on diversity indicators in the context of grazing and conservation goals since the various parties involved may be biased toward the protection of different species or plant groups [15, 18]. The standard indices of biodiversity are also equally influenced by rarities and trivial species [20]. One recent study in northernmost Fennoscandia concluded that reindeer are important for regional biodiversity as their presence seems to favor rare and threatened plants, at least on relatively rich dolomitic substrates [20]. As tundra/taiga vegetation has co-evolved to a large extent with important factors like reindeer (and fire), it is to be expected that biodiversity effects will be somewhat cyclical in response to the periodicity of these ecosystem drivers.

The trampling associated with grazing (Figure 18.1) is also an important driver for below ground impacts. Although changes in soils and surface waters are typically less apparent than those occurring in vegetation structure and cover, they may be critical for long-term ecosystem dynamics [21]. Trampling seems to be a key mechanism

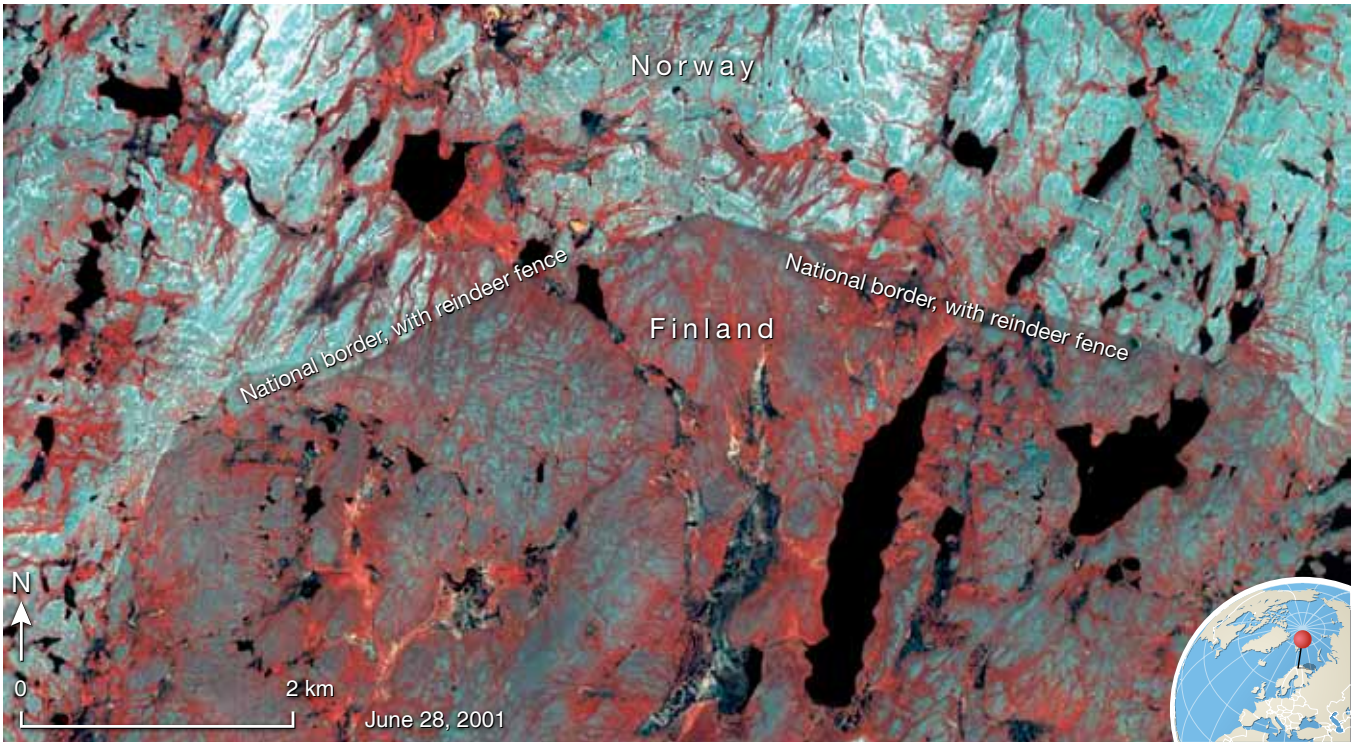

Figure 18.1: A very high-resolution false color Ikonos-2 satellite image of Jauristunturit in the border zone shared by Norway and Finland. Image acquired 28 June 2001. The main vegetation type is lichen dominated tundra heath with dwarf shrubs. The difference in whiteness is due to lichen coverage, and the national border with reindeer fence visibly divides the area. The northern portion is Norway, where fruticose lichen coverage is higher. This is a consequence of different pasture management. The Norwegian side is used only in late winter when there is snow cover and no grazing or trampling occurs in summer. The Finnish area is used in early summer, when vulnerable lichen mats have been progressively trampled over several decades [25].

for the deceleration of soil carbon cycling [22]. Studies in upland tundra heaths in Norway and Finland have documented degradation of the organic layer, followed by significant leaching away of essential plant nutrients, a reduction in plant available water, and consequently soil fertility [22, 23]. An intact organic layer, similar to a thick lichen or bryophyte mat, serves to insulate the mineral soils beneath and their removal can result in significant and long-term increases in summer and decreases in winter soil temperatures [23, 24].

Concerns for the future

There is a great deal of geographic variation in the environmental and anthropogenic drivers that affect modern reindeer-based, socio-ecological systems across Eurasia [26]. In Fennoscandia, there is a danger that with animal populations so high, even supplemental feeding to buffer against losses may become prohibitively expensive. Other significant stakeholders include local residents, hydroelectric power facilities (including large artificial lakes), tourism/recreation, mining, and nature conservation/protected areas. On top of this, the annual losses to predators continue to increase [27–29]. Given the increasing costs, competition from other users for land, restrictions on controlling predators, and the overall risks involved, may be influencing the number of owners and families involved in reindeer management which continues to decline in Fennoscandia [1].

In Russia, the main threat for the most productive post-Soviet reindeer herding areas in the Nenets and Yamalo-Nenets Autonomous Okrugs is the rapidly accelerating oil and gas extraction (Figure 18.2). Herders remain in favor of development overall, since they receive tangible benefits such as health care, assistance with transport, the ability to barter for goods on the tundra, and a few jobs [2, 30–32]. However, they fully recognize that the current pace of development will render the official objective of mutual coexistence impossible if their concerns are not properly addressed through meaningful consultation and accompanying action [31, 33]. As such, they continue to rank hydrocarbon development as a more serious ongoing and future problem than climate change [11]. In general, industrial impacts tend to decrease the biodiversity of tundra vegetation [34, 35].

The distribution of wild versus semi-domestic populations will remain fluid given the many places where their ranges directly overlap or at least come into close contact [1, 6]. The increasing ratio of private to state-owned animals in Russia, a trend which began in the waning days of the Soviet Union, may well accelerate [2, 36]. At the same time, pressure to reduce herd sizes will most likely remain in place within both Fennoscandia and Russia as long as state-funded management institutions continue to perceive high numbers of animals as ecologically unsustainable.

Figure 18.2: A false color Quickbird-2 satellite image of a portion of the Bovanenkovo Gas Field on the Yamal Peninsula in West Siberia. Image acquired 4 July 2004. The construction phase began in the late 1980s. From that period onward there remain visible signs of extensive off-road vehicle traffic across the terrain. Many of those tracks have naturally revegetated and now appear as bright red, indicating dense grass- and sedge-dominated vegetation. The road network was built in the mid-1990s, which has reduced off-road traffic significantly. However, infrastructure blocks segments of migration routes for Nenets and their reindeer herds, and pasture quality can be negatively affected by road dust, petrochemicals, trash left on the tundra, and even feral dogs abandoned by workers [25].

