NORTHERN CANADA

CHAPTER 3
Northern Canada

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KEY FINDINGS

The climate of the Arctic has shown an unprecedented rate of change during the past 50 years. Over the last half century, the Canadian Arctic has experienced significant increases in both temperature and precipitation, consistent with trends in other circumpolar regions. Increases in air temperature have resulted in many of the most extreme warm years throughout the entire Canadian North being recorded in the last decade, with the greatest temperature increases observed over the western Arctic. All global climate models project continued increases in temperature and precipitation over the Canadian Arctic, with greatest temperature changes at higher latitudes. As a result, there will continue to be significant changes in the physical environment, particularly in the cryosphere (snow, glaciers, permafrost and river/lake/sea ice).

There is increasing evidence that changes in climate are already having impacts on ecological, economic and human systems in northern regions, and that some individuals, communities and institutions are already taking action to reduce harmful impacts. Current levels of exposure to climate-related changes and sensitivities, as well as limitations in adaptive capacity, make some northern systems and populations particularly vulnerable to the effects of climate change. Key findings include the following:

- **Climate-induced changes in the cryosphere (permafrost, sea ice, lake ice and snow) have important implications for infrastructure maintenance and design.** Much of the infrastructure in the North is dependent upon the cryosphere to, for example, provide stable surfaces for buildings and pipelines, contain wastes, stabilize shorelines and provide access to remote communities in the winter. Permafrost warming and thaw may require remedial action or further engineering modifications to existing infrastructure. Waste retention ponds and lakes that rely on the impervious nature of permafrost to retain environmentally hazardous materials are a particular concern. Climate change is already being considered in the design of most major projects in the North, including tailings containment structures, pipelines and roads, and large buildings. In the longer term, marine and freshwater transportation will need to shift its reliance from ice routes to open-water or land-based transport systems. Coastal areas and communities will also become more vulnerable to erosion due to loss of sea ice compounded by increased storminess and rising sea levels. Changes in the timing of river flows will require modifications to the infrastructure and flow strategies used in generating hydroelectricity.

- **As the climate continues to change, there will be consequences for biodiversity shifts and the ranges and distribution of many species, with resulting impacts on availability, accessibility and quality of resources upon which human populations rely.** This has implications for the protection and management of wildlife, fisheries and forests. The northward migration of species, and disruption and competition from invading species, are already occurring and will continue to alter terrestrial and aquatic communities. Shifting environmental conditions will likely introduce new animal-transmitted diseases and redistribute some existing diseases, affecting key economic resources and some human populations. Stress on populations of iconic wildlife species, such as the polar bear, at the southern limit of their distribution will continue as a result of changes to critical sea-ice habitat. Where these stresses affect economically or culturally important species, they will have significant impacts on people and regional economies. Widespread proactive adaptation to these changes will be required in natural resource management sectors.

- **Increased navigability of Arctic marine waters and expansion of land- and fresh water–based transportation networks will lead to a less 'remote' northern Canada, bringing both opportunities for growth in a range of economic sectors and challenges associated with culture, security and the environment.** Diminishing sea ice, particularly in Hudson Bay and the Beaufort Sea, and a lengthened summertime shipping season associated with warming, will increase opportunities for shipping and passage within Canadian Arctic waters. It is likely that adaptations in the form of increased surveillance and policing will be required. Loss of sea ice and fresh ice will also lead to the development of marine ports and all-season road networks to interior portions of the northern mainland and Arctic islands, particularly to access natural resources whose development has previously been uneconomic. Socioeconomic and cultural impacts on Arctic communities from increased economic activity, including increased marine traffic and access associated with the opening of the Northwest Passage, may be far reaching.

- **While maintaining and protecting aspects of traditional and subsistence ways of life in many Arctic Aboriginal communities may become more difficult in a changing climate, new opportunities will also be presented.** Young and elderly Aboriginal residents, in particular those pursuing aspects of traditional and subsistence-based ways of life in more remote communities, are the most vulnerable to the impacts of climate change in the North. An erosion of their adaptive capacity via the social, cultural, political and economic changes taking place in many communities today will further challenge their abilities to adapt to changing environmental conditions. However, enhanced economic opportunities may provide significant benefits to communities, making the net impacts on human and institutional vulnerability difficult to predict.

1 INTRODUCTION

There is strong evidence from scientists and local residents that Canada's North is already experiencing changes in its climate (e.g. Ouranos, 2004; Huntington et al., 2005; McBean et al., 2005; Overpeck et al., 2005; Bonsal and Prowse, 2006). The western and central Canadian Arctic experienced a general warming during the past 50 years of approximately 2 to 3°C (Zhang et al., 2000). In the eastern Canadian Arctic, cooling of approximately 1 to 1.5°C occurred during the same period (Zhang et al., 2000), but with warming reported in the last 15 years. Local Aboriginal hunters and elders have reported significant warming throughout the region in recent decades, which corroborates the scientific observations (e.g. Huntington et al., 2005; Nickels et al., 2006). These climatic changes have resulted in significant decreases in the extent and thickness of sea ice in some parts of the Arctic, thawing and destabilization of permafrost terrain, increased coastal erosion, and shifts in the distribution and migratory behaviour of Arctic wildlife species (Arctic Climate Impact Assessment, 2004, 2005). Climate model projections suggest that these recently observed changes across the North will continue (Kattsov et al., 2005; Bonsal and Prowse, 2006), with a myriad of implications for human and wildlife populations and future regional development (Arctic Climate Impact Assessment, 2004, 2005; Ford et al., 2006b; Furgal and Seguin, 2006).

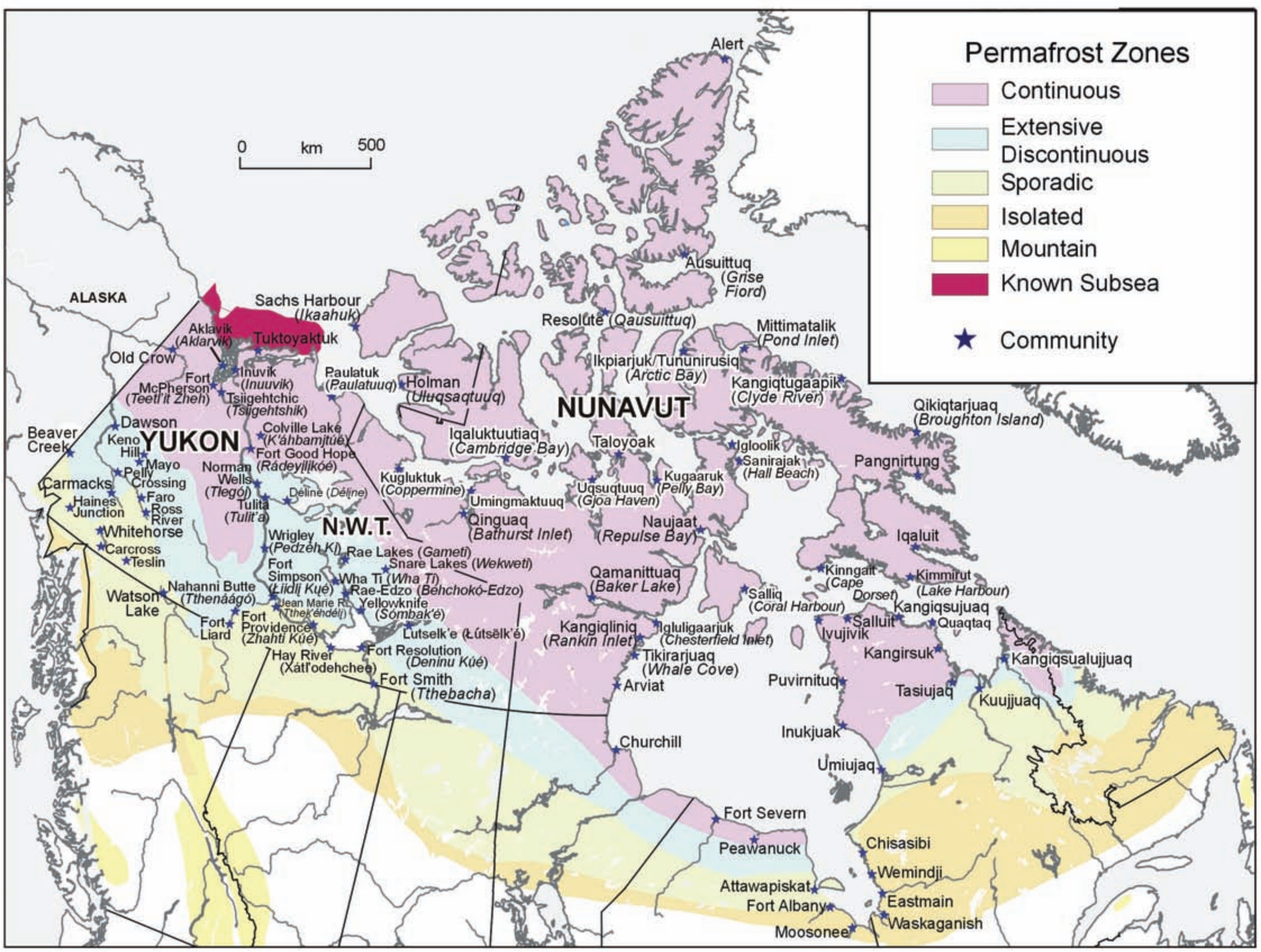


FIGURE 1: Political boundaries and communities of the Canadian North, superimposed on a map of permafrost zones (*derived from* Heginbottom et al., 1995; Furgal et al., 2003).

A number of recent scientific assessments have examined changes in climate and in socioeconomic, environmental and political conditions, and the impacts of these changes on Arctic regions (e.g. Intergovernmental Panel on Climate Change, 2001a, b, 2007a, b; Arctic Monitoring and Assessment Program, 2002; Arctic Climate Impact Assessment, 2004, 2005; Einarsson et al., 2004; Chapin et al., 2005). These works provide a strong foundation for evaluating the impacts of climate change on the services that the Arctic environment provides to local, regional and national populations and economies, and the vulnerabilities of human systems to change. This chapter builds on these previous assessments and adopts aspects of a vulnerability approach to climate assessment, primarily through a review of existing and projected exposures and adaptive capacity (*see* Chapter 2). In so doing, it moves towards a more comprehensive understanding of climate impacts and adaptation across the northern regions of the country.

In the context of this chapter, Northern Canada refers to the three territorial administrative regions (Yukon, Northwest Territories and Nunavut) north of latitude 60°N in Canada. Although these areas share many biogeographic characteristics, each has unique environmental, socioeconomic, cultural and political characteristics. Together, they form a vast region encompassing nearly 60% of Canada's landmass and many ecological zones, and feature nearly 100 communities of diverse languages and cultures (Figure 1).

Sections 1 and 2 of this chapter provide an introduction to climate change in the Canadian Arctic, a review of past and current conditions, and projections for future climate in the North. Section 3 discusses the impacts that climate change is expected to have on key components of the Arctic environment, many of which are the basis for livelihoods in northern communities. Section 4 discusses the implications of these changes for regional and national services, with a focus on identifying specific vulnerabilities of various sectors and systems. Section 5 then addresses implications for large and small northern communities, and provides perspectives from potentially vulnerable populations, such as Arctic Aboriginal groups. Finally, key conclusions are presented in Section 6.

This chapter draws on a number of different sources and methods to assess the current and potential future impacts of climate change across Northern Canada (*see also* Chapter 2). For topics presented in Sections 1 to 3, the chapter relies primarily on review and assessment of the published scientific literature. Where appropriate, authors have drawn on government reports and other 'grey' literature sources. For many of the topics presented in Sections 4 and 5, scientific research in the Arctic is still underway or just in its initial stages. As a result, these sections rely more heavily on grey literature and on documentation of local observations and traditional knowledge, and on the expert judgement of the assessment team.

2 REGIONAL OVERVIEW

2.1 PHYSICAL GEOGRAPHY

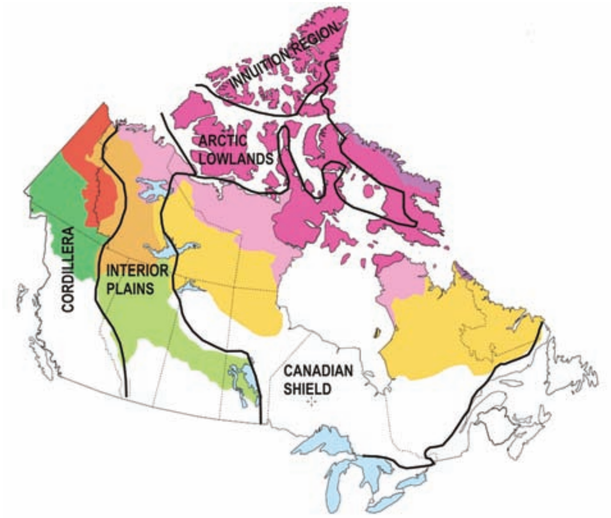
Physiography

Northern Canada includes five major physiographic regions: Canadian Shield, Interior Plains, Arctic Lowlands, Cordillera and Innuitian Region (Figure 2; Fulton, 1989). The Canadian Shield dominates the eastern and central portions of the Arctic mainland, and the eastern portions of the Arctic Archipelago. Rolling terrain contains a maze of lakes and rivers and a high proportion of exposed bedrock, while the mountainous terrain of Baffin Island features glaciers and ice fields. The Interior Plains lie to the west of the Canadian Shield and comprise a series of low-lying plateaus and extensive wetlands. The Arctic Lowlands, which form part of the Arctic Archipelago, lie between the Canadian Shield and the Innuitian Region. This region contains lowland plains with glacial moraines in the west and uplands with plateaus and rocky hills in the east. The complex terrain of the Cordillera lies immediately west of the Interior Plains and encompasses steep mountainous terrain with narrow valleys, plateaus and plains. Extensive ice fields and many of the highest peaks in North America are found in the St. Elias Mountains on the Yukon Pacific coast (Prowse, 1990; French and Slaymaker, 1993). The Innuitian Region encompasses the Queen Elizabeth Islands, the most northern and remote area of the country.

Consideration of physiography, together with regional differences in climate, vegetation and wildlife, allow definition of eight ecoregions in the North (Furgal et al., 2003), which are depicted and described in Figure 2.

Climate

Northern Canada is characterized by long cold winters interrupted by short cool summers. Precipitation is light and concentrated in the warmer months. Mean annual temperatures (1971–2000) range from approximately –1 to –5°C in more southerly regions of the Canadian Arctic to near –18°C in the



Ecozone	Landforms	Climate	Vegetation	Wildlife
Arctic Cordillera	Massive icefields and glaciers cap the rugged mountains	Very cold and arid	Largely absent due to permanent ice and snow	Polar bear, walrus, seals, narwhal, whales
Northern Arctic	Lowland plains with glacial moraines in the West, and uplands with plateaus and rock hills in the East	Very dry and cold	Dominated by herbs and lichen	Caribou, muskox, wolf, arctic hare, lemmings
Southern Arctic	Broadly rolling upland and lowland plains	Long, cold winters and short cool summers	Dwarf shrubs that decrease in size in the North	Muskox, wolf, arctic fox, grizzly and polar bear, caribou
Taiga Plains	Broad lowlands and plateaus, incised by major rivers	Semi-arid and cold	Dwarf birch, labrador tea, willows and mosses	Moose, woodland caribou, wolf, black bear, marten
Taiga Shield	Rolling terrain with uplands, wetlands and innumerable lakes	Subarctic continental climate, with low precipitation	Open forests and arctic tundra	Caribou, moose, wolf, snowshoe hare, black and grizzly bears
Taiga Cordillera	Steep, mountainous topography with sharp ridges and narrow valleys	Dry, cold winters and short, cool summers	Shrubs, mosses, lichens, dwarf birches, willows	Dall's sheep, caribou, lynx, wolverine
Boreal Plains	Level to gently rolling plains	Moist climate with cold winters and warm moderately summers	Spruce, tamarack, jack pine, white birch, balsam, poplar	Woodland caribou, mule deer, coyote, boreal owl
Boreal Cordillera	Mountain ranges with high peaks and extensive plateaus	Long, cold, dry winters and short, warm summers	Spruce, alpine fir, trembling aspen, white birch	Woodland caribou, Dall's sheep, mountain goat, marten, ptarmigan

FIGURE 2: Physiographic regions (*from* Fulton, 1989) and ecoregions of the Canadian North (Furgal et al., 2003).

islands of the high Arctic. On a seasonal basis, average winter temperatures range from around –37°C in the north to –18°C in the south, and summer values from +6 to +16°C (Environment Canada, 2006). Within these averages, there exists a high degree of variability on intraseasonal, interannual and interdecadal scales (Bonsal et al., 2001a).

Northern Canada receives relatively low amounts of precipitation, particularly at very high latitudes. Annual values typically range from 100 to 200 mm over the islands of the high Arctic to nearly 450 mm in the southern Northwest Territories. Higher precipitation occurs over the east coast of Baffin Island (600 mm/a) and the Yukon, where annual amounts can range from approximately 400 to 500 mm in southeastern areas to more than 1000 mm in the extreme southwest (Phillips, 1990).

Mean annual evaporation decreases from approximately 250 to 400 mm at latitude 60°N to less than 100 mm in the central portions of the Arctic Archipelago (den Hartog and Ferguson, 1978). Evaporation is greatest during the summer, especially in areas of low relief characterized by numerous bogs and lakes. On large deep bodies of water, such as Great Slave Lake, heat stored from the summer months continues to produce significant evaporation during the fall (Oswald and Rouse, 2004). North of the wetland and forested zones, transpiration decreases because of the lower vegetation density and the increasing proportion of mosses and lichens. However, the relative importance of evapotranspiration in the overall water balance tends to increase northward because of the more rapid decrease in precipitation. Moisture loss to the atmosphere also occurs through sublimation of snow and ice (Pomeroy et al., 1998).

Permafrost

The term 'permafrost' refers to earth materials that remain below 0°C for two consecutive summers. The permafrost region covers about half of the Canadian landmass (Figure 1). In more northerly areas, permafrost is continuous and may be several hundred metres thick (Heginbottom et al., 1995; Smith et al., 2001a). Southward, its distribution becomes discontinuous and patchy, and it is only a few metres thick at the southern fringe of the permafrost region. Subsea permafrost is also found offshore in parts of the Canadian Arctic.

The presence of permafrost and associated ground ice strongly influence the properties and performance of earth materials, landscape processes and surface and subsurface hydrology, and also control much land and property development. Permafrost restricts infiltration of water and has led to the formation of extensive wetlands and peatlands in areas of low relief (e.g. Brown et al., 2004; Mackenzie River Basin Board, 2004). Differential thawing of ice-rich permafrost results in hummocky or thermokarst topography. Runoff response in permafrost regions is controlled by the depth of the seasonal thaw (active) layer, which may exist for as little as 2 months.

Water

Eighteen per cent of Canada's fresh water is found north of latitude 60°N, primarily in lakes (e.g. Great Bear and Great Slave lakes) on the mainland Canadian Shield of the Northwest Territories and Nunavut (Prowse, 1990). This percentage does not include the extensive glacierized areas that total in excess of 150 000 km^2 on the islands of the Arctic Archipelago and 15 000 km^2 on the territorial mainland. Twenty per cent of

Canada's wetland area is found in the Arctic (Hebert, 2002). Runoff in the North is strongly influenced by snowmelt and/or glacier ablation (Woo, 1993).

Freshwater ice seasonally covers all lakes and rivers in the Northern Canada, with mean thickness in excess of 2 m on lakes at the highest latitudes. Duration of river-ice coverage is less than that of lake ice because rivers freeze up later in the year and are first to break up in the spring. Complete clearance of lake ice does not always occur in the far North, and multi-year ice develops on some lakes because of the brevity of the melt season. Multi-year ice accretions can also be found in the extreme North, where groundwater flow has contributed to the development of exceedingly thick surface ice.

Northern rivers are a major source of fresh water to the Arctic Ocean and contribute to the thermohaline circulation of the world's oceans, a regulator of global climate (Carmack, 2000). The dominant hydrological system in the North is the Mackenzie River, the largest river basin in Canada (1 805 200 km^2). The Yukon River drains approximately three-quarters of the Yukon as it flows northwest into Alaska (Prowse, 1990).

Marine Environment

Canada's northern seas consist of the Arctic Ocean, Beaufort Sea, Hudson Bay, Foxe Basin, Baffin Bay and various channels and straits between the islands of the Arctic Archipelago. The most striking characteristic of these waters is the seasonal to multi-year cover of sea ice, often several metres thick. Permanent pack ice occurs in the central Arctic Ocean. Open water develops in the late summer off the west coast of Banks Island and in the Beaufort Sea. Farther south, Hudson Bay freezes by the end of December and begins to clear in July. Overall, the distribution and thickness of sea ice are extremely variable. Of ecological importance are open-water areas during the winter, called polynas, that occur in the Beaufort Sea, Arctic Archipelago and northern Baffin Bay (Barry, 1993).

