UNIVERSITY OF THE ARCTIC

Module 12
Arctic Biodiversity in a Global Context

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Key Terms and Concepts

- global connectivity
- cryospheres
- Arctic contribution to global biodiversity
- threats to Arctic biodiversity
- climate change
- risk assessment
- sustainability
- traditional environmental knowledge (TEK)
- conservation
- Arctic Climate Impact Assessment (ACIA)

Learning Objectives

Upon completion of this module, you should be able to

1. identify the main features that distinguish Arctic biodiversity from those in similar environments and in other biomes of the world.
2. assess the causes and relative importance of different threats to biodiversity in the Arctic compared to other regions of the globe.
3. consider the potential effects on biodiversity of different threats and the potential of Arctic biodiversity to resist change.
4. stimulate discussion on the implications for conservation and resource management of the forthcoming publication of the Arctic Climate Impact Assessment (ACIA).

5. encourage discussion on the proper place of the conservation of biodiversity in the wider context of the rights of indigenous peoples and of sustainable development.

Reading Assignments

AMAP (1997), "Petroleum Hydrocarbons," in *Arctic Pollution Issues: A State of the Arctic Environment Report*, [online] http://amap.no/.

CAFF (2001), "Conservation," in *Arctic Flora and Fauna: Status and Conservation*, 96, [online] www.caff.is.

Caulfield (2000), "Political Economy of Renewable Resources in the Arctic," in *The Arctic: Environment, People, Policy*, 485–513.

Nuttall (2000), "Indigenous Peoples' Organisations and Arctic Environmental Co-operation," in *The Arctic: Environment, People, Policy*, 621–637.

Overview

The Arctic is intimately connected to the rest of the world in all its dimensions. It interacts through climate, ocean circulation, animal migration, pollution, industry, and policies**.** In terms of biodiversity, the Arctic supports many unique and highly adapted species. It has some parallels with other cold-dominated regions of the Antarctic and alpine/high mountain areas, but these three regions are distinct in their biogeography.

The Arctic constitutes only 3–4% of global land and 4% of all oceans. For many taxonomic groups on land, the Arctic contributes less than 1% of global species diversity, but some groups are more strongly represented. Their ability to thrive in extreme environments and their genetic diversity are important features for conservation.

The dominant threat to Arctic biodiversity is from climate change—in contrast to other biomes, where land use and pollution are bigger threats. The response of organisms is usually individualistic and is often greatest at the edge of their range with extension northwards. Such movement can compromise the aim of protected areas. Climate change is occurring over much of the Arctic, and more there than in other parts of the world. But change is not uniform, and some areas are experiencing cooler conditions than others. The Arctic Climate Impact

Assessment (ACIA) will be published in 2004 and will provide extensive analysis and predictions.

Other threats to biodiversity include chemical pollutants generated locally and in lower latitudes. Persistent organic pollutants (POPs) are particularly important because of their concentration within food chains. Introduction of species from lower latitudes is increasing through tourism and imports. Human populations in the Arctic have doubled in the last 30 years, causing increased pressures on terrestrial and marine resources. Industrial development and land use has increased and could become more extensive in response to climate change.

Risk assessment is an important tool in assessing potential impacts of various factors in different regions. Environmental protection and nature conservation must now be considered in relation to economic, cultural, and social development. The needs and knowledge of indigenous peoples are being increasingly recognized. It is the balance between all these dimensions that determines sustainable development.

Lecture

Introduction to Global Connectivity

The Arctic is intimately connected to the rest of the world in all its dimensions:

- Ozone depletion in the stratosphere and consequent enhanced ultraviolet radiation result from chemicals transported from temperate industrial areas.
- The North Atlantic Oscillation and the Southern Oscillation take cold air from the Arctic to lower latitudes.
- Oceans of the world are linked through the thermohaline circulation, or global conveyer belt.
- Birds migrate between the Arctic and all the other continents of the world, while sea mammals and fish move between the oceans of the world.
- Industries move materials and people into and out of the Arctic.
- Environmental conditions in the Arctic have important influences on environments elsewhere in the world and vice versa.

Globalization is not a modern phenomenon. Physical and biological processes in the Arctic have always been globally connected—even over geological time. Svalbard was tropical in the Cambrian era, as witnessed by the coal beds and the tropical fossils, and over the last 500 million years gradually drifted northwards to its present position. The different rocks that were laid down in succeeding eras have dramatic influences on the current ecology of Svalbard, as demonstrated by the extensive cliffs that provide nesting sites for massive seabird colonies.

In this module, we examine

1. how Arctic biodiversity compares with that of other cold regions of the world

2. the degree to which the biodiversity of the Arctic contributes to world biodiversity

3. the global changes to which the Arctic contributes and that influence the Arctic environment, biodiversity, and people

4. how the future looks for the Arctic in the context of global sustainability

Arctic, Alpine, and Antarctic Systems

The Arctic is a special place with distinct environmental conditions, ecology, and people. But is it unique? There are similar conditions, with some variations, across the world. Both the Antarctic and the high mountains—or alpine areas—are similarly dominated by their extreme cold environments: these are the "cryospheres" of the world. The comparison between the three biomes highlights some of the fundamental aspects of ecology. Their climates are similar, with low temperatures and short summers resulting in major areas of snow and ice; and they tend to have low species diversity compared with more temperate ecosystems. However, their biogeographies and evolutionary histories are distinct. A comparison of the environments and biology of these three regions provides insights into (1) the terrestrial and aquatic biodiversity and (2) the factors determining the structure and function of the ecosystems. These are the essential bases on which conservation and sustainable development policies are developed. Here is a comparison of the three regions:

- The **Arctic** is fundamentally a sea surrounded by land; it is literally a "medi-terranean." The land virtually encircles the Arctic Ocean and is the northern extremity of the major North American and Eurasian continents. There are very limited connections from the Arctic Ocean to the global oceans, mainly through the Greenland and Norwegian seas to the Atlantic, and the Bering Sea to the Pacific. This circumpolar and southern connectivity has supported land migrations since the end of the last ice age, 10,000–15,000 years ago.
- The **Antarctic** is a land surrounded by sea; it is an island continent. The continent is completely covered by ice. The Antarctic Peninsula and the

small subantarctic islands, such as South Georgia and Macquarie Island, extend into the Antarctic Ocean beyond the Antarctic Circle and have a milder oceanic climate, yet they are still within the July 10°C limit that is often used to identify polar conditions.

- The **alpine** areas are a series of highlands surrounded by lowlands; they are islands in seas of land. The alpine areas are distributed around the world without connection to each other, but each one has continuity with adjacent lowlands that allows continual movement of organisms between upland and lowland. The climate is determined by altitude rather than by latitude.

These three cryospheric regions have only one thing in common, by definition, their **cold climate**. At the core of each is an area of ice and snow—the massive Antarctic ice cap generating the most extreme low temperatures, including the world record low of –89.5°C recorded at the Russian Vostok Station (lat 78°27′S). An important distinguishing feature between the three regions, however, is the **low precipitation** in the Antarctic. Over extensive areas, the "dry valleys" have an annual precipitation around 4.5 cm (rain equivalents), with high winds and little or no lying snow. Higher precipitation, often less than 15cm yr^{-1}, occurs over much of the Antarctic continent; and only in small areas on the peninsula and oceanic islands is precipitation comparable to most other cold regions (40 cm rain equivalents). **Radiation** is another distinction between the three regions. Being at relatively low latitudes, the alpine areas have much longer summers and usually year-round daylight.

The low precipitation and complete ice cover results in another distinctive Antarctic feature: the absence of large rivers running into the Antarctic Ocean. As a result, there is no heat input to the Antarctic Ocean comparable with that of the Arctic, where summer temperatures of the slow-moving inflow may be 10–15°C. About 14% of the world's land area drains into the Arctic Ocean; and many major rivers begin their flow in the mountains of the alpine regions. These great northern rivers—the Pechora, Ob, Yenisei, Lena, Kolyma, Yukon, Mackenzie, and Nelson—also bring about 42,000 km^3 of water annually to Arctic seas, along with about 220 million tonnes of sediment, mainly from tundra soils. The sediment is an important source of fertility for the extensive and productive continental shelf. The minimal sediment input to the Antarctic Ocean may help maintain the stability of the coastal waters.