INDICATOR
19

Seabird harvest

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Nuuk, West Greenland Carsten Egevang/Arc-Pic.com

The use of living resources is fundamental to many regions of the Arctic, and for coastal people, marine mammals and seabirds are among the principal sources of harvest. The human use of seabirds varies between the circumpolar nations, both in scale and in form, but often dates back hundreds of years. Historically, birds were taken for their meat, eggs, skins, and down [1]. With the exception of skins, they are still harvested for these body parts but harvest methods have changed over time to include more efficient tools, making the seabirds more exposed to excessive harvest. By nature, most seabirds are already sensitive to adult mortality since they produce small clutch sizes and have delayed maturity [2, 3]. Further, they are generally challenged by low temperatures and reduced day length at high latitudes and periodically suffer due to extreme weather conditions [4, 5].

Although the impact of harvest on seabird populations is often poorly documented in the Arctic as a result of limited information on both seabird numbers and harvest levels in some areas, there is no question that it has played a key role in the population dynamics for many species. There are both examples of overharvesting causing substantial decreases in breeding populations and rapid population recovery following major changes in harvest regulation [6].

The fact that seabirds in the Arctic are migratory species (e.g., many breed in one country, and overwinter and are harvested in another country) makes management and assessments of harvest more complicated and makes international cooperation necessary. Within the Arctic countries, seabird harvest has been a conservation issue and focus of the Circumpolar Seabird Expert Group (CBird) under CAFF for several years, e.g., producing conservation strategies and action plans for selected seabird species [7–9].

Population/ecosystem status and trends

Until the 20th century, communities were small and hunting was done primarily from non-motorized watercraft and so likely had only a local impact on seabird populations. Since then, human population growth, mechanized transport, and the use of guns has increased the harvest of many species of seabirds. This increase in hunting pressure occurred simultaneously with increases in human disturbance at some seabird colonies related to offshore oil and gas development, commercial fisheries, tourism, and research [1].

Within the Arctic, there is a distinction between subsistence, commercial, and recreational/sports hunting. The line between these categories, however, is not always clear and differs between countries. Commercial hunting is forbidden in most countries, but in the Faroes, Iceland, and Greenland it is legal to supplement other sources of income by some domestic or local sale of "subsistence" seabird harvest [6].

Over the past three decades, depending on the country, harvest levels tended to decline as a result of factors such as more restrictive hunting regulations, declining seabird populations, fewer or less active hunters, or a combination of these factors (Figure 19.1). In some countries, particularly the Faroes, Iceland, and Greenland, the decline in harvest has been drastic. Declines in the harvest of 50% or more have been reported for several species. There is also a tendency that seabirds are increasingly harvested for cultural or recreational reasons, rather than for basic subsistence or commercial purposes. One exception is the collection of eiderdown in Iceland, which currently generates an annual revenue of up to approximately US$4 million per year [6]. In Alaska, Canada, Greenland, and Russia, it is still common practice that more extensive harvest rights apply to indigenous peoples or certain northern communities, acknowledging that subsistence harvest is essential for them to maintain a traditional lifestyle.

The number of birds presently harvested, or believed to be harvested, varies enormously between the nations. In north Norway and Svalbard, the estimated take equals less than 5,000 birds per year, while Canada, Greenland, and Iceland are, or recently were, harvesting in the order of 250,000 seabirds annually. The most common species in the harvest also varies from country to country and depends largely on traditions and accessibility to the seabirds. In a circumpolar perspective, however, murres, Uria lomvia, and eiders, Somateria sp., constitute by far the most numerous birds harvested, primarily as a consequence of their widespread distribution. Certain species are of major importance for one or two countries, such as puffins, Fratercula arctica, in Iceland and the Faroes; fulmars, Fulmarus glacialis, in the Faroes; dovekies, Alle alle, in Greenland; and auklets, Family Alcidae, in Alaska (Figure 19.1).

Country/Region	No. of species harvested	Most important species	Est. annual seabird harvest
USA/Alaska[1]	>25	Auklets, Murres	30,000 (2001–2005)
Canada	8	Murres, C. eider	260,000 (2002–2008)
Faroes	9	Fulmar, Puffin	65,000–240,000
Finland	6	Oldsquaw, C. eider	31,000 (2000–2004)
Greenland	19	T.-B. murre, C. eider, Dovekie, Terns? (eggs)	153,000–220,000 (2002–2006)
Iceland	19	Puffin, C. murre, C. eider (down, eggs)	158,000–285,000 (2002–2007)
Norway/Svalbard	5/4	Gulls/B. guillemot	4,000/150 (1995–2008)
Russia (West)	~10	Eiders, Murres, Gulls	?
Russia (East)	~20	Eiders, Alcids, Gulls, Terns, Comorants	Eiders (50–62,000), other seabirds (~100,000, mainly illegal) ~100,000 (mainly illegal)

1. Sea ducks not included; 2. Except for Common Eider; * Table updated according to personal communications [10], and [11].
(B. guillemot = black guillemot; C. eider = common eider; C. murre = common murre; T.B. murre = thick-billed murre).

Figure 19.1: Status and trends of seabird harvest in the Arctic (including sea ducks). Information from [6]*.

Concerns for the future

The distribution of some of the Arctic marine food sources upon which seabirds are dependent is changing as a result of climate change. In the North Atlantic, a northward shift in the distribution of Calanus copepods is affecting the availability of certain fish species of major importance for the seabirds, particularly sand eels, Ammodytes spp. These changes are believed to be involved in massive breeding failures among seabirds in Iceland, the Faroes, Scotland, and Norway, starting in 2004 [12]. This situation is part of the explanation for the declining trend in harvested seabirds in the Faroes and in Iceland (Figure 19.1). Analyses on a larger geographic scale have demonstrated that murre species are sensitive to climate change on a circumpolar level, but also showed that even closely related species may react differently to a given temperature change [13].

Climate change will complicate the sustainable use of seabird populations. Previous harvest levels may no longer be sustained for some species, while sustainable levels may increase for others. Future management of sustainable harvest levels will require better documentation of harvest levels and population numbers in several regions of the Arctic and the need for cooperative research, monitoring, and outreach will further increase [6]. The involvement of local users in collecting information about seabird populations and related biology can be of considerable value for their management. Should stronger harvest restrictions become necessary, direct involvement of coastal communities will facilitate such changes.

If sea ice continues to diminish as a consequence of climate change in the Arctic, access to the region will become easier and less costly in the future. This will likely increase the attractiveness of the region for further oil and gas development and may apply additional stressors to the Arctic environment, including seabirds [14].

Nuuk, West Greenland Carsten Egevang/Arc-Pic.com

Est. annual egg harvest	Overall trend in harvest	Reason for change
145,000 (2001–2005)	Variable annually, no trend evident (1995–2005)	Survey methods may not be comparable
Some	Decreasing (1980–2002)	Regulation and fewer hunters
1,000–12,000	Decreasing (1980–2006)	Regulation and decreasing pop.
Banned since 1962	Decreasing (1995–2005)	Decreasing pop. and regulation
6,600 (2006)	Decreasing (1993–2006)	Regulation and fewer hunters
Many	Decreasing2 (1995–2007)	Decreasing pop[2].
Some	Stable (1995–2008)	–
Some 1000s (<10,000) (illegal)	Increase in 1990s, now stable or decreasing	Changing law enforcement and social-economic situation
~100,000 (mainly illegal)	Decrease in early 1990s and gradual increase in 2000s	Changing law enforcement and social-economic situation

INDICATOR
20 Changes in harvest

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Violet Ford, Traditional Ecological Knowledge Coordinator for North America, Arctic Biodiversity Assessment, Ottawa, Canada.
Konstantin Klokov, St. Petersburg State University, St. Petersburg, Russia.
Evgeny Syroechkovskiy, Institute of Ecology and Evolution, Moscow, Russia.

Uummannaq, West Greenland Lawrence Hislop

"…for us, so-called subsistence activity is far more than subsistence. Hunting is more than food on the table. It is a fundamental part of who we are."
Labrador Inuit Association. Presentation to Scoping Meeting, Nain, April 1997.

"Not that finding any of those eggs was easy. Wild birds' eggs can't just be picked up like stones; they're tucked away in some pretty unlikely spots. Sometimes you have to do some cliff-climbing with a strong rope, then use a long piece of wire to pull them out from under the big overhanging rocks where birds hide them."
Inglefield, 1994.