The Arctic Ocean is connected to the Atlantic Ocean via the Greenland and Norwegian seas, as well as by numerous channels through the Arctic Archipelago to Baffin Bay and the Labrador Sea. A dominant influence on the circulation of the Arctic Ocean and pack-ice cover is the Beaufort Gyre, which results in clockwise circulation and ice movement in the Canada Basin of the Arctic Ocean. Apart from landfast ice within archipelagos and along coastlines, the sea ice is in constant motion. The movement of the marine waters and presence of extensive ice packs exert a strong influence on the climate of Canada's northern landmass (Serreze and Barry, 2005).

2.2 SOCIOECONOMIC, HEALTH AND DEMOGRAPHIC CONDITIONS AND TRENDS

Population

A little more than 100 000 people live in Northern Canada. Nearly two-thirds of northern communities are located along coastlines. The majority of Arctic communities (inland and coastal) have less than 500 residents, and these small communities together represent only 11% of the total northern population (Bogoyavlenskiy and Siggner, 2004). Only the three territorial capitals, Whitehorse, Yellowknife and Iqaluit, have populations exceeding 5000. Although Whitehorse (population 23 511 in 2005) accounts for approximately 73% of the total population of the Yukon, more than two-thirds of people in Nunavut live in communities of less than 1000 people.

The region has experienced significant demographic, social, economic and political change in recent decades, with maximum growth associated with an increase in the non-Aboriginal population, related primarily to resource development and the increase in public administration (Bogoyavlenskiy and Siggner, 2004; Chapin et al., 2005). Most growth since the establishment of communities has occurred in the three main urban centres (Einarsson et al., 2004). Over the next 25 years, greatest growth is projected in the Northwest Territories (Table 1), partly as a result of industrial development associated with the Mackenzie Valley pipeline project and new mining developments.

The average age of northern residents is younger than for Canada as a whole (Table 2), and more than 50% of residents in Nunavut are less than 15 years old. Projections for the next 25 years indicate that the population in Northern Canada will remain

TABLE 1: Current (2005) and projected (2031) populations (thousands) for Canadian northern territories under a moderate population growth scenario (Statistics Canada, 2005b).

	2005 population (thousands)	Projected population in 2031[1] (thousands)	Mean annual growth rate[1] (rate per thousand)
Canada	32 270.5	39 024.4	7.3
Nunavut	30.0	33.3	4.0
Northwest Territories	43.0	54.4	9.1
Yukon	31.0	34.0	3.6

[1] The population growth scenario assumes medium growth and medium migration rates with medium fertility, life expectancy, immigration and interprovincial migration (*see* scenario 3 in Statistics Canada, 2005b).

TABLE 2: Current (2005) and projected (2031) median age and population dependency ratios for Canadian northern territories under a moderate population growth scenario (Statistics Canada, 2005b).[1]

Indicator	Canada current (projected)	Yukon current (projected)	Northwest Territories current (projected)	Nunavut current (projected)
Median age	38.8 (44.3)	37.6 (40.7)	30.8 (35.7)	23.0 (24.5)
Percentage aged 0–14	24.9 (23.5)	23.9 (25.0)	33.7 (31.3)	54.3 (50.9)
Percentage aged 65 and over	19.0 (37.7)	9.8 (30.8)	6.9 (23.5)	4.4 (9.1)
Total dependency ratio	43.9 (61.3)	33.6 (55.8)	40.6 (54.8)	58.7 (60.0)

[1] The population growth scenario assumes medium growth and medium migration rates with medium fertility, life expectancy, immigration and interprovincial migration (*see* scenario 3 in Statistics Canada, 2005b).

young, but have a growing proportion of people over the age of 65, increasing dependency ratios across the territories (Table 2).

Just over half of northern residents are Aboriginal and represent diverse cultural and language groups, from the fourteen Yukon First Nations in the west to the Inuit of Nunavut in the east, many of whom have been in these regions for thousands of years. Non-Aboriginal residents account for 15 and 78% of the total population in Nunavut and the Yukon, respectively (Table 3; Statistics Canada, 2001). The majority of small communities are predominantly Aboriginal in composition and are places where various aspects of traditional ways are still strong components of daily life.

Health Status

The health status of northern Canadians is lower than the national average, as measured by a number of health indicators (Table 4; Statistics Canada, 2001). All territories report lower life expectancy and higher infant mortality rates than the national averages, and these disparities are particularly pronounced in Nunavut (Table 4). The health status of Aboriginal northerners is, for many indicators, significantly below that of non-Aboriginal northern residents and the national average. Higher rates of mortality from suicide, lung cancer, drowning and unintentional injuries (i.e. accidents) associated with motor vehicle accidents occur in the North relative to the rest of the country (Table 5; Statistics Canada, 2001). Accidental deaths and injuries are likely associated, in part, with the increased exposure associated with the amount of time spent 'on the land' and the high level of dependence on various modes of transport for hunting, fishing and collection of other resources, which are a strong part of livelihoods and life in the North.

TABLE 3: Population characteristics of Canadian northern territories (Statistics Canada, 2001).

Indicator	Canada	Yukon	Northwest Territories	Nunavut
Population density (per km^2)	3.33	0.06	0.03	0.01
Percentage of population that is urban[1]	79.6	58.7	58.3	32.4
Percentage of population that is Aboriginal[2]	3.4	22.9	50.5	85.2

[1] Urban areas are those continuously built-up areas having a population concentration of 1000 or more and a population density of 400 or more per square kilometre based on the previous census; rural areas have concentrations or densities below these thresholds.

[2] Aboriginal people are those persons who reported identifying with at least one Aboriginal group (e.g., North American Indian, Métis or Inuit) and/or those who reported being a Treaty Indian or a Registered Indian as defined by the Indian Act and/or those who were members of an Indian Band or First Nation.

Socioeconomic Status

The economies of many northern communities are a mix of traditional land-based renewable resource–subsistence activities and formal wage-earning activities. Estimates of Nunavut's land-based economy are between $40 and 60 million per year, with an estimated $30 million attributed to all food-oriented economic activity (Conference Board of Canada, 2005). However, the true value of such activities is difficult to measure, as they are significant contributions to the social fabric of communities and provide more than monetary benefits. The traditional economy is similarly important in other northern regions (Duhaime et al., 2004). For example, more than 70% of northern Aboriginal adults reported harvesting natural resources via hunting and fishing and, of those, more than 96% did so for subsistence purposes (Statistics Canada, 2001).

Wage-earning activities are often tied to non-renewable resource extraction or to public administration, which is the largest economic sector in many regions (e.g. 22% of territorial gross domestic product in the Yukon). Large-scale extraction of mineral and hydrocarbon resources is a significant component of the economy in some regions (Duhaime et al., 2004). Although only a fraction of the revenue from these resources remains in the regions where the activities are conducted, it nonetheless

TABLE 4: Selected health status indicators for Canada and its northern territories, 2001 (Statistics Canada, 2002).

Indicator	Canada	Yukon	Northwest Territories	Nunavut
Public health spending per capita ($)	2535	4063	5862	7049
Life expectancy at birth (males, 2002)	75.4	73.9	73.2	67.2
Life expectancy at birth (females, 2002)	81.2	80.3	79.6	69.6
Life expectancy at age 65 (males, 2002)	17.1	15.6	14.5	16.3
Life expectancy at age 65 (females, 2002)	20.6	19.5	19.2	11.4
Infant mortality rate (per 1000 live births, 500 g or more, 2001)	4.4	8.7	4.9	15.6
Low birth weight rate (% of births less than 2500 g)	5.5	4.7	4.7	7.6
Potential years of life lost due to unintentional injury (deaths per 100 000)	628	1066	1878	2128
Self-reported health (percentage aged 12 and over reporting very good or excellent health)[1]	59.6	54	54	51
Physical activity (% aged 12 and over reporting physically active or moderately active)[1]	42.6	57.9	38.4	42.9

[1] Population aged 12 and over reporting level of physical activity, based on their responses to questions about the frequency, duration and intensity of their participation in leisure-time physical activity.

TABLE 5: Selected crude mortality rates (per 100,000 population) for Canada and its northern territories, 2001 (Statistics Canada, 2006).

Indicator	Canada	Yukon	Northwest Territories	Nunavut
Major cardiovascular diseases	233.2	111.3	118.5	78.9
Acute myocardial infarction	58.9	6.5	35.5	10.3
Heart attacks	52.1	37.1	28	3.7
Lung cancer	48.2	73.2	61	209.5
Accidents, unintentional injuries	28.6	65.5	59.2	30.9
Transport accidents (motor vehicle, other land transport, water, air and unspecified)	9.9	19.6	16.6	27.5
Accidental drowning	0.8	9.8	7.1	<0.5
Intentional self-harm (suicide)	11.9	19.6	23.7	106.4

represents significant benefits in terms of wage-earning employment, significantly increasing average personal incomes. As a result, there are strong disparities in social and economic status between and within regions of the North (Table 6).

Food insecurity in Canada is highest in the three territories, where there are significantly higher numbers of female single parent households (Table 6; Statistics Canada, 2001, 2005a) and the cost of a standard list of grocery items can be up to three times higher than in southern Canada (Table 7; Statistics Canada, 2005a). In communities not accessible by road (e.g. Nunavut, Nunavik and Nunatisavut and some smaller regions and communities in the Northwest Territories and Yukon), access to market food items is reliant upon shipment via air or sea, which significantly increases the price. Data from 2001 show that 68% of households in Nunavut, 49% of those in the Northwest Territories and 30% of those in the Yukon had at least one occasion in the previous year when they did not have the financial resources for sufficient food.

Chapin et al. (2005) reported that, despite the physical, economic and administrative challenges to health for some residents in the North, the deterioration of cultural ties to land-based and subsistence activities among Aboriginal people is the most serious cause of decline in well-being within circumpolar regions. The loss of connection to the land through changes in ways of life, loss of language and dominance of non-Aboriginal education systems are impacting health and well-being in various and long-lasting ways.

TABLE 6: Selected social and economic indicators for Canada and its northern territories (Statistics Canada, 2001, 2002).

Indicator	Canada	Yukon	Northwest Territories	Nunavut
High social support[1]	-	78.0	74.5	58.1
Sense of belonging to local community (very strong or somewhat strong)	62.3	69.3	72.3	80.9
Proportion of census families that are lone female parent families	15.7	19.8	21.0	25.7
Personal average income (in dollars), 2000	29 769	31 917	35 012	26 924
Government transfer income as proportion of total, 2000	11.6	8.6	7.3	12.9
Percentage of long-term unemployed (labour force aged 15 and over)[2]	3.7	6.0	4.8	11.2
Percentage of population aged 25–29 that are high school graduates	85.3	85.4	77.5	64.7

[1] Level of perceived social support reported by population aged 12 and over, based on their responses to eight questions about having someone to confide in, someone they can count on in a crisis, someone they can count on for advice, and someone with whom they can share worries and concerns.

[2] Labour force aged 15 and over who did not have a job any time during the current or previous year.

TABLE 7: Cost ($) of Northern Food Basket[1] in 2006[2] for selected northern and southern locations (Indian and Northern Affairs Canada, 2007).

Location	Perishables	Nonperishables	Total food basket
Nunavut			
Iqaluit (2005)	114	161	275
Pangnirtung (Baffin) (2005)	127	165	292
Rankin Inlet (Kivalliq)	153	165	318
Kugaaruk (Kitikmeot)	135	187	322
Northwest Territories			
Yellowknife	65	94	159
Deline	148	161	309
Tuktoyaktuk	129	154	282
Paulatuk	180	167	343
Yukon			
Whitehorse (2005)	64	99	163
Old Crowe	169	219	388
Selected southern cities			
St. John's, NF (2003)	66	78	144
Montreal, QC (2005)	64	90	155
Ottawa, ON	72	93	166
Edmonton, AB	65	108	173

[1] The Northern Food Basket (NFB) consists of 46 items based on Agriculture Canada's Thrifty Nutritious Food Basket, which is used to monitor the cost of a nutritious diet for a lower income reference family of four (a girl age 7–9 years, a boy age 13–15 years, and a man and woman age 25–49 years). For a listing of NFB items go to <http://www.inac.gc.ca/ps/nap/air/Fruijui/NFB/nfb_e.html>.

[2] Unless otherwise identified

2.3 CLIMATIC CONDITIONS, PAST AND FUTURE

2.3.1 Past Climate

The high natural climate variability of the Arctic, together with the relatively sparse observational data sets, make it difficult to distinguish with confidence a climate change signal in the trends observed in the instrumental period of record (McBean et al., 2005). As few stations have data prior to 1950, estimates of trends and variability are limited to the second half of the twentieth century. For the period 1950 to 1998, there is a west to east gradient in mean annual temperature trends, with significant warming of 1.5°C to 2.0°C in the western Arctic and significant cooling (–1.0°C to –1.5°C) in the extreme northeast (Zhang et al., 2000). During more recent periods, all regions show warming . Trends were strongest in winter and spring. Annual and winter temperature anomalies and annual precipitation departures over four northern regions from 1948 to 2005 (Figure 3) show greatest warming in the Yukon and Mackenzie District (2.2°C and 2.0°C, respectively). In comparison, temperatures throughout Canada as a whole increased by 1.2°C over this same period (Figure 3a; all trends are significant at the 0.05 level). Many of the extreme warm winters in these regions have occurred during the latter part of the record, including 2006. For northwestern Canada in general, the period 1950 to 1998 exhibited a trend towards fewer days with extreme low temperature and more days with extreme high temperature during winter, spring and summer (Bonsal et al., 2001b).

Annual precipitation totals (1948–2005) increased throughout all of northern Canada, with the largest increases over the more northerly Arctic Tundra (+25%) and Arctic Mountain (+16%) regions (Figure 3c). The increase in high Arctic regions is evident during all seasons, with strongest trends in fall, winter and spring (*see also* Zhang et al., 2000). The magnitude of heavy precipitation

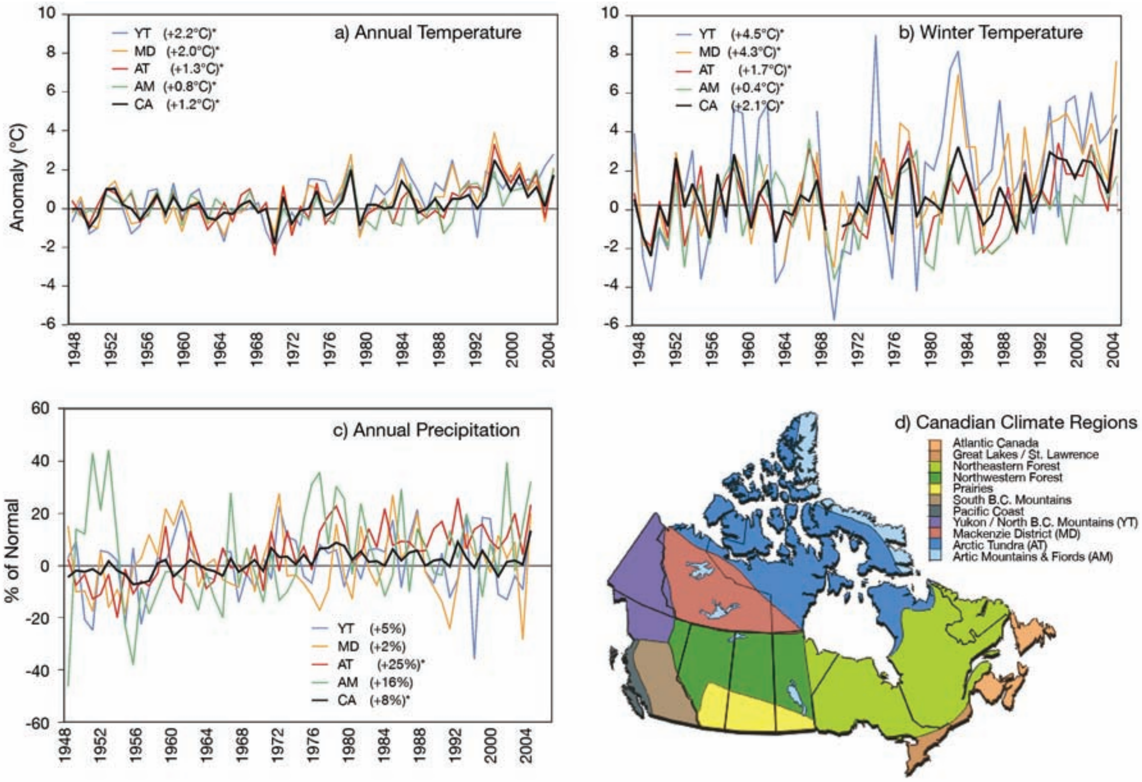


FIGURE 3: Regional temperature anomalies and precipitation departures from normal in the Canadian North: a) annual temperature; b) winter temperature; c) annual precipitation; d) Canadian climate regions. Linear trends over the period of record are given in parentheses. Asterisks signify significant trends at the 0.05 level. Data were obtained from Environment Canada's Climate Trends and Variations Bulletin.

events increased during the period of record (Mekis and Hogg, 1999), and there has been a marked decadal increase in heavy snowfall events in northern Canada (Zhang et al., 2001b).

The observed trends and variability in temperature and precipitation over northern Canada are consistent with those for the entire Arctic (McBean et al., 2005). Throughout the circumpolar Arctic (north of lat. 60°N), annual air temperatures during the twentieth century increased by 0.09°C per decade. This included a general increase from 1900 to the mid-1940s, then decreases until the mid-1960s and accelerated increases thereafter. Although most pronounced in winter and spring, all seasons exhibited an increase in temperature during the past several decades. In terms of precipitation, the entire Arctic has shown a significant positive trend of 1.4% per decade for the period 1900 to 2003. Largest increases generally occurred in fall and winter. Some studies have also suggested that the fraction of annual precipitation falling as snow has diminished, which is consistent with widespread temperature increases (McBean et al., 2005).

The pre-instrumental climate history of northern Canada is known from various natural archives, including tree rings, lake and marine sediments and glacier ice, and from the mapping and dating of glacial moraines and other geomorphic features (McBean et al., 2005). The climate of the North during the last 10 000 years has been characterized by relative warmth and remarkable stability (Figure 4). In the last 2000 years, climate has been characterized by multi-centennial oscillations ranging from mild conditions (similar to the modern era) to widespread persistence of relatively cool conditions (Figure 5). The general pattern of variability is believed to reflect primarily long-term natural fluctuations in circumpolar atmospheric circulation, expressed during the Little Ice Age (ca. AD 1500–1800) by increased southward penetration of cold Arctic air due to intensified meridional circulation (Kreutz et al., 1997).

Climate of the last 400 years has been characterized by warming and related changes over most of the Arctic, including retreat of glaciers, reduction in sea-ice extent, permafrost melting, and alteration of terrestrial and aquatic ecosystems (Overpeck et al., 1997). During the past approximately 150 years, however, it is evident that the rate and nature of change are unprecedented since the abrupt warming at the onset of the current interglacial period more than 10 000 years ago. This rapid acceleration in temperature increase over the Arctic is projected to continue throughout the twenty-first century (Kattsov et al., 2005).

2.3.2 Future Climate

Comparisons of the ability of seven Atmosphere-Ocean General Circulation Models (AOGCMs, *see* Chapter 2) to simulate the mean values and spatial variability of current (1961–1990) temperature and precipitation over four regions spanning Northern Canada revealed considerable inter-regional and

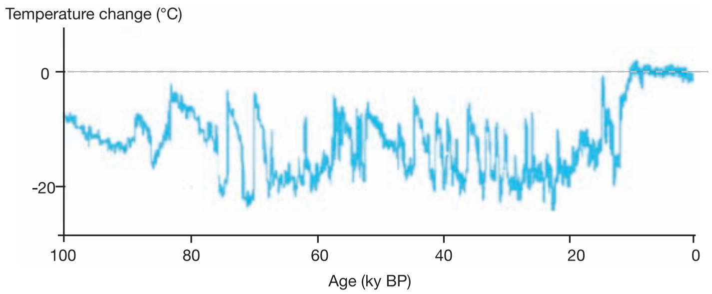


FIGURE 4: Temperature change (departure from present) during the past 100,000 years reconstructed from Greenland ice core (Ganopolski and Rahmstorf, 2001).

