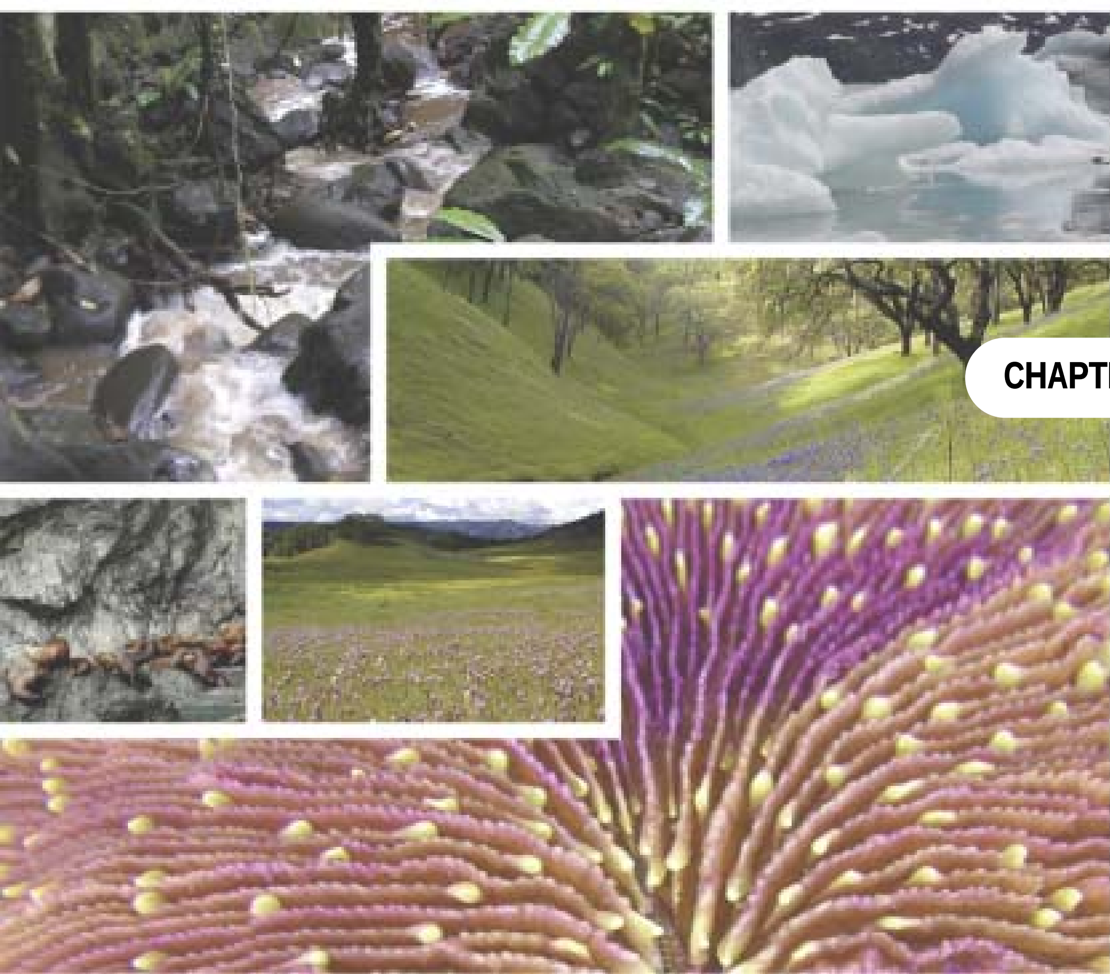
BUYING TIME:

# A User's Manual for Building Resistance and Resilience to Climate Change in Natural Systems



## CHAPTER 4: Arctic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# Building Resilience in Arctic Ecosystems

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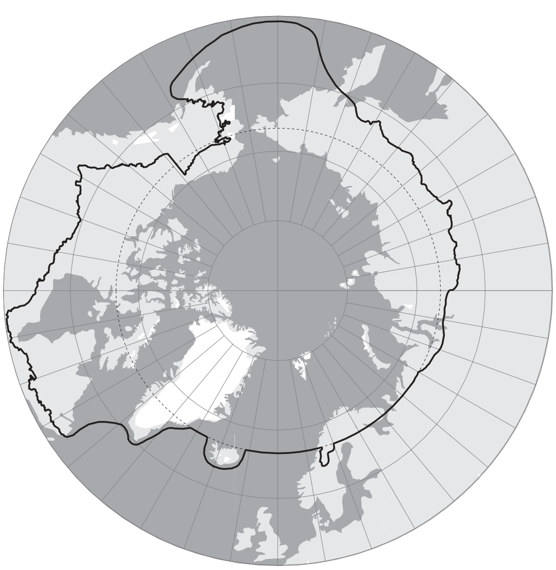
**IN THE ARCTIC, CLIMATE CHANGE** is expected to be among the most rapid and extensive of any region on Earth. Warmer temperatures and melting ice dramatically altering the structure and function of arctic ecosystems over the next century. However, the impacts of climate change cannot be considered in isolation from other forces of change affecting the region. For example, while arctic habitats are relatively unmodified by human activities, economic development in the region depends on the exploitation of both living and non-living resources. As a consequence, there is added potential for impacts on biodiversity.

The challenge this chapter faces is to provide suggestions for action that can be taken in response to cummulative impacts, the details of which are poorly understood, while the effects are likely to be widespread and substantial.

## Crucial Aspects of Arctic Ecosystems

While various definitions exist to describe the geographical extent of the Arctic, we use the boundary defined by the Conservation of Arctic Flora and Fauna (CAFF) working group in this discussion (Figure 1). It encompasses the ecosystems found from the forest-tundra transition zone northward on land, and in adjacent marine areas north to the arctic basin.

**Figure 1: The CAFF boundary is used in this discussion to delimit the Arctic. Source: CAFF.**



Since the Arctic is a vast geographical area distinguished by a variety of landforms and complex interactions between land, water and the atmosphere, the characteristics of biodiversity in arctic ecosystems are unique (Hansell et al., 1998). Arctic ecosystems contribute significantly to the diversity of life on Earth since they contain many species, habitats, ecological processes and biological adaptations not found elsewhere on the planet.

Relative to other ecosystems, the Arctic is species-poor. On an evolutionary time scale, the terrestrial ecosystems are very young and rapidly evolving (Jonasson et al., 2000). Many species in the Arctic live within marginal habitats at the edge of their ranges. A species at the edge of its range tends to be highly sensitive to environmental conditions, so the abundance and distribution of its population can undergo wide swings as conditions change. While few endemic genera and species are found in the Arctic, there are relatively more endemic subspecies, and the genetic diversity within a species can be high (Jonasson et al., 2000). The few endemic species that are found in the Arctic are adapted to a range of habitats and food resources that otherwise would be occupied by competing species if they were present.

The dominant feature of the marine environment is sea ice. Pack ice is present at the North Pole year round permitting limited light penetration into the water column and resulting in low primary production. Around the periphery of the Arctic Ocean and in the marginal shelf seas, ice forms and melts annually. Seasonal ice cover varies from year to year. The annual release of freshwater during the spring melt creates a highly productive environment. Large numbers of organisms from all trophic levels can be found along ice edges, leads and polynyas where the interaction of ice, sunlight and water currents is greatest (Stirling, 1997).