The harvest of natural resources is a key feature of traditional lifestyles and economies throughout the Arctic, and a continuing reliance on it as a mainstay of indigenous existence in the north is evident. The following sections describe current trends in natural resource harvest in four regions of the Arctic: Alaska, Canada's Northwest Territories (NWT) and Nunavut, and the Russian North.

Population/ecosystem status and trends

Alaska

In Alaska, wild food harvests vary considerably by geographic area. The total harvest has been estimated at about 43.7 million pounds (approximately 19.8 million kg) of wild resources, an average of about 375 pounds (170 kg) per capita [1, 2]. This is in comparison with an estimated 16–40 pounds (7–18 kg) per capita of fish and wildlife resources harvested by people living in urbanized parts of the state [2]. The majority of the subsistence harvest is fish (60% by weight), followed by land mammals (20%), marine mammals (14%), birds (2%), shellfish (2%), and plants (2%) [1, 2]. Subsistence harvests account for about 2% of the total fish and wildlife harvest state-wide, compared with 97% taken by commercial fisheries and 1% by sport fishing and hunting [2].

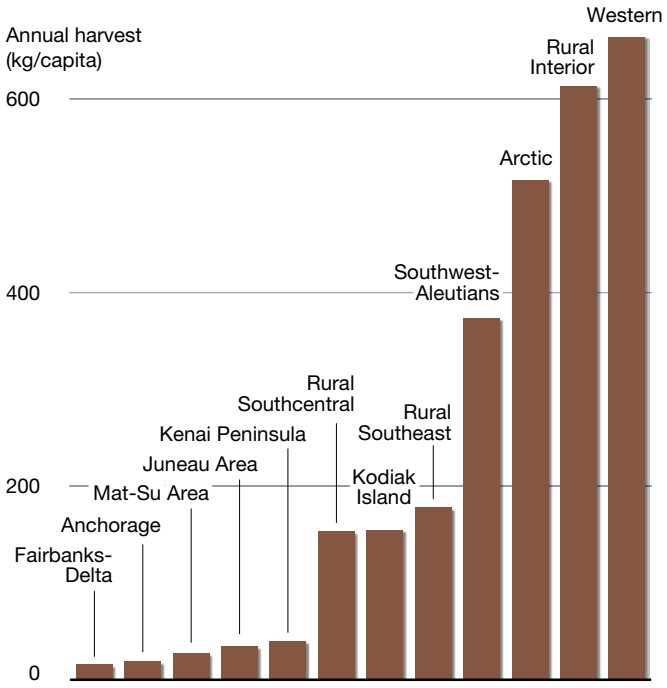

Figure 20.1: Wild food harvests in Alaska by area, 1990s [1, 2].

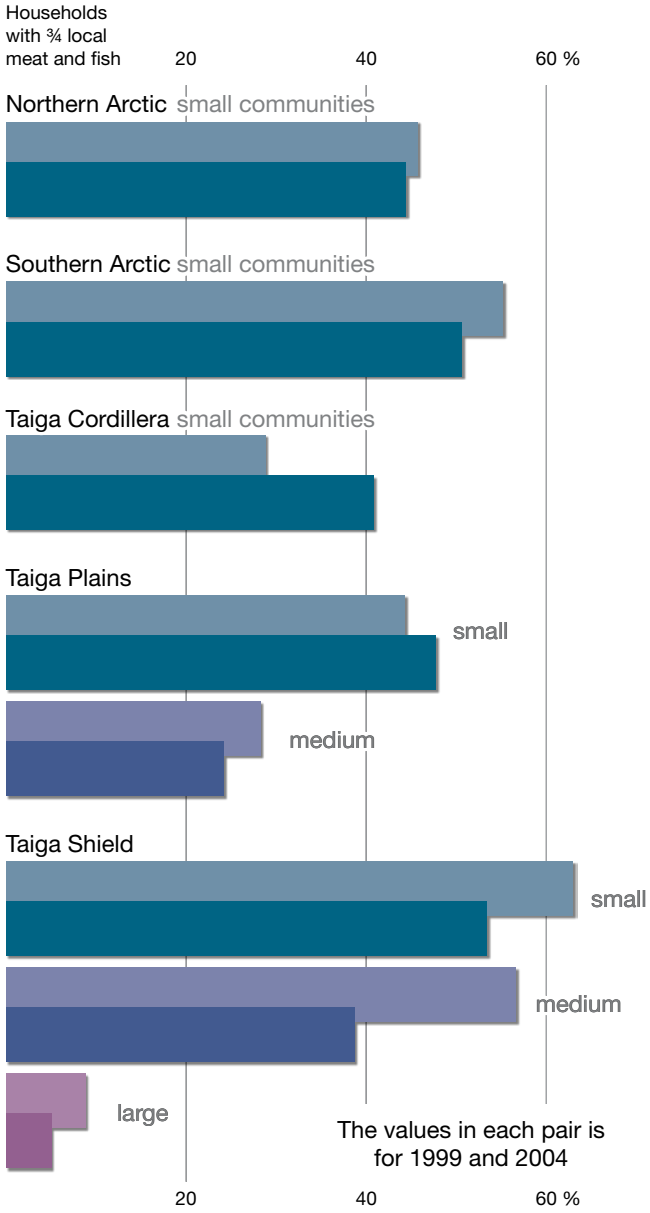

Figure 20.2: Percentage of households who reported that more than 75% of meat-fish was harvested from the NWT [5].

Land mammals harvested for subsistence include moose, Alces alces; caribou, Rangifer spp.; black and brown bear, Ursus spp.; Dall sheep, Ovis dalli; mountain goat, Ovis spp.; deer, Odocoileus; elk, Cervus spp.; and muskox, Ovibos moschatus. Migratory waterfowl provide an important source of fresh meat in the spring. Other birds harvested include ptarmigan, Lagopus spp., and grouse. Fish species harvested for subsistence include five species of salmon, Salmo spp., as well as whitefish, Coregonus clupeaformis; sheefish, Stenodus leucichthys; halibut, Reinhartius hippoglossoides; herring, Clupea harengus; trout, Salmo salar; grayling, Thymallus arcticus; char, Salvelinus alpines; and pike, Esox lucius. Trapping is at least as important for its cultural and symbolic attributes as for its economic attributes. Marten, beaver, wolf, fox, and wolverine are important resources targeted for trapping. Marine mammals harvested for subsistence and handicraft purposes by Alaska Natives include bowhead, Balaena mysticetus, and beluga whales, Delphinapterus leucas; seals; sea lions, Eumetopias jubatus; walrus, Odobenus rosmarus; and sea otter, Enhydra lutris. In addition to fish and game, berries and greens are also gathered, providing an essential and highly valued contribution to the diet.

A comparative analysis of subsistence harvests by the same community over a period of twenty years (1964–1984) found that not only had the composition of the harvest changed over time, the per capita harvest had declined by roughly 25% [3]. According to another study that examined subsistence fishery harvest patterns and trends in Yukon River communities, declining salmon runs during the 1990s resulted in significant declines in subsistence fish harvests that, because of their magnitude, are virtually impossible to make up for with harvests of other species. From 1990 to 2000, total subsistence salmon harvests by Yukon River communities decreased by about 60% [4].

Northwest Territories, Canada[1]

According to Northwest Territories (NWT) Labour surveys, about 37–45% of NWT residents went hunting or fishing in 2002 [6]. This has changed little since the first survey in 1983, and is high compared to southern Canada. According to the licensing system, the number of resident hunters declined by about 3% per year between 1990 and 2004, and stabilized at about 1200–1300 hunters annually in recent years. The number of hunters at outfitted camps in the Taiga Cordillera (primarily Dall sheep hunters) has not changed significantly in the past 10 years (350–400

1. Information on harvest in the NWT is taken from [5].

hunters). The number of outfitted hunters in the southern Arctic (mostly for barrenland caribou) was increasing until 2002, but has levelled down to about 650–700 hunters during the past 3 years.