Biodiversity in these three environments is very distinctive. The extensive cold environment of the Antarctic continent has limited the flora to moss cushions and lichen patches and only two native vascular plants, the grass *Deschampsia antarctica* and the cushion growth of the dicotyledon *Colobanthus quitensis* at Signy Island on the peninsula. The exceptionally mild, oceanic Macquarie Island (lat 54°38′ S, long 159°55′W), with monthly mean temperatures ranging between 3.3 and 7.0°C, has grass heaths, herbfield, and tussock grassland. These very limited floras contrast with the 3,000 higher plants in the Arctic and about 8,000–10,000 in the alpine regions. The relatively high diversity in the Arctic and alpine biomes reflects their wider range of climates and soil conditions. The higher alpine diversity relates to the geographic isolation of individual mountain regions, which restricts species migration between different alpine regions and promotes speciation. At a more local scale in the mountains, the environmental heterogeneity of slopes and the exposure of different geological strata encourages both habitat and species diversity.

Faunal diversity is also distinctive, with a complete lack of native terrestrial mammals in the Antarctic but a diversity of ground-nesting birds, including many flightless species (e.g., penguins), the latter relating to the absence of predators, which, unfortunately, has changed with the accidental introduction of rats. The flightless great auk (*Alca impennis*), which nested on offshore skerries in the Arctic, became extinct on June 4, 1844, owing to human predation. The introduction of rabbits has also resulted in major changes on Macquarie Island, as have reindeer on South Georgia. Clearly, the geographical isolation of the Antarctic has prevented the natural arrival and establishment of mammals, in contrast to the Arctic and alpine areas of the world. The diversity of freshwater species numbers is low in both the Arctic and the Antarctic with, for example, only 11 native fish in the Arctic and none in the Antarctic. This probably results from a combination of geographical isolation and the short time since deglaciation.

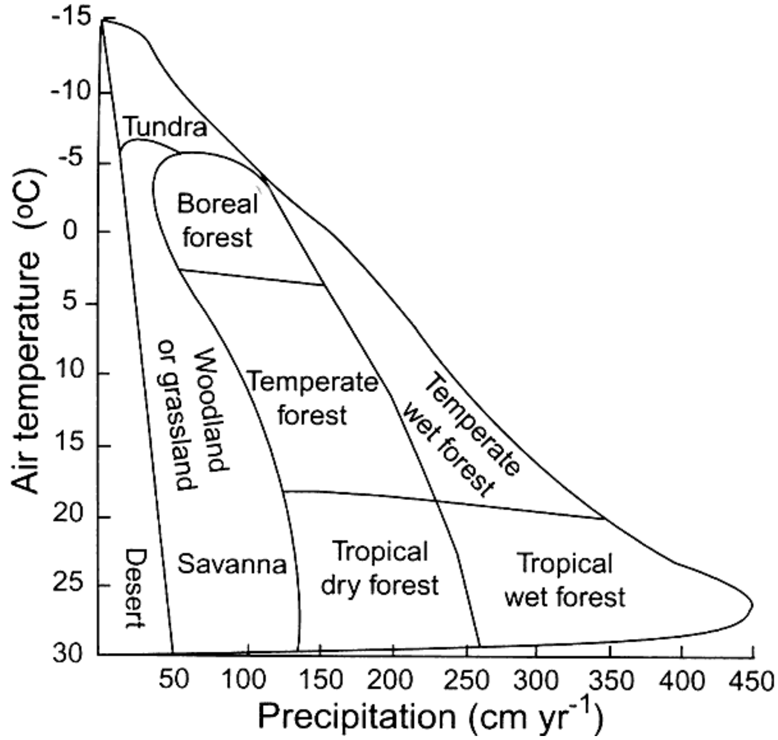
Genetic diversity is widespread across all of the cold-dominated environments, a characteristic that probably relates to the early stage of their evolution relative to the older, more temperate biomes and to the limited species richness, which encourages wide niche breadth. Strategies to overcome the limitations of the extreme environment are broadly consistent across the cryosphere, but there are some variations. For example, antifreeze compounds are more widely distributed in Antarctic than in Arctic fish, and this has been interpreted to relate to the longer phase of evolution in the Antarctic.

The Arctic is not unique in its environment and ecology. The three major cold regions of the world provide a natural experiment that helps to clarify the factors influencing the ecology of cold environments. Comparisons show that species richness and related biological processes are restricted by the low temperatures and short summers associated with increasing latitude and altitude or with ocean circulation patterns. However, other factors—ranging from local precipitation, soil heterogeneity, and nutrient availability to large-scale geographic isolation, geological structure, and evolutionary time—all play a major part in determining the biological patterns and processes. (Chapin and Korner 1995; Fogg 1998)

The Arctic Contribution to Global Biodiversity

The Arctic is known for its low diversity of species. How low compared with the rest of the world? Is it low in all phyla? To what extent is this phenomenon owing to the Arctic climate or to the relatively small size of the Arctic? Is the productivity of the Arctic ecosystems also low compared to other biomes? In exploring these and related questions it is important to recognize that many of the quantitative data are approximations. Most of the biological information comes from localized studies and surveys that have to be extrapolated to large areas; so, these data should be treated with caution, with a focus on general patterns rather than fine details. Similarly, the physical environmental data that are important for comparisons are derived from various sources and have often been calculated from general maps.

Relative to other biomes of the world, the tundra, including both poles, is clearly extreme in its climate. The mean annual temperature and precipitation are the lowest in the world (see fig. 12.1). The cold, dry polar deserts grade into the warm and hot dry deserts of other regions. The area of Arctic tundra is of the order of 5.6 x 10^6 km^2. This is one of the smallest terrestrial biomes and is only 3–4% of the global land surface of about 150 x 10^6 km^2. It generates less than 1% of the global net primary production; but, because of the extensive peat cover in wetlands, it contains about 5% of the global soil carbon (see table 12.1). The Arctic Ocean, covering 14 x 10^6 km^2, is the fourth-largest ocean in the world but is only about 4% of the total ocean. It has an exceptionally wide continental shelf, extending to 900 km off northern Siberia; and the freshwater input is among the largest in the world. Primary production in the Arctic Ocean is extremely patchy and estimates are variable. As on land, some parts of the ocean are barren while others—for example, parts of the Chukchi Sea—are as productive as many temperate seas.



Source: Chapin et al. (2002)

Fig. 12.1 Distribution of the major biomes in relation to mean annual temperature and precipitation

Table 12.1 The global distribution of land area, biomass, and soil carbon; and net primary production (Chapin et al. 2002)

Biome	**Area (10^6 km^2)**	**Total C pool (PgC)**	**Total NPP ($PgCyr^{-1}$)**
Tropical forests	17.5	340	21.9
Temperate forests	10.4	139	8.1
Boreal forests	13.7	57	2.6
Mediterranean shrublands	2.8	17	1.4
Tropical savannas and grasslands	27.6	79	14.9
Temperate grasslands	15.0	6	5.6
Deserts	27.7	10	3.5
Arctic tundra	5.6	2	0.5
Crops	13.5	4	4.1
Ice	15.5		
Total	**149.3**	**652**	**62.6**

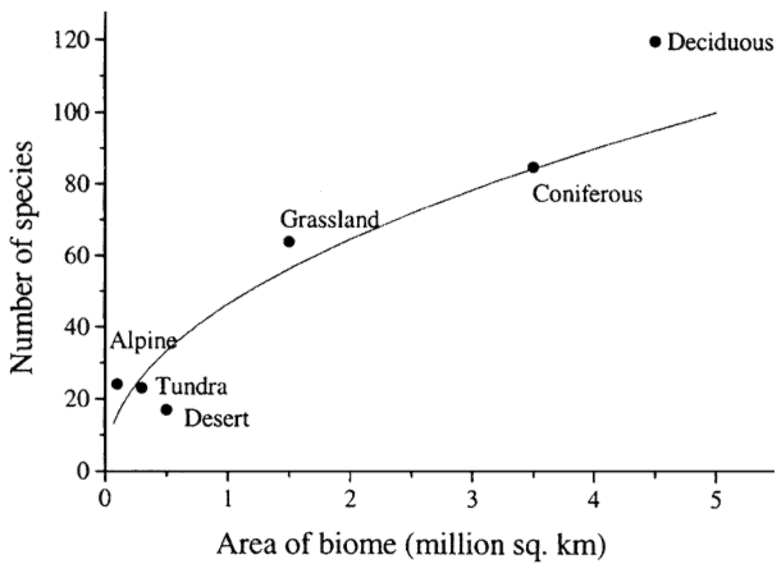
Species Richness

Species richness in the terrestrial flora and fauna is reasonably well documented. In total, the Arctic has about 6,000–7,000 species of terrestrial vertebrate and invertebrate fauna; 3,000 flowering plants; and about 8,000 lower plants. In general, for the main taxonomic groups, this represents an average of about 2.5% of the world species (see table 12.2). The species richness of major taxonomic groups is not uniform. Some groups, particularly mosses and lichens, are better represented than other groups because they are well adapted to rapid response when conditions are favourable and to resist desiccation and cold when necessary. They make a particularly large contribution to the world diversity (see table 12.2). Similarly, although insect diversity is generally low (0.3%), two taxonomic groups, Diptera (two-winged insects) and Collembola (springtails), are well represented (1% and 7.0–8.0%, respectively). For terrestrial mammals in Europe, there is a clear relationship between the number of species present and the size of the biome (see fig. 12.2). The tundra species belong to Insectivora (shrews; 4spp.); Carnivora (weasels; 9spp.); Artiodactyla (deer; 2spp.); Rodentia (mice; 7spp.); and Lagomorpha (rabbits; 1sp.). No Chiroptera (bats) or Primates (monkeys) are present in the tundra. Numbers of species are similar in the alpine areas of Europe, but with a much higher proportion of Chiroptera (the insect-feeding bats absent from the tundra). The size of area appears to be an important determinant of species richness, but that correlation is also associated with changes in habitat diversity and productivity.