These highly productive waters sustain important fishery resources. Fisheries in northern waters account for about 47% of total global production (FAO, 2002). The western Bering Sea has the largest fish biomass for Pacific cod and cod-like fishes, the world's largest pollock fishery is in the eastern Bering Sea, and the Barents' capelin stock is potentially the largest in the world (Duda and Sherman, 2002; NOAA et al., 2003). Other commercially valuable species found in northern waters include herring, halibut, salmon, and shrimp.

The Arctic has been home to indigenous peoples for millennia. Their historical patterns of resource use reflected the environmental conditions of the day. These conditions often varied from season to season and year to year, and settlement patterns correspondingly adapted to resource availability. Today, the traditional use of living resources for hunting, trapping, fishing and reindeer husbandry remains an important part of the culture of many arctic indigenous peoples. The importance of this special relationship to land and resources in the Arctic is reflected in the growing number of political and institutional arrangements at the local, national and international levels. Home rule in Greenland, land claims in Alaska and parts of northern Canada, and the continuing discussions of such matters in Scandinavia and Russia, has led to varying degrees of self-government, land ownership, and influence over ecosystem and resource management decisions by indigenous peoples in the Arctic.



As part of their natural function, arctic ecosystems provide goods and services that are crucial both locally and globally. To maintain the flow of ecosystem goods and services it is critical to maintain ecosystem function including the cycling of water, the cycling of nutrients, the flow of energy, and biodiversity (Pimm, 1986). In the Arctic, local goods and services include the resource base that provides food, supports cultural traditions, opportunities for recreation, research and education, economic activity and energy resources. The Arctic is also intimately linked by air masses, ocean currents, river systems and migratory species to other ecosystems around the globe, thereby providing global goods and services. Some examples of these include: the storage of 40% of the world's reactive soil carbon, global heat transport through ocean currents and energy exchanges with the atmosphere, freshwater input into the Arctic Ocean which may influence the thermohaline circulation of the global oceans, and fisheries contributions to the global food supply (IPCC, 2001a). The Arctic is a source of potentially large feedbacks to the global climate system. The net effect or time scale of these feedbacks is poorly understood; nevertheless, the impacts of ecosystem changes on the ability of arctic ecosystems to provide these various goods and services will be felt across the world.

## Stresses Due to Factors Other Than Climate Change

The influence of human activity can now be detected in even the remotest regions of the Arctic. Climate change is only one of the many factors affecting the future of arctic ecosystems. Industry, infrastructure development, and large-scale resource exploitation are advancing in arctic ecosystems. Major economic and community development benefits are expected in connection with these activities. At the same time serious threats to the cultural, spiritual and environmental heritage of the Arctic are also likely.

Forces of change in arctic ecosystems include overfishing, shipping, the exploitation of natural resources, pollution and the long-range transport of contaminants, and increased ultraviolet (UV) radiation due to the depletion of stratospheric ozone (AMAP, 2002; CAFF, 2001; IPCC, 2001b). These non-climate stresses may impede the ability of arctic ecosystems to respond to climate change.

### OVERFISHING

Today, global production from capture fisheries and aquaculture is currently the highest on record and is very important for global food security. While recent increases in capture fisheries production have come mainly from the southeast Pacific, fleets based in the eight arctic countries are among the top producers and account for more than 14% of global fish landings (FAO, 2002).

Unfortunately, the number of populations that are overfished, as well as the indirect effects of fisheries on marine ecosystems through bycatch and habitat destruction, indicate that management has failed to achieve its principal goal of sustainability (Botsford et al., 1997). Since 1975, several stocks in the Barents Sea have suffered from overfishing leading to substantially reduced yields in the 1970s and 1980s. While strong fisheries management measures have since been put into place, actual catches of fish have frequently exceeded the advised limits (Nakken, 1998).

In addition, certain harvesting methods pose a serious threat to non-target species. Extensive bottom trawling for cod and prawns, as well as sea-floor dredging for scallops, takes place throughout the Arctic. Such fishing techniques can alter the structure and diversity of complex benthic communities by leveling the seafloor, removing slow-growing sedentary organisms, and increasing suspended sediment loads.

## SHIPPING

Shipping has a significant impact on the marine environment through atmospheric emissions, noise, leakage of antifouling agents, and operational discharges of sewage, garbage, sludge, bilge, solid oil and waste oil (Table 1). Discharges resulting from accidental events such as collisions, groundings, and fires have major environmental impacts. Among wildlife, the biophysical conditions of the Arctic have resulted in specialists that are long-lived, slow to mature, and have conservative reproductive strategies. The loss of mature adults has a disproportionate impact on the ability of the population to renew its numbers (Musick, 1999). Large oil spills and similar accidents can be devastating because mature adults are the most impacted, leaving behind a younger population that is slow or unable to recover.

**Table 1: Maritime operations and their impact on the marine environment. Source: after PAME (2000).**

| Activity/operation | Issue of concern |
|---|---|
| Onboard production of oily wastes, sewage and garbage | Illegal discharges to sea |
| Discharge of ballast water of foreign origin | Biodiversity impacts due to competition or predation from introduced species |
| Loading and unloading activities | Increased risk of discharges of oil and bilge water |
| Tanker traffic | High accident potential |
| Heavy bunker oil as cargo and fuel | Substantial negative impacts when discharged |
| Operation in areas of high ice concentration | Increased accident risk and greater risk of marine pollution |
| Tugging / Towing | Increased accident risk |
| Cruise / Passenger vessels | Large-scale operational discharges plus increased accident risk near ice |

Climate change will favor increased shipping along high-latitude routes (IPCC, 2001b). Moreover, exotic organisms and pathogens carried in ships' ballast water have devastated native flora and fauna all over the globe, and in the Arctic where most organisms are likely to be at the margins of their thermal tolerances, warming may give exotic species increased opportunities to survive, spread, and form problem populations.



### RESOURCE EXPLOITATION

If not properly managed, commercial exploitation of the Arctic's natural resources—including fisheries, wildlife, oil and gas, and minerals—can seriously threaten biodiversity, ecosystem function, and traditional cultural practices. Cumulative environmental effects assessment recognizes that the effects on the environment from individual human activities can combine and interact with each other to cause effects that may be different in nature or extent from the effects of the individual activities themselves (Hegmann et al., 1999).

The National Research Council in the United States (2003) undertook a study of the cumulative environmental effects of oil and gas activities on Alaska's North Slope since 1965. The NRC's findings indicate that Alaska's environment and culture have been significantly affected by oil infrastructure and activities. Effects have accumulated from road building, damage from off-road travel, interference with subsistence activities, and social changes in local communities—although these are noted to be both positive and negative.

Animal populations have been affected in a number of ways. Bowhead whale migrations seem to have been displaced by the noise of seismic exploration. In addition, garbage and food produced in oil field operations have resulted in higher than normal densities of predators (e.g. polar bears, arctic foxes, and glaucous gulls) which prey on the eggs, nestlings and fledglings of birds. As a result, the reproduction rates of some bird species in industrial areas, including various geese, eiders and shorebirds, are in some years insufficient to balance death rates (NRC, 2003).

