4 Animal species' diversity, ranges, and distrubution will change.

The Arctic is home to animal species that are admired around the world for their strength, beauty, and ability to survive in the harsh northern environment. Animals including caribou/reindeer, polar bears, and many species of fish and seals are also an essential part of the economy, diet, and culture for arctic peoples. Climate change will impact arctic species in ways that will affect conservation efforts as well as those who harvest wildlife resources on land and sea.

In the Marine Environment

More than half of the Arctic region is comprised of ocean. Many arctic life forms rely on productivity from the sea, which is highly climate-dependent. Climate variations have profound influences on marine animals. For example, the climate-related collapse of capelin in the Barents Sea in 1987 had a devastating effect on seabirds that breed in the area. And years with little or no ice in the Gulf of St. Lawrence in Canada (1967, 1981, 2000, 2001, 2002) resulted in years with virtually no surviving seal pups, when in other years, these numbered in the hundreds of thousands.

Polar bears are unlikely to survive as a species if there is an almost complete loss of summer sea-ice cover.

Polar Bears

Polar bears are dependent on sea ice, where they hunt ice-living seals and use ice corridors to move from one area to another. Pregnant females build their winter dens in areas with thick snow cover on land or on sea ice. When the females emerge from their dens with their cubs in spring, the mothers have not eaten for five to seven months. Their seal hunting success, which depends upon good spring ice conditions, is essential for the family's survival. Changes in ice extent and stability are thus of critical importance, and observed and projected declines in sea ice are very likely to have devastating consequences for the polar bear.

The earliest impacts of warming would be expected to occur at the southern limits of the bears' distribution, such as James and Hudson Bays in Canada, and such impacts have already been documented in recent years. The condition of adult polar bears has declined during the last two decades in the Hudson Bay area, as have the number of live births and the proportion of first-year cubs in the population. Polar bears in that region suffered 15% declines in both average weight and number of cubs born between 1981 and 1998. Later formation of sea ice in autumn and earlier break-up in spring means a longer period of annual fasting for female polar bears, and their reproductive success is tightly linked to their fat stores. Females in poor condition have smaller litters and smaller cubs that are less likely to survive. Climate change is also likely to increase bear deaths directly. For example, increased frequency and intensity of spring rains is already causing some dens to collapse, resulting in the death of females and cubs. Earlier spring break-up of ice could separate traditional den sites from spring feeding areas, and young cubs cannot swim long distances from dens to feeding areas.

Polar bears are unlikely to survive as a species if there is an almost complete loss of summer sea-ice cover, which is projected to occur before the end of this century by some climate models. The only foreseeable option that polar bears would have is to adapt to a land-based summer lifestyle, but competition, risk of hybridization with brown and grizzly bears, and increased human interactions would then present additional threats to their survival as a species. The loss of polar bears is likely to have significant and rapid consequences for the ecosystems that they currently occupy.

Ice-dependent Seals

Ice-dependent seals, including the ringed seal, ribbon seal, and bearded seal, are particularly vulnerable to the observed and projected reductions in arctic sea ice because they give birth to and nurse their pups on the ice and use it as a resting platform. They also forage near the ice edge and under the ice. Ringed seals are likely to be the most highly affected species of seal because all aspects of their lives are tied to sea ice. They require sufficient snow cover to construct lairs and the sea ice must be stable enough in the spring to successfully rear young. Earlier ice break-up could result in premature separation of mothers and pups, leading to higher death rates among newborns.

Adapting to life on land in the absence of summer sea ice seems highly unlikely for the ringed seal as they rarely, if ever, come onto land. Hauling themselves out on land to rest would be a dramatic change to the species' behavior. Giving birth to their pups on land would expose newborns to a much higher risk of being killed by predators. Other ice-dependent seals that are likely to suffer as sea ice declines include the spotted seal, which breeds exclusively at the ice edge in the Bering Sea in spring, and the harp seal, which lives associated with sea ice all year. Unlike these ice-associated seal species, harbour seals and grey seals are more temperate species with sufficiently broad niches that they are likely to expand their ranges in an Arctic that has less ice coverage.

Seabirds

Some seabirds such as ivory gulls and little auks are very likely to be negatively impacted by the decline of sea ice and subsequent changes to the communities in which they live. The ivory gull is intimately associated with sea ice for most of its life, nesting and breeding on rocky cliffs that offer protection from predators, and flying to the nearby sea ice to fish through cracks in the ice and scavenge on top of the ice. As the sea ice edge retreats further and further from suitable coastal nesting sites, serious consequences are very likely to result. Major declines have already been observed in ivory gull populations, including an estimated 90% reduction in Canada over the past 20 years.

The Walrus and the Ice Edge

The ice edge is an extremely productive area and is very sensitive to climate change. The most productive areas are nearest the coasts, over the continental shelves. As sea ice retreats farther from the shorelines, the marine system will lose some of its most productive areas. For walrus in many areas, the ice edge provides the ideal location for resting and feeding because walrus are bottom feeders that eat clams and other shellfish on the continental shelves. As the ice edge retreats away from the shelves to deeper areas, there will be no clams nearby. Walrus also normally travel long distances on floating ice, allowing them to feed over a wide area.

4 Animal species' diversity, ranges, and distrubution will change.

Diver sampling sea-ice algae at Cape Evans. The underside of the sea ice is colored brown by the algae. Brine channels that form as the ice melts form pinnacles of ice hanging down into the water column and these become heavily colonized by ice algae.

Research in the Beaufort Sea suggests that ice algae at the base of the marine food web may have already been profoundly affected by warming over the last few decades.

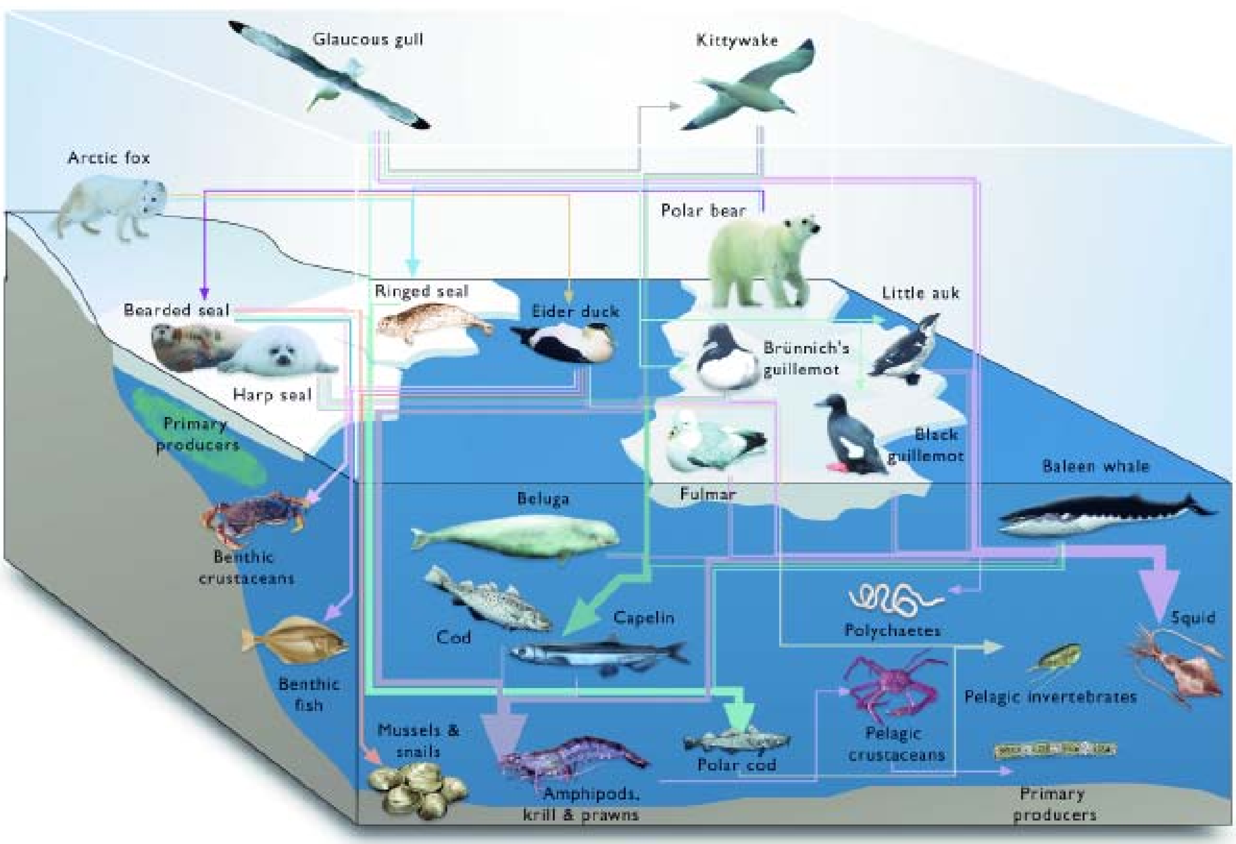
Ice Algae and the Related Food Web

The vast reduction in multiyear ice in the Arctic Ocean is likely to be immensely disruptive to microscopic life forms associated with the ice, as they will lack a permanent habitat. Research in the Beaufort Sea suggests that ice algae at the base of the marine food web may have already been profoundly affected by warming over the last few decades. Results indicate that most of the larger marine algae under the ice at this site died out between the 1970s and the late 1990s, and were replaced by less-productive species of algae usually associated with freshwater. Researchers say that this is likely to be related to the fact that melting has formed a 30-meter thick layer of relatively fresh water below the remaining ice, one third deeper than it was 20 years before. Among the areas likely to be most severely affected by such changes will be the Bering Sea and Hudson Bay, in the lower Arctic, where sea ice is already disappearing earlier in spring and forming later in the autumn. As the Arctic continues to warm, sea ice will melt rapidly in the spring over continental shelf areas and withdraw toward the deep ocean of the central Arctic.