Table 12.2 Estimated numbers of species in selected taxonomic groups worldwide and in the Arctic (CAFF 2000)

Group	Total	Arctic	Arctic proportion%
Fungi	65,000	5,000	7.6
Lichens	16,000	2,000	12.5
Mosses	10,000	1,100	11.0
Liverworts	6,000	180	3.0
Ferns	12,000	60	0.5
Conifers	550	8	1.2
Flowering plants	270,000	3,000	1.2
Spiders	75,000	1,000	1.2
Insects	950,000	3,000	0.3
Vertebrates	52,000	860	1.6
Fishes	25,000	450	1.8
Reptiles	7,400	4	>0.1
Mammals	4,630	130	2.8
Birds	9,950	280	2.8

Data based on expert evaluation and literature: Groombridge and Jenkins 2000, Wilson and Reeder 1993, Matveyeva and Chernov 2000.



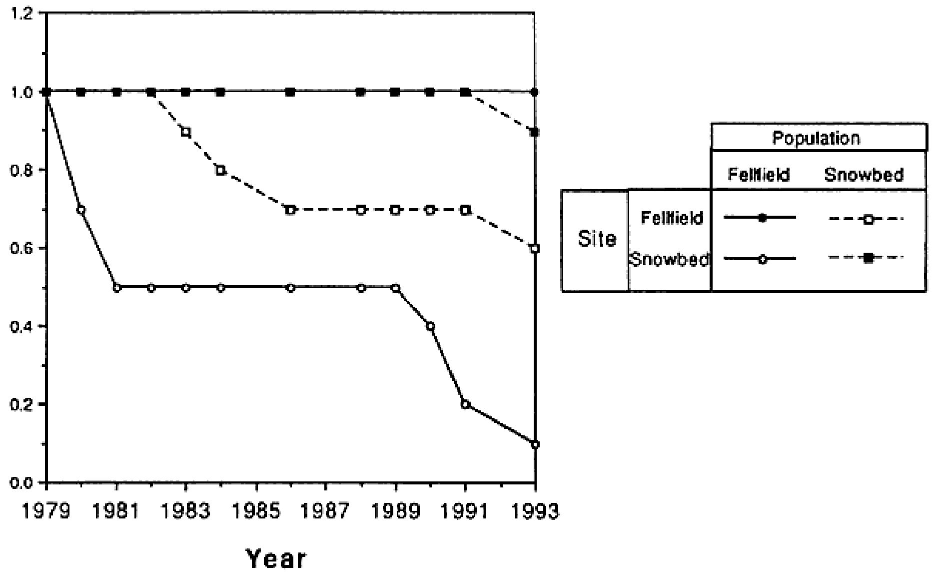
Source: Danell (1999)

Fig. 12.2 The relation between biome area and the number of native terrestrial mammal species within the six biomes of Europe

Documentation of aquatic diversity is less comprehensive and rather more difficult to define because of the wide distribution in the seas. The Arctic seas support more than 150 fish species, 10 seal species, and 11 whale species—a little less than temperate waters but much less than the tropics. Although limited in number of species, the large biomass of zooplankton supports some of the largest populations of seabirds in the world. Several million little auks (*Alle alle*) nest along the coast of northwest Greenland in summer, and seabird populations tend to be higher than in the tropics.

Genetic Variation

Genetic variation is widespread within Arctic plant species. This effectively expands the range of tundra species, often across great physical distances or sharp environmental gradients. For example, *Dryas octopetala* in Alaska has ecotypes that form steep clines over distances of up to 100 m across snowbank gradients. Restricted gene flow amongst populations, combined with large differences in the environment across the gradient, has led to markedly different populations within the species. When plant samples from different populations were transplanted over the snowbed gradient, survival over the next 15 years was related to the environment of origin and growth: snowbed plants tended to die when planted in the fellfield environment and vice versa (see fig. 12.3). This is just one example of the genetic variation with selective advantages to local conditions that are widespread among Arctic flora and also amongst the fauna. The Arctic char (*Salvalinus alpinus*) is a species complex and is a good example of genotypic and ecotypic variation. It is the only fish species to live in the High Arctic and has long been an important food source for indigenous peoples. Isolated populations (allopatry) show phenotypic flexibility, bimodal size distribution, and a variety of food niches including cannibalism. Where the Arctic char is farther south and living in association (sympatry) with brown trout in Scandinavia or brook trout in Canada, competitive and predatory interactions occur. In winter, the ability of the Arctic char to feed at lower temperatures than the trout allows it to maintain its position. The Arctic char has many different strategies to meet different environments and interactions. These genetic traits are expressed in morphological, physiological, and behavioural variations that have been recognized and often used to identify different varieties or even species of Arctic char (Hammer 1989).



Source: McGraw (1995)

Fig. 12.3 Survival over 15 growing seasons of two ecotypically differentiated populations of *Dryas octopetala*, planted at two sites along a snowbed environmental gradient

The number of species, largely identified on morphology, does not take full account of biodiversity. Variations in genetic composition can provide distinct physiological or behavioural advantages within a species but may not be expressed in morphological features. This genotypic expression adds to the morphologically recognized variation within a species and is particularly important in the highly variable and evolutionarily young environment of the Arctic. The low species diversity, combined with the genetic diversity, provides considerable opportunity for Arctic organisms to overcome the extreme climatic conditions, often with niche flexibility. In terms of biological conservation, the native species and genotypes are a distinctive resource and show considerable variation within and between populations. Thus, **conservation** of distributed populations within a species may be just as important as conservation of different species. Although similar environmentally adapted organisms occur in Antarctic and alpine environments, they are different species and genotypes from those in the Arctic. Although the Arctic flora and fauna represent only a small part of the world's biodiversity, the case for its conservation is logically strong because it represents extremes of life on Earth; it contains exceptional adaptations and is vulnerable to disturbance.

Student Activity

1. How many species of birds or flowers (or other organisms) do you have in your region? Is your area rich or poor in species diversity compared to other Arctic areas or to more temperate regions?

2. Is there any evidence of past changes in biodiversity in your locality? What do you consider were the main causes of change? What do you think will be the main changes in biodiversity in the next 50 years?

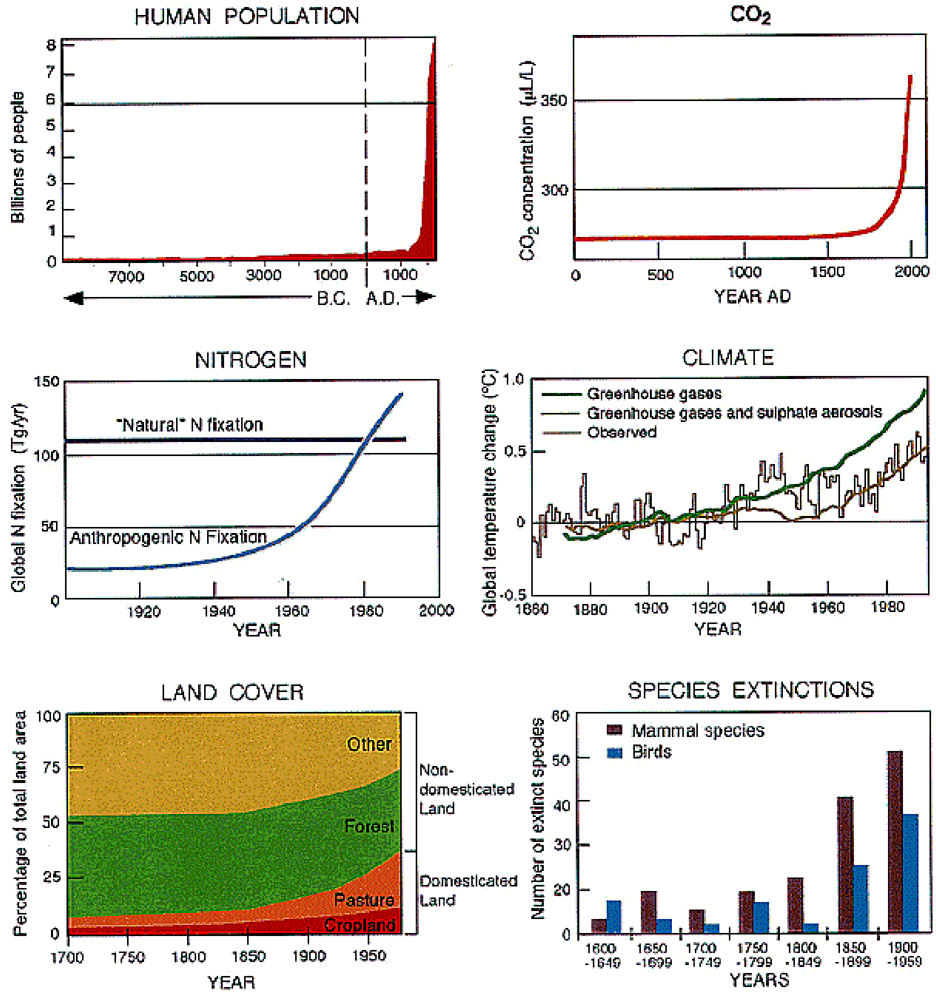
3. What actions are taken locally to conserve biodiversity? What improvements, if any, should be made?