In the Arctic there is a significant degree of overlap between biologically important areas and the continental shelf where considerable reserves of hydrocarbons exist (Stirling, 1997). Threats associated with the operation of offshore facilities include the risk of blowout, discharges of produced water, chemicals and drilling muds, leaks from pipelines, sea floor disruption, and increased shipping to and from installations and processing facilities. A large oil spill in marine waters would likely have substantial effects on animal populations because current cleanup methods can remove only a small fraction of spilled oil under conditions of broken ice. At present there is just one truly offshore facility operating in the Arctic, the Northstar facility in Alaska, however planning for a number of new facilities is currently underway.

### CONTAMINATION AND POLLUTION

Environmental contaminants occur at relatively high levels in some arctic species and, in many cases, the long-term biological and ecological effects are not yet known. Local pollution from industrial activities, such as mining and oil and gas development, can negatively affect the environments surrounding these developments. However, in the mid-1980s, persistent organic pollutants (POPs) were discovered to be accumulating in arctic food webs (Downie and Fenge, 2003). These include PCBs, pesticides like DDT, dioxins, furans, and brominated flame retardants which are transported to the Arctic through air, river and ocean currents from points of origin further south. POPs accumulate in the body fat of animals, so marine mammals and scavengers at higher trophic levels are most susceptible. Mammals such as the polar bear, arctic fox, killer whale, northern fur seal, and birds such as the glaucous gull, all tend to carry high contaminant loads (CAFF, 2001).

Mercury, lead and cadmium are all present in the Arctic. According to the most recent assessment of arctic pollution, there is a trend of increasing mercury levels in marine birds and mammals in the Canadian Arctic and possibly also western Greenland; cadmium levels in some seabirds are high enough to cause kidney damage; and while levels of anthropogenic radionuclides in the Arctic are declining, releases from reprocessing plants have resulted in increases in levels of technetium-99 and iodine-129 in the European Arctic (AMAP, 2002).

### OZONE DEPLETION

The release of the synthetic chemicals called chlorofluorocarbons (CFCs) into the atmosphere, through various industrial processes and other human activities, causes ozone depletion in the stratosphere. The problem is most pronounced over polar regions during spring because of cold temperatures and lack of sunlight. For each 1% decrease in stratospheric ozone, the amount of UV-B radiation reaching the Earth's surface increases by 1.5% to 2%. Enhanced UV-B radiation can have subtle but long term impacts on ecosystem processes that reduce nutrient cycling and indirectly decrease productivity (Fergusson and Warlde, 1998).

Since the signing of the Montreal Protocol in 1987, which banned the use of CFCs, the rate of ozone destruction has slowed to around 3-5% per decade. There is preliminary evidence of a reversal in the Earth's ozone decline (Newchurch et al., in press), however, global warming may interfere with ozone recovery by altering the way in which air mixes in the lower stratosphere. Model simulations suggest that warming over Northern Hemisphere continents could delay arctic ozone recovery (Shindell, 2003), thus posing a longer term threat of ecosystem damage due to increased UV radiation.

## Present and Future Stress Due to Climate Change

The Arctic is already demonstrating clear evidence of change consistent with what is expected to result from warming temperatures, and matches trends that have been projected by general circulation models. According to the most recent assessment carried out by the Intergovernmental Panel on Climate Change (IPCC), extensive land areas in the Arctic show a 20th century warming trend in air temperature by as much as 5°C accompanied by an increase in precipitation (IPCC, 2001b). As a result, regional studies have been undertaken to assess the impacts of climate change in the Mackenzie Valley (Cohen, 1997), Bering Sea (Weller and Anderson, 1999), and Barents Sea (Lange, 2002). Recognizing the general vulnerability of arctic ecosystems, the Arctic Council[3] has commissioned the Arctic Climate Impact Assessment (ACIA). The goal of ACIA is to gather knowledge on climate change and ultraviolet radiation in order to provide reliable information to governments and people; environmental, human health, social, and economic impacts will be included in the assessment (ACIA, 2000). A peer-reviewed volume synthesizing the current science of arctic climate change will be published late in 2004.

Early results from ACIA show that while the greatest warming is expected over the Arctic Ocean, by 2070 temperatures will on average increase by 3.4°C for the area north of 60° latitude; this is double the projected global average. Changes of this magnitude will irrevocably alter arctic ecosystems, leaving behind a natural world that will be nearly unrecognizable to today's arctic residents.

Patterns of climate change within the Arctic are complicated, as they vary in rate and magnitude by region and by season. Some anticipated impacts of climate change in terrestrial and marine ecosystems are summarized below, as are vulnerabilities.

### TERRESTRIAL ECOSYSTEMS

Arctic landscapes have already begun to reveal the impacts of climate change. Regions underlain by permafrost have decreased in extent. A general warming of ground temperatures and the thickening of the active soil layer has been observed in many areas, particularly at the southern margins of the Arctic close to and south of the treeline (IPCC, 2001b).

Important ecological changes that appear to have been triggered by warming are also being documented in terrestrial ecosystems across the circumpolar north. Reduced nutritional value of caribou and moose browse, decreased water availability, and increased forest fire tendencies have been detected (Weller and Lange, 1999). The Arctic Transitions in the Land-Atmosphere System (ATLAS) program has recorded an advance and infilling of trees at the treeline, as well as an expansion of shrubs in the northern portion of the Arctic (Chapin, 2002). These vegetation changes may also explain some of the summer warming that has recently been recorded in northern Alaska and the other regions of the Arctic.

The effects of climatic warming on local environmental conditions have not gone unnoticed by the indigenous communities living in the Arctic. Krupnik and Jolly (2002) documented observations of change from the perspective of twenty-three indigenous communities. Elders report that they are seeing species of birds and animals farther north than previously recalled, and new species are appearing that have never been seen before. Elders also note that the weather is more unpredictable than it used to be (Jolly et al., 2002).

3 The Arctic Council (www.arctic-council.org) is a high-level intergovernmental forum established by the countries whose borders cross the Arctic Circle: Canada, Denmark, Finland, Iceland, Norway, the Russian Federation, Sweden, and the United States. Decisions and priorities are set with active participation and full consultation of arctic indigenous representatives.

Changes in arctic climate are expected to continue throughout the 21st century and persist for many centuries to come, bringing with them major physical, ecological, sociological and economic transformations (IPCC, 2001b). The greatest changes in temperature are projected to take place during the winter months; extreme cold temperatures are expected to be less severe and occur less often. Precipitation in terrestrial ecosystems will increase by 10-20% in summer months, and by 5-80% in winter months (IPCC, 2001b). In almost all regions, these projections are well beyond the range of variability of the current climate patterns.

As warming occurs, there will be changes in species compositions with a tendency for poleward and elevational shifts in species assemblages, the establishment of new assemblages of species, and the loss of some polar species (IPCC, 2001b). Vast areas of the Arctic may develop entirely different ecosystems from those that exist currently (Everett and Fitzharris, 1998). Ecosystem models project that the area of tundra will decrease by two-thirds from its present size, due to an expansion of the boreal forest (Everett and Fitzharris, 1998). Vegetation changes that result from warming are expected to further enhance regional temperature increases in the Arctic. Chapin (2002) has found that altering the vegetation of the tundra from its current state of no shrubs to one of being shrub-dominated would increase mean July temperatures by 1.5 to 3.5 °C.