Additional Climate-Related Threats to Marine Species

Climate change poses risks to arctic marine mammals and some seabirds beyond the loss of habitat and forage bases. These include increased risk of disease due to a warmer climate, increased pollution impacts as rising precipitation brings more atmospheric and river-borne pollution northward, increased competition as temperate species expand their ranges northward, and impacts due to increased human traffic and development in previously inaccessible, ice-covered areas.

Arctic Marine Food Web



Chemicals and Climate Interact to Impact Polar Bears

The increase in environmental stress on polar bears caused by climate change interacts with the stresses caused by chemical contaminants. Polar bears, at the top of the marine food chain, accumulate contaminants in their fat by eating ringed seals and other marine mammals who have absorbed the chemicals by eating contaminated species lower on the food chain. High levels of chlorinated compounds and heavy metals have been found in polar bears. In some cases, contaminants may be stored in fat, keeping the chemicals from affecting the bears' health when fat reserves are high. But during a poor feeding season, when the fat reserves must be used, the chemicals are released into the body. Polar bears in some areas of the Arctic have been observed to have less fat reserves in recent decades as sea ice breakup occurs progressively earlier, forcing them ashore where they are required to fast for increasingly longer periods.

Climate and Social Changes Interact to Impact Marine Hunters

Many arctic communities depend on hunting polar bear, walrus, seals, whales, seabirds, and other marine animals. Changes in the species' ranges and availability, and the decreased ability to travel safely in changing and unpredictable ice conditions are making people feel like strangers in their own land. Some societal changes have increased vulnerability to climate-induced changes. For example, over recent decades, many Inuit hunters have switched from dog sleds to snowmobiles, and while dogs could sense dangerous ice conditions, snowmobiles cannot. (On the other hand, snowmobiles allow people to hunt over larger areas and to transport bigger loads.) In addition, people are no longer nomadic, following animals' seasonal movements. Because people now live in permanent settlements, their ability to adapt to changing climatic conditions and/or animal availability by moving has been greatly reduced.

4 Animal species' diversity, ranges, and distrubution will change.

Marine Fisheries

Arctic marine fisheries provide an important food source globally, and a vital part of the economy of the region. Because they are largely controlled by factors such as local weather conditions, ecosystem dynamics, and management decisions, projecting the impacts of climate change on marine fish stocks is problematic. There is some chance that climate change will induce major ecosystem shifts in some areas that would result in radical changes in species composition with unknown consequences. Barring such shifts, moderate warming is likely to improve conditions for some important fish stocks such as cod and herring, as higher temperatures and reduced ice cover could possibly increase productivity of their prey and provide more extensive habitat.

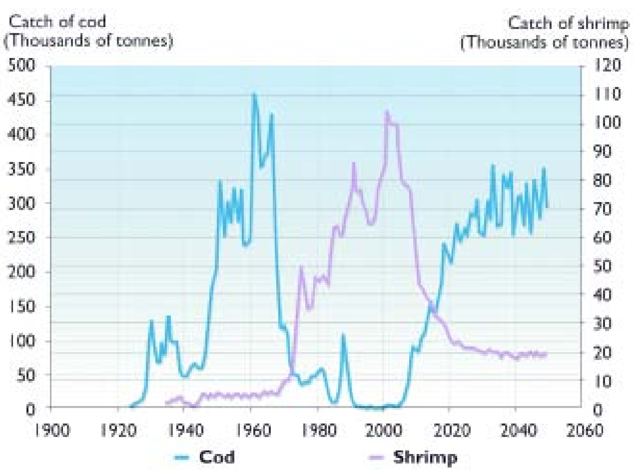
Greenlandic Cod and Climate

A striking example of a positive climate-related impact involves West Greenland cod. Under the very cold conditions between around 1900 and 1920, there were few cod around Greenland. In 1922 and 1924, large numbers of cod were spawned in Icelandic waters and drifted from Iceland to East Greenland and then to West Greenland where they flourished, resulting in the start of a significant fishery beginning in the mid- to late 1920s. Large numbers of these cod returned to Iceland to spawn in the early 1930s and then remained there. However, many other cod stayed and spawned off West Greenland, giving rise to an independent, self-sustaining cod stock. During the warm period that spanned the middle of the 20th century, the Greenland cod stock grew very large, sustaining an annual average catch of about 315 000 tonnes between 1951 and 1970. The cold conditions that have prevailed since about 1965 appear to have rendered cod incapable of reproducing in Greenlandic waters. The only significant catches since then have been based on fish born in Icelandic waters in 1973 and 1983 that drifted to Greenland from Iceland.

While projected conditions are likely to benefit some species, such as cod, they are likely to negatively affect others, such as northern shrimp, necessitating adjustments in commercial fishery operations. The area inhabited by some arctic species, including northern shrimp, will probably contract and the abundance of those species decrease. This would reduce the large catch (about 100 000 tonnes a year) of northern shrimp

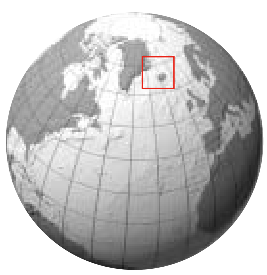
While projected conditions are likely to benefit some species, such as cod, they are likely to negatively affect others, such as northern shrimp, necessitating adjustments in commercial fishery operations.

Observed and Projected Harvests



Past and potential future development of cod and shrimp harvest off Greenland with climate change.

Mixing Waters and Fish Drift Routes



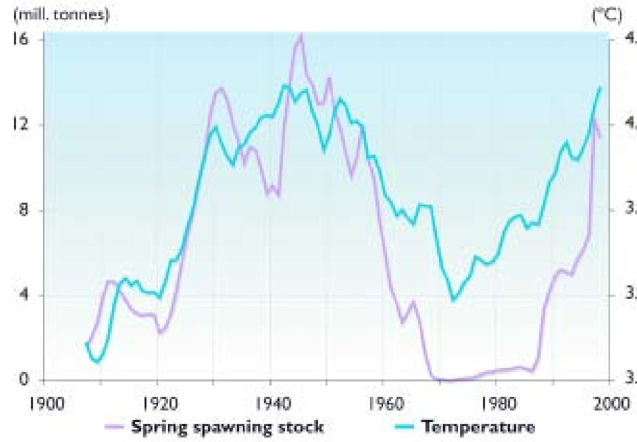
The main water masses in the Iceland-East Greenland-Jan Mayen areas. The red arrows indicate the main drift routes of larvae and fish less than one year old.

currently taken from Greenlandic waters. Furthermore, northern shrimp are an important part of the diet of cod in the waters off Greenland. Thus, if the cod stock were to grow as it did in the last century, the decline in the northern shrimp population could negatively affect the diet and growth of the cod stock. Because the commercial value of a healthy cod stock would be much greater than the value of the shrimp catch, the shrimp fishery would have to be curtailed even further.

Climate, Overfishing, and Norwegian Herring

In the early 1950s, the stock of Norwegian spring-spawning herring was as large as 14 million tonnes, the world's largest herring stock, and was important to Norway, Iceland, Russia, and the Faroe Islands. At that time, these herring migrated west across the Norwegian Sea to feed in the zooplankton-rich waters north and east of Iceland as well as in the oceanic area between Iceland and the island of Jan Mayen (71˚N, 8˚W). In 1965, a sudden and severe cooling of these waters resulted in the decimation of the tiny crustacean (*Calanus finmarchicus*) that was by far the most important single food item in the diet of these herring. The herring's feeding areas were displaced to the east and northeast by several hundred nautical miles, thus placing the stock under severe environmental stress. In the 1960s, the stock was also subjected to severe overfishing and collapsed during the latter half of the decade. Although high fishing intensity of both adults and juveniles was the primary reason for the collapse, the climatic cooling probably contributed to the decline.

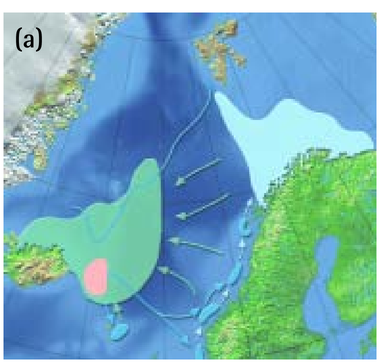
Herring Spawning Stock and Temperature



Norwegian spring spawning herring stocks increased greatly during the warming period of the 1920s-1930s and then declined rapidly beginning in the late 1950s. Overfishing was the primary cause of the collapse of the population, although climatic cooling was probably a contributing factor.

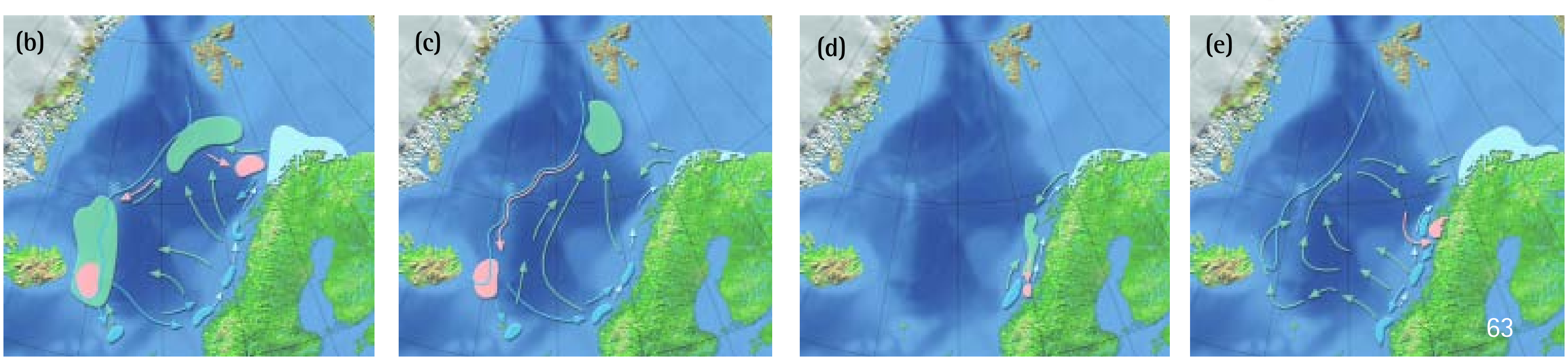
In the 1970s, the small numbers of herring that were left did not need to search far to feed and thus stayed close to the Norwegian shore. What was left of the fishery was strictly regulated, and fishing was prohibited for several years. These restrictions, coupled with favorable climatic conditions, contributed to the stock's increase to three to four million tonnes and limited fishing began again. In 1995, the stock reached five million tonnes and extended its feeding grounds and migratory range into international waters. The stock therefore became available for fishing outside Norway's jurisdiction, making the Norwegian management regime insufficient to protect the stock and threatening its continued recovery. In 1996, an agreement was reached between Norway, Russia, Iceland, the Faroe Islands, and the European Union to set quotas for allowable catches of Norwegian spring spawning herring. Such agreements will be crucial in the future as climate change alters fish stocks and their ranges.