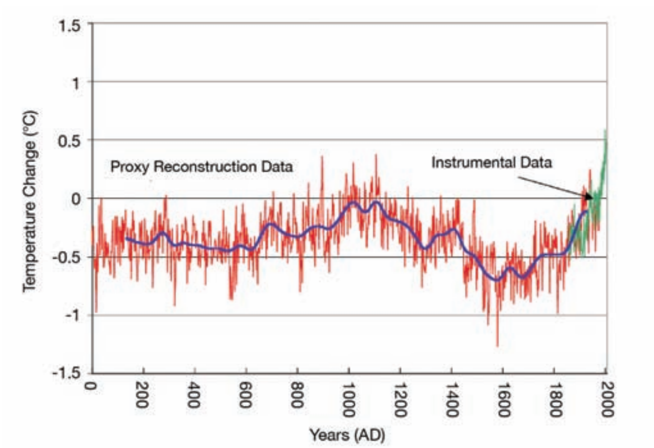


FIGURE 5: Reconstruction of northern hemisphere mean annual temperature, expressed as departures from the 20th century mean (Moberg et al., 2005).

seasonal variability, with temperature being more accurately simulated than precipitation (Bonsal and Prowse, 2006; *see also* Kattsov et al., 2005). The British Hadley Centre for Climate Prediction and Research (HadCM3), the German Max Planck Institut für Meteorologie (ECHAM4) and the Japanese Centre for Climate Research Studies (CCSRNIES) models best replicated annual and seasonal temperature values over all subregions, with the Canadian Centre for Climate Modelling and Analysis (CGCM2) and American National Centre for Atmospheric Research (NCAR-PCM) models having intermediate accuracy and the Australian Commonwealth Scientific and Industrial Research Organisation (CSIROMk2) and American Geophysical Fluid Dynamics Laboratory (GFDL-R30) models being least representative. Collectively, the AOGCM temperature simulations displayed a similar degree of accuracy over all subregions. Conversely, precipitation was only accurately simulated by the majority of models over northern Quebec and Labrador. Annual and seasonal precipitation amounts were substantially overestimated by all AOGCMs in the western and central Canadian Arctic.

Climate Change Projections for the Canadian North

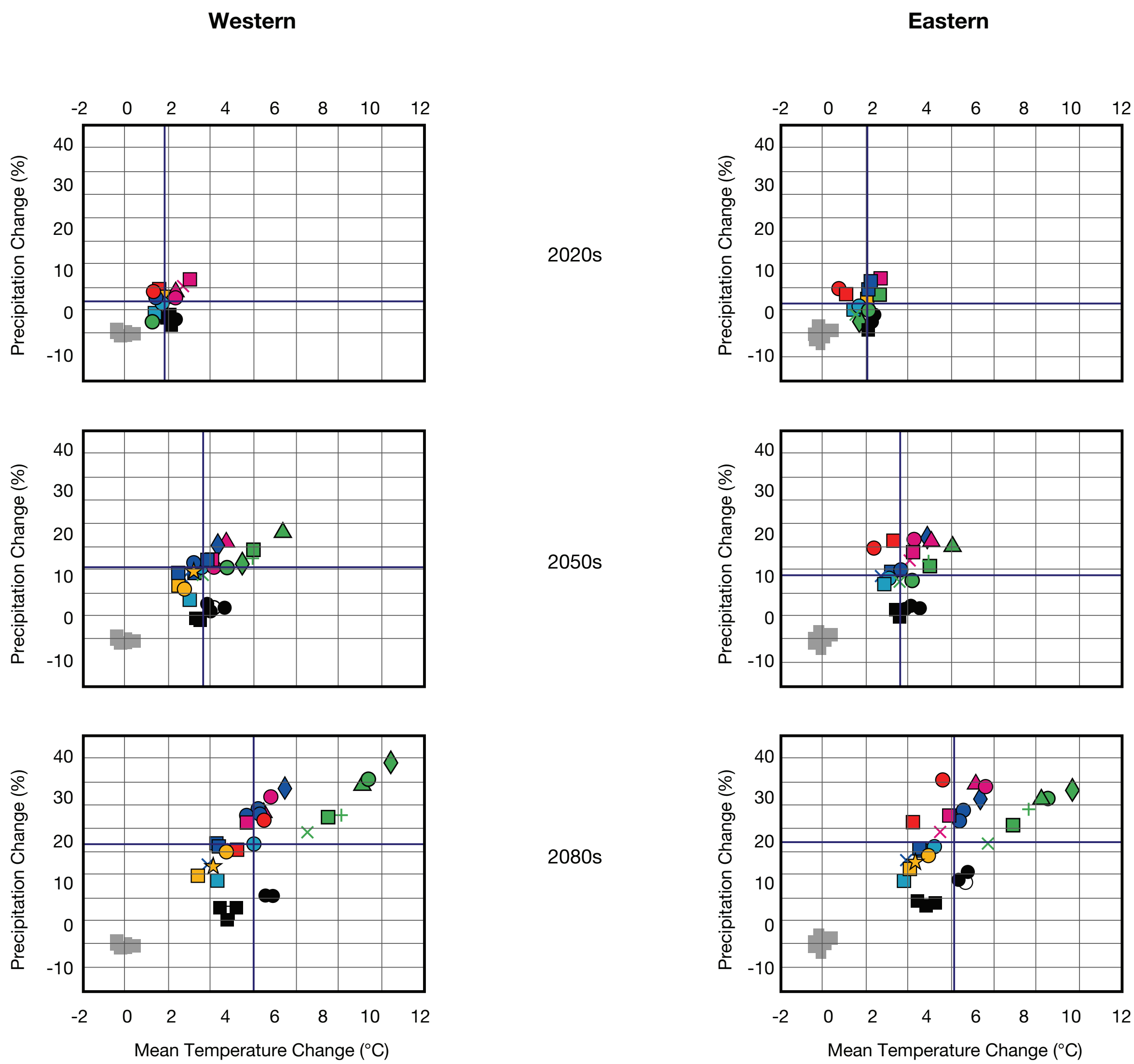
Scenarios of climate change with respect to the 1961–1990 baseline for the 30-year periods centred on the 2020s (2010–2039), 2050s (2040–2069) and 2080s (2070–2099) are presented in scatterplot and map format (*see* Appendix 1 of Chapter 2 for descriptions).

Scatterplots for the western and eastern regions of the North, divided at longitude 102°W, reveal little difference in projections between the two regions (Figure 6). For the 2020s, both western and eastern regions exhibit mean annual temperature changes concentrated near +2.0°C and precipitation increases ranging from 5 to 8%. Intermodel variability is greatest during the 2080s: median temperature changes for the western region are near +6.0°C but range from +3.5°C (NCAR-PCM B2 scenario) to +12.5°C (CCSRNIES A1FI scenario); most scenarios project a 15 to 30% increase in annual precipitation. Note that projections during all periods fall outside the range of modelled natural variability indicated by the grey squares in Figure 6.

Insights into projected seasonal climate change are evident in scatterplots for the 2050s (Figure 7). Despite considerable intermodel variability, the greatest temperature changes are projected to occur during winter. The eastern Canadian Arctic exhibits slightly higher projections of winter temperature than the west. Summer has the lowest projected temperature increases and the least amount of intermodel scatter. With respect to precipitation changes, values during winter range from near 0% over both regions to more than 40% in the east, with most scenarios projecting winter precipitation increases of 20 to 30%. During summer, all models project increases between 5 and 20%, with median values of 10%.

Spatial characteristics of annual and seasonal projected temperature changes over northern Canada indicate that the greatest temperature changes will occur at higher latitudes, particularly in the extreme northwest (Figures 8 and 9). Seasonally, the greatest temperature changes over the entire region are projected to occur during winter and fall. Annual and seasonal precipitation changes show considerable spatial variability in the Canadian Arctic, with the greatest annual percentage increases projected over more northerly regions (Figures 10 and 11). Seasonal maps for the 2050s show even higher variability, with minimum changes associated with decreases in precipitation over parts of the region during all seasons. The median projections tend to show greatest increases during winter and fall, particularly in more northerly regions.

The high degree of variability inherent in Arctic climate increases the uncertainty of projected changes in temperature and precipitation. Given the findings of Bonsal and Prowse (2006), it is recommended that a range of future climate projections be used when examining potential impacts across the North (*see also* Chapter 2). Individual model outliers, such as the CGCM2 low precipitation projections and the CCRSNIES high temperature increases (Figure 8), should be used with caution due to their inconsistency with other model projections.



Legend			
Global Climate Model		Emissions Scenario	
CGCM2	■	Natural climate variability	
CGCM2	♦	A1FI	
HadCM3	+	A1T	
CCSRNIES	▲	A1	
CSIROMk2	★	A1B	
ECHAM4	●	A2	
NCARPCM	×	B1	
GFDL-R30	■	B2	

FIGURE 6: Scatterplots of projected mean annual temperature and precipitation changes in eastern (right) and western (left) regions of Northern Canada. Blue lines represent median changes in mean temperature and precipitation derived from suite of scenarios on plot (*see* Appendix 1 of Chapter 2 for details).

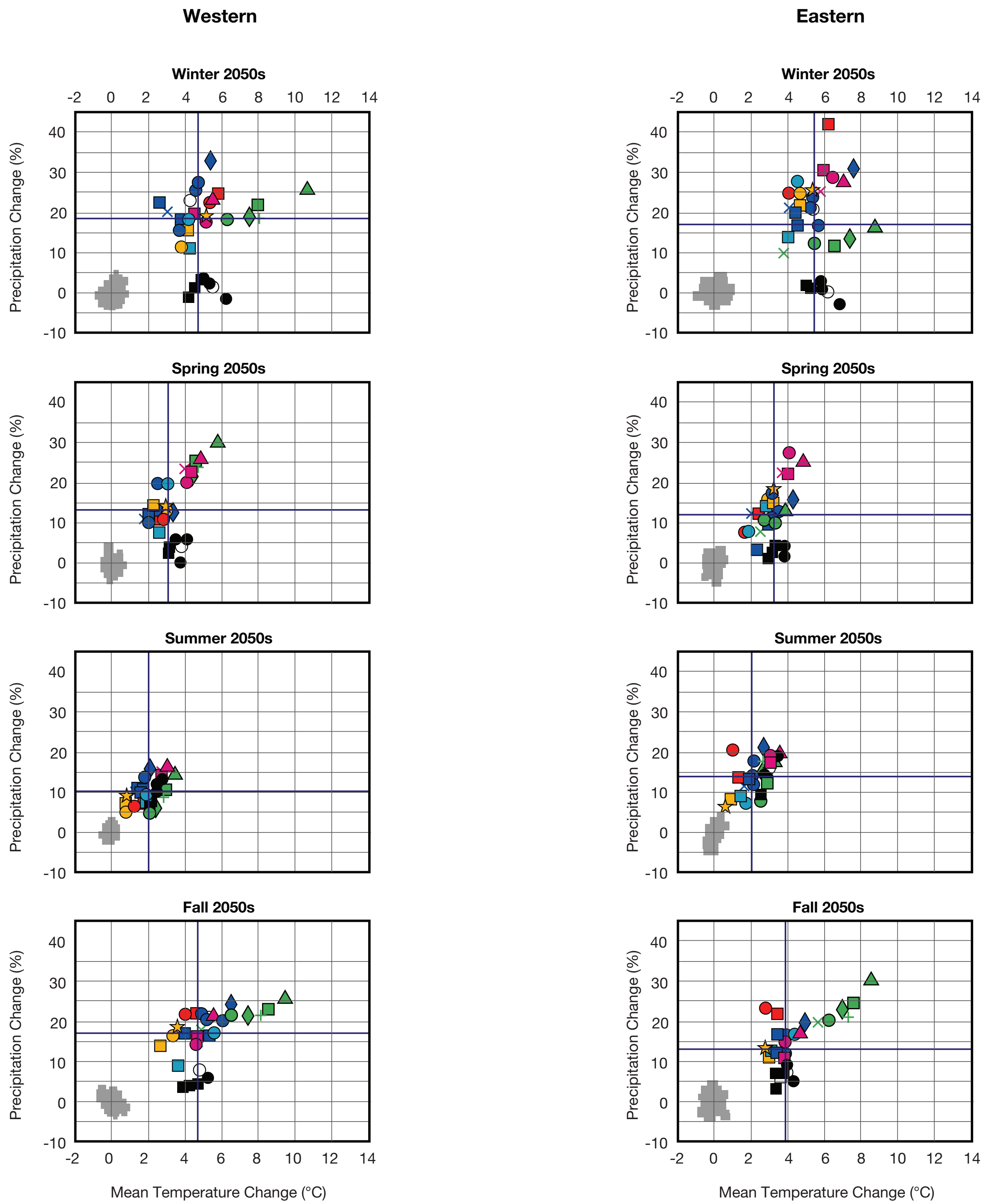


FIGURE 7: Scatterplots of projected seasonal temperature and precipitation changes for the 30 year period centred on the 2050s over eastern (right) and western (left) regions of Northern Canada. Blue lines represent median changes in mean temperature and precipitation derived from suite of scenarios on plot (*see* Appendix 1 of Chapter 2 for details).

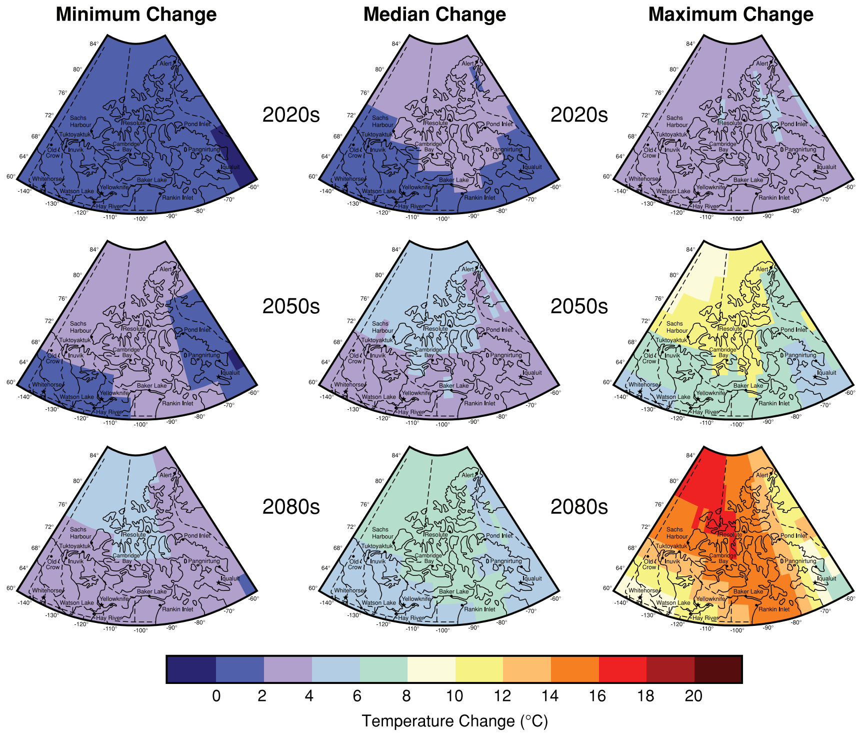


FIGURE 8: Maps of projected changes in mean annual temperature over Northern Canada.

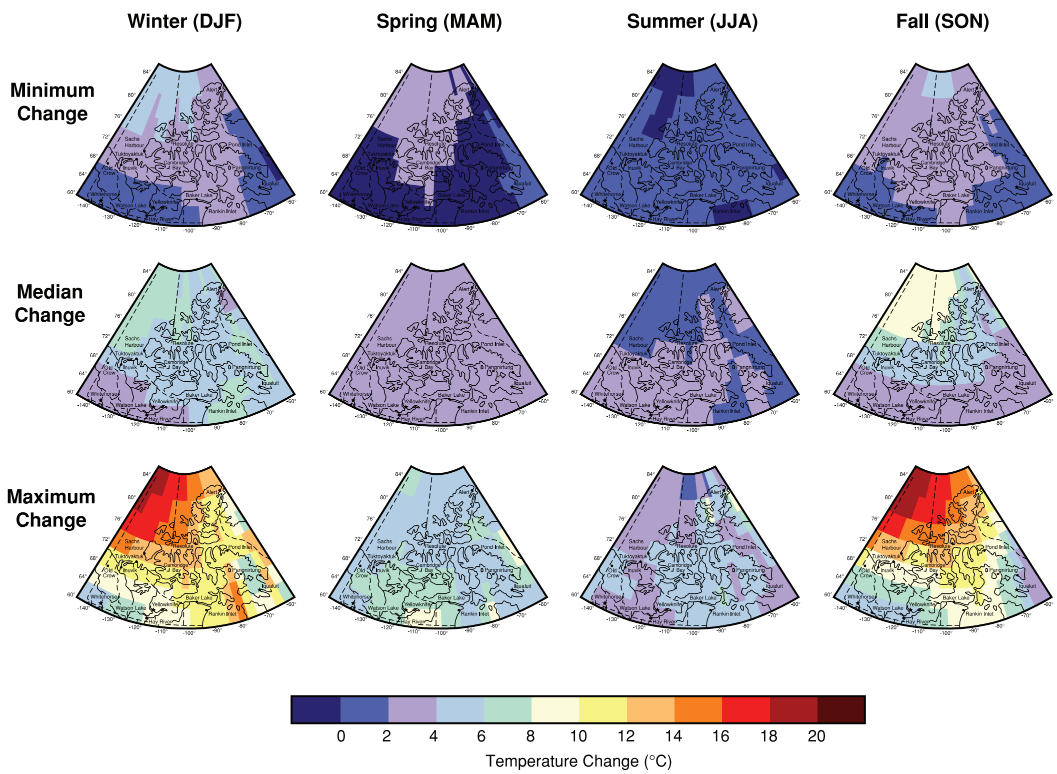


FIGURE 9: Maps of projected seasonal changes in temperatures for the 30-year period centred on the 2050s over Northern Canada.

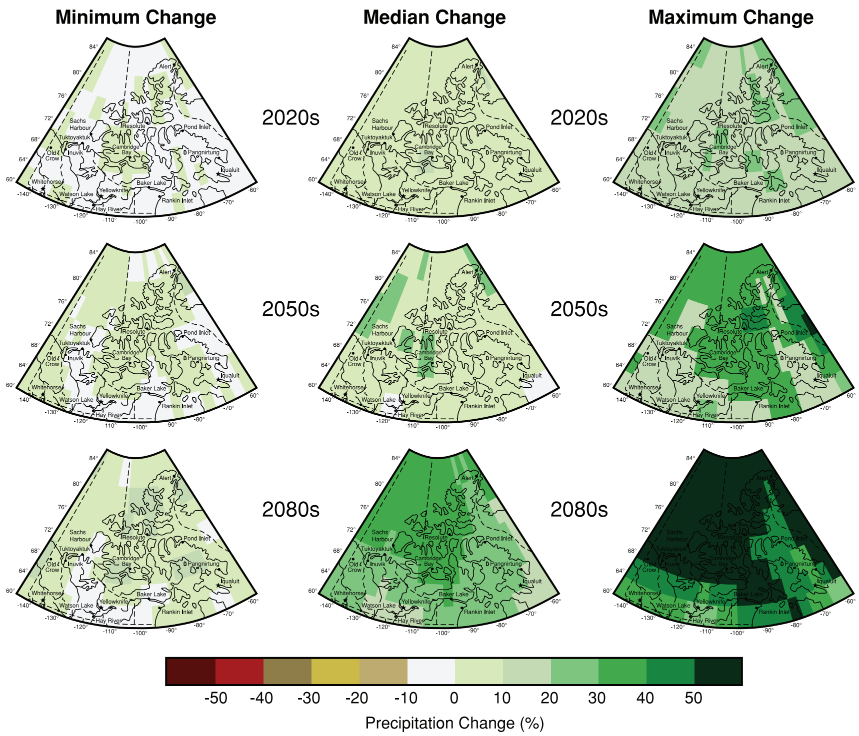


FIGURE 10: Maps of projected changes in mean annual precipitation over Northern Canada.

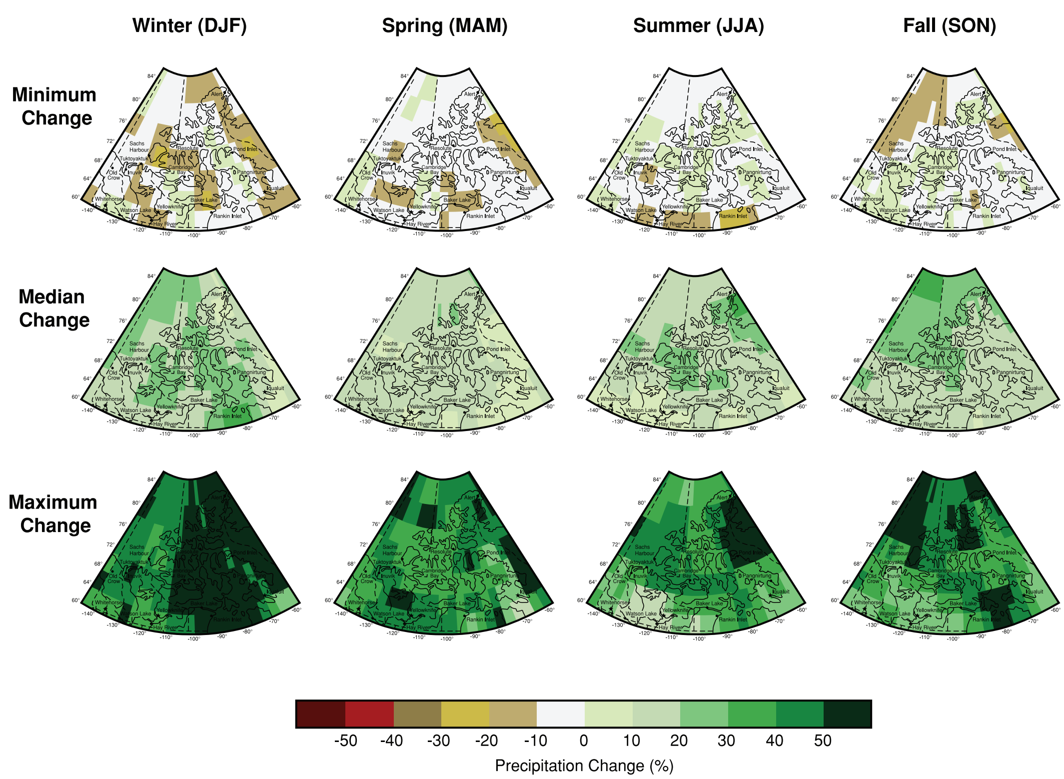


FIGURE 11: Maps of projected seasonal changes in precipitation for the 30-year period centred on the 2050s over Northern Canada.

