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CHAPTER 10

Biophysical and Habitat Changes in Response to Climate Alteration in the Arctic and Antarctic

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Polar bear family on ice floe.

The prediction of enhanced rates of climate change, particularly temperature increase, at high northern and southern latitudes is a common feature of most global circulation models (GCMs). It is also generally accepted that one factor underlying the low terrestrial biodiversity of polar regions relative to lower latitudes is the set of severe environmental stresses that biota must overcome. This combination of high predicted rates of climate change and associated environmental change defines the polar regions as being likely to show particular sensitivity and rapid, visible ecosystem responses. The IPCC Third Assessment (IPCC 2001) also singled out the polar regions as an area of special concern.

In combination, these factors make the polar regions a "canary in the coal mine"—places in which multiple and cascading impacts of climate change might first be observed. Indeed, observations are now matching predictions in many polar physical and biological systems. Using examples from both the marine and terrestrial environments, and both polar regions, this chapter highlights how these changes are giving scientists an initial glimpse into the complexity and depth of impact which climate changes are having on biodiversity.

Despite their similarities in latitude, Antarctica and the Arctic are, in many ways, not closely comparable. Much of the Arctic has a long-term history of human habitation and exploitation. It is also relatively close to major centers of population and industry which have degraded the Artic's environment, both directly and through long-distance transport of contaminants. The Arctic is formed by the northern fringes of major continental landmasses surrounding a relatively small ocean, while the Antarctic is a large, high continental landmass isolated from the other southern continents by 1–5,000 km of cold sea and atmospheric circulations.

Antarctica is the only continent with no natural human population. Its exploration has been completed only during the last century, while its transient human population, associated with scientific research stations and tourist activities, amounts to a maximum of a few thousand individuals during the austral summer, and considerably fewer during winter. Remote from most human influences, the isolation of Antarctica and its climatic severity have, thus far, largely protected its terrestrial environment. In contrast, human exploitation of the rich biological resources of the Southern Ocean, which commenced with the uncontrolled depredations of the sealing and whaling industries during the nineteenth and early twentieth centuries, continues today. The climate contrasts between the two regions in both terrestrial and marine ecosystems are considerable (Danks 1999; Dayton 1990).

This chapter will first review predictions and observations of climate change and anticipated ecosystem response in the polar regions. The potential vulnerability of human populations and economic interests has meant that much of this research has been conducted in the Arctic, with less information available for the Antarctic. The chapter will then outline the evidence available, from both the scientific literature and Traditional Environmental Knowledge (TEK), of observed climate and related environmental changes.

CLIMATE CHANGE

Temperature

Low thermal energy input is a feature of polar habitats. Terrestrial habitats, in particular, spend long periods near or below minimum threshold temperatures for many physiological processes. Hence, any increase in thermal energy input may have a disproportionately large impact on biological processes.

Climate change is not a new challenge for polar biota—both wide and rapid variations in climate and the extent of ice cover during the Pleistocene are well documented in both polar regions. However, recent trends of air temperature increase at locations in the Antarctic Peninsula region, some sub-Antarctic islands, and parts of the Arctic are among the most rapid worldwide, and several sites have seen increases in annual temperature means of 1–2°C or more over only the last 30–50 years (e.g., King & Harangozo 1998; Bergstrom & Chown 1999; Serreze *et al.* 2000).

At some locations, the strength of the warming trend varies with season. For example, along the Antarctic Peninsula there has been very significant warming in winter (4–5°C over the same 30–50 year time period), while summer temperatures have increased by a much smaller amount (King 1994). While mid-winter warming may have no direct impact on biota, the related consequences—earlier spring thaws and later autumn freezing events—increase the active period available to organisms.

The temperature increases in this region appear to be linked to decreases in the extent of winter sea, decreases which are thought to be related to El Niño Southern Oscillation (ENSO) events in the southern Pacific Ocean (Cullather *et al.* 1996). Alternatively, recent Antarctic Peninsula warming has been linked with changes in the strength of the circumpolar vortex mediated by photochemical ozone losses (Thompson & Solomon 2002). However, it must also be noted that, although many GCMs predict high rates of warming at polar latitudes, the current levels of Antarctic Peninsula warming are anomalous, as detailed spatial models (such as HadCM2) do not predict significant regional warming there. Serreze *et al.* (2000) have noted that, although there is general agreement between annual mean warming projected by GCMs and observed trends in the Arctic, some important seasonal discrepancies remain in modelled and recorded temperature changes.