Historic Changes in Migration Routes



Changes of migration routes, and feeding and wintering areas of Norwegian spring spawning herring during the latter half of the 20th century. (a) Normal migration pattern during the warm period before 1965. (b-c) After a pulse of sea ice and freshwater from the Arctic sent cold, low-salinity water into the East Greenland and the East Icelandic currents, until the stock collapsed in 1968. (d) During years of low stock abundance (1972-1986). (e) The present day migration pattern.

Spawning areas
Juvenile areas
Main feeding areas
Spawning migrations
Feeding migrations
Spawning migrations



4 Animal species' diversity, ranges, and distrubution will change.

Climate Shifts and Fisheries Impacts

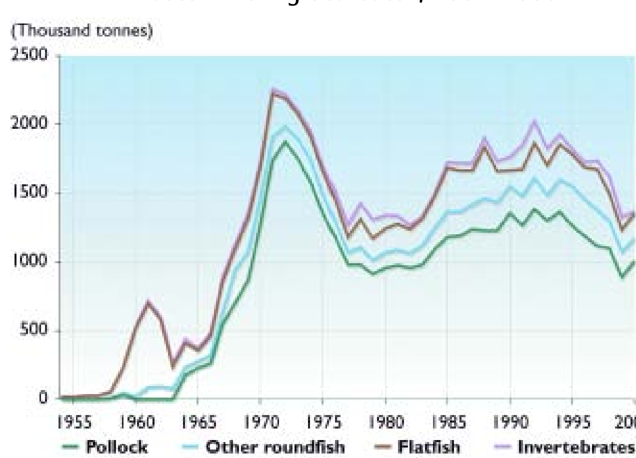
A climate shift occurred in the Bering Sea in 1977, abruptly changing from a cool to a warm period, perhaps a reflection of the Pacific Decadal Oscillation. The warming brought about ecosystem shifts that favored herring stocks and enhanced productivity for Pacific cod, skates, flatfish, and non-crustacean invertebrates. The species composition of living things on the ocean floor changed from being crab-dominated to a more diverse mix of starfish, sponges, and other life forms. Historically high commercial catches of Pacific salmon occurred. The Walleye pollock catch, which was at low levels in the 1960s and 1970s (two to six million tonnes), has increased to levels greater than ten million tonnes for most of the years since 1980.

The Bering Sea is experiencing a major warming in bottom water temperature that is forcing cold-water species of fish and mammals northward and/or into decline.

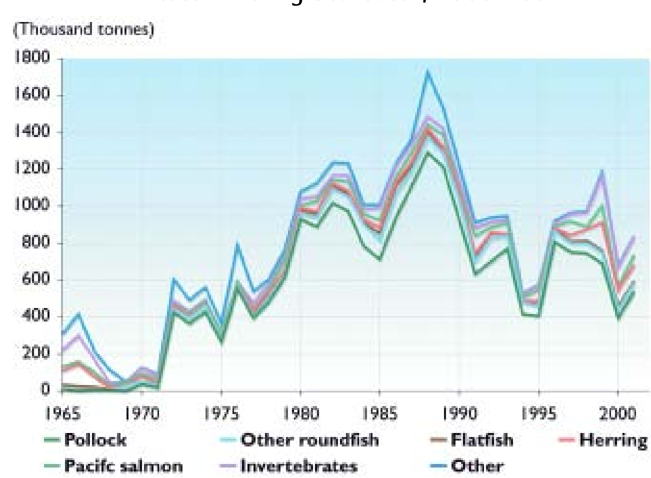
For most of the North Atlantic, the total effect of climate change on arctic and sub-arctic fish stocks is likely to be of lesser magnitude than the effects of fisheries management, at least for the next two to three decades. This is mainly due to the relatively small warming expected for the first part of the 21st century in this area. In the Bering Sea, however, rapid climate change is already apparent, and its impacts significant. The Bering Sea is experiencing a major warming in bottom water temperature that is forcing cold-water species of fish and mammals northward and/or into decline. The first concern of Bering Sea fisheries management is thus likely to be managing for the ecosystem reorganization that is and will continue to be taking place as a result of climate change.

While it seems unlikely that climate change effects on fisheries will have long-term arctic-wide social and economic impacts, certain areas that are heavily dependent on fisheries are likely to be affected. Very severe dislocations are possible and have occurred historically. For example, when the Labrador/Newfoundland cod fishery collapsed due to overfishing, shifts in oceanic conditions, and other factors in the early 1990s, many cod fishermen went out of business or switched to other species, and the value of the fish catch in the province declined sharply. The cod stock has still not recovered, although a decade has passed. The shrimp and crab fisheries that eventually replaced the cod fishery are much less labor intensive and employ far fewer people, although the total commercial value of the fishery is about twice the value of the cod fishery. So while the fishing industry can generally adapt at the national level, particular people and places can be strongly affected.

Eastern Bering Sea Catch, 1954-2000



Western Bering Sea Catch, 1965-2001

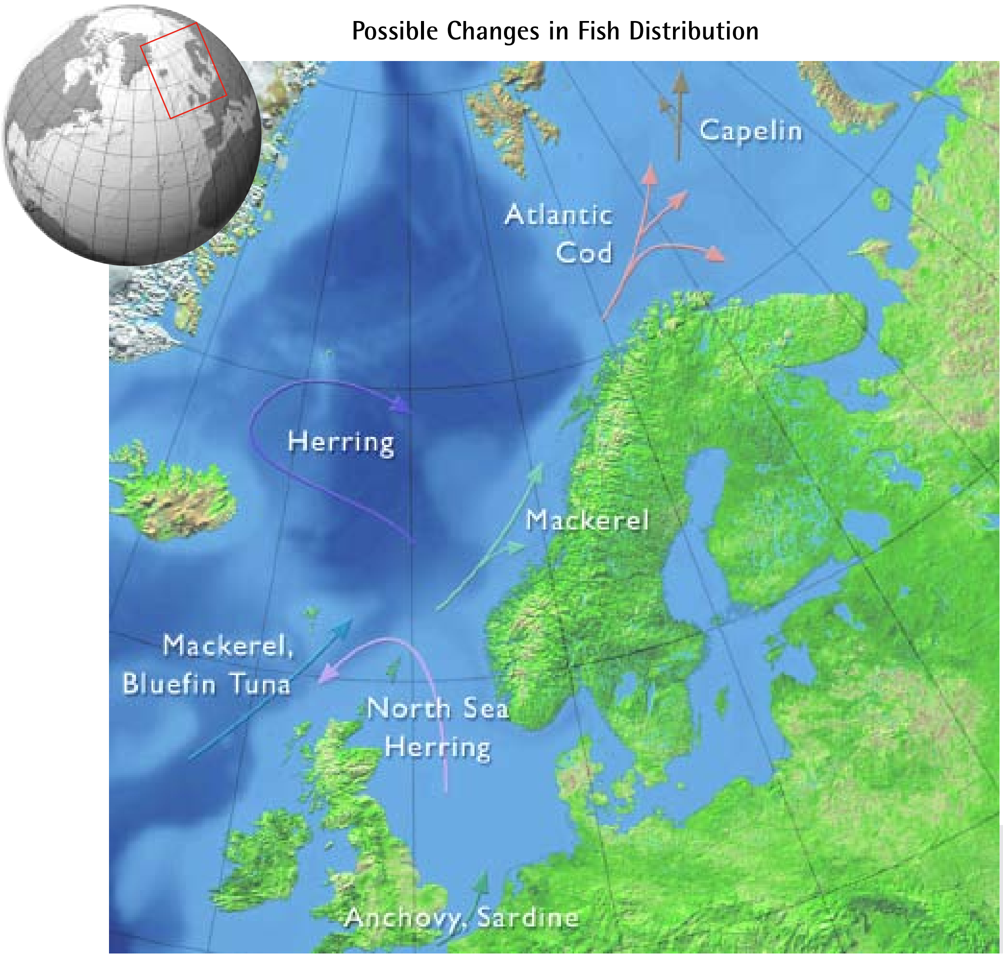


Seal Hunting, Fishing, and Climate Change in West Greenland: A Historical Perspective

Historical changes in West Greenland provide a good example of the relationship between climate change and associated social and economic changes. A climatic variation resulted in warming of the waters to the south and west of Greenland in the 1920s and 1930s, causing seal populations to shift northward, making seal hunting more difficult for the local Inuit. At the same time, cod (as well as halibut and shrimp) moved into the warmer waters, enabling the development of a cod fishery. Some local people, such as those in the west coast town of Sisimiut, were able to take advantage of the opportunities that arose due to social and technological factors. Sisimiut became an important fishing center with other new industries and a diverse economic base.