3 IMPLICATIONS OF CHANGING CLIMATE FOR THE ARCTIC ENVIRONMENT

Of the many components that constitute the Arctic environment, the cryosphere is the most sensitive to the effects of changing climate. The cryosphere includes sea ice, seasonal snow cover, glaciers and ice caps, permafrost, and river and lake ice. All of these are effective indicators of climatic trends and important in various climate feedbacks through changes in energy, moisture and gas fluxes (e.g. Intergovernmental Panel on Climate Change, 2007a; Anisimov et al., 2007; Lemke et al., 2007; Trenberth et al., 2007). Terrestrial, freshwater and marine ecosystems will be impacted by changes in the cryosphere and by other aspects of climate change (Arctic Climate Impact Assessment, 2004, 2005). The following summary of several of the most important changes to the cryosphere and related ecosystems draws extensively on relevant chapters of the Arctic Climate Impact Assessment (Callaghan et al., 2005; Walsh et al., 2005; Wrona et al., 2005).

3.1 SEA ICE

Sea-ice areal coverage varies generally from 5 to 6 million km^2 at the end of the summer to 14 million km^2 at the end of the winter (Parkinson et al., 1999). Sea-ice thickness increases along the path of sea-ice drift and convergence from west to east (from the Siberian side of the Arctic to the Canadian Arctic Archipelago). The annual averaged area of sea ice in the Northern Hemisphere has decreased by 7.4% (3% per decade) between 1978 and 2003 (Johannessen et al., 2004). The annual maximum ice area has shrunk less rapidly, at about 2% per decade, whereas the annual minimum has declined more rapidly, at about 5.6% per decade. Much of the decrease in annual minimum ice area is a consequence of decline in the area occupied by multi-year ice, about 14% (6.7% per decade) between 1978 and 1999 (Johannessen et al., 1999). The loss of thick old floes from the polar pack has caused an obvious decrease in ice thickness in the central Arctic Ocean (Rothrock et al., 1999; Holloway and Sou, 2002).

The primary cause of reductions in ice thickness and in late summer ice extent has been an increased export of multi-year ice from the Arctic via Fram Strait during 1989–2003, not atmospheric warming (Rigor et al., 2002; Fowler et al., 2004; Rigor and Wallace, 2004; Belchansky et al., 2005). Data from Siberia and northern Canada during the second half of the twentieth century revealed no significant change in the thickness of first-year ice (Brown and Coté, 1992; Polyakov et al., 2003). Although the rate of decrease in late summer ice extent is consistent with the trend in multi-year sea ice (Comiso, 2002), this decrease has been especially large north of the Russian and Alaskan coasts, and considerably less within Canadian waters (Walsh et al., 2005). Even in the much cooler mid–nineteenth century, the extent of summer sea ice in the Canadian Archipelago, insofar as it is shown from ship tracks and the logbooks of explorers, was similar to the present (Wood and Overland, 2003).

All AOGCMs project decreases in sea-ice extent during the twenty-first century. Projections from the CGCM2 model indicate an ice-free Arctic during September by the mid–twenty-first century, whereas other models project ice-free summers in the Arctic by 2100. Therefore, although models differ in their projections of when ice-free Arctic summers can be expected, they agree in projecting that such conditions will eventually develop. By the year 2100, model projections of decreases in annual sea-ice extent vary from about 2 to 4 million km^2, and none of the model projections is close to ice free for the month of March. A modest future retreat of pack ice in winter is anticipated where it meets temperate oceans (i.e., in the Labrador, Greenland, Barents, Okhotsk and Bering seas).

Atmosphere-Ocean General Circulation Models have limitations when projecting future changes in sea ice. Scientific understanding of sea-ice dynamics is incomplete and the representation of the Arctic atmosphere-ice-ocean system in global climate models is relatively primitive. Also, the modelling of sea-ice climate is very sensitive to positive feedbacks between sea ice and climate, and small errors in representing this feedback can have large implications (Walsh et al., 2005). For example, the spatial grid of the modelled ocean is generally too coarse to represent the Canadian Arctic Archipelago (*see* Kattsov et al., 2005, Table 4.1). Therefore, the observational record of sea-ice extent in Canadian Arctic waters, and an understanding of the physical processes involved, become particularly important in projecting future changes in sea-ice regime.

3.2 SNOW COVER

In the Arctic regions, snow can account for up to 80% of annual precipitation. Snow insulates the ground, affecting the ground thermal regime and permafrost distribution (Marsh, 1990). Snow also influences surface radiation balances and water budgets (Gray and Prowse, 1993), and affects the habitat of terrestrial and aquatic biota (e.g. Adams, 1981).

From 1972 to 2003, average annual snow-cover extent in the Northern Hemisphere decreased by about 10%. The largest decreases occurred during spring and summer, which correlated with a large spring warming over northern land areas (Brown, 2000; Walsh et al., 2005). The largest changes in snow depth in northern Canada for the period 1946 to 1995 were decreases observed for the Mackenzie River basin (Brown and Braaten, 1998), although even more recent records (1955–1956 to 2002–2003) have also shown significant decreases in the mean and maximum depths of snow cover for the eastern and western Arctic stations (Environment Canada, 2007). Decreases in snow depth have been accompanied by reductions in spring and summer snow-cover duration and extensive reductions in spring snow-covered area (Brown et al., 2004).

Projected increases in temperature will decrease the length of time available for accumulation of a winter snowpack, thereby affecting the magnitude of the spring snowmelt, the major hydrological event of the year in most northern systems (Marsh, 1990). Although changes in mean annual snow cover are generally not expected to be very large for the present century, even for the period 2071 to 2090 when the projected changes vary from –9 to –18% (Walsh et al., 2005), the most pronounced changes in snow extent are expected in the shoulder seasons, November and April, the latter being most influential for spring runoff.

3.3 GLACIERS AND ICE SHEETS

The estimated total volume of land ice in the circumpolar Arctic is approximately 3.1 million km^3, which is equivalent to about 8 m of sea level (Dowdeswell and Hagen, 2004). Although the majority of this is contained on Greenland, Canada has major glaciers and ice caps in the high Arctic and Yukon. In general, glaciers and ice caps across the Arctic (apart from the Greenland Ice Sheet) show a retreat in glacier fronts and volume decreases since about 1920, although there are large regional variations (Walsh et al., 2005). For the Canadian high Arctic (data since about the 1960s), the monitored glaciers and ice caps on the Queen Elizabeth Islands (except the Meighen Ice Cap, which may be cooled from an increasingly open ocean nearby) show a weak but significant trend towards increasingly negative mass balances, primarily due to slight summer warming (Koerner, 2005).

The mass balance for all ice caps in the Canadian Arctic Archipelago over a five-year period at the end of the last century is estimated to be –25 km^3/a of ice, which corresponds to a global sea-level rise of 0.064 mm/a (Abdalati et al., 2004). Although this is significant, more pronounced ablation has been recorded for the Yukon-Alaska glacier network, where accelerated melting of 1.5 ± 0.5 mm/a has contributed almost 9% of the observed global sea-level rise during the past 50 years, and possibly as much as 3.2 mm/a during the past decade or so (Arendt et al., 2002). From the mid-1990s to 2000–2001, enhanced thinning of Yukon-Alaska glaciers likely equates to a sea-level rise almost double that estimated for the Greenland Ice Sheet during the same period (Rignot and Thomas, 2002).

Over the long term, the Greenland Ice Sheet is projected to make the largest contribution to future sea-level changes, but meltwater from glaciers in Alaska-Yukon are also projected to make a significant addition (Arendt et al., 2002; Meier and Dyurgerov, 2002). Future contributions from the high Arctic remain to be quantified but could also be significant (Abdalati et al., 2004). Glacier ablation also affects the magnitude and timing of river flows and drainage patterns (e.g. Clague et al., 2006).

3.4 PERMAFROST

Active layer and permafrost thermal-monitoring activities during the last two to three decades indicate that recent warming of permafrost has occurred in many regions of the Canadian permafrost zone (e.g. Broll et al., 2003; Couture et al., 2003; Kershaw, 2003; Smith et al., 2003, 2005), and that summer thaw penetration has increased in the 1990s (e.g. Smith et al., 2001b, 2005; Mackay and Burn, 2002; Nixon et al., 2003; Tarnocai et al., 2004). The magnitude of permafrost warming has varied both regionally (Smith et al., 2005) and temporally, with generally greater warming occurring in the western Arctic and later warming occurring in the eastern and high Arctic (Brown et al., 2000; Smith et al., 2005). The response of the active layer to extreme warm conditions, such as those of 1998 (e.g. Smith et al., 2001b), is consistent with that observed for other components of the cryosphere (Atkinson et al., 2006).

Approximately half of the area underlain by permafrost in Canada contains permafrost warmer than –2°C that could ultimately disappear under projected climate warming (Smith and Burgess, 2004; Figure 12). Where permafrost is thicker and colder, thickening of the active layer and warming and thinning of permafrost will likely occur. Projections of increases in the active-layer depth range from 0% to more than 50% during the next 50 years (Walsh et al., 2005). The largest percentage increases in Canada are projected for the Yukon. Degradation of continuous permafrost to discontinuous permafrost, and disappearance of discontinuous permafrost, are projected to occur at the southern boundaries of these permafrost zones. Thawing of permafrost has the potential to release large pools of carbon, which can act as feedback to the climate system (e.g. Tarnocai, 2006; Callaghan et al., 2005; Zimov et al., 2006).

Thaw sensitivity and settlement of permafrost have important implications for landscape stability and the performance of any overlying infrastructure. National-scale mapping by Smith and Burgess (2004; Figure 13) demonstrated that thaw sensitivity is moderate to high in about 50% of the present permafrost zones (excluding areas where massive ice is present and where thaw sensitivity may be higher than indicated). Regions where frozen soils are thaw sensitive include the silty clay and organic terrain in

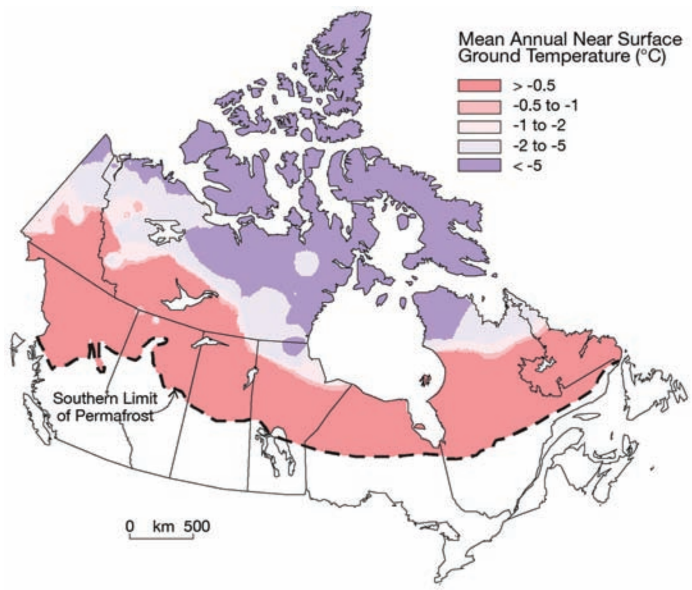


Figure 12: Variation in mean annual near surface ground temperature for the Canadian permafrost zone (Smith and Burgess, 2004).

the Mackenzie region and the peatlands of the northern Prairies and Hudson Bay Lowlands.

Frozen ground plays an important role in northern hydrology through its influence on infiltration, runoff and groundwater storage and flow. The implications of climate-induced changes in permafrost for northern hydrology have been summarized by Woo et al. (1992), Michel and van Everdingen (1994), Brown et al. (2004), Mackenzie River Basin Board (2004) and Smith and Burgess (2004). Active-layer thickening and permafrost degradation in response to climate warming can lead to increased infiltration, greater groundwater storage, lower spring runoff and increase in base flow (Woo et al., 1992). As a result, groundwater will play a greater role in future streamflow, with implications for surface-water quality (Michel and van Everdingen, 1994). As ground ice thaws, differential settlement and ponding may occur, leading to changes in drainage and the distribution of surface water. Thawing of ice-rich permafrost may also cause some lakes and wetlands to drain, leading to loss of fish and wildlife habitat (Labrecque and Duguay, 2001; Marsh and Neumann, 2001).

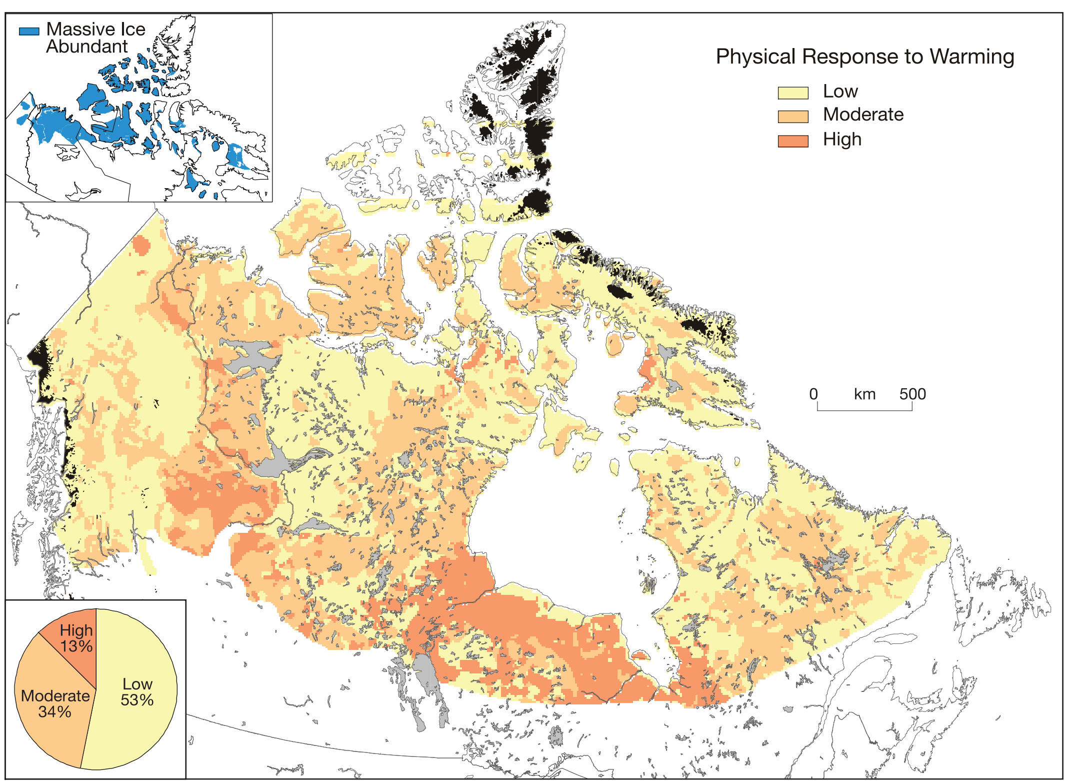


FIGURE 13: The relative physical response (thaw sensitivity) of permafrost to climate warming (Smith and Burgess, 2004).

3.5 RIVER AND LAKE ICE

Freshwater ice is responsible for the timing and severity of many hydrological extremes in northern systems, such as low flows and floods that are experienced during freeze-up and break-up periods (e.g. Beltaos and Prowse, 2001; Prowse and Carter, 2002). River ice is also a major factor in river ecology (Prowse and Culp, 2003), particularly in the Mackenzie Delta (Marsh and Lesack, 1996).

From 1846 to 1995, freeze-up and break-up trends for lakes and rivers in the Northern Hemisphere, including a long-term site on the Mackenzie River, show an average delay of 5.8 days per century in freeze-up dates and an average advance of 6.3 days per century in break-up dates (Magnuson et al., 2000). Canadian data for the period 1947–1996 show that western sites have a predominant trend towards earlier break-up dates, and that there has been a nationwide trend towards earlier freeze-up dates (Zhang et al., 2001a). Break-up–freeze-up trends are complex, however, and depend on the interval considered, but generally reflect trends in fall and spring air temperatures (e.g., Lacroix et al., 2005; Duguay et al., 2006).

Prowse and Beltaos (2002) outlined the complexities of freshwater-ice responses to changing climate. Although changes are difficult to predict (Bonsal and Prowse, 2003), future warming will likely lead to a shortened ice season and thinner lake- and river-ice covers, and cover composition (i.e. proportion of white ice) might be altered by increases in winter snowfall. Changes in winter snowfall will be a major factor in determining whether the severity of river-ice events, such as ice-jam flooding, increase or decrease (Walsh et al., 2005).

3.6 FRESHWATER DISCHARGE

Rivers flowing into the Arctic Ocean have low winter runoff, high spring flow rates (driven by snowmelt) and rain-induced floods in the summer and autumn. Snowmelt accounts for most of the flow in high-Arctic rivers and streams (Woo, 1990). Flow of large rivers, such as the Mackenzie, is strongly influenced by the hydrological regimes in their non-Arctic southern headwaters (Prowse et al., 2006).

Observed trends in river discharge vary regionally, with studies documenting both increases and decreases in flow since the 1960s. From 1964 to 2003, the total annual river discharge for 64 rivers draining into the Labrador Sea, Hudson Bay, Arctic Ocean and Bering Strait decreased by 10% (Dery et al., 2005). Between 1967 and 1996, Zhang et al. (2001a) found a trend towards increasing streamflow discharge for Chesterfield Inlet, whereas rivers in northern Ontario and Quebec showed a decrease in discharge. No significant trend was found in discharge from the Yukon River for the period 1964–2000 (McClelland et al., 2006).

Future projections, based on model scenarios for 2050, suggest increases in discharge. For example, Arnell (1999) concluded that annual discharge could increase between 12 and 20% relative to the 1961–1990 baseline for the Mackenzie River, and between 20 and 30% for the Yukon River. Broadly speaking, projections of future climate suggest that total annual discharge to the Arctic Ocean from Arctic land areas could increase between 10 and 20% by about 2050, with winter discharge likely to increase between 50 and 80%. It is also expected that 55 to 60% of annual discharge will enter the Arctic Ocean between April and July (peak runoff season; Arnell, 1999; Arora and Boer, 2001).

3.7 SEA-LEVEL RISE AND COASTAL STABILITY

Climate change will lead to rising sea levels in the Arctic Ocean (Proshutinsky et al., 2001) and other northern seas. Climate warming affects global sea level through ocean thermal expansion and additional water transfers to the ocean basins from melting glaciers and ice sheets. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (2007a) has projected a rise in global mean sea level (MSL) of between 0.18 and 0.59 m by 2100 (2090–2099 MSL relative to 1980–1999 MSL). The rise in sea level will not be uniform throughout the globe and some areas, including parts of the Arctic, may be subject to more rapid rates. In addition, the relative sea-level change along any coast (the trend measured by a tide gauge) is a combination of sea-level change and any vertical motion of the land surface. Vertical motion in the Arctic is dominated by ongoing postglacial isostatic rebound, with uplift in some places being as high as about 1 m per century. Other areas around the margins of the former ice sheets (the Beaufort Sea coast, the western margin of the Canadian Arctic Archipelago and a narrow band on eastern Devon Island and the east coast of Baffin Island) are subsiding (Forbes et al., 2004).

Sea-level rise increases the risk of flooding and erosion on Arctic coasts and may exacerbate other coastal hazards, such as ice ride-up and pile-up. In the western Arctic, sea-level rise and coastal erosion threaten cultural heritage sites (e.g. former habitations and burial sites) on the Yukon coast (e.g. Herschel Island), seasonal settlements (e.g. Shingle Point, YT) and coastal communities (e.g. Tuktoyaktuk, NT; e.g. Colette, 2007). Coastal erosion is a concern at other communities in the western Arctic, including Sachs Harbour and, to a lesser extent, Ulukhaktok, NT (Manson et al., 2005), while high water levels have been noted as an issue in Cambridge Bay, NU (Shirley, 2006). In the eastern Arctic, high-water and erosion concerns have been noted at Hall Beach, Iqaluit, Pond Inlet and Arctic Bay, NU, prompting discussions about adaptation options (Shirley, 2006; Ford et al., 2006a; Bhabesh Roy, Regional Engineer, Government of Nunavut, pers. comm., March 14, 2007). With the exception of Hall Beach, the affected communities are in areas of nearly stable or subsiding crust, where sea-level rise may overwhelm residual uplift or add to the rate of subsidence. Reduced sea ice, more open water and more energetic waves may be important in a number of places, including Hall Beach, where postglacial uplift and coastal emergence are ongoing.