About 40–60% of NWT residents living in small communities rely on traditional/country foods for at least 75% of their meat and fish. This percentage has not changed greatly for the past 10 years. The percentage of NWT residents living in medium and large communities that consume traditional/country foods is lower than for people living in small communities, and has declined during the past 10 years. The lowest percentage (less than 10%) of people who eat traditional/country foods (meat and fish) live in Yellowknife, the only large-sized community in the NWT.

Nunavut, Canada

Environmental change in Arctic regions is a key contributing factor to changing Inuit subsistence patterns. As examples, the Inuit speak of the thinning of the ice which makes hunting more challenging; species they once relied upon are disappearing; berries are not ripening. The impacts of climate change affect travel patterns and prevent the Inuit from reaching certain species. These shifts in the time and place of harvesting affect their ability to respond to the changes taking place.

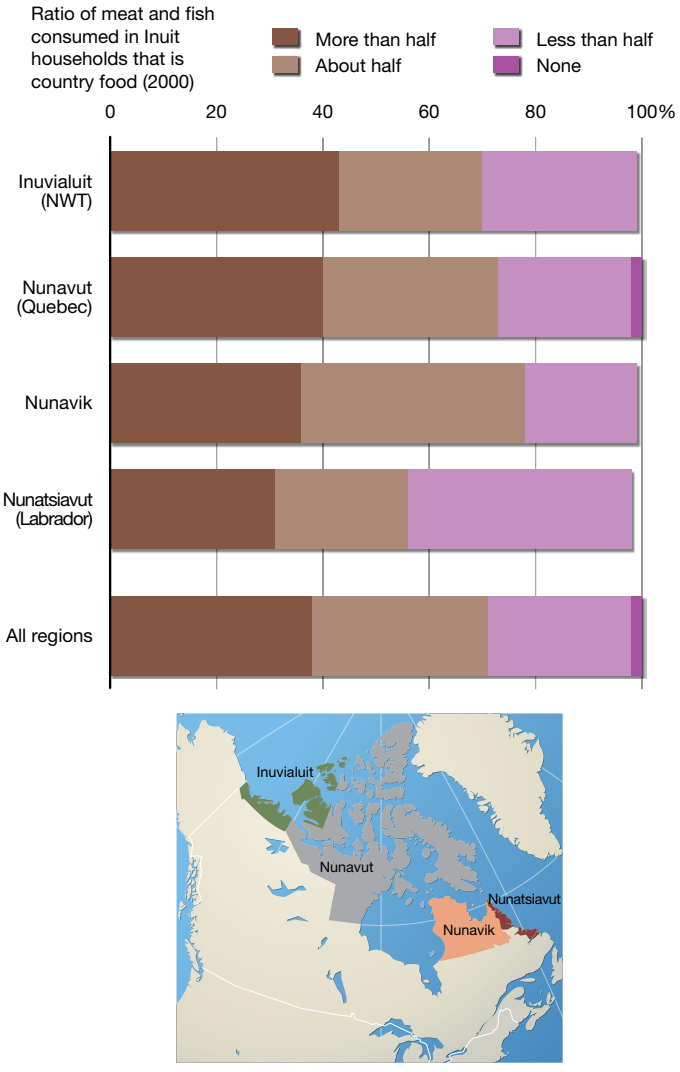

Figure 20.3: Consumption of harvested meat/fish in Inuit Households [9].

Yet despite these impacts to the Arctic ecosystem, Inuit continue to benefit from their traditional knowledge, or as Inuit sometimes call it, Inuit science, which has been passed from one generation to the next. A series of workshops was recently held in the four Inuit regions of the Canadian Arctic focussing on environmental change and what it means for communities there [7]. They showed that some Inuit have already made changes to the traditional times of the year when they travel on the land, and some find themselves collecting their winter wood and other supplies in the spring when they only used to do so in the fall. Inuit fishers check their nets more often, and harvesting activities are now carried out earlier in the year [7]. It is also important to note that even in times of change, the Inuit cultural activity of sharing food continues [8].

Russia

In the Soviet period of Russia, i.e., prior to the early 1990s, both commercial and subsistence consumption was increasing for almost all types of natural resources. This resulted in the depletion of some resources, consequently followed by a decrease in harvesting activities. This was the case for waterfowl in the eastern sector of the Russian Arctic, and for some populations of Coregonus whitefish and salmonids. In addition to over-harvesting at the local level, declines in waterfowl, and therefore waterfowl harvest, was also related to deteriorating conditions in the non-breeding grounds in wetlands of China and other countries of eastern Asia [10].

In the post-Soviet period, as a result of increased prices for vehicles, emigration of the non-resident population, and the closing of a large number of settlements, the overall area where natural resources were harvested was substantially reduced. In addition, the commercial use of all types of natural resources, although primarily fur, fish, and ungulates, has declined due to increased transportation costs and lowered demand (and hence reduced prices). An interesting result of the decline in commercial harvest has been the revival of some long-forgotten traditional uses of natural resources, such as whale and walrus hunting by Chukchi and Yupigyt (Eskimo) people, collection of waterfowl eggs (which has increased substantially in some areas of Chukotka), and hunting for moulting geese. Yet, as the harvest of marine mammals nowadays is predominantly to provide for the traditional needs of local indigenous people, and especially so in Chukotka, harvesting has declined for almost all species, and in particular for walrus [11].

Overall, subsistence consumption has slightly decreased as the food supplies to the Arctic have improved. However, its relative significance, i.e., the amount of harvested natural resources per indigenous family, remains higher in comparison to the Soviet era. In addition, commercial use of natural resources, such as hunting of sable and wild reindeer, collection and sale of berries and mushrooms, and commercial fisheries, has returned to previous levels.

Noticeable changes in the amounts, ratios, and species composition of harvested waterfowl have also occurred since the 1970s and 1980s. Since then, harvest pressure on bird populations in the Russian Arctic has decreased by 30% to 60% depending on the region [10].

According to assessment of the authors the area used for game hunting and fishing activities in the Russian Arctic has been reduced by at least 50% compared to the 1980s, and by more than two-thirds when compared to 1950s due to the closing of settlements and a reduction of rural populations. This is also result of reductions in reindeer herding activities and a total collapse of hunting for Arctic fox, Alopex lagopus.

Chukotka, Russia Anatoly Lolis/Topham Picturepoint/UNEP

Concerns for the future

Environmental and economic changes and their combined effects on subsistence harvests are dynamic and complex. This is particularly so in Russia, where overall trends in subsistence harvests have become much more dependent upon local conditions since the economy was decentralized, rendering the evaluation of trends much more complicated.

Subsistence and commercial fishing are often inextricably linked, and in some cases performed by the same people, thus decreases in commercial harvest results in less cash being available to subsistence users. The recent record-high price of oil and gas compounds the problem, as it not only limits the ability to travel, but also increases the costs of imported food, equipment, and supplies. Further, increasing prices for non-renewable resources are prompting increased mineral exploration and resource extraction activities. While these activities can provide new sources of employment and cash, they can also alter or destroy fish and wildlife habitat, and bring in people who compete for resources.

Finally, climate change is causing erratic weather patterns and changing the timing of freeze-up and break-up, which in turn affects migratory and harvesting patterns. Subsistence harvesting remains an important component of life in remote Arctic areas, and the subsistence harvest of fish and wildlife by indigenous and local residents is likely to continue well into the future. In light of the changing and increasingly challenging circumstances in the Arctic, however, more protection and ongoing monitoring will be required of harvested species.

INDICATOR
#21 Changes in protected areas

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Donald McLennan, Parks Canada Agency, Ottawa, Canada.

Svalbard, Norway Bjørn Gjelsten/iStockphoto

Protected areas have long been viewed as a key element for maintaining and conserving Arctic biodiversity and the functioning landscapes upon which species depend. Arctic protected areas have been established in strategically important and representative areas, helping to maintain crucial ecological features, e.g., caribou migration and calving areas, shorebird and waterfowl staging and nesting sites, seabird colonies, and critical components of marine mammal habitats.