Modifications to wildlife populations are also projected to result from warmer temperatures in the Arctic, including changes in population size, structure, and migration routes. A consensus has not been reached on the probable impacts of climate change on ungulates. On the one hand, changes in the timing and location of food sources, an increase in parasites and insect-borne disease, and more insect harassment may lead to declines in animal populations such as caribou and muskox (Gunn, 1995). On the other hand, caribou appear to be highly resilient to changing environmental conditions because they are generalist feeders (Callaghan et al., 1998). Insects will benefit from a warmer Arctic, since many insects are constrained from expanding north due to cold winter temperatures (Parmesan, 1998). Permafrost melting may substantially alter ecosystems in situations where the melted permafrost results in landslides, leading to poor water quality that is detrimental to fish and other wildlife.

Small increases in temperature will amplify the melting of snow and ice, the hydrology of the North is particularly susceptible to warming since snow and ice drive virtually all of the major hydrological processes and related aquatic ecosystems in the Arctic (IPCC, 2001b). The runoff regime is expected to be driven increasingly by rainfall, with less seasonal variation in runoff. Because the ice cover on lakes and rivers will be thinner, freeze up later, and breakup earlier, the rates of primary productivity in aquatic ecosystems will be affected (Rouse et al., 1997). Also related to hydrology is the ability of arctic wetlands to act as a source or sink for carbon dioxide ($CO_2$) and methane. Peatlands may dry out because of increased evaporation and plant transpiration, thus becoming a source of greenhouse gases. With a doubling of atmospheric $CO_2$ concentrations, the southern boundary of peatlands in Canada is projected to move northward 200-300 km

(Gignac and Vitt, 1994). It is still uncertain as to whether the current status of northern peatlands as a global sink for $CO_2$ will change to a source.

MARINE ECOSYSTEMS

Arctic sea ice is both an indicator of climate change (through changes in extent and thickness) as well as a factor capable of influencing global climate through ice-albedo feedbacks and thermohaline circulation.

Sea ice is sensitive to temperature changes in the air above as well as in the ocean below. Winter maximum ice extent decreased by approximately 3% per decade through the 1980s and 1990s (Parkinson et al., 1999) while summer minimum extent has shrunk by 9% per decade over the same period (Comiso, 2002). New period-of-record minima have been reached several times over the past ten years (Serreze et al., 2003). Ice thickness, as observed from submarine transects, is estimated to have decreased by 40% between 1958 and 1997 (Rothrock et al., 1999), however, models have shown that these observations may not necessarily be true for the whole of the Arctic Ocean (Holloway & Sou, 2001).

Global warming, as forced by observed greenhouse gases and tropospheric sulfate aerosols, has been shown to cause reductions in the area covered by sea ice (Vinnikov et al., 1999). Probable changes in sea ice over the next century will alter the albedo of the surface, creating a feedback to the global climate system. Sea ice is important because it reflects more incoming solar radiation than the sea surface (i.e., it has a higher albedo). Therefore, a reduction in sea ice gives a positive feedback on climate warming. Significant changes in albedo over large areas also have the potential to produce a nonlinear, accelerated change (IPCC, 2001b).

The Arctic Ocean plays a significant role in the thermohaline circulation of the world's oceans. Most coupled ocean-atmospheric models show a weakening of thermohaline circulation from the North Atlantic by 2100 due to increased freshwater input from large arctic rivers and melting of the Greenland ice sheet. Although there remains considerable uncertainty as to the likelihood of an irreversible collapse of global thermohaline circulation, perturbations caused by increased freshwater inputs resulting in a reorganization of global ocean circulation can lead to abrupt climate change (IPCC, 2001b; Manabe and Stouffer, 1994).

The most recent assessment of circumpolar climate change indicates that primary production in marine environments will likely increase, species assemblages will shift northward, and ice-associated species will decline (IPCC, 2001b). It is important to recognize, however, that changes in water temperature, ocean currents and sea ice regimes will be non-uniform across arctic marine ecosystems and our understanding of marine biodiversity is insufficient to draw reliable conclusions about the probable effects. While impacts on individual species and species groups can be generalized by changes in physical habitats, food availability, and predator-prey relationships we should expect surprises along the way! Arctic marine food webs can be very complex but with only a few key species connecting the different levels, so changes in one trophic level can easily propagate to others.

*CHANGES TO PHYSICAL HABITATS*

The changes in physical habitats likely to result from different water temperatures and sea ice regimes will produce both winners and losers. Warmer temperatures will favor many fish species while the reduction of sea ice will have substantial impacts on marine mammals (IPCC, 2001b). Temperature appears to be a major determinant in several aspects of fish ecology and recruitment seems to be significantly better in warm years than in cold years; the same is true for growth (Loeng, 1989). Distributions of fish stocks that are determined by water temperature are likely to retract north while new species introductions will arrive from southern waters.

There will be negative consequences for marine mammals and seabirds dependent on ice for breeding and foraging (Tynan and DeMaster, 1997). Changes in the extent and type of ice cover will reduce the ability of polar bears to access prey, forcing them to move north or to stay on land for longer periods, thus increasing nutritional stress and lowering reproductive success (Stirling and Derocher, 1993). Polar bears in Wapusk National Park in western Hudson Bay are expected to be extirpated from the park (Scott and Suffling, 2000), although population numbers there are currently stable (Lunn et al., 2002). Ice-associated seals, especially ringed seals, are particularly vulnerable to changes in the extent and character of sea ice because they depend on ice for so many aspects of their life cycle (Tynan and DeMaster, 1997). True arctic cetaceans—bowhead, beluga and narwhal—spend much of their time in areas with significant amount of ice cover, having specialized in foraging for ice-associated species, and will likely see increased competition from migratory whale species (Kovacs, 2003).

*CHANGES TO FOOD AVAILABILITY*

Thinner ice cover will increase the solar radiation penetrating to the underlying water thereby increasing photosynthetic production. Earlier melting of the ice in spring will also extend the growing season, although this is dependent on local changes in upwelling, vertical mixing, and freshwater inputs (IPCC, 2001b). Of increasing interest are the effects that the Arctic Oscillation and North Atlantic Oscillation (AO/NAO) have on ecological processes (Stenseth et al., 2002). This atmospheric pattern accounts for major variations in weather and climate around the world and may affect the relative timing of food requirement and food availability known as the “match-mismatch hypothesis” (Cushing, 1990). The concept of match and mismatch is essential in food-web energy transfers: a match implies that the predators are located in the same space and at the same time as their prey, while mismatch implies that they are not.

Match and mismatch are important for primary production in terms of grazing (which drives food webs) and sedimentation (which controls nutrients) (Sakshaug, 2003; Sakshaug et al., 1992), however it can also be applied to the foraging success of many seabirds

(Kovacs, 2003). Seabirds are vulnerable to changes in prey availability particularly during the breeding season where a major constraint on breeding distribution is the distance between suitable nesting sites on shore and feeding zones at sea. If the temporal distribution of macrozooplankton shifts outside of the reproductive season, or their spatial distribution moves away from nesting proximity, then a mismatch occurs which can result in reproductive failure. Matches and mismatches are both likely to occur and suggests that the impacts of climate change on sea birds will vary geographically (Kovacs, 2003).