The most severe flooding risks in low-lying communities, such as Tuktoyaktuk, are associated with large storm surges, which may reach more than 2 m above MSL (Manson et al., 2005). Storm waves during severe surges can cause rapid coastal retreat of 10 m or more in a single event. Sea-level rise will increase the upper limit of potential storm-surge flooding, and also increase the frequency of flooding at lower levels. Storm frequency in the Canadian Arctic shows no clear trends during the past 50 years (Atkinson, 2005). Erosion rates may be accentuated by warmer ground temperatures, deeper summer thaw and volume loss on melting of excess and massive ground ice where exposed in coastal cliffs (Forbes, 2005). Despite some suggestions of increased erosion rates in the western Arctic, including the Yukon and Alaska coast, a regional analysis for the southern Beaufort Sea detected no significant trend in areas of rapid erosion for the 1972–2000 time interval (Solomon, 2005). However, further warming, combined with sea-level rise and reduced sea ice, can be expected to maintain or increase the already rapid rates of coastal retreat along this coast.

3.8 TERRESTRIAL VEGETATION ZONES AND BIODIVERSITY

The extreme temperature gradients of the Arctic mean that plant communities will likely show a quick and strong response to temperature change. For currently widespread grass, sedge and flowering species, such as *Carex bigelowii/arctisibirica*, *C. stans*, *Dryas octopetala/punctata*, *Cassiope tetragonal* and the moss *Tomentypnum nitens*, continued temperature increase will result in higher productivity and abundance, and an expansion in range to the north. Other species found exclusively (hyperarctic; e.g. grasses — *Poa abbreviate*) or primarily (euarctic; e.g. polar willow — *Salix polaris*) at high northern latitudes, on the other hand, will likely respond to climate warming with a narrowing of their ecological niche (Callaghan et al., 2005).

Latitude and light regimes currently limit the distribution of some plant species, so these will not be able to migrate northward in response to increasing temperatures. Other important factors to be considered when projecting a whole-system response to climate change include: 1) the importance of carbon-nutrient interactions; 2) the interactions of carbon and nutrient cycles with temperature, water and snow cover; 3) the magnitude of dissolved organic and inorganic carbon losses in soil water; and 4) the magnitude and role of wintertime processes. The cumulative impacts of climate change on these factors will likely result in new communities, with different structures and species composition (Callaghan et al., 2005).

Vegetation-model projections for the present century indicate that, depending on location, the boreal forest will displace between 11 and 50% of all Arctic tundra (Harding et al., 2002; Skre et al., 2002). However, recent observations of the latitudinal treeline show a southward displacement, suggesting that a northward displacement, projected on the basis of changing climatic conditions alone, is unlikely (Callaghan et al., 2005). Increased disturbances, such as pest outbreaks and fire, will locally affect the direction of treeline response. In general, the treeline will show many different responses depending on the magnitude of temperature change, as well as changes in precipitation, permafrost conditions, forest composition and land use.

3.9 FRESHWATER ECOSYSTEMS

Climate change will affect the structure and function of Arctic freshwater ecosystems. Community and ecosystem attributes, including species richness, biodiversity, range and distribution, will be affected by changes in physical and chemical environmental parameters, and will consequently affect food-web structures and production levels (Rouse et al., 1997; Vincent and Hobbie, 2000; Poff et al., 2002; Wrona et al., 2006a).

The northern freshwater fish fauna of Canada consist of approximately 35 species, with another 15 anadromous species present (Richardson et al., 2001; Evans et al., 2002; Coad and Reist, 2004; Reist et al., 2006b). Relative to the South, low biological productivity is pervasive in aquatic ecosystems of the North, which is partly a result of low energy inputs. General knowledge of the biology of aquatic biota is low, particularly with respect to understanding potential connections with climate drivers and ecosystem structural and functional responses (Wrona et al., 2006a). Although large uncertainties remain in projecting species- and system-specific responses, it is likely that locally adapted Arctic species will disappear from certain areas when environmental conditions begin to exceed their physiological tolerances and/or ecological optima. The most vulnerable species are those with limited climatic ranges. Extinctions of Arctic species across their entire range are not expected, although some species will be marginalized geographically and/or ecologically (Wrona et al., 2006b).

Changing climate will also result in alterations to the geographic ranges of freshwater species due to loss of optimal habitat for 'native' Arctic species and the northward expansion of more southerly species (Wrona et al., 2006b). Ecological observations by trappers on the Peace-Athabasca Delta of the Mackenzie River system indicate that muskrat abundance is likely to increase in high-latitude lakes, ponds and wetlands due to the expected increases in the abundance of aquatic vegetation (Thorpe, 1986). Projected impacts and changes among marine species are discussed in Section 4.8.

4 IMPLICATIONS FOR ECONOMIC DEVELOPMENT AND ADAPTATION WITHIN KEY SECTORS

4.1 HYDROELECTRIC DEVELOPMENT

Demand for electricity is rising in all three territories, due to increasing population and heavy industry, such as diamond mines in the Northwest Territories and Nunavut. Alternative renewable energy sources, such as solar, wind, wood and even geothermal power, could help to meet some of the increasing demands for electricity, and territorial government agencies have indicated that they are committed to increasing renewable energy supply. There is already a significant dependence on hydroelectric generation, with seven large (>10 m in height) hydroelectric dams operating in the Yukon and Northwest Territories (Canadian Dam Association, 2003), along with a range of small, often privately owned, micro-hydro facilities. Further expansion of micro-hydro facilities is under consideration, but the major northern rivers still offer some of the largest potential (Prowse et al., 2004).

Changing climate will affect the capacity and operations of current and future hydroelectric developments, as well as affecting the demand for electricity. Projected increases in winter runoff from rainfall and enhanced winter snowmelt will lead to a decline in winter snow storage. Reservoir capacities on current and future developments may need to be expanded to offset this loss in natural storage. For some sites, this could be achieved by raising the height of the retention dam, thereby increasing storage area and volume. Where the landscape (e.g. relatively low relief) or operations (e.g. run-of-river power plants) preclude such an approach, adaptation measures may involve the construction of additional storage or facilities in other locations. The gradual loss of meltwater contributions from glaciers as they ablate and retreat will also need to be factored into future calculations of capacity.

Changes in the magnitude and seasonality of flows will also necessitate an increased focus on the safety of existing dam structures (World Commission on Dams, 2000). Of particular importance is a need to redefine the Inflow Design Flood (IDF: volume, peak, duration, shape and timing), commonly defined as the most severe inflow flood for which a dam and its associated facilities are designed (Zielinski, 2001). Concern that changing hydrological conditions will require reassessment of IDFs has already been noted for hydroelectric operations on the Snare River (Bruce et al., 2000). Changes in river-ice regimes will alter threats from downstream ice jamming (Prowse and Beltaos, 2002). Fuller assessment of the risks to hydroelectric facilities under a changing climate, however, requires hydrological models capable of predicting flow in northern regions that often lack flow gauges (e.g. Spence et al., 2005).

4.2 OIL AND GAS

The oil and gas industry involves exploration, extraction, production and delivery. Although changes in climate need to be considered for all four, exploration activities are likely to be most affected. In 2006, there were active and potential exploration activities in the Eagle Plains area of the Yukon and in the Cameron Hills, Fort Liard and Mackenzie Delta areas of the Northwest Territories. Some of the largest future potential reserves exist within the Canadian Arctic Archipelago (e.g. Drummond, 2006), and projected decreases in sea-ice cover may result in this area becoming a focus of additional exploration activity.

Thawing of permafrost and changes in snow cover will necessitate an increased focus on low-impact vehicles and/or changes in seasonal scheduling of exploration activities. The unpredictability of the winter season and the winter ice-road system will necessitate greater flexibility in scheduling of exploration and extraction activities. The greatest impact of changing climate on exploration, however, may relate to the use of in-ground sumps for drilling wastes. Disposal in sumps relies on the presence of permafrost to prevent subsurface movement of drilling wastes into the surrounding environment (French, 1980; Dyke, 2001). Increased ground temperatures resulting from increases in air temperature and/or snow depth (Jenkins et al., 2005) will increase the likelihood of contaminant transport. Alternate drilling-waste practices, including remote sumps, central processing facilities, down-hole injection or transportation of waste to outside the territories (e.g. Environmental Studies Research Funds, 2004), represent potential adaptations to climate change.

Offshore exploration drilling, such as that recently conducted by Devon Canada Corporation in the Beaufort Sea, will be affected by decreasing sea-ice cover. Future development may require design changes to drilling platforms to counter the effects of increased wave action and storm surges. One possible adaptation would be to increase the use of exploration drill ships (Croasdale, 1993).

Processing plants, one of the largest infrastructure components of production, must maintain their structural integrity over the multi-decade lifetime of a project. Design of production facilities needs to consider the effects of climate change on permafrost and ground stability. For facilities located on river channels or coasts, such as in the Mackenzie Delta region, additional factors such as river-ice break-up and ice-jam flooding, coastal erosion and sea-level rise must be considered. One recently proposed method to avoid some potential impacts involved using a barge for production facilities, rather than a land-based facility.

Oil and gas are delivered to markets through pipelines that are designed according to environmental conditions, many of which are influenced by climate. Currently there are three small pipelines operating in the North, but Imperial Oil Resources Ventures Limited Canada (Imperial Oil Resources Ventures Limited, 2004) submitted an application in 2004, as part of the Mackenzie Gas Project, to construct a large diameter (30-inch), high-pressure chilled pipeline to deliver natural gas from three fields in the Mackenzie Delta to northern Alberta. If approved, the Mackenzie Gas Project would be the largest industrial development in the Canadian Arctic. A number of geotechnical–climate change issues need to be addressed when constructing pipelines in permafrost zones, such as changes in the ground thermal regime, drainage and terrain stability, all of which may result from a warming climate over the lifetime of such a project (*see* Section 4.4). Experience from the Norman Wells pipeline illustrates the need to closely monitor the performance of both pipeline and right-of-way to determine if actions are required to maintain pipeline integrity and to minimize environmental impacts (e.g. Agra Earth and Environmental Limited and Nixon Geotech Ltd., 1999; Nixon and Burgess, 1999; Oswell, 2002). Adaptation, such as adding insulation or using thermosyphons to induce artificial cooling, may be required, especially along sensitive slopes.

4.3 MINING

There are currently three major mines operating in the northern territories: two diamond mines in the Northwest Territories and one diamond mine in Nunavut. Other projects have recently been approved or are in the advanced stages of environmental assessment and regulatory process in all three territories. Moreover, development of integrated land and marine transportation networks in response to projected declines in sea-ice cover is likely to stimulate further mine exploration and development (*see* Case Study 1). The principal mineral deposits include diamonds, gold, tungsten, silver, lead, iron, copper, zinc, nickel, coal, tantalum, niobium, lithium, cobalt, bismuth, uranium, beryllium and barium.

Resupply of existing mines is generally limited to winter periods and the availability of ice roads, whereas exploration activities are usually restricted to short summer periods, with access by air. Climate-change should be considered in the engineering design, during operations and in final closure and abandonment of mines, a planning process termed “designing for closure” (Milburn and Brodie, 2003). Of particular concern for mine access is the expected reduction in the availability of ice roads, which may necessitate development of all-season roads and/or water-based transportation systems (*see* Section 4.5.2). Another concern is the impact of climate change on permafrost and ground stability (*see* Section 4.4). The stability of waste-rock piles, tailings piles and tailings-containment impoundments often depends on maintenance of frozen conditions to ensure that contaminants and acid-metal leachate (or acid-rock drainage) are not discharged to the environment (Mine Environmental Neutral Drainage Program, 1997).

4.4 INFRASTRUCTURE

Permafrost and the ground ice it contains present challenges for the design, construction and operation of infrastructure in northern Canada (e.g. Smith et al., 2001a; Couture et al., 2003) and throughout the circumpolar region (Instanes et al., 2005). Although ice-bonded frozen ground can provide a strong foundation for infrastructure, thawing of the ground leads to loss of strength, as well as to settlement and instability. The removal of insulating vegetation/organic cover and other disturbances of the ground surface that generally accompany construction can significantly alter the ground thermal regime, resulting in warming and thawing of permafrost. Additional warming may occur due to heat generated by the structure itself (e.g. heated buildings and buried water, sewage or hydrocarbon pipelines). For larger structures, particularly such linear structures as runways, roads and pipelines that cover large distances, concerns include differential settlement due to spatial variations in soil characteristics and ice content, and slope instability resulting from permafrost thawing.

Climate warming presents an additional challenge for northern development and infrastructure design. In the short term (years), the impacts associated with ground disturbance and construction will be of far greater significance than those related to climate. The impacts of changing climate become increasingly significant over longer time scales (decades). For example, permafrost monitoring along the Norman Wells pipeline corridor has shown that the climate signal is largely obscured by the effect of disturbance of the ground surface related to right-of-way clearing (Burgess and Smith, 2003). This was especially true in the first 5 to 10 years following the disturbance, when permafrost was responding to an abrupt change in ground-surface temperature of 2 to 4°C, and large increases in thaw depth occurred. In contrast, changes in ground thermal regimes related to climate occur much more slowly, with changes in ground-surface temperature on the order of 2 to 4°C occurring gradually over a period of several decades.

Failure to take proper precautions in the engineering design of infrastructure in permafrost regions can have serious consequences. This was the case in the Yukon in the 1890s, when

CASE STUDY 1

Opportunities for Growth in the Mining and Transportation Sectors

Reductions in the duration and extent of sea-ice cover as a result of changing climate present new opportunities for marine transport in the Canadian Arctic (*see* Case Study 2). These opportunities, in turn, will potentially increase the competitiveness of both existing and planned resource development. Recent expansion of large-scale gold, base metal and diamond projects in the Slave geological province of the Northwest Territories and Nunavut, in concert with the prospect of a longer shipping season, greatly enhance the economic rationale for construction of a deep-water port along Canada's northern coastline. Such a port would ideally be fed by an all-weather road network, linking it with the inland mine sites.

One proposal currently under consideration calls for development of a port at the southern end of Bathurst Inlet, NU, capable of handling 50 000-ton vessels and smaller barges serving western Nunavut (Kitikmeot) communities (Figure 14; Kunuk and Stephens, 2003). The port development would be augmented by 211 km of all-weather gravel roads connecting Bathurst to Contwoyto (Figure 14). The economic benefits of such mining activities could be substantial (Kunuk and Stephens, 2003). Moreover, development of the port and road infrastructure would likely stimulate additional development at known mineral deposits along the transportation corridor, attract new mineral exploration and link Nunavut communities to an enhanced Arctic Ocean marine traffic system.

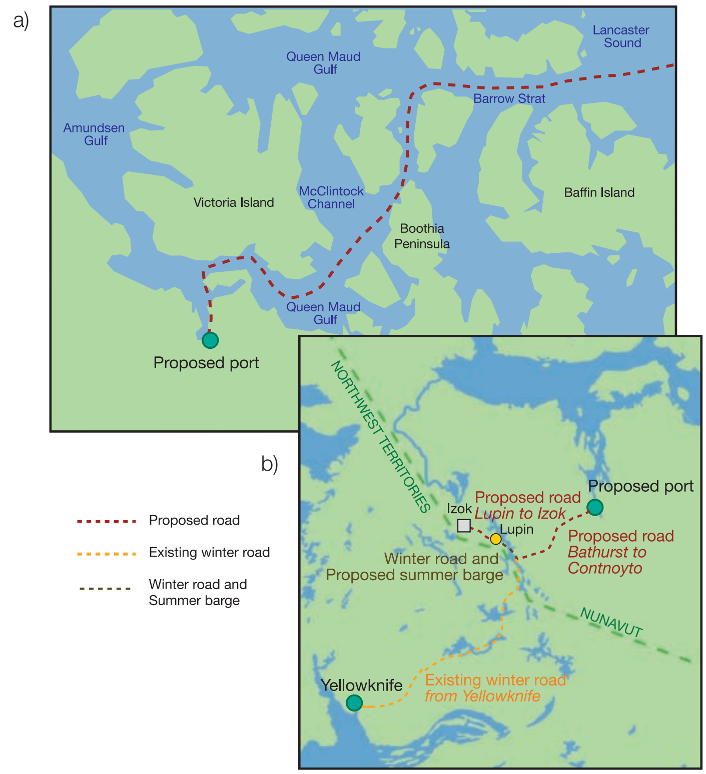


FIGURE 14: Proposed marine and land transportation network in northern Canada, consisting of a) shipping route to new port at Bathurst Inlet, showing average date of ice break-up; b) road network linking the port to resource developments in Nunavut (Bathurst Inlet Port and Road Joint Venture Ltd., 2003, 2007).

construction in Dawson proceeded with no consideration for the ice-rich alluvial sediments that underlay the site (Hughes, 1989). Subsequent thawing of ground ice and associated settlement damaged buildings, causing many to become uninhabitable, and made many roads impassable. Until the middle of the twentieth century, the presence of permafrost was often not recognized. Current engineering practices, however, have the objective of minimizing both disturbance to the terrain and the impacts on structures. Locations are generally chosen to avoid thaw-sensitive soils, and modern infrastructure is designed to preserve thaw-sensitive permafrost, limit thaw settlement and withstand thaw settlement where it does occur.

In the past, climate warming was not considered in engineering design, even for such large projects as the Norman Wells pipeline, which was designed in the early 1980s. Climate warming, however, has increasingly been recognized as a critical factor over the lifetime of major infrastructure projects in northern Canada, and has been incorporated in the engineering design and environmental impact assessments of such developments since the late 1990s. A risk-based project screening tool has been developed for considering climate change in engineered facilities and for gauging the level of analysis required for a particular facility (Environment Canada, 1998). A key factor in the screening process is the consequence of failure, so that the level of analysis is higher where the potential consequences of failure are greater (e.g. for a waste-containment facility).

For significant recent projects, such as water-retention or tailings-containment structures, large buildings and linear infrastructure such as pipelines and roads, climate change has been considered in the design phase. Indeed, such consideration is a requirement of the Canadian environmental assessment process (e.g. Lee, 2000; Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment, 2003). For example, climate warming was recognized as a concern over the lifetime of the Ekati diamond mine, which opened in 1998, and the potential impacts were considered in the design of the mine's frozen-core tailings dams (EBA Engineering Consultants Ltd., 1995). Other recent mining projects in the Northwest Territories and Nunavut, as well as the proposed Mackenzie Gas Pipeline, have considered climate warming in both their engineering design and environmental-impact assessment. Design of recently constructed large buildings, such as the Inuvik Regional Health Centre, has considered the impact of climate warming on the underlying permafrost (Hayley, 2004).

For structures built prior to the late 1990s, climate change may cause increased thaw depth and settlement beyond the original design values, potentially resulting in increased maintenance costs and remedial work to ensure structural integrity. Concerns about thaw settlement will be less where soils have low ice content, structures are founded on bedrock or constructed on deep foundations, and for smaller structures built on adjustable foundations. Structures on thaw-sensitive soils built on shallow foundations are at greatest risk. A pilot study of Norman Wells and Tuktoyaktuk, NT compiled digital databases of all available borehole geotechnical data and an inventory of infrastructure and foundation systems, to identify those structures where impacts of climate warming may be of concern (Couture et al., 2000, 2001; Chartrand et al., 2002). Similar databases could be compiled for other communities to aid climate change adaptation planning for existing structures, and to facilitate future land-use planning.

Of greatest concern in the context of changing climate are structures that need to maintain their integrity over periods of many decades to centuries, and/or have significant consequences associated with failure. Waste-containment facilities present a particular challenge, as facilities constructed several decades ago were not designed for the warmer conditions presently being experienced, and certainly did not consider the warmer conditions projected for the future. Failure of frozen-core dams on tailings ponds due to thawing and differential settlement, or thawing of tailings piles associated with climate warming, could result in contaminants being released into the surrounding environment, with subsequent impacts on ecosystems and human health. Remedial action may be required at these older sites, possibly including the use of thermosyphons to ensure the maintenance of frozen conditions, or modification to covers of land-based tailings piles to ensure that the tailings remain encapsulated in permafrost (e.g. BGC Engineering Ltd., 2003; Mine Environmental Neutral Drainage Program, 2004). New containment structures in the southern part of the continuous permafrost zone may need to consider techniques presently used in the discontinuous permafrost zone or in non-permafrost areas, such as the use of impermeable liners.