This stands in contrast to the development of the southwest Greenlandic town of Paamiut around the same time. Paamiut's development was based largely on plentiful resources of cod. With few other resources available in commercially viable quantities, there was little incentive to diversify the local economy. The concentration on a single resource made the town vulnerable to environmental change. When the cod population began to fall, due to a combination of climatic change and overfishing, the economy and population of Paamiut declined as a result. This points to the importance of recognizing in any adaptive strategy that local conditions (environmental, social, economic, technological, etc.) are important factors in determining the success of a region subject to change.

Possible Changes in Fish Distribution



Possible changes in the distribution of selected fish species the Norwegian and Barents Seas resulting from an increase in ocean temperature of 1 to 2˚C.

Key Finding #4

4 Animal species' diversity, ranges, and distrubution will change.

Aquaculture

Salmon and trout are the two major aquaculture species in the Arctic, farmed by a high tech industry employing advanced equipment, in many ways more akin to pig or poultry farming than to fishing. Norway has developed a large industry over the past two decades and is now the world's largest farmed salmon producer. Total production in 2000 was valued at 1.6 billion US dollars, making salmon the single most important species in terms of economic value in the Norwegian fishing industry.

If the Atlantic waters that run north along the coast of Norway warm by a couple of degrees, aquaculture operations would probably have to shift northward, incurring significant costs.

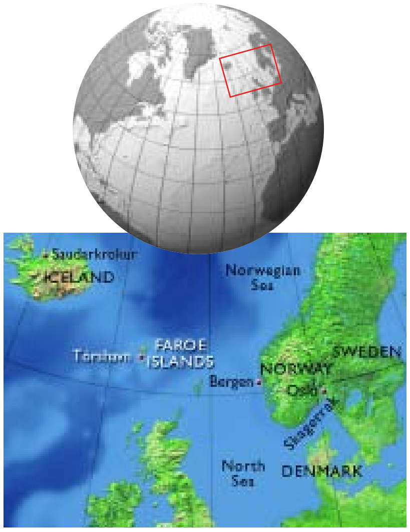
Slightly warmer water might be expected to increase fish growth rates but any more than slight warming could exceed the temperature tolerances of farmed species. In addition, warmer waters would have other negative effects, such as an increase in diseases and toxic algal blooms. If the Atlantic waters that run north along the coast of Norway warm by a couple of degrees, aquaculture operations would probably have to shift northward, incurring significant costs. Aquaculture in marine systems off Newfoundland and Labrador is problematic due to their latitudes. It is not uncommon for the temperature in the upper water layers to rise above the tolerance of many of the species currently cultivated.

The aquaculture industry depends on a huge supply of wild fish captured from the open ocean to provide the fishmeal and oils that are important dietary components of farmed fish such as salmon and trout. The quantity of supplies needed is so high that the industry is sensitive to rapid fluctuations in important wild fish stocks, and such fluctuations can be brought about by climatic factors. For example, El Niño events in the Pacific Ocean have already affected the industry through huge impacts on anchovy stocks. From 1997 to 1998, the global anchovy fishery was reduced by nearly eight million tonnes, mainly due to El Niño. Furthermore, many species now harvested elsewhere to provide fodder for farmed fish are also highly important in the diet of wild stocks that are of much greater commercial value but which are presently not abundant

due to overfishing. Should fisheries managers succeed in enlarging these wild stocks, large reductions might be needed in the fish farming operations that currently turn these important prey species into fishmeal and oil.

Aquaculture in the Faroe Islands

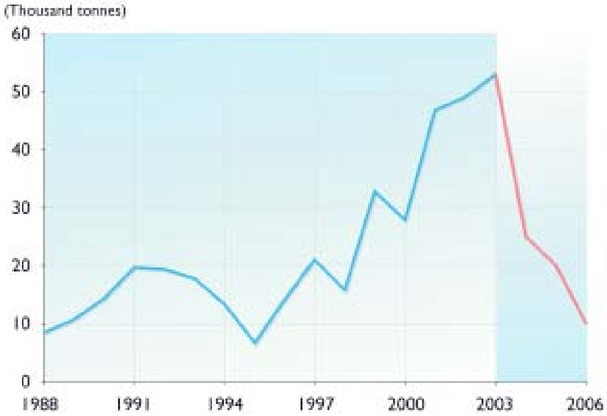
The ocean surrounding the Faroe Islands is part of the most important feeding grounds for wild stocks of northern European Atlantic salmon. The islands of this archipelago are loosely clustered, and have short fjords and inlets, creating a relatively open area with pronounced ocean currents that prevent water stagnation. This offers good conditions for farming Atlantic salmon and rainbow trout, by far the most prominent farmed species. In the 1980s, fish farming became an industry in the Faroe Islands, with annual production reaching about 8000 tonnes by 1988. In the early-to-mid 1990s, the industry collapsed because the numerous small fish farms could not survive the large drop in the market price of farmed salmon. Fish diseases also played a role in the collapse. Production increased again in the late 1990s, and in 2001, Faroese fish farming was consolidated into a few large companies that now operate at 23 sites. There is now a fish farm in nearly every suitable bay and fjord in the archipelago.



The Faroe Islands have become an important international player in salmon farming, harvesting a record 53 000 tonnes (gutted weight) of salmon and rainbow trout, valued at about 180 million US dollars in 2003. With a population of approximately 45 000 people, this corresponds to a production of almost 1200 kilograms of farmed fish per person. More than 300 people are directly employed on Faroese fish farms. In addition, a work force of 1000 is employed in processing and transporting fish, manufacturing fish food, and other related industries. In recent years, aquaculture has become of greater importance to the Faroese economy than in any other country. In 2001-2003, fish farming products constituted approximately 25% of total earnings from exported goods. Wild marine fisheries products constitute the only other major export, accounting for approximately 70% of the earnings from exported goods.

However, aquaculture faces growing problems. Financial strains are increasing due to salmon diseases and the large reduction in market prices. Some untreatable diseases, notably infectious salmon anemia and bacterial kidney disease, occur with unusual frequency in the Faroe Islands. The industry needs an influx of capital if they are to continue the high level of production of recent years and the problems with diseases and low market prices make such an influx unlikely. It has thus been predicted that production during 2004-2006 will drop as shown in the figure. A warming climate can have both positive and negative effects. If warming does not exceed about 5°C, fish growth rates and the length of the growing season are expected to increase. Greater increases in temperature could exceed the thermal tolerance of the fish. Warming also tends to increase incidence of fish diseases and toxic algal blooms.

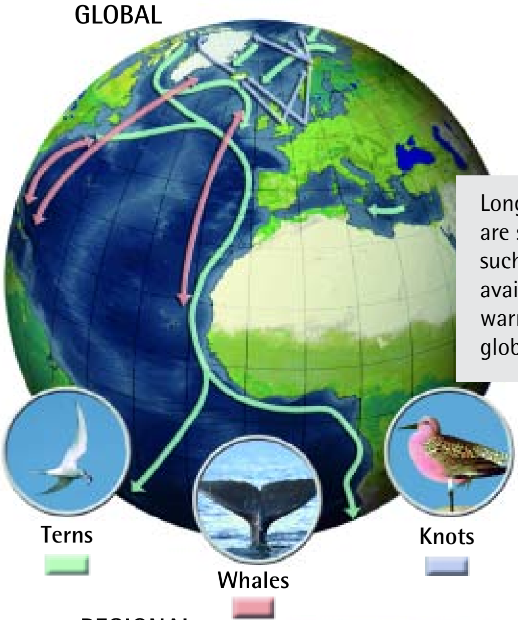
Possible Changes in Faroe Island Aquaculture Production



The production of farmed Atlantic salmon and rainbow trout 1988-2003. The red line is a projection for 2004-2006. The projected decrease reflects problems caused by fish diseases and economic issues. Climate change adds additional uncertainties.

4 Animal species' diversity, ranges, and distrubution will change.

GLOBAL



Long-distance animal migration routes are sensitive to climate-related changes such as alterations in habitat and food availability. The amplification of warming in the Arctic thus has global implications for wildlife.

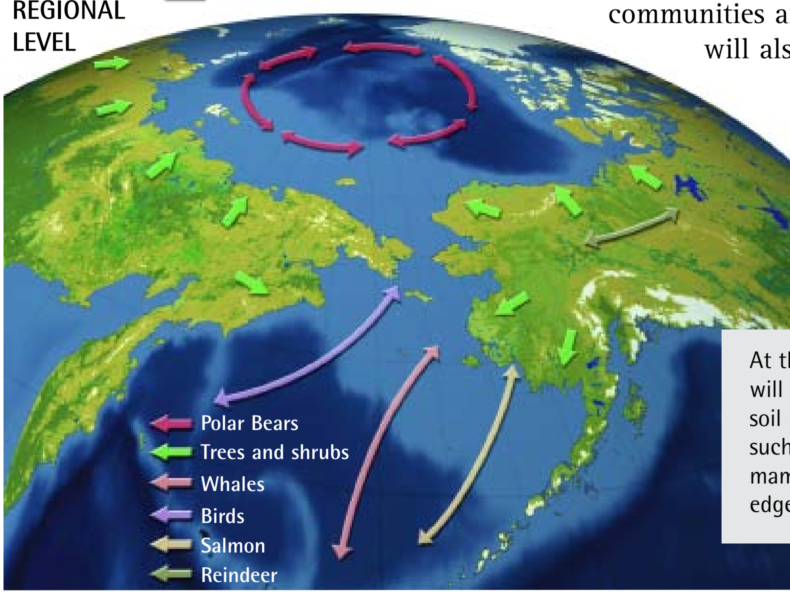
Animal Species on Land

Arctic animals on land include small plant-eaters like ground squirrels, hares, lemmings, and voles; large plant-eaters like moose, caribou/reindeer, and musk ox; and meat-eaters like weasels, wolverine, wolf, fox, bear, and birds of prey.