*CHANGES IN PREDATOR-PREY RELATIONSHIPS*

As individual species adjust to climate change, interactions among species will also change, especially in predator-prey relationships. If ice-inhabiting seals or walrus, for example, are forced to haul out on land to complete their molt or maintain proximity to food sources, they could be more exposed to new predators such as grizzly bears and wolves (Lowry, 2000). At the same time, studies of fish species in the Barents Sea show that changes in sea temperature may increase metabolic rates of cod and result in an increase in consumption of capelin by 100,000 tons per degree Celsius (Bogstad and Gjøsæter, 1994).

Some of the changes in predator-prey relationships may actually represent the natural adaptive capacity of the species themselves. In western Hudson Bay, for example, where direct impacts to polar bears have been observed due to a reduced feeding period in the late spring and early summer when seals—especially young ringed seals—are most available (Stirling et al., 1999), studies of alternative prey species are underway. These include assessments of species which may change in their relative and absolute abundance in relation to changes in sea ice and winter availability of open water. It is possible that populations of bearded and harbour seals may increase in western Hudson Bay as the amount of open water during winter increases. If so, these alternate prey species will become more important in the diet of polar bears there, potentially prolonging the survival of the western Hudson Bay population, at least in the short term while there is still enough annual ice present in the bay (Stirling pers. comm.).

VULNERABILITIES

Arctic ecosystems are often considered to be fragile. However, some arctic scientists are skeptical of this assessment since many arctic species are generalists that can survive over a wide range of conditions, making them highly disturbance adapted. The high genetic diversity and the vast numbers of sub-species within arctic populations are a reflection of how arctic species have adapted to local conditions over time. This natural adaptive capacity is an important characteristic that can help protect arctic species from the impacts of environmental changes. Endemic species, however, are vulnerable to both competition by species invading from the south and habitat loss; this is especially true for ice-associated species such as the walrus, ringed seal and polar bear. In addition, the Arctic's low-diversity, species-poor ecosystems have limited functional redundancy (CAFF, 2001). In such ecosystems, certain ecological roles may depend on relatively few species. As a consequence, while an individual species may be resilient to environmental alteration, the system as a whole may be vulnerable to the inability of a single species to adapt, especially if that species performs a key ecosystem function.

Climate change has the potential to have significant effects on commercial and industrial activity in the Arctic, resulting in both positive and negative economic impacts (IPCC, 2001b; Maxwell, 1997; Weller and Lange, 1999). Longer, warmer summers could increase tourism and the number of visitors to the region. Increases in precipitation could require costly upgrades and redesign of tailing dams and water diversion structures in the mining industry. In addition, an increase in the length of the annual frost-free period could affect access to many oil and gas exploration sites, currently reached via winter roads built on frozen ground. In areas where permafrost is susceptible to climate change, melting may cause the foundations of buildings to shift unevenly, the rupture and buckling of pipelines and storage tanks, and the structural integrity of older buildings, water supplies and waste disposal infrastructure to be threatened. Failure to retrofit old structures as conditions change will pose a risk of serious polluting events.

Due to the potential implications of global warming for traditional ways of life, resource development and conservation, the projected impacts of climate change are of considerable concern to residents of the North. Northern indigenous peoples have demonstrated their resilience to change over time; however, the cumulative effects of climate change and human development may result in unexpected challenges to cultural sustainability. Shifts in the habitat and diversity of food species due to climate change could impact the cultural and religious lives of some indigenous peoples (Gitay et al., 2002). Changes to traditional diets have already resulted in an increased incidence of diabetes, heart disease and obesity in some indigenous populations, and any additional dietary changes may be detrimental to the health of northern residents. Langdon (1995) concluded that the combination of alternative cultural lifestyles and altered subsistence opportunities resulting from global warming may pose the greatest threat of all to the continuity of indigenous cultures.

## Assessment of Adaptation Options

If ecosystems are to adapt successfully to climate change, effective management must support and build on species' and ecosystems' natural resilience while reducing vulnerabilities.

In an environmental context, resilience is the ability of ecosystems, habitat types and species to maintain a relatively constant state in the face of disturbance and stress, and to recover quickly after a temporary disturbance (Noss, 2001). Some arctic species are more resilient to climate change than others, for example by being better able to migrate to more favorable habitat; thus, in the marine environment pelagic communities are generally more resilient than benthic communities.

Vulnerability is the susceptibility of ecosystems, habitat types and species to the adverse impacts of change. As defined by the IPCC, vulnerability is a function of the character, magnitude, and rate of change of climatic variation to which a system is exposed, as well as its sensitivity and adaptive capacity. Some arctic species—for example, those that depend on sea ice—are more vulnerable to the effects of climate change than others.

Because global warming is expected to change many of the defining characteristics of the Arctic, there are few options for adapting to climate change. In fact, the best chance arctic ecosystems have for long-term biodiversity conservation is to slow, and eventually stop, anthropogenic climate change. However, two traditional conservation approaches can be applied to support the resilience of species and ecosystems: habitat protection and the reduction of non-climate stresses.

## HABITAT PROTECTION

The establishment of protected areas is the conventional way to protect landscapes, ecosystems, and habitats. Identifying and protecting key areas prior to development is a luxury in many areas of the Arctic that is no longer possible in some of the more developed parts of the world. However, industrial development and commercial activity in the Arctic are increasing pace, and experience from other regions shows that once major development begins, options for large-scale habitat protection are foreclosed. While the establishment of protected areas is important for conservation, it is highly unlikely that the more traditional approach to designating protected areas in the Arctic will be adequate in the long-term to protect biodiversity, given the magnitude of ecosystem impacts that are projected to arise from climate change. New and creative approaches to protecting habitats will be required.

The vast majority of arctic ecosystems remain unprotected, especially in the marine environment. Yet arctic governments have committed to protecting a circumpolar network of protected areas under CPAN[4]. Establishing a representative network linking terrestrial, coastal and marine ecosystems must be a top priority. Special emphasis should be on representing habitat types across environmental gradients following the expected path of climate change and shifting habitats, and protecting heterogeneous ecosystems and habitats with high species diversity. Protected area design should be guided by the following.

### *PROTECT RESILIENT AND VULNERABLE ENVIRONMENTS*

An urgent priority for scientists and managers is to identify and protect particularly resilient and vulnerable habitat types, species, and populations/stocks. This analysis should include resilience and vulnerability to the effects of climate change, as well as the cumulative effects of non-climate stresses. Many sources of knowledge can contribute to such an analysis, including traditional knowledge, field studies and modeling.
Protect keystone species

Certain species are so essential to ecosystem function that their disappearance, or a sharp reduction in their numbers, can result in the disappearance or reduction of other species. These so-called keystone species thus play a key role in the maintenance of healthy ecosystems. Resource managers should identify keystone species for their ecosystems and implement conservation strategies for them, such as precautionary harvesting targets.

*PROTECT ALONG CLIMATIC GRADIENTS*

While protected areas can be established to either shelter keystone species or to conserve representative ecosystem types, perhaps the most significant influence on the ability of ecosystems in the Arctic to adapt to climate change is the ability of arctic flora and fauna to move northwards with rising temperatures. Protected area strategies will need to ensure the continuity of habitat areas along environmental gradients.

*PROMOTE CONNECTIVITY*

The degree of connectivity between protected areas, along with the uses adjacent to them, influence the resilience of flora and fauna to climate change (Feenstra et al., 1998). Removing impediments to migration and preventing the creation of new impediments will be critical to facilitate the northward movement of species with climate change. This can be achieved by linking protected areas through the establishment of migration corridors.