Adaptation of northern infrastructure to climate change will largely involve approaches already in use to reduce the impacts of ground disturbance. These include the use of pile foundations (that may need to be deeper to account for climate change), insulation of the surface (which may require thicker gravel pads), clearance of snow (to promote colder winter ground temperatures), adjustable foundations for smaller structures, and increased use of artificial cooling to ensure that foundation soils remain frozen (Couture et al., 2003). Recently developed techniques, such as air-convection embankments (Goering, 1998, 2003), may also be utilized. Where permafrost is thin, frozen ice-rich material may be excavated and replaced with thaw-stable material, or intentionally thawed by clearing vegetation and postponing construction for several years until the permafrost has completely degraded and the ground has settled (cf. Brown, 1970).

Finally, an important element of any adaptive response will be monitoring to: 1) evaluate infrastructure performance; 2) determine if changes in permafrost conditions deviate from those predicted; and 3) decide whether additional adaptation measures are required.

4.5 TRANSPORTATION

4.5.1 Marine Traffic

The many different types of sea ice and glacier ice in Arctic marine environments, in addition to such conventional factors as storm waves and shoals, present unique risks to transport. In turn, marine transport presents potential risks to the Arctic environment, including the possibility of fuel and cargo spills, disturbance of wildlife via vessel presence and underwater and airborne noise, and destabilization of fast ice that can disrupt both animal and human travel. The Canadian Arctic provides three routes for marine shipping: to the port of Churchill and other communities in Hudson Bay via Hudson Strait; to the Beaufort Sea via Bering Strait or the Mackenzie River; and through the Arctic Archipelago via the Northwest Passage. The Northwest Passage extends from Baffin Bay through Lancaster Sound to the Beaufort Sea via a number of alternative waterways (Figure 15; Case Study 2), including:

- the Viscount Melville Sound–M'Clure Strait route, which is the most heavily choked with ice;
- the Viscount Melville Sound–Prince of Wales Strait route, which is the next most difficult, but would be the preferred route for deep-draft vessels; this is the route that was taken by the SS Manhattan and the USCGC Polar Star; and
- the Prince Regent Inlet–Larsen Sound–Victoria Strait–Coronation Gulf route, which is the one most commonly used by Canadian Coast Guard icebreakers, commercial ships and smaller vessels, despite the somewhat narrow and difficult passage through Bellot Strait and the generally shallower waters; the route via Pell Sound to Larsen Sound provides an alternative should Prince Regent Inlet be ice bound; the most challenging ice conditions along either of these routes are usually found in Victoria Strait.

Another route through the Arctic Archipelago, not normally considered to be part of the NWP, is through Hudson Strait, Foxe Basin, Gulf of Boothia and Bellot Strait to Larsen Sound.

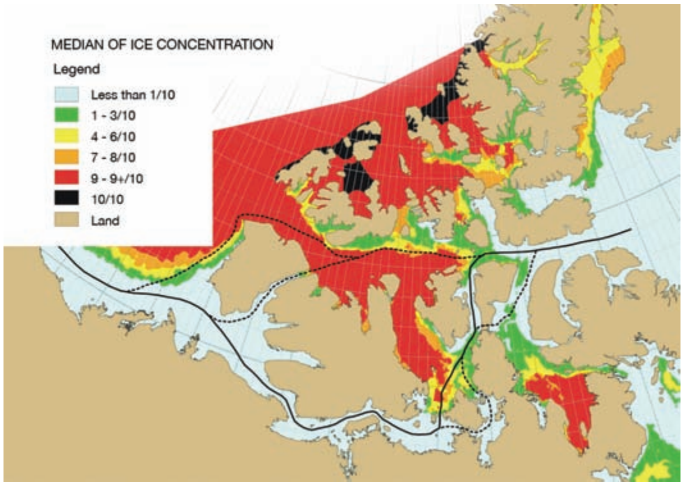


FIGURE 15: Typical routes for the Northwest Passage, superimposed on charted median ice concentration (1971-2000) for September 3. Colour indicates ice concentration in tenths (*courtesy of* Humfrey Melling, Fisheries and Oceans Canada).

Although strong tidal currents present navigational challenges in Fury and Hecla Strait, reduced ice in Foxe Basin and the much shorter sailing distance from the central Arctic to the south have made this an attractive route in recent years (J. Falkingham, Environment Canada, pers. comm, March 20, 2007).

Arctic seaways are used for the resupply of communities, export of raw materials and cruises for sovereignty, tourism or science. Resupply of communities generates the most predictable traffic. Ocean-going ships are generally used for the eastern sea-lift, while tugs and barges are better suited to the shallow waters of the western Canadian Arctic. Raw materials have been exported at times during the last 25 years. Although this type of use is presently dormant, there are expectations that at least two high-grade iron mines could start production and export of concentrate in the next few years. Scientific cruises to the Arctic have increased dramatically since 1990, and are frequently multitasked on Canadian Coast Guard (CCG) icebreakers that simultaneously serve other roles, such as navigational support and maintaining a Canadian government presence. In 2004, the CCGS Amundsen was outfitted specifically to support research on the impacts of climate change in the coastal Canadian Arctic, as part of the ArcticNet Network Centre of Excellence (ArcticNet, 2007), and now regularly traverses the Northwest Passage. Similarly, tourist cruises through the passage are becoming increasingly common. Although international shipping represents another usage of marine waterways, initiatives by the tanker Manhattan in 1969 and 1970 revealed the serious challenges to safe, cost-effective and predictable transshipment through the Northwest Passage.

Arctic Canada has never seen year-round shipping, nor is it expected to for decades to come (Wilson et al., 2004). Resupply presently begins in July and ends in October, and frequently requires support from Canadian Coast Guard icebreakers even within that window. Winter shipping is difficult relative to summer shipping due to that fact that winter ice is colder, and therefore stronger, than summer ice. In addition, winter ice is consolidated from shore to shore, without the cracks (leads) that make it easier for a ship to pass through. Additionally, near-total darkness and bitter cold make winter navigation exceedingly hazardous. Multi-year ice, which does not soften much in summer, is a serious hazard to ships year round. At high concentrations, multi-year ice is a barrier to all but the most powerful icebreakers, even in summer. In winter, it is effectively impenetrable.

The most obvious impact of changing climate on Arctic marine transportation will be an increase in the length of the summer shipping season, with sea-ice duration expected to be 10 days shorter by 2020 and 20–30 days shorter by 2080 (Table 8; Loeng et al., 2005), although there is no expectation of an ice-free Arctic in winter. Even though a longer shipping season appears beneficial, ice conditions in all areas of the Canadian Arctic are highly variable from year to year and will likely remain that way. Hence, there will continue to be summers with ice conditions either more benign or far worse in the future.

Future trends in the sea-ice environment of northern Canada will likely differ somewhat from those outlined in Section 3.1 for the Arctic as a whole. The persistent and preferential occurrence of multi-year ice on the Canadian side of the Arctic (Rigor and Wallace, 2004) is likely to present challenges to northern shipping for at least several decades. At present, much of the ice cover of the Canadian Arctic Archipelago is land-locked for up to 10 months each year, and drifts slowly southward from the Arctic Ocean to the Northwest Passage (Melling, 2002). The longer thaw season of a warmer climate will promote a longer period of weakness in the pack, resulting in more rapid drift of Arctic Ocean multi-year ice through the Arctic Archipelago and into the Northwest Passage. This will tend to maintain, or even increase, the hazard to shipping in the Northwest Passage as long as there is a supply of ice from the Arctic Ocean.

Hudson Bay and the Beaufort Sea, because of their very different ice regimes, are both likely to see increased numbers of transits by large ships. A longer summer shipping season will likely encourage shipping through the port of Churchill on Hudson Bay; in the Beaufort Sea, it will increase the appeal of offshore hydrocarbon development and of shipping oil and gas in large ships westward and through Bering Strait. Increased wind fetch will increase risks from waves and surges to barge traffic, coastal infrastructure and small-boat use by northern residents. The increase in marine traffic and some hazards are likely to increase demands for:

- updated navigational charts;
- marine-weather forecasting, including storm waves and surges;
- ice reconnaissance and forecasting;

CASE STUDY 2

The Future of the Northwest Passage

The Northwest Passage is a series of seven major channels running through the islands of Canada's Arctic Archipelago (Figure 15). Considerable debate has emerged during the past two decades regarding the future of the Northwest Passage, mainly because of the projection of future reductions in sea-ice cover. Historically, multi-year sea ice has entered the archipelago via the small channels along the northwestern side of the Queen Elizabeth Islands and has grown in situ in Viscount Melville Sound, to be exported eastwards and westwards (Figure 15; Melling, 2002). In heavy ice years, multi-year pack ice extends southward to the Tuktoyaktuk Peninsula.

An ice-free Northwest Passage would create a significant economic opportunity for shipping companies, as it provides a route that is about 7000 km shorter for travel between Tokyo and London than using the Panama Canal. It also offers the advantage of allowing passage of ships that cannot fit through the canal systems and, for example, are forced to travel around Cape Horn. The capacity to accommodate even supertankers was demonstrated with the 1969 passage of the SS Manhattan (modified for ice breaking service) between the oilfields of Prudhoe Bay and the east coast of the United States. In some instances, the shelter from storms provided by the archipelago, compared to the open Pacific shipping routes, is another advantage of the Northwest Passage, as evidenced by the successful 1999 towing of a dry dock from Vladivostok, Russia eastward through the passage en route to its final destination of Bermuda (Huebert, 2001).

An alternative for cross-Arctic transit, the northern coast of Eurasia, is expected to open before the Northwest Passage, since the remnant ice pack will tend to shift towards North America. Furthermore, significant variability in ice conditions and resulting shipping hazards will likely persist in the Northwest Passage, even in the warmest summers. The persistence of such hazards might reduce interest in use of the Northwest Passage for commercial shipping (e.g. Griffiths, 2003).

While international disputes about Canada's claims to the lands and islands in the Arctic Archipelago were largely resolved in the 1930s, the Northwest Passage remains the focus of international discussion. The two opposing views are that: 1) the Northwest Passage is part of Canada's 'historic internal waters' found within straight baselines enclosing the archipelago, giving the country unfettered authority to establish controls and conditions to protect its safety, security, environmental and Inuit interests; and 2) the Passage is an international strait through Canadian territorial waters where the right to regulate is subject to some limitations. As summarized by Pharand (2007), Canada has exercised jurisdiction over shipping in the Passage through the creation of an arctic shipping regime consisting of a number of laws and regulations (18 in the case of passenger vessels), including the oldest of these laws, the Arctic Waters Pollution Prevention Act (AWPPA) of 1970. Canada led the effort for the inclusion of Article 234, known as the 'Arctic Exception', in the 1982 United Nations Convention of the Law of the Sea (UNCLOS). Article 234 allows coastal states to enforce laws relating to maritime pollution out to 200 nautical miles when virtually year-round ice creates exceptional navigational hazards (Charron, 2005; Barber et al., 2006), and legitimized Canada's authority to enforce a very strict anti-pollution regime. As customary international law developed, Canada also amended its legislation to extend the definition of the territorial sea (and hence coastal state rights) from 3 to 12 nautical miles (Killaby, 2006). This is significant, given that the narrowest point of the Northwest Passage is less than 24 nautical miles across (*see also* Barber et al., 2006).

As long as ice conditions remain hazardous and unattractive to commercial shipping, there is little incentive for any country to challenge the Canadian position. However, changing climate and associated changes in sea-ice regimes may increase pressure to designate the Northwest Passage an international strait. Enhanced marine traffic through the Northwest Passage is likely to lead to a number of additional issues that will need to be addressed by Canada and northerners. These include the use of northern coastlines for illegal activities (e.g. smuggling), spread of new and exotic species and diseases, and increased marine-traffic accidents and related threats from pollution (e.g. Kelmelis et al., 2005). Adaptive responses to such issues may include increased Arctic surveillance and policing, and additional enforcement of environmental standards and regulations (e.g. Huebert, 2003; Charron, 2005; Barber et al., 2006). The reduction in sea ice and increased marine traffic would have significant negative impacts on the traditional ways of life of northern residents, but also offer opportunities for economic diversification in new service sectors supporting marine shipping. It has even been envisaged that some settlements, such as Tuktoyaktuk and Iqaluit, could become important ports of call in the future (Huebert, 2001), leading to significant socioeconomic changes in these communities.

TABLE 8: Summary of projected changes in ocean conditions (Loeng et al., 2005).

	2020	2050	2080
Sea ice:			
Duration	Shorter by 10 days	Shorter by 15–20 days	Shorter by 20–30 days
Winter extent	6–10% reduction	15–20% reduction	Probable open areas in high Arctic (Barents Sea and possibly Nansen Basin)
Summer extent	Shelves likely to be ice free	30–50% reduction from present	50–100% reduction from present
Export to North Atlantic	No change	Reduction beginning	Strongly reduced
Type	Some reduction in multi-year ice, especially on shelves	Significant loss of multi-year ice, with no multi-year ice on shelves	Little or no multi-year ice
Landfast ice:			
Type	Possible thinning and a retreat in southern regions	Probable thinning and further retreat in southern regions	Possible thinning and reduction in extent in all Arctic marine areas

- icebreaking support services and search-and-rescue capability;
- marine-traffic surveillance, control and enforcement;
- coastal facilities for fuelling and loading cargo;
- ice-class vessels for new sea conditions and cargos (e.g. barges, tugs, tankers and bulk carriers); and
- specialized crews for the Arctic trade.

Climate change is also expected to change the nature of the risks to shipping traffic in many areas of the Arctic. Rather than being confronted with extensive ice pack that necessitates icebreaker escort, ships in the future will see easier navigating conditions in general, punctuated by frequent occurrences of ice pressure in congested straits, multi-year ice in low concentrations that is difficult to detect, and extreme variability of conditions from one year to the next. As such, there will be a need for continued, if not increased, icebreaking support for increased and more broadly dispersed shipping activities.

4.5.2 Freshwater Transport

Historically, open-water transport on rivers and lakes was the main method of transporting goods to northern communities using, for example, the main stem and major tributaries of the Yukon and Mackenzie river systems. The Mackenzie remains a major freshwater transportation system, with goods (largely bulk fuel, equipment and general cargo) that originate from the northern railhead at Hay River being transported via barge–tug boat trains across Great Slave Lake to riverside communities and ultimately to Tuktoyaktuk. Here, barges are uncoupled and transported by ocean-going tugboats to as far east as Taloyoak on the Boothia Peninsula and as far west as Barrow, Alaska.

An increase in the river ice-free season as a result of climate warming will expand the potential period of operation for Mackenzie barges from its current four-month season between mid-June and mid-October. Lonergan et al. (1993), for example, projected that a 6 to 9 week reduction in the ice season could result in a 50% increase in the use of barge-based transport along the Mackenzie, although this figure pales compared to the 600% increase in transport forecast to occur in the next few years as a result of the Mackenzie Gas Project in the Mackenzie Delta (Neudorf, 2005; *see* Section 4.2). However, these forecasts do not include consideration of how climate-related changes in lake and river levels (cf. Kerr, 1997; Blanken et al., 2000; Rouse et al., 2003) could affect the use of flat-bottomed barges in an already relatively shallow river system, particularly during late summer low-lake and low-flow periods. Upstream flow regulation is another factor influencing low-flow levels and has contributed to increasingly difficult river navigation during the last half century (e.g. Gibson et al., 2006).

Dredging selected portions of the channel may offer localized, short-term solutions to decreased water levels but is unlikely to be a practical long-term adaptive measure, given the rapidly changing bed morphology of the Mackenzie and other northern river systems (e.g. Prowse, 2001). Upstream flow regulation could be used to increase late-summer flows but would, in turn, negatively impact hydroelectric-generating potential. The most obvious adaptation measure to increasingly difficult river transport is an increase in all-season road networks, although there would be significant engineering challenges in constructing and maintaining such roads in permafrost terrain (*see* Section 4.4).

4.5.3 Winter Roads

Although lake and river ice have historically served as natural transportation routes, and modern engineering has led to increasingly sophisticated methods of winter-road construction and expansion, little scientific literature exists about the effects of climate on these systems. The most relevant information, even about the basic winter-road network, is contained only within consultant and local government reports or news media. Since the 1950s, the seasonal road network has evolved into a large suite of private and public lake and river crossings linking northern communities and all-season road systems. Ice roads and ice bridges that are constructed and maintained each winter provide a relatively inexpensive way to supply northern communities and industry, particularly the rapidly expanding mining sector that relies on ice roads to move heavy equipment, materials and fuel for the remainder of the year. Additionally, they form critical travel routes connecting communities and facilitating the ability to continue social and cultural activities during winter months.

Although minor on-ice travel occurs in the Yukon (e.g. Dawson City ice crossing, mine access roads and an occasional ice road to Old Crow), the primary ice-road networks are found in the Northwest Territories and Nunavut, the latter having no long-distance all-season highways. Extensive winter-road networks are also found in the northern parts of several provinces (*see* Chapters 6 and 7). The longest winter road, the 'Tibbitt to Contwoyto Winter Road' (TCWR), is 600 km long, with 495 km located on frozen lakes (EBA Engineering Consultants Ltd., 2001). It is the main supply road for the Ekati and Diavik diamond mines, the Lupin gold mine (currently inactive), the Snap Lake and Jericho mine developments and several other mineral exploration projects. The TCWR is currently licensed and operated by the Winter Road Joint Venture (WRJV), a private-sector partnership between BHP Billiton, Diavik Diamond Mines and Echo Bay Mines, who share the cost based on use, while other companies using the road pay a tonne/kilometre charge. The TCWR typically operates for two months each year, February and March, at an approximate annual cost of $10 million, with trucks running almost 24 hours/day and convoys leaving at approximately 20 minute intervals. Between 1997 and 2003, it carried up to 8000 truck loads per year, each weighing an average 30 tonnes (t), with the load capacity rising as the ice thickens and increases in bearing strength. The economic importance of the TCWR is projected to continue for many years (Figure 16; EBA Engineering Consultants Ltd., 2001).

The main ice-only road in the Canadian North forms a 150 km winter link between the communities of Inuvik and Tuktoyaktuk, and is constructed and maintained by the Government of the Northwest Territories. Numerous smaller winter roads and ice bridges are found throughout the northern territories, with the Northwest Territories public road system almost doubling in length during the winter (approximately 1400 km in total). Operating windows vary by location and year, but typically extend from November – December until March – April.

Methods of ice-road construction vary by use, and some also involve tandem development with winter road construction on land. The more formalized road and bridge networks enhance the load-bearing capacity through snow removal or snow compaction to reduce its insulating effects. Rapid ice thickness can be achieved by surface flooding or by spray-ice techniques similar to snow-making. In both cases, the ice thickness can be increased beyond that possible due to normal ice growth for a given set of climatic conditions. Melt events can reduce surface usability even when the load-bearing capacity is high (Figure 17). Large

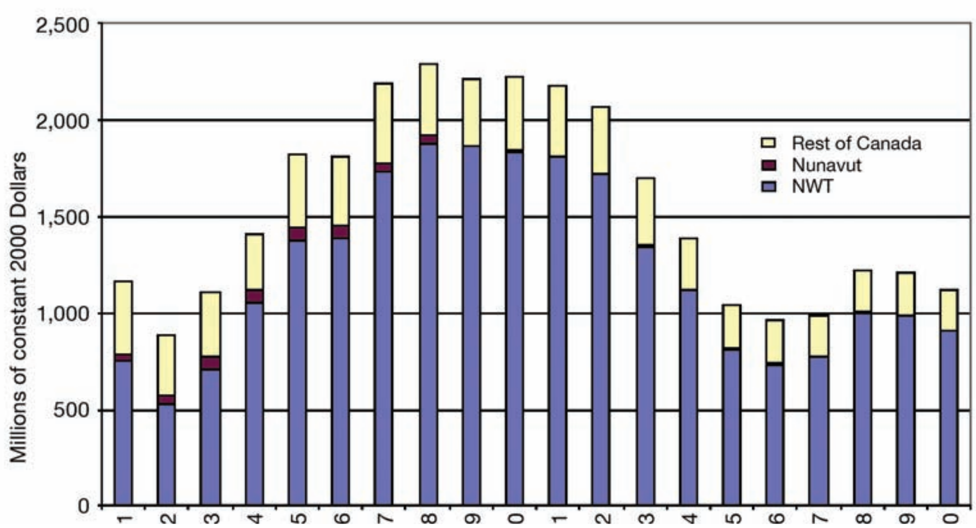


FIGURE 16: Annual contribution of the Tibbitt to Contwoyto Winter Road and associated projects to gross domestic product in the Northwest Territories (NWT), Nunavut and rest of Canada, 2001-2020 (EBA Engineering Consultants, 2001).

FIGURE 17: Transport truck crossing deteriorating ice road, Liard Ferry crossing near Fort Simpson, Liard River, NT (Terry D. Prowse).

snowfalls near the start of the season can cause a significant delay in ice growth and development of load-bearing capacity.