Climate-related changes are likely to cause cascading impacts involving many species of plants and animals. Compared to ecosystems in warmer regions, arctic systems generally have fewer species filling similar roles. Thus when arctic species are displaced, there can be important implications for species that depend upon them. For example, mosses and lichens are particularly vulnerable to warming. Because these plants form the base of important food chains, providing primary winter food sources for reindeer/caribou and other species, their decline will have far-reaching impacts throughout the ecosystem. A decline in reindeer and caribou populations will affect species that hunt them (including wolves, wolverines, and people) as well as species that scavenge on them (such as arctic foxes and various birds). Because some local communities are particularly dependent on reindeer/caribou, their well-being will also be affected.

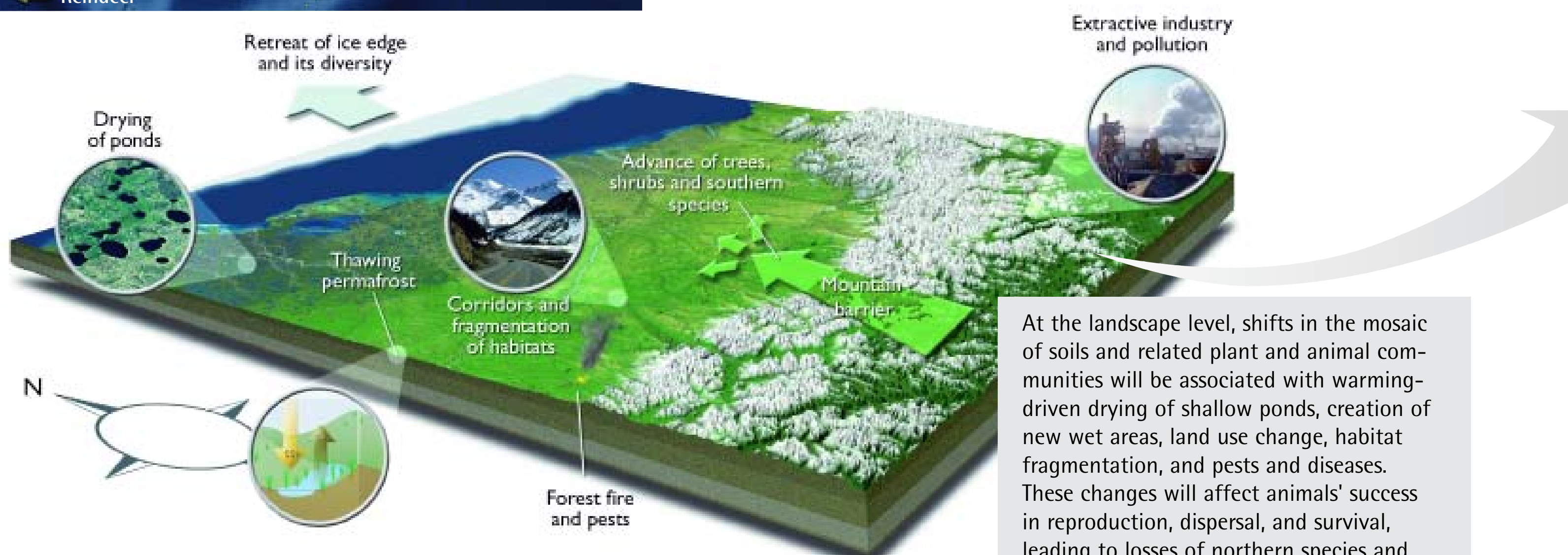
Ice crust formation resulting from freeze-thaw events affects most arctic land animals by encapsulating their food plants in ice, severely limiting forage availability and sometimes killing the plants. Lemmings, musk ox, and

REGIONAL LEVEL



At the regional level, vegetation and the animals associated with it will shift in response to warming, thawing permafrost, and changes in soil moisture and land use. Range shifts will be limited by geographical barriers such as mountains and bodies of water. Shifts in plankton, fish, and marine mammals and seabirds, particularly those associated with the retreating ice edge, will result from changes in air and ocean temperatures and winds.

LANDSCAPE LEVEL

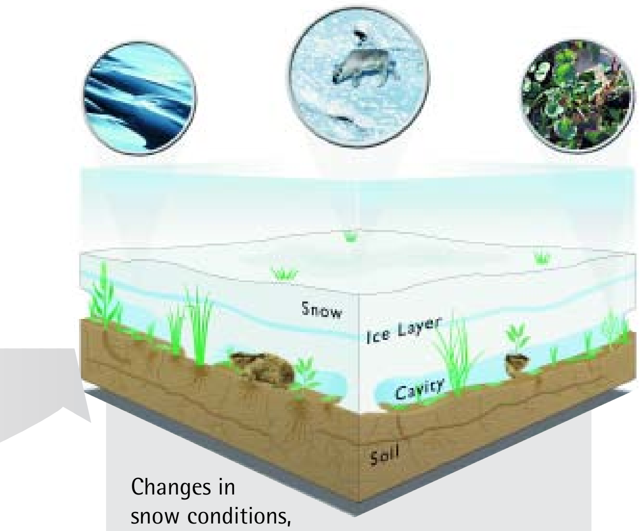


At the landscape level, shifts in the mosaic of soils and related plant and animal communities will be associated with warming-driven drying of shallow ponds, creation of new wet areas, land use change, habitat fragmentation, and pests and diseases. These changes will affect animals' success in reproduction, dispersal, and survival, leading to losses of northern species and range extensions of southern species.

reindeer/caribou are all affected, and dramatic population crashes resulting from ice crusting due to freeze-thaw events have been reported and their frequency appears to have increased over recent decades. The projected winter temperature increase of over 6˚C by late this century (average of the five ACIA model projections) could result in an increase in alternating periods of melting and freezing. Inuit of Nunavut, Canada report that caribou numbers decrease in years when there are many freeze-thaw cycles. Swedish Saami note that over the last decade, autumn snow lies on unfrozen ground rather than on frozen ground in summer grazing areas and this results in rotten and poor quality spring vegetation.

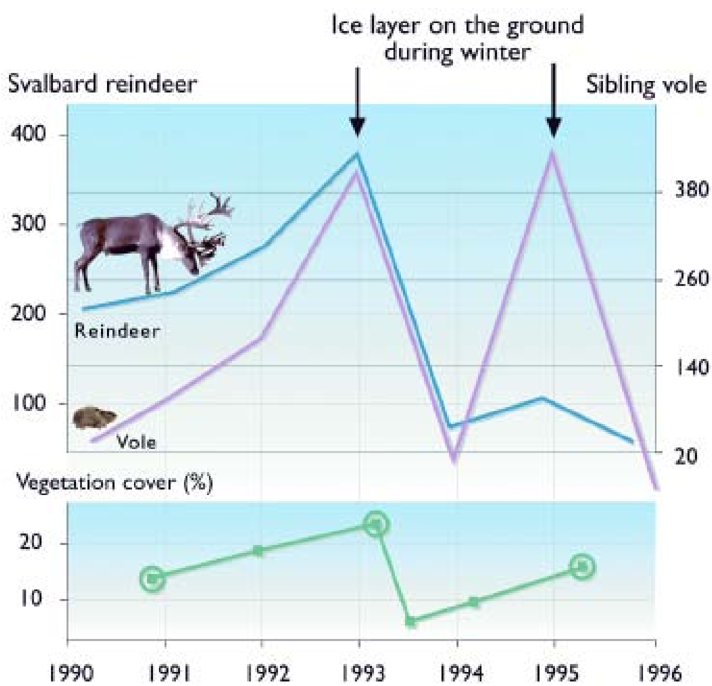
Warming leads to other cascading impacts on arctic land animals. In winter, lemmings and voles live and forage in the space between the frozen ground of the tundra and the snow, almost never appearing on the surface. The snow provides critical insulation. Mild weather and wet snow lead to the collapse of these under-snow spaces, destroying the burrows of voles and lemmings, while ice crust formation reduces the insulating properties of the snow pack vital to their survival. Well-established population cycles of lemmings and voles are no longer seen in some areas. Declines in populations of these animals can lead to declines in the populations of their predators, particularly those predators that specialize in preying on lemmings, such as snowy owls, skuas, weasels, and ermine. A decline in lemming populations would be very likely to result in an even stronger decline in populations of these specialist predators. More generalist predators, such as the arctic fox, switch to other prey species when lemming populations are low. Thus, a decline in lemmings can also indirectly result in a decline in populations of other prey species such as waders and other birds.

PLOT LEVEL



Changes in snow conditions, ice layers, the cavity beneath the snow, summer temperatures, and nutrient cycling act on individual plants, animals, and soil microorganisms leading to changes in populations. It is at the level of the individual animal and plant where responses to the climate take place leading to vegetation shifts across the earth.

Cascading Impacts in a Changing Climate



Population dynamics (number of individuals in a particular area) of Svalbard reindeer and sibling voles on Svalbard, along with observed (circles) and projected (squares) changes in vegetation.

4 Animal species' diversity, ranges, and distrubution will change.

"During autumn times, the weather fluctuates so much, there is rain and mild weather. This ruins the lichen access for the reindeer. In some years this has caused massive loss of reindeers. It is very simple - when the bottom layer freezes, reindeer cannot access the lichen. This is extremely different from the previous years. This is one of the reasons why there is less lichen. The reindeer has to claw to force the lichen out and the whole plant comes, complete with roots [bases]. It takes extremely long for a lichen to regenerate when you remove the roots of the lichen."