Protected areas in the Arctic are also important for global biodiversity conservation. The majority of Arctic species use the region seasonally, with Arctic habitats providing resources for the maintenance of many bird and mammal species that migrate to areas around the world. The importance of this role is increasing due to climate-driven ecological change, industrial development, and resource exploitation. International conventions, such as the Convention on Biological Diversity (CBD), and organizations, such as the International Union for Conservation of Nature (IUCN), address the issue of protected areas worldwide but do not have any Arctic-specific programs. This gap highlights the need to develop a circumpolar protected areas strategy for the Arctic that would build on ongoing national initiatives, e.g., marine protected areas planning, to permit more effective conservation planning in a global context.

In many Arctic countries, protected areas are co-managed with indigenous and local peoples, through which access to resources is maintained and knowledge is shared. Traditional knowledge provided through co-management allows indigenous perspectives to contribute to protected areas management. By maintaining ecological integrity, protected areas can help maintain the spiritual and traditional lifestyles of Arctic Indigenous peoples.

Population/ecosystem status and trends[1]

The first protected areas dataset for the Arctic was created by CAFF in 1994 and was last updated in 2004 [1][2]. The data presented in this chapter represent the first results of the 2009 update, and were officially submitted by each of the Arctic Council countries.

The first protected areas in the Arctic were established in Sweden and Alaska at the beginning of the 20th century. The area under protection remained low until the 1970s when it began to increase significantly with additions of large areas such as the Greenland National Park (Figure 21.1). By 1980, 5.6% of the Arctic was classified under some degree of protection. This has steadily increased until today where 11% of the Arctic[3], about 3.5 million km^2, has protected status in 1127 protected areas (Figure 21.2). Of course, the nature of protection and governance of these areas varies throughout the circumpolar region, and there are varying levels of protection within countries. In addition, over 40% of Arctic protected areas have a coastal component but for the majority of these areas it is not possible at present to determine the extent to which they incorporate the adjacent marine environment.

1. Note on information sources: Data used to compile the information for this analysis came from each of the representatives of the Arctic Council countries to CAFF.
2. Subsequent to this, UNEP's World Database on Protected Areas (WDPA) has stored data on Arctic protected areas, although the Arctic data is of variable quality.
3. The Arctic, as defined by the CAFF boundary, covers an area of over 32 million km^2.

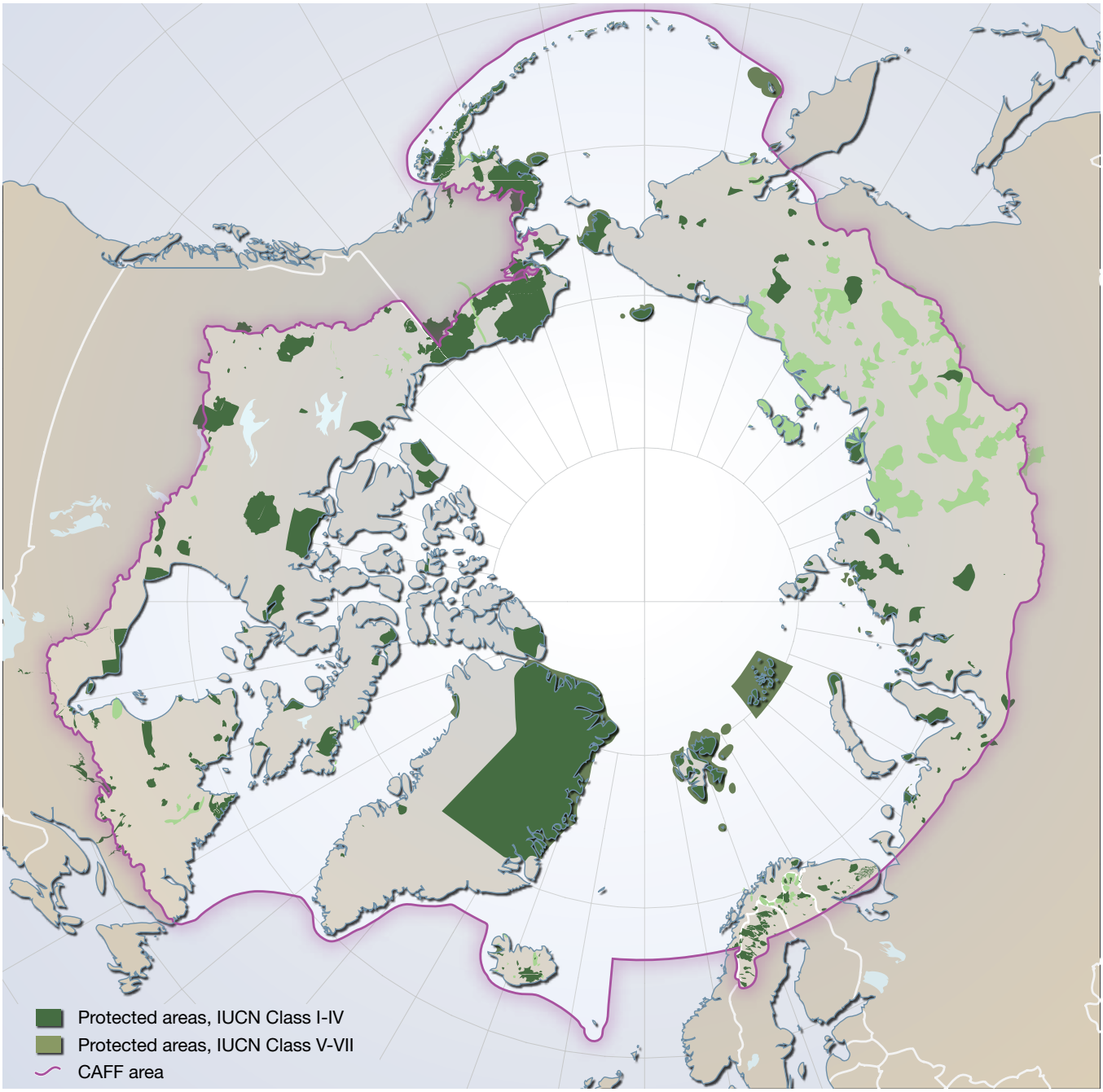

Figure 21.1: Protected Areas in the Arctic classed after their IUCN category [2].

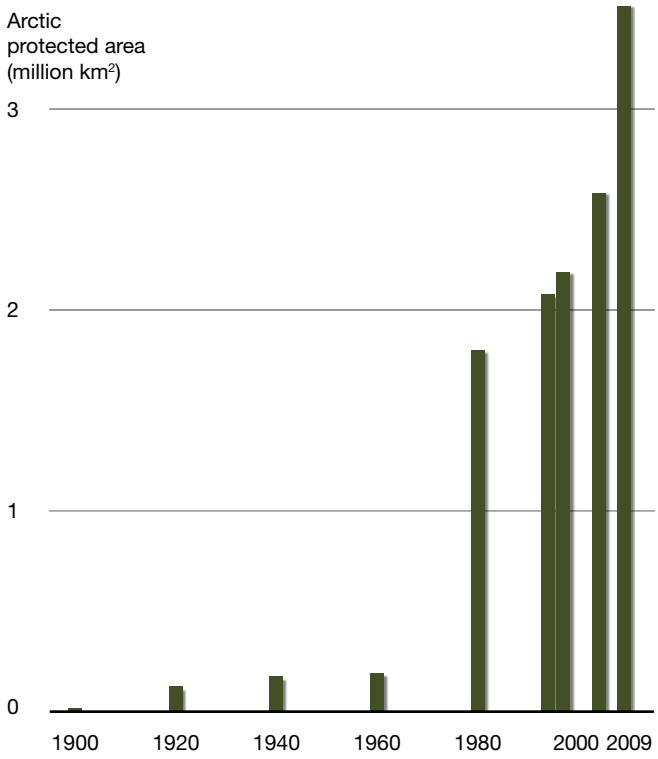

Figure 21.2: Change in extent of protected areas in the Arctic [2].