Although regular records are kept regarding the opening and closing of ice roads/crossings, no comprehensive trend analysis of such dates has been conducted. However, observations for the Mackenzie River Crossing Ice Road show that the average opening date for light traffic has been delayed by more than 3 weeks since 1996, whereas it had remained relatively constant (between December 8 and 19) during the previous 30 years or more (Northern Climate Exchange, 2006). Reductions in ice thickness associated with climate warming reduce the maximum loads that can be safely transported. Initially, modifications in ice-road construction (as described previously) may serve as an effective adaptation. At locations where transport capacity is not already maximized, it is possible to modify transport schedules to concentrate shipping into the core portion of the winter when ice thickness is maximized. A possibility also exists for transporting heavy loads over ice with the assistance of balloons, as suggested for the movement of oilfield equipment in Alaska and the Canadian Arctic (cf. Prentice and Turriff, 2002). This combination of impacts associated with decreased length of the ice-road season and reduced ice thickness translates into increased difficulties in resupplying northern communities and industrial sites during winter months.

Where and when the use of winter roads becomes impractical, there will be a need to provide alternative transportation routes. Where an open-water network is viable, increased use of barge transport might be possible. In land-locked locations, such as those currently serviced by the TCWR, construction of land-based roads is likely the only viable option to carry the enormous total annual loads of freight (*see* Case Study 1). All-weather roads are significantly more costly than winter roads to build and maintain. Costs vary but, as an example, Dore and Burton (2001) cited costs of at least \$85 000 per km for all-weather roads to be constructed in northern Ontario, plus costs of between \$64 000 and \$150 000 per bridge.

4.6 FORESTRY

Significant areas of the Yukon (22.79 million ha) and the Northwest Territories (33.35 million ha) are covered by boreal forest, together constituting about 13% of Canada's total forest cover. The cultural, spiritual, social and economic well-being of many First Nations is dependent on a healthy forest ecosystem. Gathering of food and the exercise of cultural practices are important uses of forest land in the Yukon and Northwest Territories. Less than 30% of the Yukon forest cover is of a species or size that might support timber-harvesting activities (Government of Yukon, 2006), with the majority of merchantable forests located south of latitude 61°N. Farther north, Yukon forests are more affected by cold soils, poor drainage and aggressive fire regimes.

The Yukon is moving towards a legislative framework and more regulated practices for forestry activities, including the development of a *Yukon Forest Resources Stewardship Act*. Responsibilities for forest management are shared by the Government of Yukon, First Nation governments and renewable resource councils. The first strategic forest management plan in the Yukon was adopted in December 2004 for the Champagne and Aishihik Traditional Territory (Case Study 3).

Salvage harvest opportunities are currently driving the forest industry in the Yukon in response to recent expansive forest disturbance. In 2005, more than 300 000 m^3 in timber permits were issued to salvage wood from areas that were burned during the record fire season of 2004 (e.g. Green, 2004). The 2004 fires also created the opportunity for a large mushroom harvest, a lucrative post-fire non-timber forest product. In 2006, a request for proposals for 1 000 000 m^3 in timber permits was issued to salvage wood from the spruce bark beetle infestation in the Champagne and Aishihik Traditional Territory of southwestern Yukon (*see* Case Study 3). The contribution of harvested wood products to the Yukon economy in 2004 was estimated at a million dollars, and is poised to increase because of the salvage operations. In contrast, the estimated contribution of forest products to the Northwest Territories economy in 2004 was only \$70 000 (Table 9).

The mounting evidence of local ecological responses to recent climate change demonstrates the sensitivity of northern forested ecosystems to climate change (Parmesan and Yohe, 2003; Juday et al., 2005; Ogden, 2006; Scholze et al., 2006). Indeed, many of the projected impacts of changing climate on the northern forest sector (Table 10) are already visible. Increased forest disturbances due to insect outbreaks are almost certain to result from continued climate warming (Juday et al., 2005). The spruce bark beetle infestation of southwestern Yukon, which has led to

CASE STUDY 3

Building the Foundation for Forest Management in a Changing Climate

There is accumulating evidence that climate change is affecting the Champagne and Aishihik Traditional Territory of the southwestern Yukon. During the past 40 years, average annual temperatures have been increasing and winters have had fewer periods of prolonged severe cold. There has been a decrease in average summer precipitation. One result of these warmer winters and warmer and drier summers has been a severe outbreak of spruce bark beetle (*Dendroctonus rufipennis*), causing widespread mortality of white spruce. This mortality has also led to the loss of merchantable timber and significant changes to the regional ecology. The spruce beetle infestation has also increased quantity, flammability and extent of forest fuels, thereby increasing the fire hazard.

The spruce bark beetle outbreak is driving forest management and planning efforts in the southwestern Yukon. In November 2004, the Government of Yukon and the Champagne and Aishihik First Nation approved the first community-directed forest management plan that identifies reduction of fire hazard, forest renewal, economic benefits and preservation of wildlife habitat as forest management and planning priorities. The plan also explicitly incorporates an adaptive management framework, considered to be an essential response to climate change.

Examination of forest management actions that could be undertaken to reduce the vulnerability of forest ecosystems, and the people and economies that depend on them, to climate change was undertaken by the Northern Climate Exchange (Ogden, 2006). Activities included a workshop on 'Our Changing Boreal Forest', hosted by the Champagne and Aishihik First Nation and the Alsek Renewable Resource Council, and involving local residents, governments and management agencies, and researchers. The workshop outcomes provided a foundation for a preliminary research framework to support forest management decision-making in the changing climate of southwestern Yukon.

The region has been designated a Special Project Area of the Canadian Model Forest Program, securing funding for the Champagne and Aishihik First Nation to do additional research on issues of community sustainability. Future work will include seeking the perspective of community members on the applicability of various adaptation management actions in the local context, conducting a scenario planning exercise to examine the effectiveness of forest management options under possible future climates, and incorporating traditional and local knowledge into the adaptive management framework.

widespread mortality of white spruce, is the largest and most intense outbreak to affect Canadian trees and is a notable example of ecosystem response to recent warming (Table 11; Figure 18; *see* Case Study 3; Juday et al., 2005). Climate change is also projected to increase the frequency, extent and severity of forest fires, thereby reducing mean fire return intervals, shifting age class distributions toward younger forests, triggering more frequent shifts from conifer- to deciduous-dominated successional trajectories, and decreasing the amount of terrestrial carbon stored in the boreal forest (Flannigan et al., 2000; Stocks et al., 2000; Juday et al., 2005; McCoy and Burn, 2005; Johnstone and Chapin, 2006).

Depending on species, site type and region, warmer temperatures in the last several decades have either improved or decreased tree growth. In some areas where declines have been observed, drought stress has been identified as the cause, whereas declines in other areas remain unexplained (Juday et al., 2005). Drought stress is also impeding the re-establishment of spruce forests following fire in some areas of southwestern and south-central Yukon, which are highly vulnerable to climate change if trends towards drier conditions continue (Hogg and Wein, 2005). Most projections of future climate result in conditions that are very likely to limit the growth of commercially valuable white spruce types and widespread black spruce types in large parts of Alaska and probably the western boreal forest of Canada (Barber et al., 2000; Hogg and Wein, 2005; Juday and Barber 2005; Juday et al., 2005). Climate-related changes in forest productivity will likely have significant impacts on northern forest-dependent communities (Hauer et al., 2001; Davidson et al., 2003).

The principles and practice of sustainable forest management embody many of the activities that will be required to respond to the effects of climate change (Spittlehouse and Stewart, 2003). Of those forestry practitioners in the Yukon and Northwest Territories who were surveyed about the likely impacts of climate change on forest sector sustainability and potential adaptation options, 71% agreed that the seven criteria of sustainable forest management[3] could also serve as goals for climate change adaptation in the forest sector (Ogden and Innes, in 2007b). The three impacts most frequently identified as already having affected sustainability were changes in the intensity, severity or magnitude of forest insect outbreaks; changes in extreme weather events; and changes in the intensity, severity or magnitude of forest fires (Table 12; Ogden and Innes, in 2007b). However, more than half of the respondents indicated that commodity prices, availability of timber, trade policies, environmental regulations and the ability to secure needed capital presently have more of a negative impact on sustainability than climate change (Table 13; Ogden and Innes, in 2007b).

[3] Criteria outlined in the 1995 Santiago Declaration are: 1) conservation of biological diversity; 2) maintenance of productive capacity of forest ecosystems; 3) maintenance of forest ecosystem health and vitality; 4) conservation and maintenance of soil and water resources; 5) maintenance of forest contribution to global carbon cycles; 6) maintenance and enhancement of long-term socioeconomic benefits to meet the needs of societies; and 7) legal, institutional and economic framework for forest conservation and sustainable management.

TABLE 9: Profile of Canada's Northern Forest Sector (Natural Resources Canada, 2005).

	Canada	Yukon Territory	Northwest Territories	Nunavut
PROFILE				
Population[1]	32 100 000	31 227	42 944	29 6583
Land area (ha)	979 100 000	48 490 000	128 120 000	200 600 000
Forest and other wooded land	402 100 000	22 790 000	33 000 000	940 000
Parks	26 500 000	not available	13 363	not available
RESOURCES				
Ownership[2]				
Federal	16%	100%	100%	100%
Provincial/Territorial	77%	0%	0%	0%
Private	7%	0%	0%	0%
Forest type[2]				
Softwood	66%	79%	53%	52%
Hardwood	12%	2%	47%	48%
Mixedwood	22%	19%	0%	0%
Potential harvest (m^3)[3]	238 800 000	238 000	not applicable	
Harvest (volume) – industrial roundwood (m^3)[3]	193 700 000	7 000	6 000	
Harvest (area) – industrial roundwood (ha)[3]	974 472	44	31	
Area planted (ha)[4]	427 051	310	112	
Area seeded (ha)[4]	18 906	not available	not available	
Area defoliated by insects and beetle-killed trees (ha)[3]	19 200 000	41 640	not available	
Number of fires[2]	6634	282	297	
Area burned (ha)[2]	3 300 000	1 800 000	515 621	
Industry				
Value of exports[2]	$44 600 000 000	$961 842	$69 954	
Softwood lumber	24.71%	1.5%	17.61%	
Major export markets[2]				
United States	80%	100%	37.38%	
European Union	6%	0%	62.62%	
Japan	5%	0%	0%	

Source: Natural Resources Canada (2005); data reported are from Statistics Canada

[1] for 2005 [2] for 2004 [3] for 2003 [4] for 2002

TABLE 10: Examples of the impacts of climate change on the northern forest sector (*modified from* Lemmen and Warren, 2004).

Biophysical impact	Socioeconomic impacts
Changes in forest productivity	Changes in timber supply and rent value
Increased atmospheric greenhouse gases	Introduction of carbon credit-permit mitigation policies that create a carbon sequestration market
Increased disturbances	Loss of forest stock and non-market goods
Northward shift of ecozones	Change in land values and land-use options
Change in climate and ecosystems	Economic restructuring leading to social and individual stresses
Ecosystem and specialist species changes	Changes in non-market values
Ecosystem changes	Dislocation of parks and natural areas, increased land-use conflicts

TABLE 11: Climate Change and the Spruce Bark Beetle (Juday et al., 2005).

Direct controls on insect populations:	Two successive cold winters depress the survival rate of the bark beetle
	Abnormally warm summers enable the beetle to complete its life cycle in one year, thus dramatically increasing its population
Indirect control on tree resistance:	Drought stress reduces ability of trees to resist beetle attacks
'Fingerprint' of climate warming:	Greater frequency of insect outbreaks
	More extensive areas of tree mortality during outbreaks
	Greater intensity of insect attack, resulting in higher tree mortality rates in outbreak areas

Despite not perceiving climate change as the most important influence on forest sector sustainability (Ogden and Innes, 2007b), northern forest managers are already adapting reactively to the impacts of changing climate, most notably in response to the spruce bark beetle infestation in southwestern Yukon (*see* Case Study 3; Alsek Renewable Resource Council, 2004). Possible proactive adaptations include targeted regeneration, silviculture or protection strategies to address long-term shifts in forest disturbance patterns (Ohlson et al., 2005). Proactive adaptation is more likely to avoid or reduce damage than reactive responses (Easterling et al., 2004). The perspectives of forest practitioners on the importance of adaptation options that may be considered to meet the goals of sustainable forest management were explored. The options assessed are presented in Table 14 (Ogden and Innes, 2007b). Practitioners also identified what they felt were the most important research needs to assist decision-making. These include understanding the impacts of climate change on the intensity, severity and magnitude of forest insect outbreaks and forest fires, as well as net impacts on forest growth and productivity (Ogden and Innes, 2007b).

TABLE 12: Percentage of forestry practitioners surveyed who perceive that the following climate change impacts have had a very significant or quite significant effect on the sustainability of the forest-sector or forest-dependent communities in the northern territories (Ogden and Innes, 2007b).

Climate change impact	Respondents (%)
Intensity, severity or magnitude of forest insect outbreaks	66
Extreme weather events	47
Intensity, severity or magnitude of forest fires	44
Lifestyles	34
Land values and land-use options	31
Length of winter road season	31
Economic opportunities	25
Forest carbon budget	22
Phenology	22
Timber supply	22
Species abundance, movement and ranges, including invasive species	19
Forest cover type	19
Forest growth and productivity	16
Location of treeline	16
Availability of non-timber forest products	9

TABLE 13: Percentage of forestry practitioners surveyed who perceive that the following factors presently have more of a negative impact than climate change on the sustainability of the northern forest sector or forest-dependent communities (Ogden and Innes, 2007b).

Influence on sustainability is presently more important than that of climate change	Respondents (%)
Commodity prices	56
Availability of timber	53
Trade policies	50
Environmental regulations	50
Ability to secure needed capital	50
Competitiveness	47
Oil and gas	41
Habitat fragmentation	41
Aboriginal involvement and governance	35
Public participation in forest management and planning	35
Minerals	35
Tourism	35
Community health and well-being	35
Invasive species	29
Unemployment	29
Contaminants	26
Participation in traditional lifestyles	21
Availability and security of traditional food supplies	18
Availability of recreational opportunities	15
Ozone depletion	6

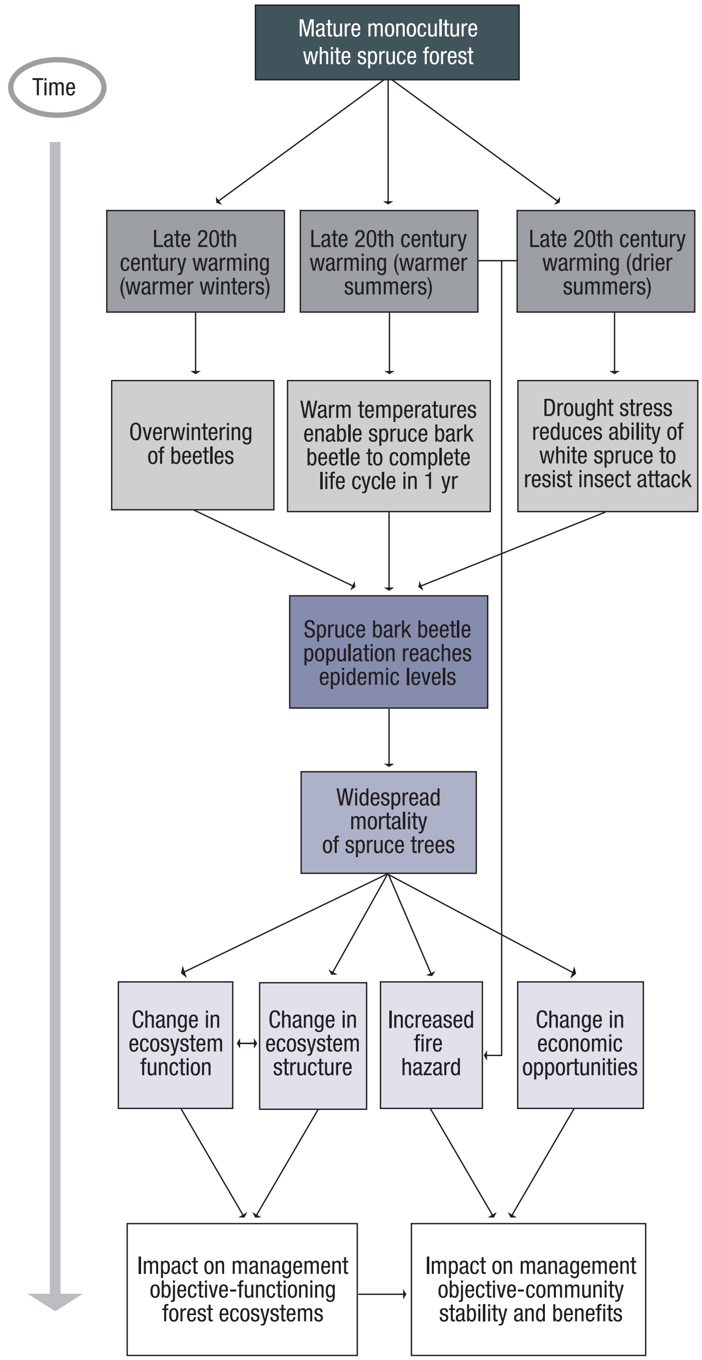


FIGURE 18: Influence of climate warming on spruce bark beetle populations in the southwest Yukon (Ogden, 2006).

TABLE 14: Strategic and operational-level climate change adaptation options that may be considered to meet the goals of sustainable forest management, as defined by the Montreal Process (*Source* Ogden and Innes, 2007a).

Adaptation goals	Conserve biological diversity	Maintain productive capacity of forest ecosystems	Maintain forest ecosystem health and vitality	Conserve and maintain soil and water resources
Strategic-level adaptation options	• Minimize fragmentation of habitat and maintain connectivity • Maintain representative forest types across environmental gradients in reserves • Protect climate refugia at multiple scales • Identify and protect functional groups and keystone species • Maintain natural fire regimes • Provide buffer zones for adjustment of reserve boundaries • Create artificial reserves or arboreta to preserve rare species • Protect most highly threatened species *ex situ* • Maintain natural fire regimes • Develop a gene management program to maintain diverse gene pools	• Practice high-intensity plantation forestry in selected areas to promote the growth of commercial tree species, especially in areas where an increase in disturbance is anticipated • Enhance and minimize disturbance to forest soils	• Breed for pest resistance and for wider tolerance to a range of climate stresses and extremes in specific genotypes • Reduce non-climatic stresses to enhance ability of ecosystems to respond to climate change by managing tourism, recreation and grazing impacts • Reduce non-climatic stresses to enhance ability of ecosystems to respond to climate change by regulating atmospheric pollutants • Reduce non-climatic stresses to enhance ability of ecosystems to respond to climate change by restoring degraded areas to maintain genetic diversity and promote ecosystem health • Adjust harvest schedules to harvest stands most vulnerable to insect outbreaks	• Avoid constructing roads in landslide-prone terrain where increased precipitation and melting of permafrost may increase hazard of slope failure • Enhance and minimize disturbance to forest soils
Operational-level adaptation options	• Allow forests to regenerate naturally following disturbance, favouring natural regeneration wherever appropriate • Control invasive species • Practice low-intensity forestry and prevent conversion to plantations • Assist changes in the distribution of species by introducing them to new areas	• Assist in tree regeneration • Employ vegetation control techniques to offset drought • Plant genetically modified species and identify more suitable genotypes • Enhance forest growth through forest fertilization • Actively manage forest pests • Underplant with other species or genotypes where the current advanced regeneration is unacceptable as a source for the future forest • Selectively remove suppressed, damaged or poor-quality individuals to increase resource availability to the remaining trees (pre-commercial thinning) • Reduce the rotation age followed by planting to speed the establishment of better-adapted forest types • Control those undesirable plant species that will become more competitive in a changed climate • Relax rules governing the movement of seed stocks from one area to another • Include climate variables in growth and yield models in order to have more specific predictions on the future development of forests • Design and establish a long-term multi-species seed-lot trial to test improved genotypes across a diverse array of climatic and latitudinal environments	• Plant genotypes that are tolerant of drought, insects and/or disease • Reduce disease losses through sanitation cuts that remove infected trees • Used prescribed burning to reduce fire risk and reduce forest vulnerability to insect outbreaks • Employ silvicultural techniques to promote forest productivity, and increase stand vigour (i.e. partial cutting or thinning) by lowering susceptibility to insect attack • Shorten the rotation length to decrease the period of stand vulnerability to damaging insects and diseases and to facilitate change to more suitable species	• Maintain, decommission and rehabilitate roads to minimize sediment runoff due to increased precipitation and melting of permafrost • Minimize the impacts on infrastructure, fish and potable water of changes in the timing of peak flow and volume in streams resulting from more/earlier snow melt

TABLE 14: *Continued*

Adaptation goals	Maintain forest contribution to global carbon cycles	Maintain and enhance long-term multiple socioeconomic benefits	Legal, institutional and economic framework for forest conservation and sustainable management
Strategic-level adaptation options	• Mitigate climate change through forest carbon management • Increase forested area through afforestation • Reduce forest degradation and avoid deforestation • Enhance and minimize disturbance to forest soils	• Anticipate variability, and change and conduct vulnerability assessments at a regional scale • Enhance capacity to undertake integrated assessments of system vulnerabilities at various scales • Foster learning and innovation, and conduct research to determine when and where to implement adaptive responses • Diversify forest economy (e.g., explore dead-wood product markets, value-added products) • Diversify regional economy (non-forest based) • Enhance dialogue among stakeholder groups to establish priorities for action on climate adaptation in the forest sector • Develop technology to use altered wood quality and tree species composition, and modify wood-processing technology • Make choice about preferred tree species composition for the future; establish objectives for the future forest under climate change • Include risk management in management rules and forest plans, and develop an enhanced capacity for risk management • Conduct an assessment of greenhouse gas emissions produced by internal operations • Increase awareness about the potential impact of climate change on the fire regime and encourage proactive actions regarding fuels management and community protection	• Provide long-term tenures • Relax rules governing movement of seed stocks from one area to another • Provide incentives and remove barriers for enhancing carbon sinks and reducing greenhouse gas emissions • Provide opportunities for forest management activities to be included in carbon-trading systems (as outlined in Article 3.4 of the Kyoto Protocol) • Practice adaptive management (a management approach that rigorously combines management, research, monitoring and means of changing practices so that credible information is gained and management activities are modified by experience) • Measure, monitor and report on indicators of climate change and sustainable forest management to determine the state of the forest and identify when critical thresholds are reached • Evaluate the adequacy of existing environmental and biological monitoring networks for tracking the impacts of climate change on forest ecosystems, identify inadequacies and gaps in these networks and identify options to address them • Support research on climate change, climate impacts and climate adaptations • Support knowledge exchange, technology transfer, capacity-building and information-sharing on climate change • Incorporate new knowledge about the future climate and forest vulnerability into forest management plans and policies • Involve the public in an assessment of forest management adaptation options
Operational-level adaptation options	• Allow forests to regenerate naturally following disturbance, favouring natural regeneration wherever appropriate • Control invasive species • Practice low-intensity forestry and prevent conversion to plantations • Assist changes in the distribution of species by introducing them to new areas	• Protect higher-value areas from fire through ‘firesmart’ techniques • Increase amount of timber from salvage logging of fire- or insect-disturbed stands	

Sources listed in Ogden and Innes, 2007a.