Heikki Hirvasvuopio
Kakslauttanen, Finland

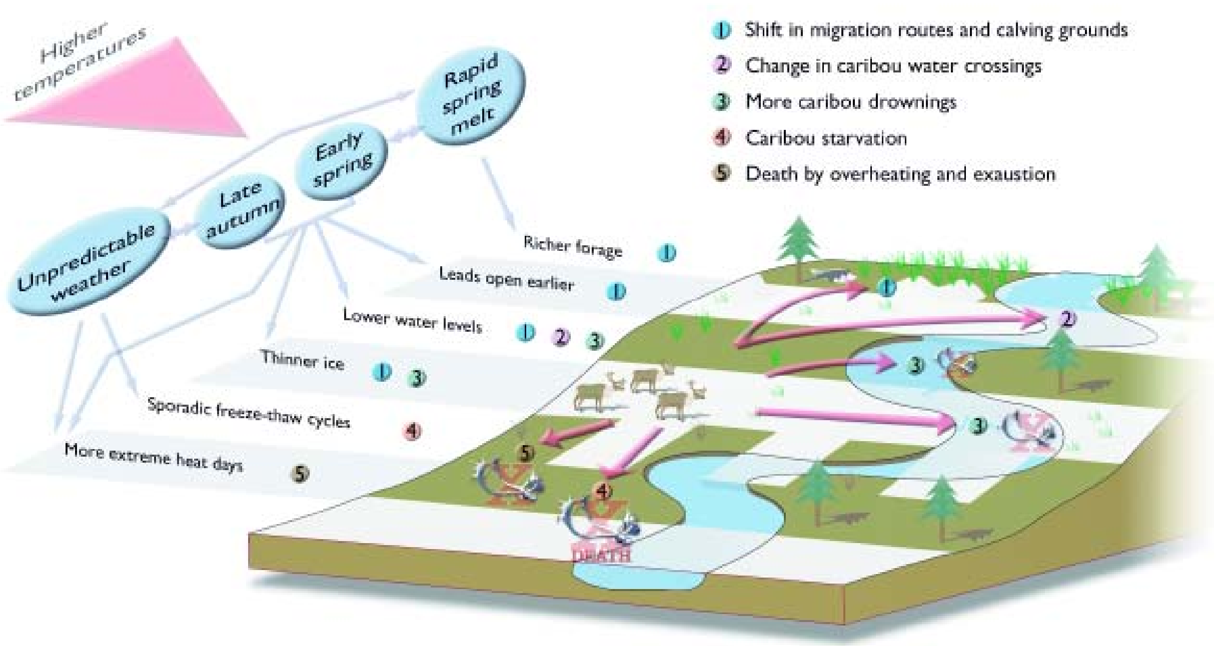
Caribou/Reindeer

Caribou (North American forms of *Rangifer tarandus*) and reindeer (Eurasian forms of the same species) are of primary importance to people throughout the Arctic for food, shelter, fuel, tools, and other cultural items. Caribou and reindeer herds depend on the availability of abundant tundra vegetation and good foraging conditions, especially during the calving season. Climate-induced changes to arctic tundra are projected to cause vegetation zones to shift significantly northward, reducing the area of tundra and the traditional forage for these herds. Freeze-thaw cycles and freezing rain are also projected to increase. These changes will have significant implications for the ability of caribou and reindeer populations to find food and raise calves. Future climate change could thus mean a potential decline in caribou and reindeer populations, threatening human nutrition for many indigenous households and a whole way of life for some arctic communities.

Peary Caribou

The present reduced state of Peary caribou (a small, white sub-species found only in West Greenland and Canada's arctic islands) is serious enough that a number of communities have limited and even banned their subsistence harvests of the species. The number of Peary caribou on Canada's arctic islands dropped from 26 000 in 1961 to 1000 by 1997, causing the sub-species to be classified as endangered in 1991. The decline of Peary caribou appears to have been caused by autumn rains that iced the winter food supply and crusted the snow cover, limiting access to forage. Also, annual snowfall in the western Canadian Arctic increased during the 1990s and the three heaviest snowfall winters coincided with Peary caribou numbers on Bathurst Island dropping from 3000 to an estimated 75 between 1994 and 1997.

Kitikmeot Inuit Observations of Impacts of Warming on Caribou

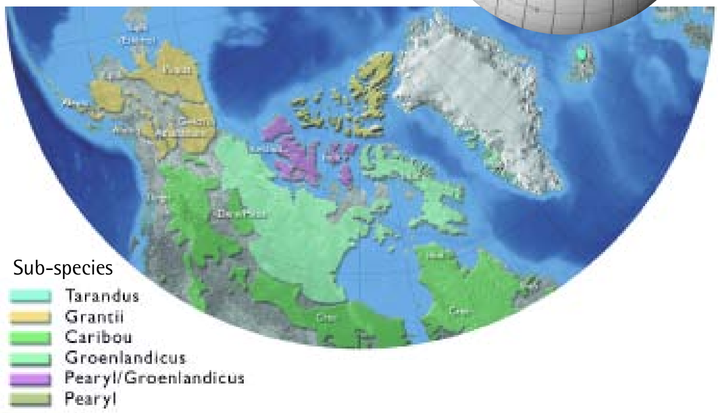


The Porcupine Caribou Herd

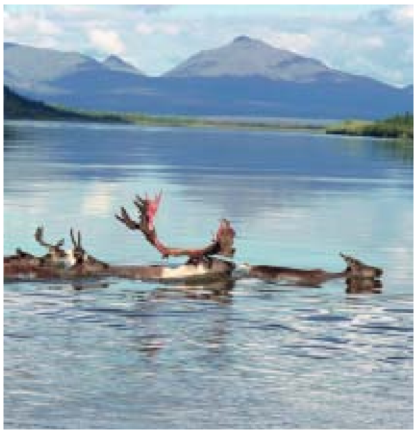
The Porcupine Caribou Herd is one of approximately 184 wild herds of caribou globally, the eighth largest herd in North America, and the largest migratory herd of mammals shared between the United States and Canada. The Porcupine Herd has been monitored periodically since the early 1970s. The population grew at about 4% per year from the initial censuses to a high of 178 000 animals in 1989. During the same period, the populations of all major herds increased throughout North America, suggesting that they were responding to continental-scale events, presumably climate-related. Since 1989, the herd has declined at 3.5% per year to a low of 123 000 animals in 2001. The Porcupine Caribou Herd appears to be more sensitive to the effects of climate change than other large herds.

The ecosystem defined by the range of the Porcupine Herd includes human communities, most of which depend on harvesting caribou for subsistence. Among these are the Gwich'in, Iñupiat, Inuvialuit, Han, and Northern Tuchone whose relationships with this herd have persisted over many millennia. Historically, caribou have served as a critical resource, allowing northern indigenous people to survive the hardships of the severe arctic and sub-arctic conditions. Times of caribou scarcity were often accompanied by great human hardship. Records and oral accounts suggest that periods of caribou scarcity in North America coincided with periods of climatic change.

Caribou Ranges and Indigenous Peoples of North America

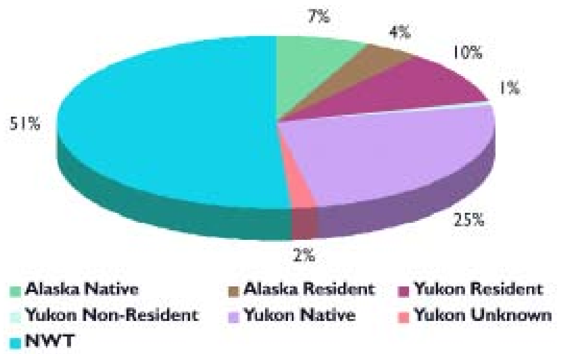


Today, caribou remain an important component of the mixed subsistence-cash economy, while also enduring as a central feature of the mythology, spirituality, and cultural identity of Indigenous Peoples. The harvesting of the Porcupine Caribou Herd varies from year to year, depending on the distribution of animals, communities' access to them, and community need. The total annual harvest from this herd typically ranges from approximately 3000 to 7000 caribou. Responsibility for management of the herd and protection of its critical habitat is shared in Canada between those who harvest the caribou (mostly Indigenous Peoples) and the government agencies with legal management authority.



Key Finding #4

Harvest of Porcupine Caribou Herd by User Group



This chart apportions annual average harvest of the Porcupine Caribou Herd in northwestern Canada and northeastern Alaska by user group. Approximately 89% of the harvest is taken in Canada, and more than 90% of the total harvest is taken by indigenous communities.

4 Animal species' diversity, ranges, and distrubution will change.

The Gwich'in and the Porcupine Caribou Herd

The Gwich'in have been living in close relationship with the Porcupine Caribou Herd for thousands of years. Gwich'in communities are named for the rivers, lakes, and other aspects of the land with which they are associated. The Vuntut (lake) Gwich'in of Old Crow (population 300) in Canada's Yukon, are located in the center of the Porcupine Caribou Herd's range, providing opportunities to intercept caribou during both their autumn and spring migrations. Average harvest of caribou is as high as five animals per person per year. Sharing among households in the community and with neighboring communities is an important cultural tradition and is also believed to help ensure future hunting success.

"If I were a caribou, I'd be pretty confused right now."

Stephen Mills
Old Crow, Canada

Climate-related factors influence the health of the animals and the herd's seasonal and annual distribution and movement. Climate-related factors also affect hunters' access to hunting grounds, for example, through changes in the timing of freeze-up and break-up of river ice and the depth of snow cover.

Every spring for many generations, the Porcupine Caribou Herd has crossed the frozen Porcupine River to its calving grounds in the Arctic National Wildlife Refuge in Alaska. In recent years, the herd has been delayed on its northern migration as deeper snows and increasing freeze-thaw cycles make their food less accessible, increase feeding and travel time, and generally reduce the health of the herd. At the same time, river ice is thawing earlier in the spring. Now when the herd reaches the river, the river is no longer frozen. Some cows have already calved on the south side and have to cross the rushing water with their newborn calves. Thousands of calves have been washed down the river and died, leaving their mothers to proceed without them to the calving grounds.