4. Are there any interest groups in your area aware of how biodiversity affects them?

5. How might distant communities cooperate on sustaining biodiversity?

The Earth Is Faster Now: Threats to Arctic Biodiversity

The Arctic is changing, or "the Earth is faster now," to quote Mabel Toolie (1912–2004), talking to her nephew Caleb Pungowiyi (Krupnik and Jolly 2002) about how the weather patterns were changing. The Arctic is feeling the pressures that are affecting the rest of the world. Some of these pressures are manifested locally (e.g., hydroelectric dams); others are generated outside the Arctic but their effects are felt locally (e.g., atmospheric pollutants). Conversely, some of the changes taking place within the Arctic have their influence much farther south (e.g., the melting of glaciers, which is raising sea levels). The changes that are causing concern are fundamentally the result of the growth of the world population and the technological and industrial developments that have changed so dramatically over the last century: indeed, the Earth is faster now! (See fig. 12.4.) How are these global changes influencing the environment, ecology, and biodiversity in the Arctic? And how do the changes in the Arctic influence the rest of the world? How important are climate change, pollutants, introduced species, renewable resource management, tourism and recreation, and industrial and urban development? These topics are briefly considered individually and then comparatively in the following text.



Source: Walker and Steffen (1997)

Fig. 12.4 Components of global change: increase in human population; increase in atmospheric CO_2 concentration; anthropogenic alteration of the nitrogen cycle; modelled and observed changes in global mean temperature; change in global land cover; and increase in extinction of birds and mammals

Climate Change

The world climate and that in the Arctic have always been subject to change. Ice ages have come and gone. There have been fluctuations in climate over recent centuries, for example, the Little Ice Age in the fifteenth to nineteenth centuries, and the Medieval Warm Period in the eleventh to fourteenth centuries. Climate change is not unusual. But the historical changes were small compared to the twentieth-century changes. The human use of fossil fuels, the increased production of rice and cattle, the harvesting of forest, and other factors have caused major increases in carbon dioxide (CO_2), methane (CH_4), and other gases in the atmosphere. These gases cause radiation to be retained in the Earth's atmosphere—which causes global warming. The theory has been known for more than 50 years, and the increases in gas concentrations are now clear. Evidence of climate warming is now apparent not only from weather stations, but by reconstruction from ice cores, lake sediment profiles, and tree rings. There is much debate about climate change and its consequences. Some people accept the concept and the evidence; others reject it, often because of the lack of consistency in the evidence, or for political reasons. The concept is based on sound theoretical science: there is increasing scientific and traditional evidence from a wide variety of sources that the climate is becoming warmer, wetter, and with more extreme events; and that oceans currents, salinity, and temperature are changing. Apparent inconsistencies, such as the growth of some glaciers or the cooling in western Greenland, are now more understandable, as the links between different forces are unravelled. The available evidence consistently forecasts *continued* change in climate over the twenty-first century in response to enhanced human release of atmospheric gases—the greenhouse effect, or anthropogenic climate change.

However, the available evidence also includes information from those who have lived for generations in the Arctic and whose knowledge has been passed down through the generations. Increasingly, traditional environmental knowledge (TEK) is being documented and shown to provide detailed, site-specific understanding of change, including climate change. Summarizing such information as seen from an Inuit perspective has its limitations because "general statements are viewed as vague and confusing, whereas specific statements are seen as providing much more interesting information" (Krupnik and Jolly 2002, 31). However, the observations shared among Inuit suggest some common patterns of change that expand the broader scientific assessments (see table 12.3).

Table 12.3 Examples of environmental changes observed by Inuit in Iqaluit, Igloolik, and Clyde River (Krupnik and Jolly 2002)

Iqaluit	• winds change suddenly, weather changes used to be more subtle • weather unpredictable since 1990s • sun's rays feel stronger • sky is hazy, not as blue • birds arrive earlier and new species are arriving, e.g., robins since late 1990s	• *aniuvat* (permanent snow patches) are melting in the hills around the community • ice conditions becoming more unpredictable with several accidents occurring in the last few years • though some residents cited evidence of a cooling trend in the last few years, more residents noted they could not identify any temperature trends with their knowledge • more unusually hot days in summer
Igloolik	• weather increasingly unpredictable in recent years • sun's rays feel stronger • sky is hazy, not as blue	• less periods of extended clear weather • some residents claimed a warming or a cooling trend (opinion split), but more emphasis placed on variability from year to year and that weather and climate follow cycles
Clyde River	• *aniuvat* are melting all around the community • *auyuittuq* (glaciers) are changing—many are melting, though some advancing • increase in weather variability • weather increasingly difficult to predict in recent years • changes in snow distribution, depth, and colour	• winds have changed in direction and strength and change suddenly • sea ice has changed—usual leads do not form and new ones open in unusual areas; ice thinner and dangerous for travel in some areas • more icebergs • warmer springs • sun's rays feel stronger

Details of climate change and its effects are given in AMAP (1997, 1998) and CAFF (2000), but what are the predicted changes in the global and Arctic climate regime? A detailed and rigorous synthesis of existing global information and assessment of model output by IPCC (2001) can be summarized as follows:

- Mean annual surface temperature is expected to increase by 1.4–5.8°C by 2100, on average about 0.1–0.2°C per decade in your lifetime! Land areas will warm more rapidly than the global average in northern high latitudes in the cold season. Warming will be greatest in northern regions of North America and in northern and central Asia.
- Precipitation will increase over northern mid- to high latitudes in winter, with larger year-to-year variations than presently observed.
- Ocean thermohaline circulation will weaken heat transport into northern high latitudes, but warming over Europe will be maintained owing to increased greenhouse gases. The thermohaline circulation could completely shut down.
- Snow cover, sea ice extent, glaciers, and ice caps are projected to continue to decrease.
- Sea level mean will rise by 10–90 cm by 2100, mainly through thermal expansion and mass loss from glaciers and ice caps. (Projections over millennia indicate the complete melting of the Greenland Ice Sheet with a resulting sea level rise of about 7 m.)

What confidence can we have in these predictions? IPCC (2001) has made an assessment of projected changes in extreme weather and climatic events based on the output of many computer models, plus observed changes, physical plausibility, and extensive expert judgement (see table 12.4). Detailed projections for the Arctic, combined with an assessment of the likely consequences of climate change, will be available soon from the Arctic Climate Impact Assessment.