Water

The availability of liquid water to polar terrestrial biota, itself partly a function of temperature, may be more significant than temperature itself (Sømme 1995). Climate change models include predictions of changes in precipitation patterns, although they do not provide fine enough spatial resolution to be directly applicable to biological systems. Nevertheless, greater precipitation has been documented in the Antarctic Peninsula region (Turner *et al.* 1997) and some Arctic locations (e.g., Førland *et al.* 2002), including up to a 20 percent increase over northern Canada (> 55˚N) during the past 40 years (Groisman & Easterling 1994). In contrast, on sub-Antarctic Marion Island and Îles Kerguelen, and maritime Antarctic Signy Island, decreased precipitation has been observed. At the latter site, this has manifested itself as both a reduced deposition of snow in winter and a tendency towards an increased proportion of precipitation falling as rain during the summer months.

In addition to direct precipitation, terrestrial habitats may also gain liquid water from glacial retreat and loss of snow cover. These processes are widely reported at many maritime and sub-Antarctic and Arctic sites; however, locally, decreased precipitation or complete loss of ice or snow cover may lead to the opposite consequence—that of decreased or zero water input to habitats. Groisman *et al.* (1994) report that the annual extent of snow-covered area in the Northern Hemisphere has declined approximately 10 percent since 1972, while Dyurgerov & Meier's (1997) regional analysis of small Arctic glaciers found that all had diminished mass balance (including Alaska, Arctic Islands, Svalbard, Greenland, Asia) except those in the European sector.

PHYSICAL CHANGES

Ice shelves, sea ice

One highly visible aspect of environmental change observed over recent decades in the Antarctic has been the catastrophic collapse of at least seven coastal ice shelves around the Antarctic Peninsula (Vaughan & Doake 1996). While this was a predicted consequence of regional climate warming, the detailed mechanisms underlying such changes remain poorly understood (Vaughan *et al.* 2001). In that these ice shelves provide habitats for neither terrestrial nor marine biota, the immediate biological consequences of shelf collapse are likely to be negligible, except that they provide both reduced impact from ice scour and increased areas of seasonally ice-covered and benthic marine habitats suitable for colonization.

Polar marine environments experience chronically low temperatures but much greater thermal stability than their terrestrial counterparts. Here, the extent and duration of winter sea ice presence are key drivers of biological productivity, providing a unifying theme across physical and biological changes and predictions in both polar regions. The reduction in duration and extent of annual sea ice formation west of the Antarctic Peninsula is linked with recent trends of climatic warming observed, especially, during winter. Changes affecting annual sea ice in both polar regions are, arguably, more likely to have direct biological consequences than those changes which lead to the spectacular, but spatially limited, ice shelf collapses. Pack and fast ice provide important habitats for a range of marine invertebrates, and both marine and terrestrial vertebrates and the ice edge zone are linked with particularly high biodiversity and biological productivity.

In the Arctic, Serreze *et al.* (2000) have argued that observational evidence remains insufficient to determine whether the mass balance of the Greenland ice sheet has changed. However, several studies offer evidence of declining sea ice extent and thickness over the period 1978–1998. Importantly from a climate change modeling perspective, Vinnikov *et al.* (1999) found that the observed trends agree with transient simulations of sea ice extent conducted by GFDL-R15 and HadCM2 GCMs. Johannessen *et al.* (1999) determined that there had been a 3 percent reduction in sea ice cover and a 7 percent decline per decade in the area of multiyear ice. In addition to signs of diminished sea ice extent and seasonal duration, Rothrock *et al.* (1999) analyzed sea ice thickness data acquired from submarines during the two periods of 1953–1976 and 1993–1996, finding that the mean ice thickness at the end of the melt season had decreased an average of ~1.3m (42%) in the Arctic Ocean.

Arctic sea ice scenarios have projected 40–100 percent loss of summer sea ice by the end of the 21st century (US National Assessment Team 2000). Trends of decreased seasonal sea ice in the Northwest and Northeast Passages have led to predictions that this sea route may become viable for international commercial shipping during the next 50–100 years (Kerr 2002). This would substantially reduce shipping costs, while introducing the potential for pollution, smuggling, and the introduction of new diseases and alien species (Huebert 2001).