*PROTECT CLIMATE REFUGIA*

Due to localized climatic conditions, some habitats are more resistant to the effects of climate change than others. These areas are known as climate refugia. A priority for scientists and managers should be to identify potential climate refugia for arctic species; an example might be the high Canadian archipelago where polar bears have easy access to both feeding areas on the ice and denning areas on land. A conservation priority should be to protect climate refugia from non-climate stresses and include them in reserve systems that link climate-vulnerable habitat to refugia.

*AVOID FRAGMENTATION*

Many arctic species require non-fragmented habitats to maintain healthy populations. Similarly, indigenous peoples require large stretches of undisturbed landscapes in order to maintain their traditional practices (CAFF, 2001). Although the Arctic still boasts of some of the largest stretches of undisturbed habitats on the planet, shifting ecosystems caused by climate change, and habitat disturbance and fragmentation caused by development activities, are increasing threats and may become barriers to the northward migration of species. One of the best methods available to avoid habitat fragmentation is for land-use planning processes to incorporate this issue at the pre-development stage.

*PROTECT AT MULTIPLE SCALES*

Biodiversity conservation strategies need to be implemented at the local, regional and circumpolar scales. Such strategies are essential for maintaining healthy ecosystems and conserving arctic biodiversity. It is important to network protected areas on a circumpolar basis because no single country can ensure habitat protection for migratory species, and because critical areas that must be protected to maintain the biodiversity and productivity of the entire arctic ecosystem will often fall under multiple jurisdictions.

4 The Circumpolar Protected Areas Network (CPAN) was established in 1998 and is a subgroup of CAFF, the Arctic Council's working group for the Conservation of arctic Flora and Fauna.

A strategic plan to establish a circumpolar network of protected areas has been completed by CAFF and endorsed by the eight arctic countries (CAFF, 1997). The plan specifies national and circumpolar actions to fill gaps in habitat protection. While CPAN was not established exclusively to combat climate change, this network will help to maintain ecosystem function and the flow of goods and services from and within arctic ecosystems, goals that are consistent with facilitating the natural response of ecosystems to climate change.

The initial burst of creating new protected areas, particularly in the Russian Arctic, has since come to a standstill. While protected areas currently cover approximately 15% of the terrestrial Arctic area, they are unevenly distributed across ecosystems and habitats; over 35% of arctic glaciers are protected, but less than 5% of the forest tundra (CAFF, 2001). In the coming years, CPAN will need to re-establish the momentum for creating protected areas and increase both protection of marine areas as well as productive terrestrial habitats.

### REDUCTION OF NON-CLIMATE STRESSES

There is growing evidence that healthy species and ecosystems are more resilient to environmental change, including climate change (Burton, 2001). In general, the stress caused by climate change will lessen resilience to non-climate stresses such as pollution and vice versa, meaning that currently acceptable contaminant thresholds may eventually be too high. Therefore, another key adaptation strategy for arctic ecosystems is the dramatic reduction of non-climate stresses.

#### *HARVESTING REGIMES*

Harvesting wild species is perhaps the most common form of natural resource use across all regions and peoples of the Arctic (Freese, 2000). Since the distribution of flora and fauna in the Arctic is likely to change with the changing climate, changing the location or intensity of harvesting activities may become necessary. In those situations where populations of harvested species are showing serious declines, substituting store bought foods for traditional foods may need to be considered. However, this option would likely prove to be problematic for many indigenous communities, particularly in remote areas where food costs are high and where traditional foods are an important way of life.

Since hunting and fishing are of such importance to the health and well-being of arctic peoples, a better option is to manage habitats and harvesting activities to ensure an ecologically sustainable supply of wild species into the future. Freese (2000) conducted a review of what must be done to ensure that the use of wild species in the Arctic does not compromise the biodiversity and ecological integrity of the region over the long term. This review provides fifteen guidelines[5] that concern the consumptive use of wild species. If implemented, the cumulative impacts of climate change and harvesting activities on populations of wild species could be avoided.

In addition, stricter fishing quotas and the establishment of no-take zones are necessary to address the problem of overfishing. Nakken (1998) advises that management authorities take a more precautionary approach when setting total allowable catch limits due to the discrepancies that exist between recommended limits and actual catches. His research indicates that setting limits at or below estimates for total allowable catch could lower the rate of exploitation and stabilize or even increase the yields of most commercial fish stocks.

*SHIPPING STANDARDS*

Climate change will likely result in an expansion of shipping due to year-round access along the whole of the Northern Sea Route and Northwest Passage, as well as new oil and gas developments throughout the Arctic. This implies a significantly increased risk of accidents. While shipping will always entail some level of environmental risk, much can be done to reduce this risk, inter alia:

- The quality standards of ships operating in arctic waters must be high. Compliance with quality standards must be ensured by strict port controls of the vessels.
- Discharge regulations in the Arctic must be very strict, for example by granting high-latitude waters special area status under various annexes of the International Convention for the Prevention of Pollution from Ships (MARPOL). Compliance with the regulations must be ensured through surveillance and monitoring, coupled with effective sanctions toward violations.
- Ship traffic must be steered away from the most sensitive locations, for example by the use of mandatory shipping routes and “no-go” areas.
- Close surveillance and monitoring of shipping activity is needed to prevent collisions and for early detection of ships in distress.
- The whole, or parts, of the Barents Sea should be granted status as a Particularly Sensitive Sea Area (PSSA) by the International Maritime Organization. Within a PSSA, a wide range of protective measures can be applied to reduce the risks involved in shipping.

*ARCTIC POLLUTION*

Local sources of pollution are regulated by legislation within each arctic nation. However, because many contaminants originate from outside the Arctic, the mitigation of arctic pollution requires international action. Indigenous peoples were instrumental in drawing international attention to the issue of long-range transport of POPs (Downie and Fenge, 2003). Subsequently, international negotiations led to the signing of the Stockholm Convention, a global treaty signed by 151 countries that regulates the disposal, use and release of some of the worst offenders in this category of pollutants; however, about 20 nations still need to ratify the convention before it enters into force.

Unfortunately, ongoing monitoring of pollutants in the Arctic shows that other chemicals are increasing in volume, especially brominated flame retardants and organic mercury which both cause effects similar to those chemicals already banned by the Stock-

5 Available at http://www.wwf-canada.org/NewsAndFacts/Supplemental/ConsumptiveUseOfWildSpecies.pdf

holm Convention (AMAP, 2002). Regional and global agreements on these and other dangerous contaminants are necessary, as is sufficient testing and regulation of both commonly used and new chemicals. Support must also be given to the European Union's proposed regulatory system called REACH—Registration, Evaluation and Authorization of CHemicals—which will bring much needed scrutiny to the health and environmental hazards of chemicals in current use.

### *INVASIVE SPECIES*

Invasive species are any species—including its seeds, eggs, spores, or other biological material capable of propagating that species—that are not native to an ecosystem and whose introduction does or is likely to cause economic or environmental harm. While not all invasive species cause ecological stress, some can displace or eliminate native species, disrupt interactions between native species, reduce biological and genetic diversity by hybridizing with native species, introduce parasites or diseases, and cause socio-economic and recreational impacts (CAFF, 2001). Some studies have shown that ecosystems with high biodiversity have higher resistance to exotic invasions. Therefore the Arctic, with its low biodiversity, might be more vulnerable to exotic invasions than other regions in the world. Presently, the magnitude of the threat of invasive species on arctic environments is unclear; however, the potential impacts of this threat warrant further investigation and precautionary action on species introductions, especially since climate change is expected to result in the migration of new species into the region.