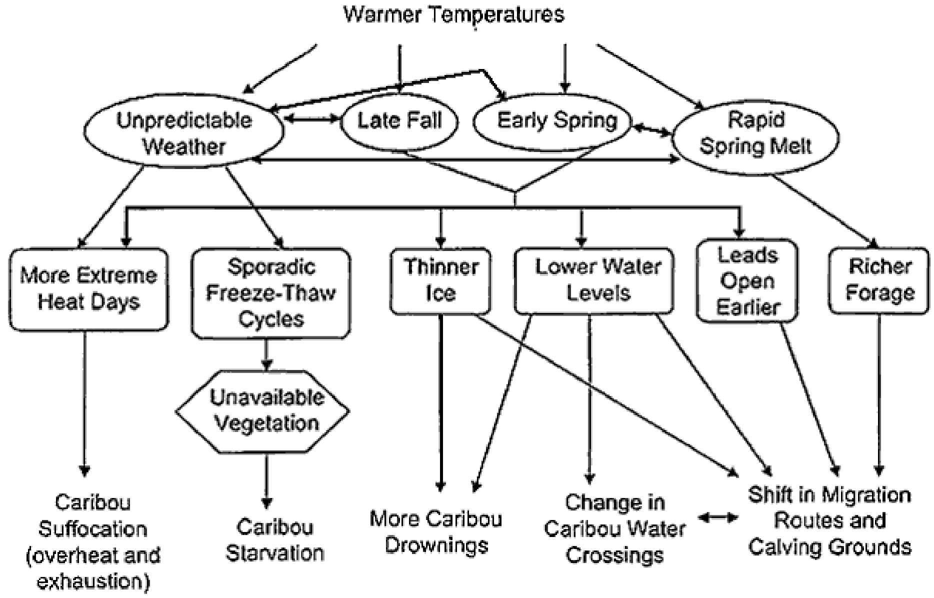
Table 12.4 Estimates of confidence in observed and projected global changes in extreme weather and climate events (IPCC 2001, table 9.6)

Confidence in observed changes (latter half of the 20th century)	Changes in Phenomenon	Confidence in projected changes (during the 21st century)
Likely	**Higher maximum temperatures and more hot days[a] over nearly all land areas**	Very likely
Very likely	**Higher minimum temperatures, fewer cold days and frost days over nearly all land areas**	Very likely
Likely, over many areas	**Increase of heat index[b] over land areas**	Very likely, over most areas
Likely, over many Northern Hemisphere mid- to high-latitude land areas	**More intense precipitation events[c]**	Very likely, over many areas
Likely, in a few areas	**Increased summer continental drying and associated risk of drought**	Likely, over most mid-latitude continental interiors (lack of consistent projections in other areas)
Not observed in the few analyses available	**Increase in tropical cyclone peak wind intensities[d]**	Likely, over some areas
Insufficient data for assessment	**Increase in tropical cyclone mean and peak precipitation intensities[d]**	Likely, over some areas

[a] Hot days refers to a day whose maximum temperature reaches or exceeds some temperature that is considered a critical threshold for impacts on human and natural systems. Actual thresholds vary regionally, but typical values include 32°C, 35°C or 40°C.
[b] Heat index refers to a combination of temperature and humidity that measures effects on human comfort.
[c] For other areas, there are either insufficient data or conflicting analyses.
[d] Past and future changes in tropical cyclone location and frequency are uncertain.

What are the expected consequences of these climate changes in the North? General statements hide the local detail. But some general responses are likely to occur, based on evidence from past climates, on observed current changes, and on known ecological responses to climatic factors:

- With warmer and longer summers and shorter, warmer winters, species will tend to move northwards. This is already happening, and historical evidence indicates that species will tend to respond individualistically rather than as communities of plants and animals moving *en bloc.* The rate of movement will vary and some species will move in occasional jumps rather than gradually.
- Movement will be greatest at the northern edge of the distribution of a species, where its populations tend to be limited by climate. At the southern end of the range, a species will tend to retreat because of warmer conditions (e.g., cod and herring), or as a result of competition from more temperate species. Local movements are likely to occur as local conditions change (see fig. 12.5).
- At the extreme north and on mountains, local extinction may occur because the land ends in the ocean or at the mountaintop.
- As species move into new habitats, population "explosions" will occasionally occur, as previous biotic controls are removed. This applies to pests and diseases, which may colonize new hosts that have not developed specific protective strategies or that are released from the constraint of winter cold (e.g., reduced egg mortality in defoliating moths).
- The genetic diversity within many Arctic species is expected to enable them to survive in a changed environment through change in the balance of genotypes within the populations—a form of "pre-adaptation" to climate change.
- Species low in the food web will tend to expand rapidly (short generation times), causing bottom-up changes in the trophic structure (e.g., in lakes). Conversely, introduction of mobile herbivores or carnivores will be more erratic but will tend to cause strong top-down responses in the food web.
- Water may hold the key to plant responses on land. Productivity and decomposition will increase through longer summers, especially in mesic conditions, where water is not a limitation and nutrient availability will also increase. Responses in currently dry conditions will be slower, except where precipitation increases significantly.
- In wet habitats, plant growth responses will be slow unless water content is reduced through evapotranspiration or drainage improves (e.g., through deeper active layer or permafrost degradation. Warmer climates will particularly influence shallow ponds, lakes, and the continental shelves, not only through heating, but also by the increased length of summer.

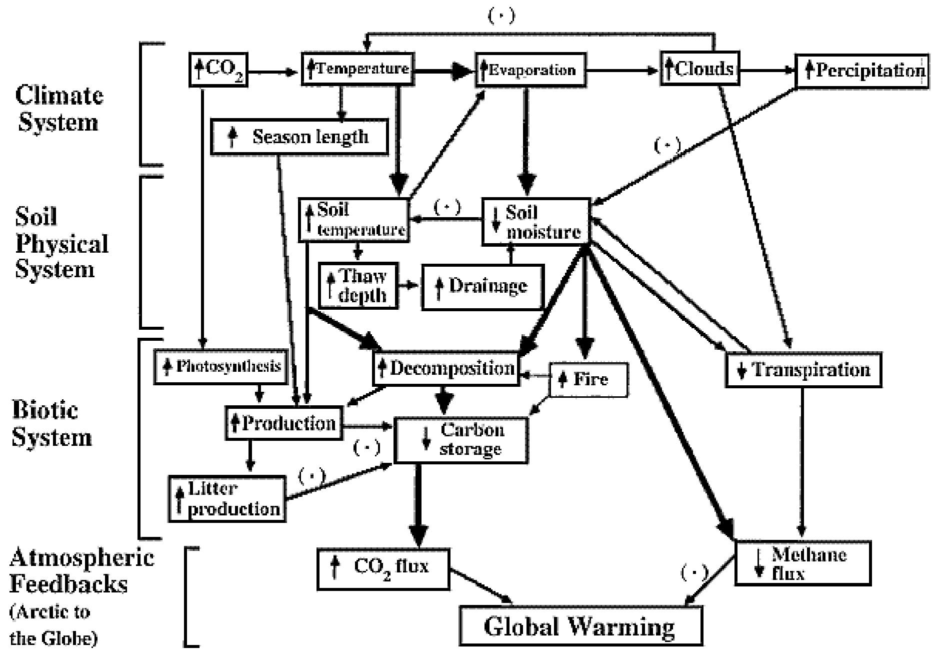


Source: Krupnik and Jolly (2002)

Fig. 12.5 Observations by Kitikmeot Inuit of Nunavut, Canada, of caribou responses to climate warming

Expect the unexpected! On land and in the seas, there are many, often complex interactions within ecosystems, as well as differential responses of individual species. For example, although trees and forests are expected to extend northwards over tundra, the reverse is likely to occur in some areas. Where precipitation increases with climate change, probably under oceanic conditions, waterlogging can increase, causing more anaerobic conditions, reduced decomposition, and peat accumulation (paludification). Such conditions can cause tree death and expand tundra in tundra–boreal areas. In Alaska, on wet peat, enhanced tree productivity, and hence weight, has caused trees to sink and die.

However, a general pattern of the major cause-and-effect links within the climate–soil–biotic system is emerging from the response to climate change in Arctic terrestrial ecosystems. Figure 12.6 illustrates the importance of both temperature and moisture and their interactions in system performance. The figure also shows the feedback to the climate system that can result from climate change. Another effect will be the change in reflection of radiation back to the atmosphere (albedo). Reduction in snow and ice cover and exposure of the darker surface of the land or water results in significant absorption of heat—a positive effect of climate warming.



Source: Chapin et al. (1992)

Fig. 12.6 Major cause-and-effect links among climate, soil, and biota in the Arctic and their effects on global climate

A key question that is in the process of being clarified is, To what extent will the Arctic act as a sink for, or a source of, atmospheric carbon? Detailed computer models of tundra ecosystems indicate that, previously, much of the tundra was a slow sink for carbon because of accumulation of soil organic matter. Projections indicate that the tundra could become a net source of carbon under climate warming. The delicate balance may depend on seasonal patterns of moisture. The model that has been developed uses the best available data and understanding of how the Arctic tundra functions. It is a good example of how such models can be used to explore the future and subject our strengths and weaknesses to critical analysis (McKane et al. 1997a and 1997b). To quote one perceptive ecologist, “models are an adjunct to critical biological thinking.” They help us to explore our ideas and understanding in an objective manner. The ecological responses to anthropogenic climate change will be many and varied; they will be local and regional; and they will be both short- and long-term. We may have a reasonable understanding of the potential changes, but we are still far from providing a detailed quantitative picture of the responses. In these circumstances, the precautionary principle is the best strategy to adopt in relation to conservation of biodiversity. Conservation of species and ecosystems in a period of change requires flexible conservation policies and management. The diversity of genotypes, species, and ecosystems need to be supported in their transition from one place or state to another.