Permafrost

Kettle *et al.* (1997) estimated that the extent of land in Canada underlain directly by permafrost would decline 43 percent under a doubling of atmospheric CO_2 levels. The southern limits of discontinuous and continuous permafrost were projected to shift northward by 300 km in many areas. Camill and Clark (2000) indicate that, in the discontinuous permafrost zone, vegetation has an important buffering effect for permafrost against climate variability. Rapid change in vegetation cover (through enhanced disturbance regimes—fire, insect, disease cycles) could therefore accelerate permafrost thaw rates. The potential for large-scale thawing of permafrost as a result of climate warming has important implications for Arctic ecosystems and human settlement. Osterkamp and Romanovsky (1999) and Pavlov (1994) provide evidence of warming permafrost in areas of Alaska and northern Russia respectively. Melting permafrost can form thermokarst topography, which substantially alters local hydrology and existing vegetation. For example, in an area of central Alaska, Jorgenson *et al.* (2001) found that permafrost degradation led to a decline in birch forest of 35 percent and a corresponding increase in fens of 29 percent between 1949 and 1995.

Radiation

Finally, changes in the radiation climate are important in two contexts. First, insolation is a function of variables such as cloud and snow cover, where changes have clear implications for primary production. Second, at high latitudes in both polar regions, changes in exposure to damaging shorter wavelength ultra-violet-B radiation are related to the phenomenon of seasonal depletion of the protective ozone layer. The formation of the spring Antarctic ozone hole has received much attention since first reported (Farman *et al.* 1985) and, more recently, some ozone depletion has been reported at Arctic latitudes (Müller *et al.* 1997). Ozone loss allows greater penetration of short wavelength UV-b radiation to terrestrial and shallow marine habitats, while leaving UV-a and visible light levels unaffected. The biological significance of Antarctic ozone loss may not lie with the maximum levels of UV-b experienced (which are little different from those normally measured in midsummer when the ozone hole is not present), but rather that they occur earlier in the season and that lower (more damaging) wavelengths penetrate at levels which are higher than normal for this time of year.

BIOLOGICAL CHANGES

Climate characteristics influence species distributions, often connected with species-specific physiological thresholds. Species can be seen as having "climate envelopes," which will move polewards or upwards with climate amelioration. The process of movement will be limited by dispersal, hence such shifts are more likely to be observed in the Arctic, where there is continuous connection of both terrestrial and marine habitats along a south-north gradient, than in the geographically isolated Antarctic. Such logic underlies reconstructions of northern European Holocene climate variations using beetle community composition as a proxy (e.g., Coope *et al.* 1998). As summarized by Walther *et al.* (2002), it is clear that such changes in species ranges have occurred affecting a range of taxonomic groups during the warming of recent decades.

Marine environment

In both polar regions, a number of highly visible vertebrate species have varying degrees of dependence on pack or fast ice. Thus, emperor penguins (*Aptenodytes forsteri*) form their rookeries on winter fast ice. Variations in sea surface temperature and fast ice extent are critical factors influencing this species' survival and breeding success. Increased sea temperature in the foraging grounds leads to greater adult mortality. Late ice break-up results in parent birds spending more time and using more resources to reach open water to forage, while early break-up may lead to destruction of the rookery and complete loss of a year's chicks (Barbraud & Weimerskirch 2001). Reduction in winter ice extent west of the Antarctic Peninsula has also been implicated in shifts in the relative ranges of Adélie (*Pygoscelis adeliae*) and chinstrap (*P. antarctica*) penguins (Fraser *et al.* 1992), as the former is more closely associated with pack ice. Over a longer timescale, the formation or loss of multi-year sea ice is thought to control the southern distribution of Adélie penguin colonies (Emslie *et al.* 1998). Although relevant data do not appear to be available, a number of Antarctic seals and whales are also closely associated with pack or fast ice for much, if not all, of their life cycle; reductions in populations of all of these species would be expected with reduced ice extent and duration.

The presence of sea ice is an important factor affecting both marine and terrestrial ecosystems in Hudson Bay and other coastal areas of Canada. While a longer open water period will increase the season for phytoplankton production and marine productivity at higher trophic levels, species such as ringed seal (*Phoca hispida*) and polar bear (*Ursus maritimus*) that depend on sea ice as habitat will be adversely affected. In the Hudson Bay region, research by Stirling and Derocher (1993) indicated that, for every week reduction in the time that female polar bears spend hunting on sea ice, they come on land 10 kg lighter and, hence, that a 1°C annual warming scenario may translate into a 22 kg loss of body weight. Notably, annual warming in the Hudson Bay region is projected by a range of SRES-forced GCMs to be in the 3–6°C range by the 2050s (Canadian Climate Impacts Scenarios 2002). The reduction in female body weight index and average births of polar bears in Western Hudson Bay over the past 20 years may be an early indicator of climate-induced stress (Stirling *et al.* 1999). It is also possible that other species such as bearded seals (*Erignathus barbatus*) and spotted seals (*P. largha*) may increase and become more important in the diet of polar bears (see Stirling 2002 and references therein), although these predictions have yet to be confirmed in detail.