IUCN categories	# of PAs	Total area (km²)	% of Arctic covered
IA	350	273,000	0.8
IB	111	795,000	2.5
II	102	1,530,000	4.7
III	103	52,600	0.2
IV	125	154,000	0.5
V	60	64,600	0.2
VI	120	648,000	2.0
No cat. assigned	156	30,800	0.1
Total	1127	3,550,000	11.0

Figure 21.3: Distribution of protected areas in the Arctic between different IUCN categories [2].

Concerns for the future

Rapid climate change has become the primary challenge to the usefulness of protected areas as a conservation tool, i.e., how will ecosystems respond to rapid change, are existing protected area networks sufficient, and how should future protected areas be selected? The establishment of protected areas has historically been based on either the protection of unique habitats or the concept of ecological representativity, whereby important areas that are sufficiently large and contain targeted components of ecological biomes are selected for protection. However, the accelerating rate of climate-driven change in Arctic ecosystems complicates this approach to protected areas, and we may find that what we desire to protect today is altered or lost through climate change (e.g., due to the northward shift of species, greening of the Arctic, invasive species, and so on). This point emphasizes the importance of environmental conservation not only within protected areas but also beyond their boundaries. The condition of unprotected areas becomes critical as corridors of connectivity that facilitate species migrations.

Nowhere is this more important than in Arctic marine ecosystems where existing protection is low compared to terrestrial areas. Recent findings show that Arctic sea ice is disappearing much more rapidly than predictions made by the most pessimistic models [3]. This will fundamentally alter the oceanography and productivity of Arctic marine ecosystems. It will result in population level effects on Arctic marine mammals, fish, benthic communities, and seabirds in ways we are only beginning to understand [4, 5].

The phenology and distribution of sea ice in the Arctic also has profound effects on Arctic coastal and terrestrial ecosystems, and can be expected to exacerbate ongoing climate-driven change in these areas [4–6]. Increased rates of coastal erosion and unpredictable changes in other coastal processes can be expected to change in ways that are poorly understood. These will result in largely unpredictable effects on freshwater, wetland, and tundra biota, both inside and outside of Arctic protected areas. Many fish and marine mammals are migratory and the current approach of area protection may not be the most effective during certain times of the year, e.g., spawning.

The CBD [7] has recognized the importance of the conservation and sustainable use of the biodiversity of wetlands – and peatlands in particular – in addressing climate change. However, these complex ecosystems are vulnerable to climate-driven ecological change, industrial development, and resource exploitation. These factors are contributing to permafrost thawing, increased carbon emissions, and changes in hydrology and ecological processes, and are causing landscape level change and losses in key ecosystem services [8]. These ecological changes will further complicate efforts to develop an effective protected areas network.

All these factors make it difficult to assess the representativity and potential effectiveness of protected areas. They also make the development of an effective strategy for establishing new areas challenging. What is clear, however, is that no one country can ensure adequate protection for all critical stages in the life cycles of Arctic biota. An effective network of Arctic protected areas requires a coordinated circumpolar approach that needs to be linked with other jurisdictions globally, and coordinated with Indigenous Peoples across the Arctic.

INDICATOR
#22 Linguistic diversity

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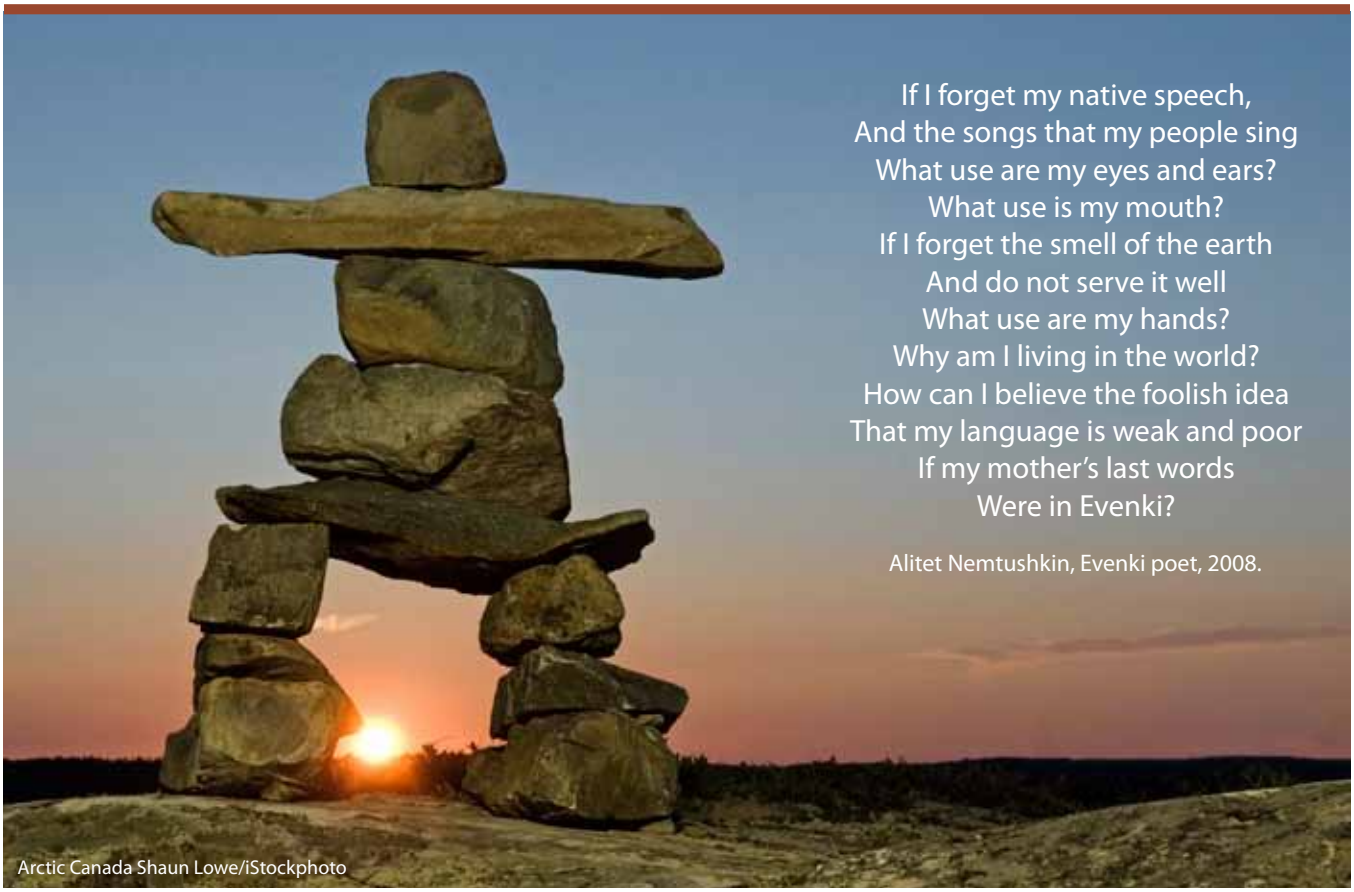

Arctic Canada Shaun Lowe/iStockphoto

Language not only communicates, it defines culture, nature, history, humanity, and ancestry [1]. The indigenous languages of the Arctic have been formed and shaped in close contact with their environment. They are a valuable source of information and a wealth of knowledge on human interactions with nature is encoded in these languages. If a language is lost, a world is lost. This deep knowledge and interconnectedness is expressed in Arctic song, subsistence practices, and other cultural expressions but especially in place names across the Arctic. Place names of the indigenous peoples reflect subsistence practices, stories, dwelling sites, spawning sites, migratory routes of animals, and links to the sacred realms of the indigenous peoples of the north.