Contamination and Pollution

For many people, the Arctic is a wilderness, a natural environment, uncontaminated by modern man. The reality is somewhat different. There are localized areas of intense industrialization, where levels of chemical pollution are as bad as anywhere in the world. These pollution "hot spots" exploit non-renewable resources, mainly oil and gas, minerals, and diamonds, which are valuable and often essential contributions to the world economy. But the Arctic also receives a cocktail of chemicals from lower latitudes—transported by wind and water, and more directly by road, rail, and ships—regional contamination, which then moves within the Arctic by diverse routes. AMAP has thoroughly reviewed the subject and identified the issues. Here, the main features of pollution in the Arctic are briefly introduced. Further details are accessible in AMAP (1997, 1998), in Reiersen (2000), and at the AMAP website, http://www.amap.no.

Types and Sources of Contaminants

A number of main types of pollutants are recognized, based on their chemical composition, which tends to determine their source, their behaviour in the environment, and their threat to wildlife and humans. **Persistent organic pollutants (POPs)** include a range of pesticides (including DDT, lindane, and toxaphene), industrial chemicals (such as polychlorinated biphenyls, PCBs), and various industrial by-products (dioxins, furans, and polycylic aromatic hydrocarbons, PAH). The POPs are generated both in Arctic and temperate industries. They are generally fat-soluble, which results in accumulation in fatty tissues of many Arctic animals; and they transfer up food chains with increasing concentration (bioaccumulation or biomagnification). **Heavy metals** occur naturally in rocks and are essential micronutrients in plants and animals, but in high concentrations they are toxic. Mercury, cadmium, and lead are the main pollutants in the Arctic, generated from industrial processing, waste incineration, and burning gasoline to produce electricity and heat. **Radioactivity** has both natural and anthropogenic sources. In the Arctic, widespread contamination has resulted from atmospheric nuclear weapons testing; releases from European nuclear reprocessing plants; and fallout from the Chernobyl accident. Local contamination has resulted from accidents (e.g., aircraft and submarine accidents). Storage of civilian and military waste and other sources form high local concentrations with potential for future accidents. **Acidifying components,** mainly sulphur and nitrogen, are generated locally and in lower latitudes from industries, energy production, and transport. **Oil pollution** is an obvious problem wherever exploration, production, and transport occur. Oil spills are guaranteed to occur sooner or later, causing localized pollution, often in unexpected places. Production of polynuclear aromatic hydrocarbons (PAH), from incomplete combustion of oil and coal or caused by seepage from natural deposits, is a separate localized problem.

Transport Mechanisms

Three modes of transport bring pollutants to the Arctic and/or move them from local sources. Atmospheric transport is a fast, long-distance pathway for pollutants emitted into the air in the industrial areas at lower latitudes. The main northward currents are in winter, and pollutants may fall as either wet or dry deposition. In the case of mercury, organochlorines, and PAHs, the pollutants may be deposited under cold conditions and then revolatolized under warmer conditions—described as “multi-hopping” or “hedge-hopping.”

The large rivers surrounding the Arctic Ocean drain vast areas of land. During the 8–10 months of winter, pollutants accumulate in snow through atmospheric deposition. In spring, the rapid melting transports the accumulated pollutants onto flooded land or down river to the estuaries, where they may be deposited as sediment in the slow flow or move out over the continental shelf and to the open ocean. This route provides different groups of organisms many opportunities for uptake.

Ocean currents provide long-distance and long-term transport from sources both within and outside the Arctic. Transport may be on ice or in surface or deep waters.

Effects of Pollutants on Biodiversity

The most obvious effects on flora and fauna occur within the vicinity of major industrial sites in the Arctic. It is here that the biota is greatly impoverished or even completely obliterated. Less obvious but more pervasive are the effects of pollutants that accumulate within the food chains. Concentrations of POPs in zooplankton may be a thousand times that in the seawater, then increased ten times in predatory fish and a further 10–100 times in seals or narwhal blubber. This biomagnification causes levels to affect reproductive success; and cause disruption of the immune system and neurological and carcinogenic disorders. The long-term effects on wildlife populations have not been fully determined, but there is serious concern over effects on human health. Accumulation of radionuclides, particularly ^{137}Cs in fungi and lichens, have been magnified in reindeer but without marked effects. Contamination by heavy metals and acidification by nitrogen and sulphur can have widespread as well as local effects. Some areas of poorly buffered acid soils are close to their critical loads threshold, above which vegetation damage will become apparent. A separate effect in fresh waters is that snowmelt in spring can cause a pulse of acidity in fresh waters sufficient to kill invertebrates and fish. Many lakes in Scandinavia are now devoid of fish through acidification. Finally, oil contamination can be lethal for many animals, especially those with fur or feathers that are critical for insulation. The effects of oil spills may be measured in years and communities seem to recover eventually, but there is always the potential that local populations of rare species can be exterminated by such pollution events.

Introduced Species and Genes

Many species are moved around or are brought into the Arctic intentionally or accidentally by human actions. The potential for negative effects on native populations is considerable. Some examples of the effects of intentional introductions on freshwater systems and particularly on Arctic char illustrates general dangers that are not widely recognized (Hammer 1989):

- Stocking of Arctic char and brown trout into previously fish-free lakes has caused the extinction of large crustaceans and a decline in diving ducks.
- Stocking of closely related salmonid species has caused hybridization and introgression and, thus, the dilution of original gene pools.
- Introduction of coregonid fish has resulted in the large-scale elimination of unique populations of Arctic char in northern Scandinavia.
- Eurasian brown trout introduced into North America have dispersed, influencing niche utilization of native salmonids and having genetic impacts on local populations of Atlantic salmon.

Farming of freshwater and marine fish in open systems with the risk of accidental escapes of large numbers of fish with manipulated genomes is a significant threat to local fish populations and to their original gene pools.

Renewable Resource Management

Forestry, farming, whaling, fishing, hunting, herding, conservation. Is our exploitation of natural resources causing decline and extinction of natural populations? What will or should happen in the future? Making use of our renewable natural resources has been a human activity throughout human existence, not only in the Arctic, but the resources in the Arctic have drawn a lot of attention:

> Renewable resources in the Arctic, particularly fish and wildlife, are the focus of growing conflict. Marine mammals, caribou, seabirds, and other resources provide a wide array of nutritional, socio-cultural, and economic benefits to Arctic peoples. Yet conservation and management of these resources is problematic. A wide array of stakeholders—including indigenous peoples, multinational corporations, national and indigenous governments, environmentalists and others—engage in contentious debates about their use and allocation. (Caulfield 2000)

Much has been written on the subject. CAFF (2000), AMAP (1997, 1998), and Bernes (1996) provide good quantitative and reasonably objective overviews. The following four features help to place Arctic renewable resource management in the global context and in relation to biodiversity:

1. The explosion of the global human population in the twentieth century is going to continue (see fig. 12.4). The global population will increase by almost one billion (10^9) people per decade for the next three decades at least. The global population is making increasing demands on renewable resources for food, and the Arctic seas are an important source of marine fish, mammals, and crustacea. Associated with this demand for food is the dramatically increased efficiency of capture through technical developments. Few species are targeted but vast amounts are caught. When target populations decline, consumption tends to switch to other large populations. There are large direct and indirect effects on the target populations and on other species and habitats.
2. The human population in the North has also increased, doubling from 5.8 to 10.5 million people between 1960 and 1990 (Knapp 2000). Total consumption of renewable resources is small compared to the global crop, but a wider range of species is targeted. Harvesting techniques are on a smaller scale but the catch of species with small populations, including birds, can be maintained through local demand. Although there is less physical habitat disturbance, regional or local food webs can be disrupted.
3. The numbers of Arctic indigenous peoples rose from 0.9 to 1.1 million between 1960 and 1990. The proportion of indigenous peoples in the local population varies greatly between regions, being high in the sparsely settled areas (Knapp 2000). The total use of fauna is small and a wide range of species is taken, with considerable local variations. Locally, fauna populations can be heavily exploited, but physical damage to habitats is minimal compared to the more industrial-scale exploitation.
4. Changes amongst the fish, mammal, and bird populations are not solely owing to human influence. Natural, large population changes result from exceptional climatic conditions, changes in currents, and in response to changes in food availability. Density-dependent population responses can cause large cyclical changes in important crop species. Further, many of the crop species are carnivores with the potential that cropping can release populations lower in the food web and enable other predators to expand—a response to top-down system control. Thus, natural population dynamics can cause large local or regional population changes in a wide range of target species, with considerable effect on food web structure but little habitat disturbance.