Changes in patterns of movement of large oceanic water masses may lead to altered water temperatures and concentrations of prey species in the vicinity of important breeding populations of marine vertebrates on Southern Ocean Islands. If these changes represent consistent trends rather than stochastic variations, they are likely to have measurable effects on population numbers. Such a link has been drawn between increased surface water temperatures and long-term population declines in rockhopper penguins (*Eudyptes chrysocome*) at widely separated locations in the southern Indian Ocean and the New Zealand sub-Antarctic islands (Cunningham & Moors 1994; Guinard *et al.* 1998).

If climate change affects important ecological processes such as recruitment (Walther *et al.* 2002), major consequences may result both in ecological and human economic contexts. Examples of this exist in both Arctic and Antarctic marine environments. In the Bering Sea, the interaction of atmospheric circulation with ocean currents varies the extent to which juvenile fish (walleye pollock, *Theragra chalcogramma*) are moved away from adults, altering the intensity of cannibalism and, hence, year class strength (Wespestad *et al.* 2000) of this important prey species, and impacting the whole Bering Sea food web. In the Southern Ocean, a reduction in winter sea ice formation near the Antarctic Peninsula is thought to lead to failure in reproduction of krill (*Euphausia superba*) and subsequent recruitment over a much wider area. Krill is a key species in the marine food web as well as being a significant human fishery target, and recruitment failure has been linked with failure in reproduction in a range of seal, penguin, and other bird species (see Loeb *et al.* 1997).

Terrestrial environment

The most visible correlate of climate amelioration in the Antarctic is the local colonization and rapid population expansion seen in the two native flowering plants, *Deschampsia antarctica* and *Colobanthus quitensis*, at many sites on the Antarctic Peninsula (Smith 1994). These changes have been assisted by the existence of soil propagule banks and an increase in the successful completion of sexual reproduction (seed maturation). Similar increases also occur in bryophyte populations, which possess both sexually and asexually produced propagules for dispersal, and are again prominent in the soil propagule bank. These population changes involve mainly locally occurring species, although a small number of examples exist of species new to a given locality. Aerobiological studies demonstrate how exotic biological material, such as spores, may arrive in the Antarctic (Marshall 1996). This is also clearly shown by the Antarctic occurrence of lower latitude species only in locations associated with geothermal activity (Convey *et al.* 2000). There are no examples of invertebrate species becoming established on the Antarctic continent via natural colonization. However, there are many records of migratory insects arriving at sub-Antarctic islands, and the moth *Plutella xylostella* has recently become established on Marion Island (Chown & Language 1994).

In the more complex terrestrial habitats of northern latitudes, changes in species ranges inevitably lead to major visible alterations of habitat and trophic structure. Vegetation modeling studies predict that the treeline in northern Canada will shift up to several hundred kilometers north under projected climate change scenarios. As part of the IPCC Regional Impacts Special Report (Neilson 1998), global vegetation distribution modeling using MAPSS and BIOME3 equilibrium biogeography models and climate change scenarios from six GCMs produced large shifts in cold-limited vegetation boundaries, with the tundra biome decreasing in area by 33–60 percent. Vegetation modeling in Canada (Lenihan & Neilson 1995; Rizzo & Wiken 1992) also projected massive losses of mainland tundra.

Movement of treelines towards higher altitudes has been reported both in Europe and New Zealand, while an increase in shrubby vegetation has been documented in Alaska (see Walther *et al.* 2002). However, Scott *et al.* (1997) have also argued that, while projected climate change this century will produce rapid increases in growth and higher rates of recruitment (increasing forest infilling), the northward expansion of tree species would experience a significant lag because of limited seed dispersal and poor soil conditions. This hypothesis is consistent with the findings of MacDonald *et al.* (1998), who concluded that, although growth rates of spruce had responded positively to higher temperatures in the 1980s, there had been no significant northward extension of spruce or continuous forest in central Canada. Also in the Canadian Arctic, correlated changes in distribution of the red fox (*Vulpes vulpes*) and the Arctic fox (*Alopex lagopus*) have been observed, with the former extending its distribution northwards as the latter retreats (Hersteinsson & MacDonald 1992).