The preservation of languages is a crucial step in allowing us to benefit from traditional knowledge and form a better understanding of our environment. The Convention on Biological Diversity (CBD) recognizes that linguistic diversity is a useful indicator of the retention and use of traditional knowledge, including knowledge of biodiversity. It has, therefore, been included in the suite of indicators being used to assess progress towards meeting the 2010 biodiversity targets.

With this in mind, this chapter considers the vitality of indigenous languages in the Arctic and explores their current status and trends. The United Nations' Educational, Cultural and Scientific Organization (UNESCO) has developed a framework comprised of six factors which can be used to determine the vitality and state of endangerment of a language [2]. This chapter looks at two of these criteria (absolute number of speakers and proportion of speakers within a total population) and applies them to the Arctic to provide an indication of the status and trends of indigenous languages. However, the assessment of language vitality is a complex issue and no single factor alone suffices. The number of speakers of a language provides an indication of the viability of a language but taken alone does not provide a complete picture. An equally important factor is the percentage of the population which can speak the language, i.e., the higher the percentage, the better the chances of a vibrant and healthy language.

Population/ecosystem status and trends[1]

The development of circumpolar statistics for indigenous languages in the Arctic is a challenging task. Information on indigenous populations and their languages varies in coverage and extent. Statistics are often not collected consistently or are only recently being done so. Thus by necessity, the creation of circumpolar datasets requires a combination of official sources and estimates. When attempting to compile circumpolar datasets, it must be remembered that even when cohesive national datasets are available, they may be chronologically difficult to compare i.e., they are collected at different intervals or address the issue of linguistics from different approaches. Therefore, circumpolar statistics for languages such as the Saami, Aleut, and Inuit must be approached with caution. Attempts to address this gap in knowledge, however, are important as they help to stimulate awareness of possible changes, encourage further research, draw attention to the challenges facing the long term vitality of many indigenous languages, and hopefully spur positive actions.

Arctic language structures

The Arctic is inhabited by an array of ethnic peoples with different cultures and language groupings. For this report, information was compiled on 90 Arctic languages. These can be grouped into six distinct language families including a number of isolated languages presently unconnected to any other language grouping (Figure 22.1).

Changes in the populations of indigenous peoples

It was possible to consider changes in populations for 47 languages (Figure 22.2). Of these, 36 had populations of fewer than 10,000, and 18 had population levels of 1,000 or less. Nineteen populations experienced decreases in size ranging from 5–50%, the majority of these being located in the Russian Federation. This implies either a decline in indigenous populations or alternatively a change in the methods used for census survey. The indigenous population which experienced the greatest increase in net population were the Inuit (Figure 22.3).

Absolute numbers of speakers and proportion of speakers within a total population

It was possible to calculate change in the absolute number of speakers and proportion of speakers for 44 of the surveyed languages (Figure 22.4). Only 4 languages displayed an increase in absolute numbers of speakers, proportion of speakers and net population (Figure 22.5). Thirty nine of the surveyed languages experienced a

1. Note on information sources: Data used to compile the information for this analysis, including Figures 26.2 – 26.6, came from a wide variety of sources both official and academic. Each of the CAFF countries where possible provided statistical information. The Indigenous Peoples organisations (Permanent Participants to the Arctic Council) provided information and further to these sources academic publications were utilised.

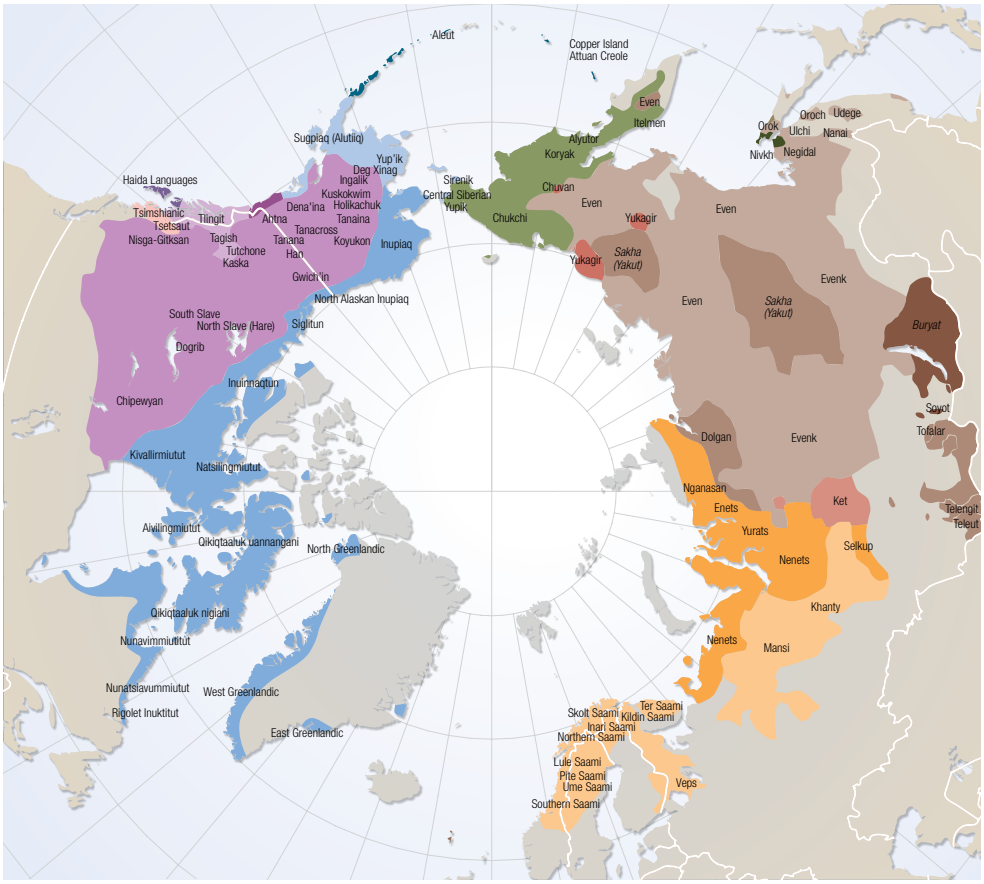

Figure 22.1: The distribution of languages and language families in the Arctic [1, 3].

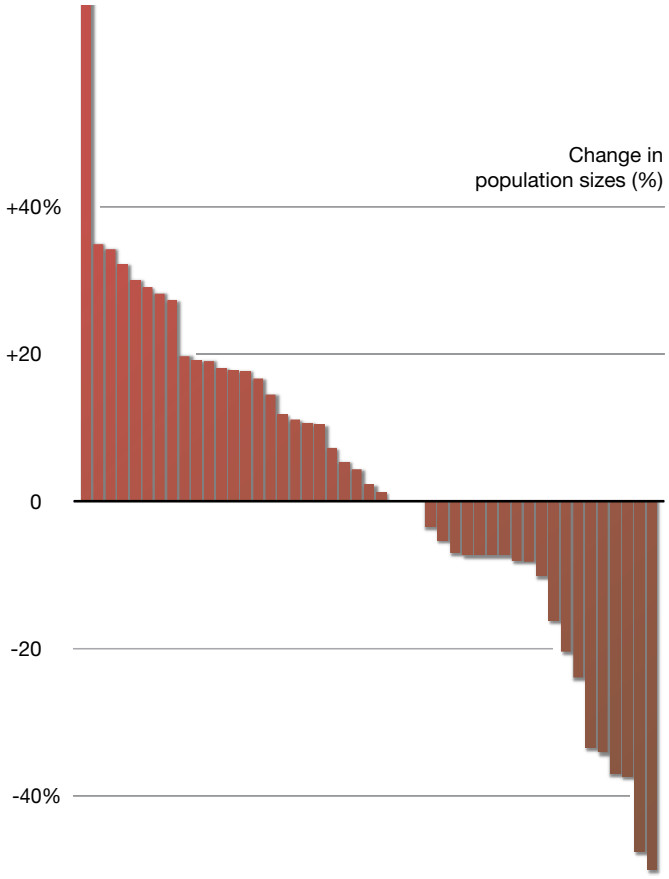

Figure 22.2: Change in population (estimated) for 47 populations between 1989–2006.