Potential Climate Change Impacts on the Porcupine Caribou Herd

Climate Change Condition	Impact on Habitat	Impact on Movement	Impact on Body Condition	Impact on Productivity	Management Implications
Earlier Snow Melt on Coastal Plain	Higher plant growth rate	Core calving grounds move further north	Cows replenish protein reserves faster	Higher probability of pregnancy	Concern over development on northern portion of present core calving area
		Less use of foothills for calving	Higher calf growth rate		
			Lower predation risk	Higher June calf survival	
Warmer, Drier Summer	Earlier peak biomass	Movement out of Alaska earlier in season	Increased harassment resulting in lower body condition	Lower probability of pregnancy	Protection of insect relief areas important
	Plants harden earlier	More use of coastal zone while in Alaska			
	Reduction in mosquito breeding sites	More dependence on insect relief areas, especially from mid- to late July			
	Significant increase in oestrid activity				
	Greater frequency of fire on winter range				
	Fewer "mushroom" years				
Warmer, Wetter Autumn	More frequent icing conditions	Caribou abandon ranges with severe surface icing	Unknown	Unknown	Protection of low snow regions
Warmer, Wetter Winter	Deeper denser snow	Increased use of low snow regions	Greater over-winter weight loss	Maternal bond broken earlier	
		Later to leave winter range			
Warmer Spring	More freeze / thaw days, snow forms ice layers	Move to windswept slopes	Accelerated weight loss in spring	Higher wolf predation due to use of windswept slopes	Concern over timing and location of spring migration in relation to harvest
	Faster spring melt	Faster spring migration			Lower productivity due to high spring mortality
Overall Effect	Calving range improves, summer, autumn and winter ranges probably lower quality	Seasonal distribution less predictable, timing less predictable	Improved June condition but later summer reduced condition, more rapid weight loss in winter and early spring	High pregnancy rates but overall lower survival and recruitment; Shift mortality later in year (late winter, spring); Herd more likely to decline	Need to assess habitat protection in relation to climate trends
	Extremes (such as very deep snow or very late melt) hard to adapt to				Need to factor climate change impacts on harvest levels
					Need to communicate impacts of climate on harvest patterns and timing
					Need to set up monitoring programs

"Sometimes when they're supposed to show up, they don't show up. Sometimes they show up when they're not supposed to show up... We've got 15 villages in northeast Alaska and north Yukon Territory, and some in Northwest Territory, where the same people are depending on one caribou herd. We're caribou people... and we all depend on that same caribou herd that migrates through our villages."

Sarah James
Arctic Village, Alaska

Key Finding #4

4 Animal species' diversity, ranges, and distrubution will change.

Freshwater Ecosystems

Freshwater ecosystems in the Arctic include rivers, lakes, ponds, and wetlands, their plant and animal inhabitants, and their surroundings. Animal life in these ecosystems includes fish such as salmon, brown and lake trout, Arctic char, cisco, whitefish, and grayling; mammals such as beavers, otters, mink, and muskrats; waterfowl like ducks and geese; and fish-eating birds such as loons, osprey, and bald eagles.

As thawing permafrost and other climate change impacts cause freshwater habitats to disappear, re-form, and be modified, major shifts in species and their use of aquatic habitats are likely.

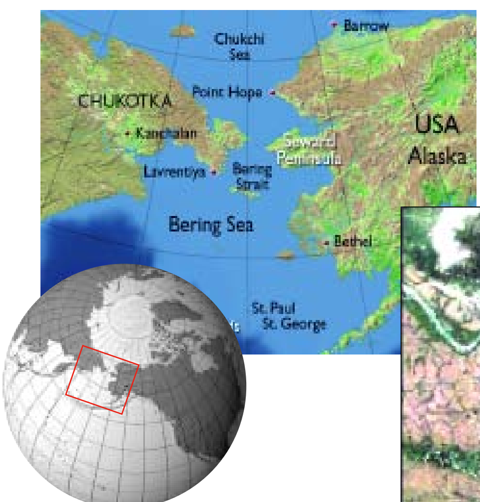
Climate change will directly and indirectly affect these animals and related biodiversity. Many of the effects will result from climate-induced physical and chemical changes to freshwater habitats. Of particular importance are increasing water temperatures and precipitation, thawing of permafrost, reductions in duration and thickness of lake and river ice, changes in the timing and intensity of runoff, and increased flows of contaminants, nutrients, and sediments. Freshwater ecosystems are also important to marine systems because they act as intermediaries between land and ocean systems, transferring inputs received from the land to the marine environment. Some examples of important physical and chemical changes that will affect freshwater ecosystems include increasing water temperatures, thawing permafrost, ice cover changes on rivers and lakes, and increasing levels of contaminants.

Water Temperature Increases

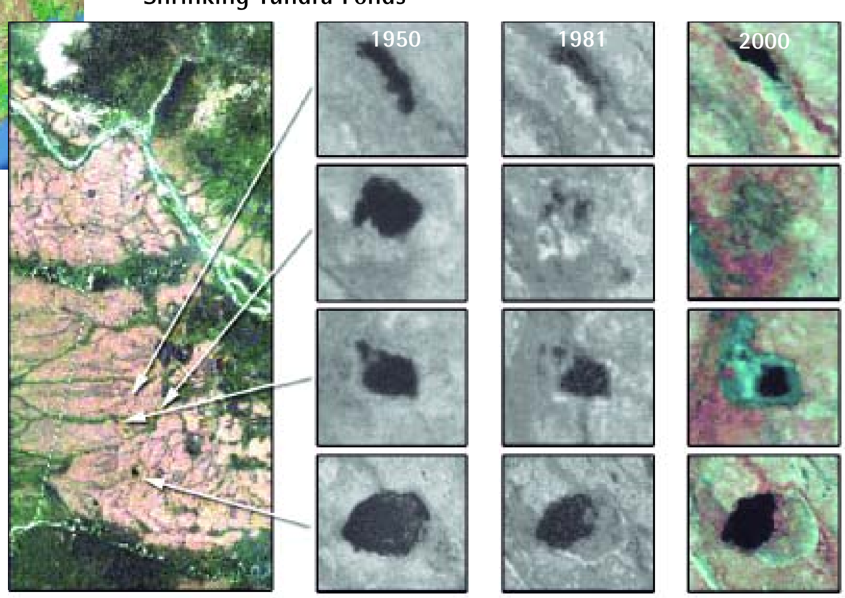
Increases in water temperature are likely to make it impossible for some species to remain in parts of streams and lakes they formerly inhabited. Less than optimum thermal conditions, combined with other possible effects, such as competition from invasive species moving in from the south, may significantly shrink the ranges of some arctic freshwater species, such as the broad whitefish, Arctic char, and Arctic cisco.

Permafrost Thawing

As rising temperatures thaw frozen soils, drainage of water from lakes into groundwater can occur, eventually eliminating the aquatic habitat in the area. On the other hand, collapsing of the ground surface due to permafrost thawing can create depressions where new wetlands and ponds can form, adding to aquatic habitat in these locations. The balance of these changes is not known, but as freshwater habitats disappear, re-form, and are modified, major shifts in species and their use of aquatic habitats are likely.

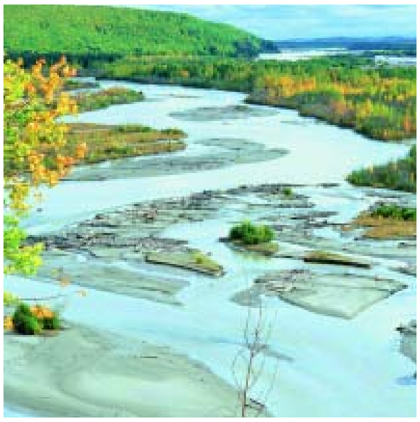


Shrinking Tundra Ponds



The ponds pictured to the left are on Alaska's Seward Peninsula. Of 24 ponds studied in this region, 22 decreased in area between 1951 and 2000. Numerous tundra ponds have decreased in surface area over the last 50 years. A probable mechanism for this shrinkage is internal drainage as shallow permafrost thaws.

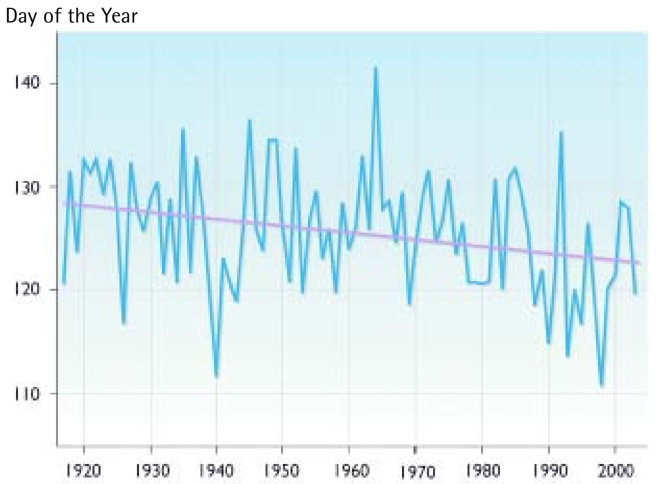
Ice Cover Changes on Rivers and Lakes



Lake and river ecology are strongly affected by ice cover and the timing of the spring melt. Ecological impacts will result from changes in the timing of ice break-up, which strongly affects supplies of nutrients, sediments, and water that are essential to the health of delta and floodplain ecosystems. Changes in ice timing and types also affect water temperature and levels of dissolved oxygen (required by most living things in the system). Changes in species composition and diversity and food web structure are among the expected results of these climate-induced changes. Reduced ice cover will also dramatically increase the exposure and related damage of underwater life forms to ultraviolet radiation.