Traditional environmental knowledge in the Arctic

In addition to scientific monitoring, the traditional environmental knowledge (TEK) possessed by indigenous peoples is another critical body of information relevant to the detection of environmental change in the Arctic. Indigenous peoples of the Arctic (Aleuts, Inuit, Athabascans, Dene, Saami) have an inextricable link to the land and wildlife and are keen observers of environmental change.

Two TEK studies have been conducted in Canada. The International Institute for Sustainable Development (Ashford & Castledon 2001) documented the observations of the Inuvialuit people of Sachs Harbour (Banks Island, Canada). Elders indicate that the weather has become less predictable over the past two decades and, in 1985, thunder and lightning were observed for the first time. Their harbor freezes up to a month later in the fall, and multi-year ice is located much further offshore in the summer, making the seal hunt more difficult. In winter, sea ice has become much more unpredictable, creating a travel hazard even for the most experienced hunters and altering hunting patterns. New species have been reported on Banks Island, including robins, red and black foxes, and new types of insects. Salmon and whitefish have also been caught for the first time in the last decade. The people of Sachs Harbour also describe changes in the behavior and timing of migratory birds. Melting permafrost has made overland travel more difficult and caused a number of slope failures along the coastline. A separate regional TEK study of environmental change in the Hudson Bay region of Canada (McDonald *et al.* 1997) also reported changes in sea ice conditions, weather patterns, and the populations, distribution, health, and behavior of wildlife.

Components of both studies corroborate scientific monitoring (in some instances predating them) and are consistent with impacts anticipated from global climate change. Furthermore, each study revealed significant changes are occurring, to the extent that the TEK developed over centuries has begun to fail (e.g., the safety of ice conditions). The long-term and potentially devastating impacts of changes in wildlife populations and migration patterns on the food supplies of Arctic indigenous peoples remain poorly understood.

CONSERVATION LESSONS AND FUTURE BIODIVERSITY IMPACTS

Some of the most visible biological consequences of climate change in both polar regions, and the most challenging to be faced in the context of conservation, are likely to be associated with changes in extent or duration of sea ice. Sea ice constitutes a major ecosystem in its own right, with a range of dependent species, as well as having key links with other terrestrial and marine systems. Both north and south, sea and pack ice dependent vertebrates (species of seal, whale, penguin, polar bear) may face a considerable threat to their continued existence. Large changes in the importance of different trophic links (i.e., changes in prey species) could take place as sea ice reduces, with unknown and unpredictable ecosystem consequences. Potential wider impacts away from the sea ice zone itself are already illustrated (above) by the changes documented in Southern Ocean krill recruitment related to sea ice extent. Such changes will have an indirect impact on human society, in this case through economic consequences on fisheries. Considerably greater direct societal impacts will be felt by indigenous human communities in the Arctic, where many elements of a traditional way of life are likely to be lost, generating unpredictable social consequences.

Natural processes of colonization are likely to become increasingly insignificant in comparison with human impact on regional biodiversity through assisting dispersal of alien biota throughout the world. Indeed, the fragmentation of natural habitats associated with human population growth and economic development may act to further reduce the effectiveness of natural colonization mechanisms in response to climate change. Climate change may also reinforce the effects of human exploitation and pollution, effectively pushing species beyond their limit for recovery and providing further negative impacts on biodiversity. The interaction between a range of environmental stress changes may lead to greater, or different, biological consequences than predicted when a single variable is considered. For instance, the combination of anthropogenic pollution and climate change is one possible explanation for reproductive anomalies in polar bears (see Wiig *et al.* 1998).

Even in the isolated terrestrial habitats of the Antarctic, human influence is noticeable although currently it is mostly restricted to the sub-Antarctic. For instance, nearly half of the vascular flora of South Georgia consists of grasses and weeds introduced from the Falkland Islands, South America, and Europe. While some of these introductions are restricted to single plants, others—such as the grass *Poa annua*—now cover large areas of ground and have taken over from native species (Smith 1996). Given the relative ease of access and greater diversity present, it is perhaps surprising that only about five percent of the vascular flora of Arctic Svalbard is thought to have been introduced by humans (Rønning 1996). The contrasting contributions of alien species to sub-Antarctic and Arctic floras may simply be a reflection of the greater ease of post-glacial colonization of the less isolated northern terrestrial habitats. However, in the absence of introduction of successful competitors, some Antarctic terrestrial ecosystems will benefit from climate amelioration, at least in the short to medium term. Thus, those of the maritime and continental Antarctic, currently severely limited by thermal energy constraints and availability of water, will experience increases in growing season, area, and productivity.