### *TOURISM IMPACTS*

The Arctic has seen considerable growth in tourism over the last decade. CAFF estimates that more than 1.5 million tourists visited the region in the year 2000, but when the entire state of Alaska is included in this estimate, the count approximately doubles. Nature and culture are the primary attractions in the Arctic. There is evidence that tourism can benefit conservation efforts by helping to provide an economic value for nature and wildlife, and creating support for protected areas (UNEP, 1995). While many visitors to the region come to see pristine wilderness, they are also more likely to be aware of environmental issues, and through their experience can become advocates for Arctic conservation in their home countries.

However, tourism is also a potential threat to the environment (CBD, 2002). Common concerns are increased fragmentation through permanent infrastructure, damage to soils and vegetation, wildlife disturbance, and increased waste and pollution. Ship-based tourism accounts for a large portion of the total tourism numbers in the Arctic, as it provides tourists with comfortable access to the remotest areas; in some arctic destinations, cruise tourism is the primary means of travel to and within the area. In this context, questions of waste water management, ballast water and exotic species introductions, and preparedness in case of accidents must be raised.

In cooperation with the tourism industry and other stakeholders, WWF has developed guidelines[6] for reducing impacts and increasing benefits of tourism for nature and local people in the Arctic. Following these guidelines will help to reduce the potential stresses that tourism can have on Arctic ecosystems.

## Guidelines for Selecting Strategies

The pace at which change is occurring requires that comprehensive adaptation strategies be developed by arctic nations in the near-term. Under the conditions of a changing climate, the challenge is to adjust human activities in such a way as to protect ecosystem function, maintain the flow of goods and services, and enhance the resilience of arctic ecosystems. The best defenses against biodiversity impacts in the face of climate change will require comprehensive strategies that involve local residents and ecosystem-based management.

### INDIGENOUS PARTICIPATION

Human habitats in the region are diverse with settlements ranging from small, remote communities to modern, industrial cities. Arctic communities have both formal (e.g. based on resource extraction) and informal (e.g. based on hunting and herding) economies that are dependent on the living and non-living resources throughout the region.

Out of a total population of around 2 million, there are about 500,000 indigenous people living in the Arctic. Their historical presence in the Arctic demonstrates the incredible resilience of indigenous cultures through time, nonetheless, indigenous peoples are more sensitive to climate change than non-indigenous groups because climate change will directly affect their traditional hunting habitats and subsistence species. Certain forms of hunting are delayed or abandoned under poor ice conditions and traditionally important species such as salmon, herring, walrus, seals, whales, and various birds are likely to undergo shifts in range and abundance (IPCC, 2001b).

The importance of involving indigenous peoples in selecting adaptation options and developing comprehensive management strategies cannot be over-emphasized. One of the clear challenges to understanding past and current climate change in the Arctic is that our scientific understanding is based on records that are often short-term, fragmentary, or both (Huntington, 2002). For generations, arctic residents have made first-hand observations of climate and environmental variability. This intimate knowledge of the land provides specific and detailed insights into changing local and regional conditions. Traditional ecological knowledge adds an important dimension to the understanding of climate change impacts that cannot be achieved through models or other scientific methods. Because the combined perspectives of science and traditional knowledge generate a broader understanding of environmental change than either knowledge system can accomplish on its own (Kofinas, 2002), understanding and addressing climate change in the Arctic cannot be done adequately without incorporating the views of indigenous peoples (Huntington, 2002).

Residents of the Arctic are best positioned to identify local vulnerabilities and develop locally-appropriate adaptation responses, especially since vulnerabilities to climate change vary across the region. In addition, involving indigenous peoples in adaptation decision-

6 Available at http://www.ngo.grida.no/wwfap/core/about/guidelines.html

making respects the magnitude of the impacts of climate change on their traditional ways of life, and the patterns of existing and emerging self-governance and land ownership.



### ECOSYSTEM-BASED MANAGEMENT

Resource managers must take into account long-term and cumulative impacts of human activities and environmental change. Through a broad and transparent process, managers should set 30-year regional or ecosystem-wide management goals that focus on conserving ecosystem structure and function. Ecosystem-based management frameworks offer an inclusive process to assess ecosystem health and the shared goals among stakeholders, and will typically yield large-scale spatial management plans regulating various types of use (e.g. through zoning, access, protection, quotas, etc.).

Ecosystem-based management (EBM) is based on the precautionary principle, which seeks to minimize the risk of damage, in particular when knowledge is scarce or non-existent. The following overview is derived from *Policy Proposals and Operational Guidance for Ecosystem-Based Management of Marine Capture Fisheries* (Ward et al., 2002) and is offered here as a means by which to approach managing the multiple stresses and competing opportunities within arctic ecosystems.

The concept of EBM has evolved over the past few decades in response to two characteristics of managed natural systems:

1. That exploited natural resources are highly connected to their surrounding ecosystems and this connectivity can have major effects on their productivity; and

2. The exploitation of natural resources can have effects on other resources and on other (non-utilized) species as well as aspects of the ecosystems where the resources occur, and these direct and indirect effects can have very major consequences for related or dependent species.

These two properties can be summarized as (1) the effect of the environment on the resource being exploited, and (2) the effect of resource exploitation on the environment. EBM attempt to address both of these environmental and ecosystem interactions.

Some approaches to EBM advocate a strictly ecological focus to maintain the capacity of an ecosystem to deliver desired goods and services. Other approaches extend the EBM concept to include human goals and aspirations for ecosystems. These latter approaches recognize the highly managed nature of terrestrial systems in particular, and that the notion of *sustainability* is driven by the socio-economic and cultural context within which resource management must reside (Pirot et al., 2000). It is this approach that needs to be applied to our use of resources and activities in all arctic environments.

Despite the diversity of views and experience with EBM in various jurisdictions, reasonable consensus is emerging across a broad range of different resource sectors (forestry, civil society, marine) about basic principles of EBM (Harwell et al., 1996; NOAA, 1999; Pirot et al., 2000; Ward et al., 1997). These principles can be summarized as:

1. Maintaining the natural structure and function of ecosystems, including the biodiversity and productivity of natural systems and identified important species, is the focus of management.

2. Human use and values of ecosystems are central to establishing objectives for use and management of natural resources.

3. Ecosystems are dynamic; their attributes and boundaries are constantly changing and consequently interactions with human uses also are dynamic.

4. Natural resources are best managed within a management system based on a shared vision and set of objectives developed among stakeholders.

5. Successful management is adaptive and based on scientific knowledge, continual learning and embedded monitoring processes.

Integrated approaches propose managing ecosystems on a regional basis and considering all uses in the context of their impacts on biodiversity. These approaches to resource use and biodiversity conservation entail agreements from all users to reduce activities that may degrade specific areas or values of conservation importance, but permit activities to occur in areas where they do not threaten regional biodiversity objectives. The regional management approach identifies specific uses that are acceptable, and identifies complementary protected areas to ensure that biodiversity is maintained. Within this context, ecosystem-based management is consistent with building ecosystem resilience to the impacts of climate change.