What is clear is that all of these factors are affecting Arctic biodiversity. Except for the natural dynamics, all the pressures on target populations have increased in recent decades and are likely to continue to increase. The combined pressure on many species is considerable. What is remarkable is that so few (if any) Arctic species have been made extinct in the last 100 years through human exploitation. Undoubtedly, many species have declined in number, and some have become locally extinct; but only 43 vertebrate species, mainly marine, are classified as Vulnerable (28spp.), Endangered (11spp.), or Critically

Endangered (4spp.) according to the criteria of the International Union for the Conservation of Nature (IUCN). In the global context, these numbers represent about 1.6% of all mammal, bird, and fish species on the World Red List (exact figures are difficult to calculate because of species and subspecies definitions). This is the same or possibly a lower number than would be expected based on the proportion of Arctic mammals, birds, and fish in the world total for those taxa. In other words, Arctic species are in no more and possibly in less danger of extinction than species elsewhere. But, given the losses in temperate and particularly tropical regions, this may not be so encouraging.

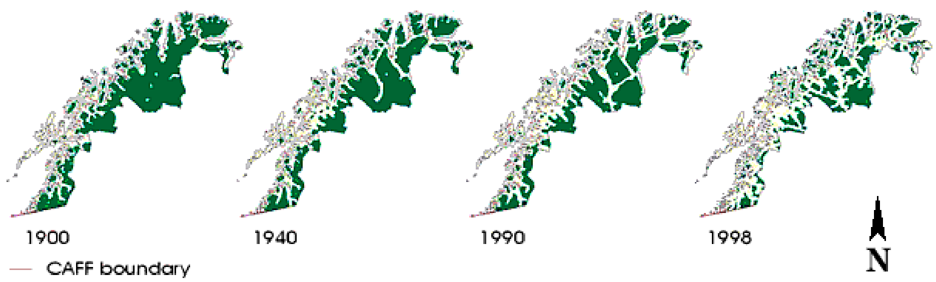
What the IUCN listing does not reflect is the vulnerability of genetic diversity that is in danger of being lost. Small populations, in only one or a few locations, have probably lost much of their genetic diversity, and even common species, such as the Arctic char, have lost some genetic flexibility through resource management. Thus, the case for careful conservation of Arctic species, especially those that are being seriously depleted, remains strong. How to implement such policies is another matter.

Tourism and Recreation

Again, more people from outside the region are being attracted to the Arctic to enjoy the "wilderness experience" and/or to participate in snow and ice sports, or to hunt and fish. Arctic residents are expanding similar activities. The technology is also allowing more extreme actions and involves greater distances (e.g., use of snowmobiles, power boats, and light aircraft). Direct effects of such activities on native biodiversity are minimal and localized. Much less obvious but more important are the following: (1) the accidental introduction of alien species, particularly plants, brought to the Arctic mainly on boots (such introductions have been particularly obvious in the Antarctic, where the native flora is so limited); (2) intentional introduction of species to enhance sporting opportunities, as illustrated by the introduction of brown trout or the fairy shrimp (*Mysis relicta*) into northern lakes; and (3) increased pollution, especially from large tour ships that release untreated waste directly into the sea. Undoubtedly, the attraction of the Arctic and its wildlife is immense and that interest can be turned into positive economic and conservation benefits through good management and education.

Industrial and Urban Development

Yet again, the pressure is rising. Although some industries that exploit non-renewable resources are declining (e.g., coal on Svalbard), others are expanding (e.g., gas in Russia, and diamonds in Canada). The influence of such developments is largely local but is potentially severe, especially through atmospheric or riverine pollution. A less obvious feature that has emerged as particularly influential is the effect of enhanced communication routes and infrastructure in response to industrial, urban, and recreational development. Roads and railways, fencing, dams for hydroelectricity cut rivers. The resulting fragmentation of habitats adds to that caused by land and water management; for example, large areas of old forest are broken by new plantings or felling. Individual developments may be small, but the combined effect over time can be large. In Norway, mapping of "wilderness" areas (areas lying more than 5 km from roads, railways, and regulated water courses) since 1900 has shown the dramatic fragmentation of the land: wilderness has shrunk from 48% of the country in 1900 to 12% at the end of the century (see fig. 12.7). Such fragmentation of habitat reduces population sizes and inhibits migration and access to feeding grounds. The mechanisms of fragmentation may be different in different habitats, but the phenomenon occurs in terrestrial, freshwater, and marine systems. In Finland, fragmentation of old forest has severely reduced populations of many species: 41% of all threatened species are rare because of forestry operations.



Source: CAFF (2000)

Fig. 12.7 Change in wilderness areas in Norway

Synthesis: Risk Assessment

How can we put together our understanding of change to prioritize actions that need to be taken? How can we assess the relative importance of different issues? Examination of data and information, with careful discussion, can generate a concerted picture of the environmental problems and focus actions. Figure 12.5 is such a synthesis; it emerged from the combined knowledge of a community assessing the environmental change and the behaviour of caribou in one area of Nunavut in Canada. It is an oversimplification of the complexity and interconnectedness of these ecological variables, but it serves to illustrate and communicate some identifiable associations. It is an effective model, a synthesis, based on traditional knowledge, and it can be used within the community—and elsewhere—to develop local practical solutions to the emerging problems. Such models, when quantified and computerized, are a key element in the wider understanding of climate change. They can provide a framework that can help people to focus on the real world situation that they have to face.

A second example of synthesis (see fig. 12.8) shows the relative effects of the different threats to Arctic biological diversity that have been discussed in this section, "The Earth Is Faster Now: Threats to Arctic Biodiversity." It is one form of risk assessment, with the matrix defining the extent and severity of damage resulting from pressures, based on the opinions of a group of people. One of the interesting conclusions is that

> the effects of the physical encroachments on the environment predominate over the effects of pollutants. Some pollutant emission has admittedly caused significant damage to these aspects of the natural environment at a local level; and other pollutants have spread throughout the Arctic. However, no form of pollution which is both widespread and is known to cause serious damage to Arctic ecosystems has been detected—or at least not yet" (Bernes 1996).

Past overhunting and future climate change are perceived as the biggest threats to the genes, species, and ecosystems that constitute Arctic biodiversity.

[Figure temporarily not available.]

Source: Bernes (1996)

Fig. 12.8 A risk assessment matrix: effects on biological diversity of various environmental threats to the Arctic

The threats to Arctic biodiversity are many and varied, and they are strongly influenced by social, cultural, economic, and environmental factors from outside the Arctic. They reflect changes in the world, generally: the growth of populations, combined with technological development and expanding economies that are the fundamental drivers of change. These drivers have individually increased the pressures on biodiversity acting locally or regionally in many different ways, in different habitats, and on different species. The impact has been a general decline in species abundance, with major decline in some species in some areas. Although some species and populations are being maintained or are expanding, the general trend is unhealthy. No single pressure is responsible for the overall change. The pressures are not acting in isolation; they are acting in combination. The magnitude of the combined pressures on genes, species, and habitats has increased in recent decades, and the evidence points to a continued rise in pressures: "the Earth is faster now."

Sustainability

The principle of *sustainable development*—"development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission 1987)—is easy to say; difficult to achieve. But it is a sensible focus of attention. To quote Mary Simon, Canada's then Ambassador for Circumpolar Affairs, at a conference on sustainable development in the Arctic,

> In the Inuit culture I come from, we believe that we have inherited our Arctic lands, that we are an integral part of the polar ecosystem, and that the land is our Aboriginal birthright. But we have always promised the land to our children and to their children. And for thousands of years we have kept our promise to the next generation and left the land and the northern environment basically as we found it. Today, in the face of globalization, it is getting harder and harder to keep this promise. Yet we are determined to keep it. And that is why the Arctic peoples are reaching out now, and asking southerners, including their governments, to join them in dealing with the threats facing the Arctic's environment and people. (Simon 1998)

Is there a clearly defined, common goal? Oran Young, at the same conference, examined emerging priorities and processes. He concluded,

> Sustainable development in the Arctic—as in other regions of the world—is not a specific goal to be pursued on the basis of an integrated campaign, like the war on poverty or the phase-out of ozone-depleting substances. Rather, it is a framework for organizing action and thought pertaining to human/environment relations to be contrasted with alternative frameworks like environmental protection or sustained economic growth. (Young 1998)