Later freeze-up and earlier break-up of river and lake ice have combined to reduce the ice season by one to three weeks, depending on location, over the past 100 years. This trend is strongest over the western parts of Eurasia and North America and is projected to continue over the next 100 years, causing a general reduction in ice cover on arctic rivers and lakes, with the greatest reductions projected in the northernmost lands. Freeze-up and break-up dates respond strongly to warming because as ice melts, it results in further warming of the surface, causing more melting, more warming, and so on. Longer ice-free periods are projected to increase evaporation, leading to lower water levels, though this may be countered by the increase in precipitation projected to result from the greater availability of ocean moisture (where sea ice has retreated). These changes will affect whether the northern peatlands will absorb or release the greenhouse gases carbon dioxide and methane. Low flow and flood patterns will change, as will levels of sediments carried by rivers to the Arctic Ocean.

Tanana River Ice Break-up Dates

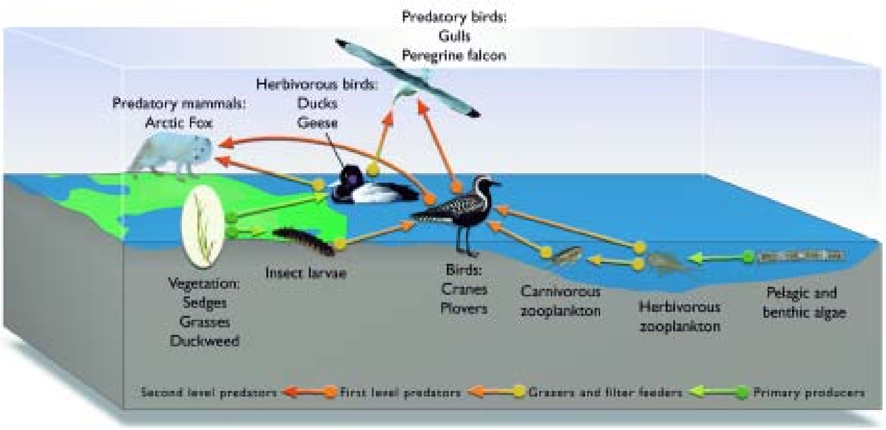


The graph shows the ice break-up dates for the Tanana River at Nenana, Alaska over the last 80 years. Though there is considerable variability from year to year, there is a trend toward earlier break-up by over a week.

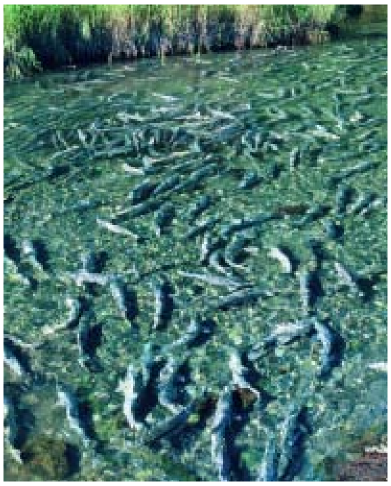
Contaminants

Warming is very likely to accelerate rates of contaminant transfer to the Arctic and increased precipitation is very likely to increase the amount of persistent organic pollutants and mercury that are deposited in the region. As temperatures rise, snow and ice accumulated over years to decades will melt, and the contaminants stored within will be released in melt water. Permafrost thawing may similarly mobilize contaminants. This will increase episodes of high contaminant levels in rivers and ponds that may have toxic effects on aquatic plants and animals and also increase transfer of pollutants to marine areas. These impacts will be amplified by lower water levels as higher temperatures increase evaporation (possibly countered by increasing precipitation in some areas). Increasing contaminant levels in arctic lakes will accumulate in fish and other animals, becoming magnified as they are transferred up the food chain.

Freshwater Food Web



4 Animal species' diversity, ranges, and distrubution will change.



Freshwater Fish

Southernmost species are projected to shift northward, competing with northern species for resources. The broad whitefish, Arctic char, and Arctic cisco are particularly vulnerable to displacement as they are wholly or mostly northern in their distribution. As water temperatures rise, spawning grounds for cold-water species will shift northward and are likely to be diminished. As southerly fish species move northward, they may introduce new parasites and diseases to which arctic fish are not adapted, increasing the risk of death for arctic species. The implications of these changes for both commercial and subsistence fishing in far northern areas are potentially devastating as the most vulnerable species are often the only fishable species present. In some southern mainland areas of the Arctic, new arrivals from the south may also bring new opportunities for fisheries, and increased productivity of some northern fish populations due to higher growth may allow for increased fishing of some species.

Arctic Char

The Arctic char is the northernmost freshwater fish in the world and occurs throughout the Arctic. Some populations are locked in lakes where they feed on midge larvae and grow very slowly. Other populations migrate to the sea in summer where they feed on crustaceans and small fish, and char in these populations grow more quickly. Increasing water temperatures in freshwaters, estuaries, and marine near-shore areas are likely to increase growth of both types of char, especially in the mid-latitudes of their distribution, assuming that there is also a parallel general increase in food chain productivity. This is likely to increase fishing opportunities, but may be offset by the effects of competition from new fish species.

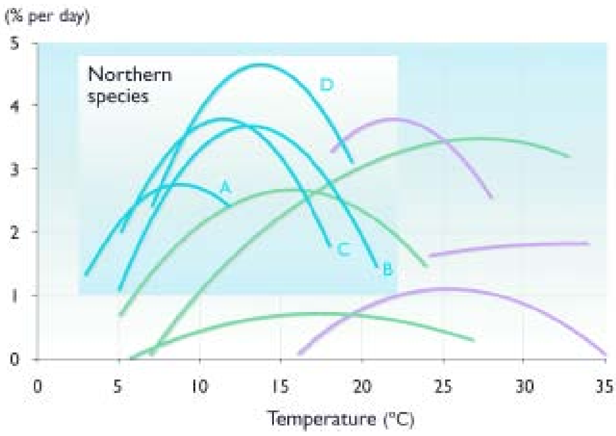
The implications of these changes for both commercial and subsistence fishing in far northern areas are potentially devastating as the most vulnerable species are often the only fishable species present.

Research on Arctic char in Resolute Lake, Canada suggests that rising temperatures cause an increase in respiration, which increases the accumulation of heavy metals in the fish. In addition, other climate-related changes described on the previous page are expected to increase the levels of contaminants in lakes. Furthermore, reduced ice cover in lakes, increased mixing between water layers, and other warming-induced changes are projected to result in lakes retaining more of the contaminants that flow into them.

Arctic Grayling

The Arctic grayling is a stream fish with about a 12-year lifespan. In some northern locations, it is the only species of fish that occupies local streams. In Toolik Lake (a small lake on Alaska's tundra), 25 years of data have been collected on

Fish Growth Rate and Temperature



These growth curves (in percent per day) for various fish species illustrate that growth typically increases with rising temperature up to a certain point and then declines as temperature continues to rise. Northern species (A. Arctic char, B. lake cisco, C. lake trout, and D. brook trout - all in blue) are grouped toward the lower temperatures on the left, and have a more peaked curve, indicating only narrow and typically low temperature ranges over which optimal growth is achieved. This suggests that their ability to adapt to a warming climate is likely to be quite limited. The unlabeled growth curves are for various lower latitude species.

the grayling, tracking each individual fish in the stream. Results indicate that while young grayling do well in warmer water, adults fare poorly, actually losing weight in warm years. Projected climate warming is thus likely to cause the elimination of this population, with no opportunities for other species to naturally come into the lake.

Lake Trout

Long-term studies project that a warmer future will severely stress lake trout, with related impacts on the food web. Impacts on lake trout will be most severe in smaller lakes in the southern part of the trout's range in the Arctic; effects in larger, more northern lakes may be positive, at least in the short-term. Long-term studies in Toolik Lake, Alaska project that a warmer future is likely to result in the elimination of this lake trout population. Research suggests that a 3˚C rise in July surface water temperature could cause first-year lake trout to need to consume eight times more food than is currently necessary just to maintain adequate body condition. This requirement greatly exceeds current food availability in the lake.

Furthermore, the projected future combination of higher temperatures, a longer open-water season, and increased phosphorus in the water (released into streams as permafrost thaws) is expected to increase production of small aquatic life forms that consume oxygen, thereby reducing oxygen concentrations in deeper water to a level below that needed by lake trout (and some other living things), thus reducing the bottom-water habitat. With surface water warming beyond the threshold required for these fish, the trout will be squeezed into a shrinking habitat between the inhospitable conditions near the surface and those at the lake bottom. The loss of the lake trout, the top predator in this system, is likely to have cascading impacts through the food web, with major impacts on both the structure and functioning of the ecosystem.

"New species of plants have arrived. We never saw them before. This is what we have observed. New plants have arrived here and on tundra. Even there are arrival species in the river, previously known in middle parts of Russia. This past summer and the previous were very hot here. Rivers and lakes are filled with small-flowered kind of duckweed, and the lake started to bloom. Life of the fish is more difficult, and likewise people's fishing opportunities, as lakes grow closed up with the new plants."

Larisa Avdeyeva
Lovozero, Russia

Aquatic Mammals and Waterfowl

The distributions of aquatic mammals and waterfowl are likely to expand northward as habitats change with warming. Seasonal migration is also likely to occur earlier in spring and later in autumn if temperatures are warm enough. Breeding ground suitability and access to food will be the primary drivers of changes in migration patterns. For example, wetlands are important breeding and feeding grounds for ducks and geese in spring. As permafrost thaws, more wetlands (formed when previously frozen ground collapses) are likely to appear, promoting the earlier northward migration of southerly wetland species or increasing the abundance and diversity of current high latitude species. However, a parallel earlier timing of the availability of local food must also occur for these outcomes to be realized.

Mammal and bird species moving northward are likely to carry new diseases and parasites that pose new threats to arctic species. Another potential threat from the northward movement of southerly species is that they may out-compete northern species for habitat and resources. Northerly species may have diminished reproductive success as suitable habitat either shifts northward or declines in availability or access.