## Recommendations

Biologically speaking, the term adaptation is used to describe the evolution of organisms or species through time; in this chapter, adaptation is defined as human-driven initiatives to support the natural resilience of arctic ecosystems and reduce their vulnerability to the adverse consequences of climate change. In this sense, adaptations are conscious, planned decisions by human beings that may result in an autonomous response by ecosystems.

The threats to arctic ecosystems are not limited to small areas or single species. In the long term, the resilience of arctic flora, fauna and peoples depends heavily on both global and local actions to preserve the integrity of arctic ecosystems. The only response to the magnitude and diversity of pressures facing the Arctic is to manage the human activities that adversely impact biodiversity.

### STABILIZE LEVELS OF GREENHOUSE GASES IN THE ATMOSPHERE

The best chance arctic ecosystems have for long-term conservation is to slow, and eventually stop, anthropogenic climate change. This requires broad scale global action on reducing greenhouse gas emissions. Resource managers have an important role to play here by engaging on climate policy and using examples of change seen in their systems as indicators of the need for action.



The goal of the United Nations Framework Convention on Climate Change (UNFCCC) is to stabilize levels of greenhouse gases in the atmosphere to levels that prevent dangerous anthropogenic interference with the climate system. While mitigation is generally not considered an adaptation option *per se,* in the long term, this strategy will have the greatest benefit in terms of reducing the vulnerability of arctic ecosystems to climate change, and supporting the natural adaptive capacity of arctic ecosystems to adjust to a new climate. Since the dominant response of arctic species to climate change is believed to be relocation rather than evolutionary adaptation, immediate action to reduce atmospheric $CO_2$ concentrations will give arctic ecosystems more time to adapt to a changing climate.

### SUSTAINABLE DEVELOPMENT

Overall, there will be increased human activity in the Arctic as a result of climate change, especially as improved sea access will enhance opportunities for expanded fisheries, new transportation routes, and development of the vast offshore oil and gas reserves. If managed wisely, the resources can bring long-term wealth and development to the region. This, however, demands that renewable resources, which can continue to support local economies and cultures long after non-renewable resources have been depleted, are not sacrificed for short-term economic gains.

WWF promotes the Conservation First principle, which was designed to balance nature conservation and industrial development. Conservation First means there should be no new or expanded large-scale industrial development in the Arctic until areas of high conservation value are identified and protected. This will safeguard important cultural and wildlife areas from industrial development for the long term. It also provides planning certainty and predictability for communities, investors, developers, government, and other stakeholders.

Conservation First is an important part of a broader ecosystem approach to the management of arctic regions. What is new about Conservation First is its focus on timing: that area protection must take place before industrial development begins and forecloses options for proactive conservation. Successful programs will:

1. Operate within a supportive policy framework.

2. Recognize economic, social and cultural interests as factors that may affect resource management.

3. Recognize ecological values and incorporate them into management.

4. Provide adequate information on exploited species and habitats to ensure that development is low risk.

5. Ensure that the resource management system is comprehensive and inclusive, based on reliable data and knowledge, and that it uses an adaptive approach.

6. Consider environmental externalities within the resource management system (Ward et al., 2002).

The Convention on Biological Diversity acknowledges that substantial investments are required to conserve biological diversity. It also points out that, in return, conservation will bring significant environmental, economic and social benefits. Implementing the Conservation First principle in the Arctic has three major advantages:

*FOR COMMUNITIES:* It conserves renewable natural resources and ecosystems that have been the basis for human survival in the Arctic for thousands of years and will be the basis for long-term, sustainable development in the future.

*FOR CONSERVATION:* It secures the survival of key species, ecosystem components, and processes that are important to and representative of the region. Some areas also have ecosystem functions far beyond the region itself, for example as havens for migratory species, ground-water preservation, or moderators for larger-scale climate processes.

*FOR BUSINESS:* The process allows conflicts to be identified and resolved before major investments are made, providing certainty and predictability for investors, developers, governments, conservationists, and other stakeholders.

Large-scale exploitation of non-renewable resources, with the accompanying growth of infrastructure and industry, provides local economic and community benefits, but industrial development also poses serious threats to the cultural, spiritual, and environmental heritage of the Arctic. Conservation First ensures that these threats are minimized. It provides a way to maintain the integrity of arctic ecosystems as an integral part of planning for development.

## Conclusion

The uncertainties concerning climate change projections are large. They stem from the gaps in knowledge of ocean and atmospheric processes, from our assumptions about the future, from the models themselves, and from inherent limitations in our ability to project the climate. Uncertainties pose a significant challenge to any effort to develop robust management strategies but the lack of complete understanding does not preclude effective ecosystem management. While we know relatively little about the nature of changes to biodiversity, enough is known to justify immediate conservation action (Costanza et al., 1998; Ludwig et al., 1993).

Projected climate change will have sweeping impacts on arctic ecosystems and careful management of natural resources will be required to secure healthy ecosystems for the future. Management efforts must be based on what is known about ecosystem components and their interrelationships, as well as the likely effects of and on human activities. As our understanding of the changes to biodiversity improves, management responses must also adapt. In many cases, adapting to climate change will not involve adopting entirely new courses of action; rather, the strengthening and the expansion of existing conservation practices may be adequate (Burton, 2001).

Discussions and development of adaptation responses in the Arctic are currently only in their very early stages. Because of the vulnerability of the region, the expected rate and magnitude of change, and some of the uncertainties related to what is known about ecosystems in general and how they will be impacted, there are few concrete management prescriptions that can be recommended and none that are being tested or implemented at the present time. Nevertheless, in order to lay the groundwork for future responses to climate change it is extremely important for resource managers to begin including climate considerations in their management plans.

Although some important groundwork has been laid, much more work remains in order to ensure the resilience of arctic communities, ecosystems and the traditions of indigenous peoples. Some guiding principles are as follows:

- Resource managers should inventory the ecosystems in their regions and the interrelationships among them, and then assess the probable impacts that climate change will have on them, along with specific adaptation options to ameliorate those impacts.

- Resource managers should only implement adaptation options that are suitable to the local circumstances in their regions, and then monitor their effectiveness in building resilience.

- Resource managers need to work closely with arctic residents (particularly indigenous peoples) in adaptation research, planning, decision-making, implementation, and monitoring of arctic habitats.

- Resource managers need to encourage mechanisms to enhance information flow among researchers and policy-makers on climate change policy and adaptations in practice.

- Resource managers need to document the changes that are taking place in the Arctic and communicate these changes broadly as arguments for international action on emissions reductions.

- To support the work of resource managers, arctic nations need to develop cooperatively a vision that guides the allocation of efforts and resources towards adaptation activities.

- To provide resource managers with more time to develop strategies to facilitate natural systems' adaptation, arctic nations need to be vigilant to ensure that international emission reduction targets beyond the Kyoto Protocol are negotiated in order to achieve the stabilization of greenhouse gases in the atmosphere at levels that prevent dangerous anthropogenic interference with the climate system.

It is important to recognize that adaptation will not be enough to completely protect arctic ecosystems from the forces of climate change. If there is to be any chance of conserving arctic ecosystems in the long term, international efforts toward mitigating the causes of climate change must be put into place. Effective management of natural resources will only buy ecosystems additional time to adjust to a changing climate until broad global action on reducing greenhouse gas emissions takes effect.

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