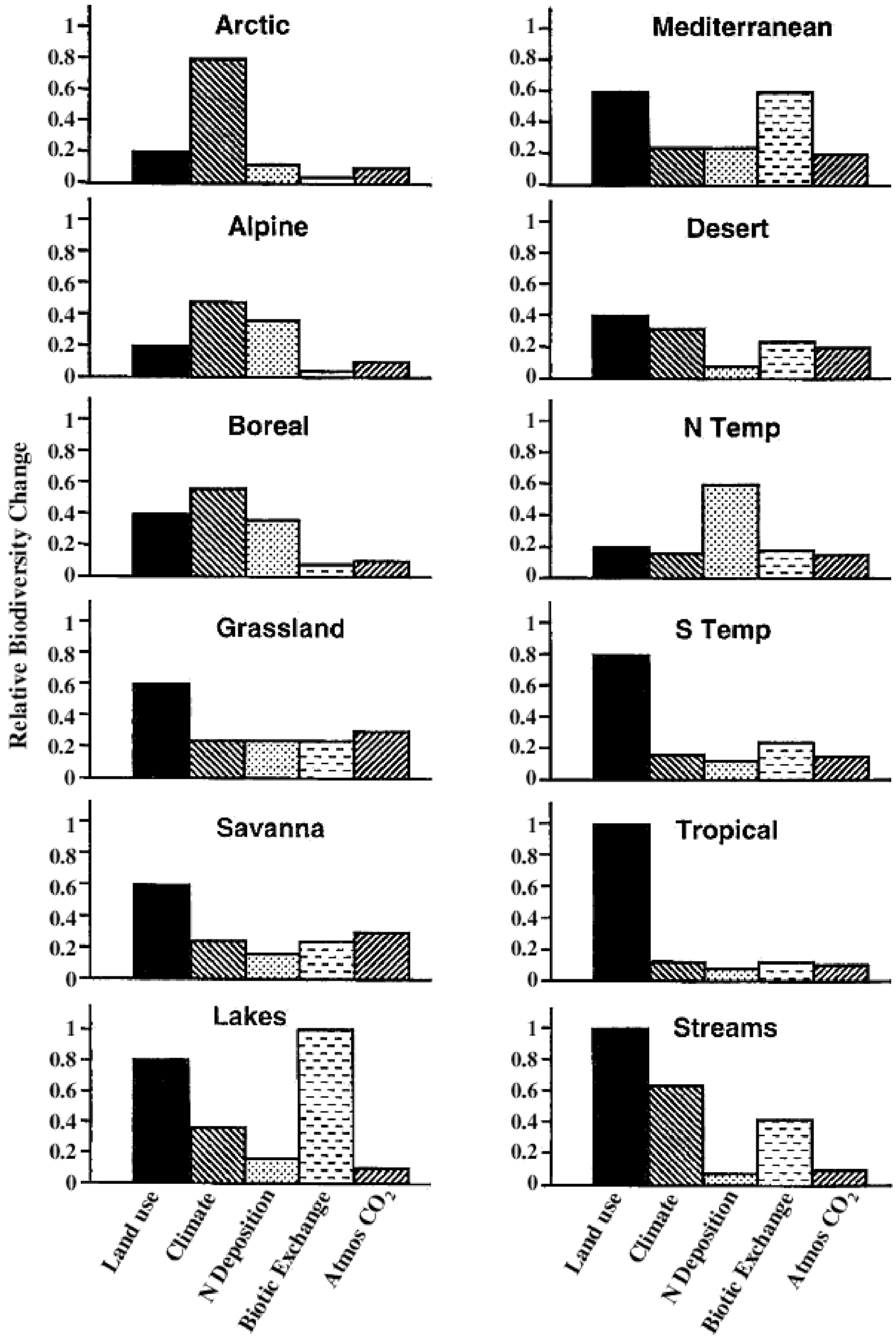
What sort of framework can help to organize action and thought? The matrix in figure 12.8 examines the effects on biodiversity of various perceived threats of local, regional, and global origins. This was, essentially, the environmentalist perspective. However, the group also looked at the perceived threats from three other perspectives: impacts on future use of natural resources (economic); on recreation (social and economic), and on human health (social) (see fig. 12.9). Is this the sort of framework that Oran Young envisaged? Yes, but it is to be developed through a participatory approach, and it is an aid to decision-making. There is no single "right" decision. The "best" option will vary between different places and different times in order to achieve a better balance between a number of distinct, but interrelated objectives.

[Figure temporarily not available.]

Source: Bernes (1996)

Fig. 12.9 Risk assessment matrices for various environmental threats to the Arctic: (a) effects on sustainability of natural resource use; (b) effects on recreational use; and (c) health risks.

But, are the threats to Arctic biodiversity different from the threats that affect biodiversity in the other biomes of the world? Sala and Chapin (2000) have examined this issue by comparing major terrestrial and freshwater biomes. They assessed the expected change in various drivers by the end of the 2100s and the sensitivity of each biome to change in each driving force. This synthesis (see fig. 12.10) showed that Arctic biodiversity is uniquely sensitive to climate change. Although climate change is a major factor influencing biodiversity in alpine and boreal biomes, land use and nitrogen contamination are also important in those regions; these two factors are much less important in the Arctic.



Source: Sala and Chapin (2000)

Fig. 12.10 Relative effect on biodiversity of land use, climate, nitrogen deposition, biotic exchange, and atmospheric CO_2 in ten terrestrial biomes and freshwater ecosystems

A key problem in implementing practical strategies for sustainable development in the Arctic is that many of the threats—the causes of change—are controlled by people outside the Arctic. This is a universal problem and has to be addressed by all who work towards sustainable development in the Arctic. It demands a participatory approach, with good communication and understanding and a willingness to take action for the common good. This will be the challenge that will arise from the Arctic Climate Impact Assessment (ACIA). ACIA will provide what is basically a risk assessment.

Student Activity

1. Sustainable development is designed to meet the needs of future generations. What action would you want the Arctic Council to take?

2. How should the University of the Arctic respond to the forthcoming publication of the Arctic Climate Impact Assessment (ACIA)?

Summary

The Arctic has always been subjected to change over geological and historical times. In all situations, the Arctic has responded to global forces. Most recently, there have been expansions in human population, commerce, industry, tourism, and pollution as well as a change in climate. All these trends are part of globalization. Biodiversity is influenced by many of these links with the rest of the world. Biodiversity is itself one of the links through the migrations of many species and also the introduction of new species from lower latitudes.

Climate change has always been a dominant influence on the composition and distribution of Arctic biodiversity. All of the evidence points towards continued climate change—within your lifetime and that of the next generation. This year, the publication of the Arctic Climate Impact Assessment (ACIA) is expected to contain both a scientific analysis with future scenarios and a response from policy makers. This is a massive exercise and it is the first time that an assessment has been made of climate change in one of the world's regions. Why the Arctic? Because (1) the Arctic climate is changing faster than any other part of the world; (2) it is a highly integrated single system that girdles the world; and (3) changes in the Arctic will have a big influence on other parts of the world.

The Arctic will become an increasing focus of world attention. Do you understand the causes and consequences of climate change? Is the Arctic ready to respond to ACIA?

Study Questions

1. Where are the cryospheres of the world? How do they differ from each other? What determines their biodiversity?

2. How does the Arctic contribute to global diversity?

3. What are the pressures common to the biodiversity of the Arctic and the rest of the world? Where do these pressures originate?

4. What evidence is there to measure the extent of the pressures on biodiversity?

5. List five predicted changes in the global and Arctic climate regime.

6. List eight consequences of climate changes in the North.

7. List the various types of contaminants and their transport mechanisms.

8. What are some examples of the effects of introducing new species and genes?

9. What are the predictions for human and animal populations? Who is taking notice?

10. Who is being attracted to the North and why?

11. What examples are there of groups of people drafting a synthesis of the problem and a plan of action?

12. What are perceived as the biggest threats to Arctic biodiversity?

13. What are some of the promising approaches to addressing the threats to Arctic biodiversity?

14. Can you identify key observations that will help to monitor the predictions of the impacts of climate change? Where and when should these observations be made?

15. List the different sources of data and information that can be used to assess changes in climate and the effects of these changes.

16. Both “indigenous knowledge” and “modern science” contribute to our understanding of biodiversity conservation. Can you list the pros and cons of both information sources?

Glossary of Terms

anthropogenic	caused by human activity (as in *anthropogenic environmental damage*).
cryosphere	cold climate.
fellfield	*Ecology* a tundra area of frost-shattered stony debris with fine interstitial particles which supports sparse vegetation, usually algae, lichens, and mosses.
mesic	*adjective* (of a habitat) containing a moderate amount of moisture.
skerry	a reef or rocky island. (*plural* SKERRIES).
speciation	*Biology* the formation of new species in the course of evolution.
species complex	a taxon comprised of a group of closely related individuals the species of which are difficult to distinguish; a collective species, or a group.

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