Deliberately or accidentally introduced vertebrates are, or have been, present on most sub-Antarctic islands, with consequential major alterations to vegetation and impacts on invertebrate and ground-nesting bird populations. Many invertebrate introductions to sub-Antarctic sites are also documented. While less visible than vertebrates, these invertebrate species also may have serious impacts on trophic interactions of the natural communities, even leading to local displacement of native species. At present, there are very few examples of long-term establishment of alien animals or plants in the more extreme environments of the Antarctic Peninsula or continent.

Increased freedom and frequency of human travel are likely to increase the rate of transfer of alien species into high latitude sites, while climate amelioration will increase their likelihood of successful long-term establishment after arrival. It is already known that, when the problems of long-distance colonization are overcome, a wide range of both plants and animals have the physiological or ecological capacity to establish and multiply under polar conditions. In contrast with the south, at northern latitudes natural colonization is generally expected to occur through a gradual northwards extension of distributions in concert with climate amelioration. One logical end point of this process is a progressive restriction of Arctic (and also Alpine) endemic species, through increased competition, as appears to be happening already in some parts of the Arctic fox distributional range. Such a process would appear to be intractable in a conservation context in the long term, if current climate trends continue.

Human exploitation of marine resources may be expected to have increasing impacts on both marine and terrestrial biodiversity. For example, fishing of long-lived groundfish species may lead to ecological change in the form of their replacement by cephalopods with much more rapid life cycles (Caddy & Rodhouse 1998). On land also, specatacular consequences may ensue for the biodiversity of terrestrial ecosystems, at least at a local scale. This is illustrated by the recent very rapid recovery in populations of Antarctic fur seal (*Arctocephalus gazella*) from near-extinction to pre-exploitation levels, through the cessation of hunting and subsequent absence of feeding competition from whales, themselves overexploited. The resulting range expansion has led resting and moulting seals to occupy terrestrial and freshwater habitats that have been previously unoccupied, with the associated trampling and increased nutrient input leading to destruction of these habitats (Smith 1988).

It is important to note that the polar regions have relatively species-poor ecosystems, more vulnerable to non-linear changes resulting from the loss of keystone species than regions with higher biodiversity. The multiple additional stresses imposed on polar ecosystems by climate change, combined with the potential for more pervasive impacts associated with increased economic development and human contact, heighten the likelihood of ecological surprises yielded by compounded perturbations (see Paine *et al.* 1998).

Some have referred to the polar regions as the “canary in the mine” of global climate change, places where the physical and ecological manifestations of changing climate would first be observable and thus signal a warning to the rest of the planet. Over the past 20–30 years, both scientists and indigenous populations have observed changes in polar environments that are consistent with those anticipated under climate change. The wide range of projected changes in physical and biological systems and the complex interactions between them make predictions for polar biodiversity highly uncertain and will pose a momentous challenge to conservation policy and planning. The implications for indigenous populations in the Arctic are clearer, and are succinctly summarized by Rosemarie Kuptana (a long-term resident of a small Inuit settlement in Canada’s Northwest Territory) in her impassioned address to COP-2 in Geneva in 1996: “Inuit have survived and flourished in the Arctic by the development of skills over thousands of years…climate change threatens our ability to practice sustainability and to survive as an Arctic people.…It is possible that a profound disruption in traditional lifestyle could occur within two generations.”

Major initiatives such as the forthcoming Arctic Climate Impact Assessment (scheduled for completion in 2004), the cross-disciplinary integration of studies of Antarctic Peninsula climate change (Domack *et al.* in press), and the integrated SCAR RiSCC (Regional Sensitivity to Climate Change in Antarctica) biological research program (http://www.nioo.nl/projects/riscc/) will provide new insights into the implications of climate change and stimulate the establishment of a climate change science agenda for the polar regions. Without an enhanced commitment to ecosystem science and effective monitoring networks in polar regions, we may lose our ability to recognize when the canary has stopped singing.