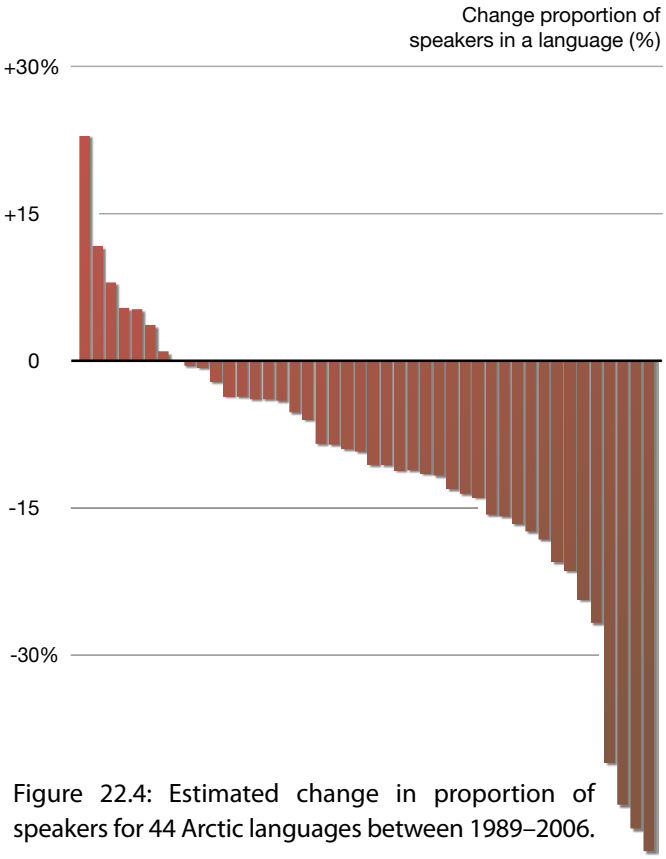

Figure 22.4: Estimated change in proportion of speakers for 44 Arctic languages between 1989–2006.

Peoples	Current population estimates	Estimated population increase	% change	Period
Inuit	107,608	18,299	+ 18%	1997–2006
Nenets	41,302	6,637	+ 19%	
Khanty	28,678	6,157	+ 27%	1989–2002
Evenk	35,527	5,364	+ 18%	
Saami	69,101	4,674	+ 7%	1989–2002

Figure 22.3: The five Arctic peoples with largest increases in population size.

Languages	Current population estimates	Estimated population increase	Estimated increase in proportion of speakers	Estimated increase in absolute numbers of speakers	Period
Inuit	107,608	+18,299	+4%	13,246	1989–2002
Saami languages	69,101	+4,674	+12%	9,841	
Yukagir	1,509	+367	+5%	207	1995–2006
Tofalar	837	+378	+1%	55	1989–

Figure 22.5: Languages displaying an increase in absolute numbers of speakers, proportion of speakers and net population.

decrease in vitality over the last decade, i.e., a decrease in numbers of speakers and in the proportion of speakers within their populations.

Thirty-five languages experienced reductions in proportion of speakers and 22 of these ranged from 10–50%. Of the remaining languages all but seven experienced reductions of over 10% in the absolute numbers of speakers within their populations. Some

languages, such as the Enet language of the Russian Federation experienced a 70% decrease in the numbers of speakers. Only twelve languages displayed an increase in absolute numbers of speakers The Inuit language(s) had the highest gain while the Chukchi language had the greatest loss (Figure 22.6).

Language	Current population estimates	Estimated changes in numbers of speakers	Period
Inuit	107608	+13246	1997–
Saami	69101	+9841	2006
Nenets	41302	+3793	1995–
Veps	8240	–2300	2006
Evenk	35527	–2307	1989–
Chukchi	15767	–3708	2002

Figure 22.6: Languages with the greatest increase and decrease in numbers of speakers.

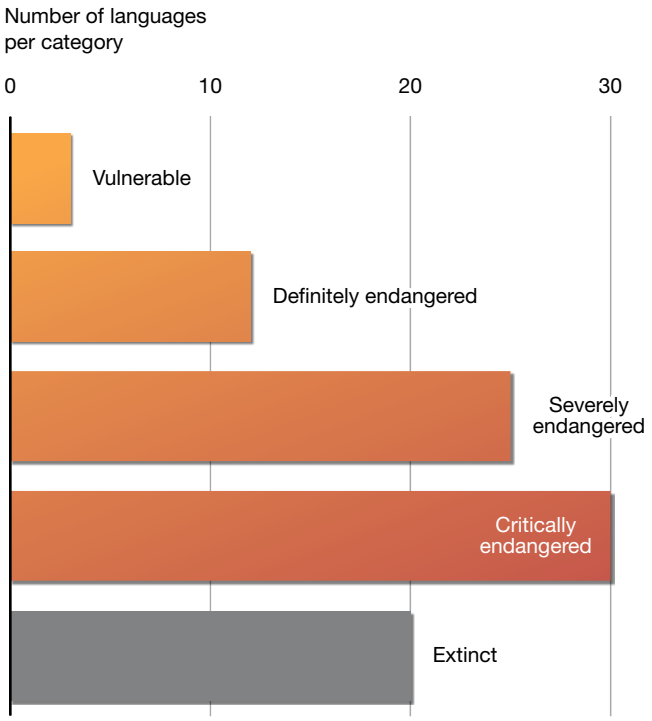

Figure 22.7: Vitality of Arctic languages as classified by UNESCO [2].

Language vitality

UNESCO has classified the vitality of each of the languages on which data was collected (Figure 22.7). It is striking to note that 20 languages have become extinct since the 1800s and that ten of these extinctions have taken place after 1990 indicating an increasing rate of language extinction. Of these extinctions, one was in Finland, one in Alaska, one in Canada, and seventeen in the Russian Federation. With this in mind, it is urgent that the 30 languages classified as critically endangered be well-documented and attempts at revitalization considered.

Concerns for the future

Since the 19th century, indigenous languages in the Arctic have been subject to pressures and challenges from the colonial powers active in the Arctic. In the early 20th century, this involved a process whereby indigenous languages were not incorporated within educational and civil systems. This often resulted in weakening ties to language and subsequently to culture and traditions. Today the dominant languages in the Arctic are Russian, English, and the Scandinavian languages.

The majority of Arctic indigenous languages have experienced significant decreases in the absolute number of speakers and the proportion of speakers. This indicates that Arctic languages are facing an uncertain future and efforts to increase our understanding of the cultures and traditions contained within these languages should be increased. However, some indigenous languages have in recent decades gained stronger status and been subject to sustained efforts to revitalize them both as tools of cultural heritage and as official languages, e.g., in Greenland, and in Nunavut and the Northwest Territories, Canada. While such developments are encouraging, it is clear that many indigenous languages face enormous challenges. The increasing rate of language extinction emphasizes the urgency and cause for concern and need for concerted efforts aimed at revitalization and documentation.

"The Indigenous landscape is decoded by stories and names and old knowledge. Every place name has a meaning."

K. Mustonen, Women of Taiga and Tundra, 2008.

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Abbreviations

ABA	Arctic Biodiversity Assessment
ACIA	Arctic Climate Impact Assessment
ASTI	Arctic Species Trend Index
CAFF	Conservation of Arctic Flora and Fauna Programme
CARMA	CircumArctic Rangifer Monitoring and Assessment Network
CBD	Convention on Biological Diversity
CBird	Circumpolar Seabird Group of CAFF
CBMP	Circumpolar Biodiversity Monitoring Program of CAFF
EEZ	Exclusive Economic Zone
GNWT	Government of the Northwest Territories
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for the Conservation of Nature
LPI	Living Planet Index
MPA	Marine Protected Area
NDVI	Normalized Difference Vegetation Index
NWT	Northwest Territories
SST	sea surface temperature
TEK	traditional ecological knowledge
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Cultural and Scientific Organization
VME	Vulnerable Marine Ecosystem

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