4.7 FISHERIES

The northern fish fauna of Canada consist of an estimated 240 species (190 marine, approx. 15 anadromous, and approx. 35 freshwater forms; Richardson et al., 2001; Evans et al., 2002; Coad and Reist, 2004). Additional fish species, not yet recorded due to poor sampling coverage, likely also occur in northern, particularly marine, waters. Adjacent regions contain additional species that may eventually be found in the North. Of the endemic species, northern fisheries target relatively few (approx. 11 species), most of which are salmonids (e.g. salmon, chars, whitefishes, grayling) captured in fresh, estuarine or nearshore waters. About five freshwater species are targeted (e.g. burbot, northern pike, suckers and perches). A further limited number (2–3) of marine fish species (e.g. Greenland halibut, Arctic cod) and a few (3–6) invertebrate species (e.g. shrimps, clams, mussels and urchins) complete the suite of exploited taxa (Nunavut Wildlife Management Board, 2004; Government of Nunavut and Nunavut

Tuungavik Incorporated, 2005; Reist et al., 2006a). Some additional species may be fished locally and/or captured as by-catch in fisheries and either discarded or used for bait or dog food.

The number of species present in the region is likely to rise as climate changes, especially along the southern margin of the North. Several southern species are known to occur as vagrants in the North, including three species of Pacific salmon in the western Arctic and Atlantic salmon in the east. Colonization could result in new opportunities for fisheries, but could also add to existing stressors as ecosystems restructure, new predators appear, competition ensues and/or parasites are introduced by the colonizing species (Reist et al., 2006b, c; Wrona et al., 2006a). Experience with the vagrants in local fisheries enhances interest in future potential for fisheries based upon those species.

Freshwater and anadromous species can be divided into three groups, based on thermal associations and preferences (*see* Wrona et al., 2005; Reist et al., 2006a):

- Arctic (thermal tolerance <10°C): species that are wholly or primarily distributed in the north (e.g. broad whitefish, an anadromous fish of the western Arctic)
- northern cold-water–adapted (11–15°C): species that reach their limits of distribution somewhere in the North
- southern cool-water–adapted (21–25°C): many of these species (e.g. Atlantic salmon) reach the northern limit of their distribution near the extreme southern margin of the North

Changing climate will affect these three groups, and associated fisheries, differently. Arctic species will likely experience declining productivity, local extirpation along the southern margin of their distribution and overall range contraction as local conditions exceed thresholds and southern species colonize and compete with or prey upon them. Both northern cold-water and southern cool-water species will likely increase in abundance and local productivity, and perhaps also extend their geographic range farther northward as conditions allow.

Particular fish species are either stenothermal (i.e. adapted to a narrow range of temperatures) or eurythermal (i.e. adapted to wide thermal ranges; e.g. Wrona et al., 2005; Reist et al., 2006a). These species are often captured together in the same fishery. In many cases throughout the North, local climate change may be positive for one species and negative for another. Such variability in the response will substantially affect fishery structure, output and sustainability, and present challenges to those fishery managers who rely primarily upon single-species management approaches. Management structures and approaches that focus on the ecosystem level are likely to be more highly responsive to climate change impacts. An ecosystem approach involves attaching differential values to local species and enabling the setting of attainable goals for sustainable fisheries and their management.

Northern fisheries can be classified into three types, household, commercial and recreational, based upon the final disposition of the catch (Clarke, 1993). Household fisheries include traditional and subsistence food fisheries conducted by Aboriginal people, as well as licensed domestic fisheries conducted by non-Aboriginal northerners. Commercial fisheries are licensed activities in which the product is sold either locally or in distant markets. Recreational or sport fisheries are licensed individual fisheries by non-Aboriginal persons. Each type of fishery and area will be affected differently by climate change, making the development of generalizations that are applicable to fisheries throughout the North difficult. Although detailed assessment of all northern fisheries is beyond the scope of this chapter, many of the issues and challenges are developed further in Case Study 4.

Commercial fisheries (*see* Case Study 4), and the very limited aquaculture occurring in the North, are generally small and widely dispersed, and conducted on small water bodies by local residents for both food and income. This results in limited economic potential measured in such typical terms as commercial cash income; however, valuation of these numerous widely dispersed fisheries must also include estimates of protein replacement and social and cultural value. In Nunavut, fisheries are estimated to contribute between $12 and 14 million annually to the economy (Government of Nunavut and Nunavut Tuungavik Incorporated, 2005). Of this, $5.8 million is estimated to accrue from Arctic char, of which $1.4 million comes from commercial sales of 800–1000 t annually and $4.4 million from the food value for subsistence use.

Inshore coastal marine and lake-based commercial fisheries and aquaculture operations are likely to face significant adaptation challenges as a result of changing climate. In addition to fairly intensive capitalization of the fishing fleet, these fisheries are supported by harbour facilities and onshore fish-processing facilities that require significant capital expenditures and regular inspection and maintenance to maintain standards for processing commercial fish products. In the North, long-term, relatively stable production is required to recoup initial investments. Current views of such activities in the North being a major contributor to economic development in the future (e.g. Government of Nunavut and Nunavut Tuungavik Incorporated, 2005) may have to be adjusted in view of the consequences of changing climate.

Inherent adaptive ways of life and resiliency of northern Aboriginal peoples will aid the process of adjusting traditional and subsistence fisheries to changing climate. By their nature, recreational fisheries are highly adaptable with respect to harvest levels, gear used and location of fishing. Thus, sport fisheries will likely be readily able to accommodate the impacts of climate change, the possible exception being where there is widespread loss of a species over a large area, in which case reprofiling such fisheries to 'new' species might be possible.

CASE STUDY 4

Commercial and Subsistence Arctic Fisheries

This case study describes and contrasts three different northern fisheries to illustrate the challenges that changing climate presents to resource management.

Nunavut Commercial Fisheries on Greenland Halibut

Both inshore and offshore commercial fisheries for Greenland halibut have been developed in Nunavut. Greenland halibut is a flatfish typically found near the bottom in deep waters of Baffin Bay and Davis Strait, as well as inshore in deeper fjords.

The inshore fishery is typically conducted through landfast ice on Cumberland Sound from December to March (Figure 19), with a quota presently set at 500 t. This fishery has been operating since 1987, with harvests varying from 4 to 430 t, 6 to 115 fishers involved annually and a season of 9 to 21 weeks duration. Recent high variability in sea-ice formation has affected the ease of travel and safety of fishers accessing the fishing grounds. In some years, ice formation has been quite distant from the best locations, resulting in low success of the fishery. This discourages entry and continued participation in the fishery, which in turn causes decreased employment at the processing plant and decreased local economic benefit.

FIGURE 19: Hauling long-lines; inshore ice fishery. Photograph courtesy of Nunavut Government.

The projected impacts of climate change on sea-ice conditions will have a significant effect on this inshore fishery. One possible adaptive response would be to diversify the inshore fishery to encompass a wider resource base, thereby increasing the resilience of the community to perturbation from climate or other factors. More extensive use of the existing Exploratory Fisheries Program could foster such diversification. The economic, social and societal benefits of diverse local fisheries have been documented for Greenland and other North Atlantic fishing communities (e.g. Hamilton and Otterstad, 1998; Hamilton et al., 2000).

The offshore fisheries in this area are also significant, accounting for 550 t of the total Canadian quota. It is a deep-water, bottom-trawl fishery involving large vessels during open-water season. Although subject to minor interannual variability due to seasonal ice conditions, access to the fishing grounds will be either unaffected or improved as a result of changing climate, although ice hazard risks may be similar to or greater than those at present. Little is known about how shifts in freshwater budgets will affect Greenland halibut production. Loeng et al. (2005) indicated that substantive restructuring of marine ecosystems will occur under changing climate, with Greenland halibut likely moving from deeper waters to shelf areas, affecting where and how fisheries could be conducted. This will necessitate adaptation (e.g. shift in gear type and possibly in vessel size) on the part of the existing fishery fleet.

Great Slave Lake Fisheries, Northwest Territories

Great Slave Lake, the eleventh largest lake in the world, supports commercial fisheries with an annual recent catch of approximately 1200 t. The principal species fished are lake whitefish, northern pike and inconnu (Figure 20). The East Arm of Great Slave Lake supports trophy sport fisheries, primarily for lake trout. Household fisheries occur in nearshore areas and local tributaries. All fishery types target multiple species. To minimize conflicts and maximize conservation and the value and sustainability of the various fisheries, fisheries managers use a system of area closures, quota limits and gear restrictions to limit both commercial and recreational activities. These same actions will likely be important tools for dealing with the impacts of changing climate.

Projected impacts of changing climate include a potential 50% increase in the number of ‘optimal growing season’ days for cold-water fish, such as lake trout, in the East Arm (McLain et al., 1994). In the relatively shallow west basin of Great Slave Lake, climate-related changes are likely to stress lake trout populations, but species with higher upper thermal tolerances, such as lake whitefish, will likely be positively impacted in terms of increased growth. Structural shifts in the lake ecosystem will likely occur as more southerly species from Alberta river systems, which are currently limited by climate, colonize and/or increase in abundance in the lake. Individual and cumulative effects of these impacts cannot be estimated with confidence because of a lack of baseline information. Adaptive management of the lake ecosystem needs to be done in the context of cumulative effects, including non-climate stresses.

(continued next page)

FIGURE 20: Lifting whitefish nets on Great Slave Lake. Photo courtesy of George Low (Fisheries and Oceans Canada).

CASE STUDY 4 Continued

Arctic Char Subsistence Fisheries

Traditional and subsistence fisheries for Arctic char and related char species are conducted wherever these fish occur, particularly in the coastal western Arctic and throughout Nunavut. Data from the harvest study conducted by the Nunavut Wildlife Management Board (2004) indicate that this species constitutes 45% (by number caught) of the top 15 harvested species reported from 1996–2001 (Figure 21). Other estimates indicate annual harvests of 1200–1500 t (Government of Nunavut and Nunavut Tuungavik Incorporated, 2005), with a high value to local economies and ways of life. All Nunavut, and most Inuvialuit and Gwich'in communities report harvests of either Arctic char or Dolly Varden. Traditional subsistence fisheries have tended to operate in a conservative fashion and are small, widely dispersed and usually short term, with low overall impact. Increases in Aboriginal populations and centralization in settlements, however, have recently limited the efficacy of this approach to northern subsistence fisheries. Where char are exploited by multiple fisheries (subsistence/household, commercial and recreational), current northern fishery management ranks traditional and subsistence fisheries as the most valued (Clarke, 1993).

Projected effects of changing climate on char will involve shifts in productivity and biodiversity, including changes from predominantly anadromous to resident life histories, complete extirpation in some areas and local declines in abundance in other areas (Wrona et al., 2005; Reist et al., 2006a). These shifts in the biological base of the fishery will have cascading ramifications. They will necessitate a variety of local adaptive responses on the part of the fishers and fishery managers, including shifting places, times or methods of capture; switching to alternative species (or life history types); adjusting levels of exploitation; and, in some cases, altering expectations and value associated with fishery resources (Reist et al., 2006c). Another key consideration is the interaction of climate change with contaminant dynamics that affect fish productivity and quality (Wrona et al., 2005), and hence fish suitability for human consumption. Monitoring of such effects, and of human health impacts, should be part of general approaches to northern fisheries.

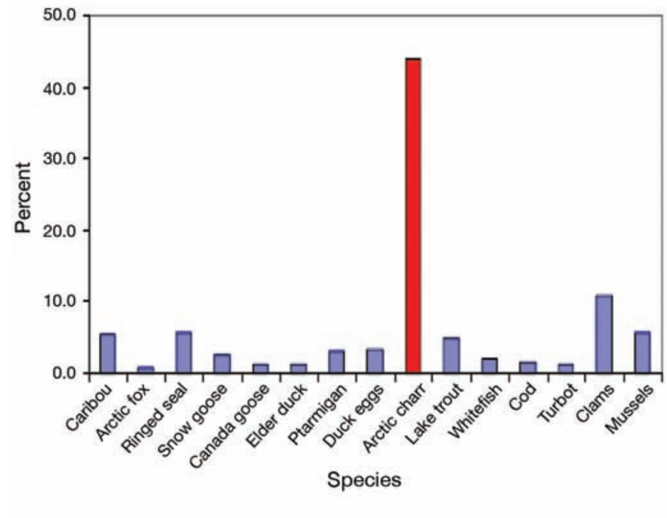


FIGURE 21: The frequency of Arctic char reported as harvested in subsistence fisheries in Nunvaut as overall counts of the top 15 harvested organisms reported in the Nunavut Harvest Study from 1996-2001 (Nunavut Wildlife Management Board, 2004). *Figure compiled by* B. Dempson, Fisheries and Oceans Canada.

An effective generalized approach to climate change adaptation involves comprehensive management and understanding of all human activities that impact northern aquatic ecosystems. For pervasive impacts in the North, such as contaminant loading, climate change, ozone depletion and increased incident ultraviolet radiation, virtually no quantification of the effects on fish populations is available. As a result, adaptive strategies should incorporate a wide buffer to enhance resiliency in the system. For fisheries, this likely means revising 'sustainable' strategies to levels below what is assumed or known to represent the 'maximum sustainable level' or 'total allowable harvest', as this most often will be the only factor that can be managed. Priority might be placed on ecosystems undergoing, or projected to undergo, the greatest changes from all stressors. It presently appears that aquatic systems in the western Arctic, particularly in the southern portion of the Yukon, along the Mackenzie Valley to the delta and along the Beaufort Sea coast, are undergoing significant shifts (e.g. Prowse et al., 2006) and are therefore at greatest overall risk.

4.8 WILDLIFE, BIODIVERSITY AND PROTECTED AREAS

A diverse range of wildlife has been critically important for Aboriginal people in the Canadian North for thousands of years. Today, wildlife continues to play a vital role in the diet, traditions and cultures of Aboriginal people, and also forms important components of local and regional economies (Nuttall et al., 2005). Many Arctic terrestrial and marine mammals and bird species have narrow habitat and niche requirements that make them particularly sensitive to climate change (Conservation of Arctic Flora and Fauna, 2001). Range-restricted wildlife species that occur near their ecological limit have been some of the first to exhibit impacts from changing climate (Parmesan, 2006). Previous assessments of projected climate change on circumpolar Arctic wildlife highlight changes in mortality rates, reduced reproductive capacity, increased competition for resources due to northward extension of southern species, and the emergence of new zoonotic diseases (Berner et al., 2005; Chapin et al., 2006).

Such changes will impact key traditional, subsistence and economic species in some regions, and their effects could be reduced by means of proactive adaptation to reduce the implications for human populations relying on these resources.

Terrestrial Species

Projected warming and shifts towards a wetter Arctic are expected to affect the diversity and accessibility of vegetation critical to several foraging mammals, such as woodland and barren ground caribou (*Rangifer tarandus*) and muskox (*Ovibos moschatus*). Changes in ultraviolet radiation, precipitation and temperature will directly affect the nutritive content of forage (Lenart et al., 2002), while changes in the composition of flora communities may result in the loss of nutritionally important plant species, which are chosen by caribou during important reproductive stages (White and Trudell, 1980). Projected increases in winter temperature and precipitation will likely result in an increase in energy expended by caribou to dig for food through deeper snow pack (Russell et al., 1993).

Some barren ground caribou in the western and central Arctic, including the Bluenose East and West, Cape Bathurst and Porcupine herds, have experienced significant declines in recent years, at least partly attributable to changes in climate. Declines have been associated with difficulties in obtaining appropriate forage and increased harassment by insects that interrupts summer feeding, resulting in poorer animal condition and a subsequent reduction in reproduction and recruitment (Russell, 1993). Similarly, recent declines of caribou and muskox occupying the islands of the south-central Arctic Archipelago (Prince of Wales, Somerset and Russell) are partly attributable to large-scale winter die-offs of both species associated with decreased access to forage due to harsh winter weather, including heavy snow events and increased icing (Miller and Gunn, 2003; Harding, 2004; Gunn et al., 2006; Tesar, 2007). Similar conditions on the western islands of the high Arctic are reported to be the cause of decline among Peary caribou, currently listed as a 'threatened' species. Additional factors involved in the decline of some herds include increased competition between caribou and muskox occupying the same habitat, increased incidence of parasitic infection, emigration to adjacent areas, wolf predation and hunting (Gunn et al., 2006). Similar impacts were projected by Brotton and Wall (1997) for the Bathurst caribou herd using four future climate scenarios.

Caribou are a key traditional and subsistence species for Aboriginal peoples of the Canadian Arctic, including Gwich'in, Tli cho, Denesuline and Inuit, and play an important role in local nutrition, economies, cultures and spirituality. The climate sensitivity of caribou highlights the need to monitor and better understand changes in small and genetically unique groups of animals, and to adjust wildlife management strategies accordingly (Miller et al., 2005; Gunn et al., 2006). Adaptation measures will need to limit the chance of undetected large-scale herd die-offs and harvesting above sustainable levels, in order to protect species from declines to levels from which they cannot recover (Brotton and Wall, 1997; Klein et al., 2005). Wildlife management boards in the Northwest Territories are currently considering implementing measures to reduce the non-resident and non-Aboriginal harvest of caribou (Tesar, 2007). Adaptive co-management strategies, involving local Aboriginal harvesters and bringing together scientific and traditional knowledge, are becoming increasingly important (Klein et al., 2005; Parlee et al., 2005).

Marine Species

The Arctic marine environment is home to a variety of large mammal species that have adapted to the unique conditions of this ecosystem. Ringed sea (*Phoca hispida*), walrus (*Odobenus rosmarus*), narwhal (*Monodon monocerus*), polar bear (*Ursus maritimus*) and beluga whale (*Delphinapterus leucas*) are widely found throughout Northern Canada and are commonly harvested by coastal Aboriginal populations (Nuttall et al., 2005), conveying important health, economic and cultural benefits (Van Oostdam et al., 2005). Many of these species are also central to important Arctic tourism and sport-hunting ventures. Changes in the distribution, stability and annual duration of sea ice and snow availability will have significant impacts on the populations of these mammals. Some species dependent on sea ice as a suitable platform for resting, pupping, moulting or feeding are already showing stress at their southern limits (Learmonth et al., 2006). Species that rely on the ice-edge environment, such as beluga, narwhal and walrus, are most vulnerable to the effects of projected decreases in sea-ice cover (Learmonth et al., 2006).

Decreased snow depth and earlier ice break-up in the spring have been shown to affect the survival and recruitment of ringed seal (*Phoca hispida*) pups in western Hudson Bay, while early spring warming and rainfall have been linked to the melting and destruction of ringed seal lairs in southeastern Baffin Island (Stirling and Smith, 2004; Ferguson et al., 2005). A review of changes in sea-ice conditions and suitability of habitat for ringed seals in M'Clintock Channel and the Gulf of Boothia by Barber and Iacozza (2004) showed large interannual variability, yet negative impacts on ringed seal habitat were evident between 1997 and 2001. For some other seal species, including harbour seals and grey seals, climate warming and decreases in sea-ice cover will mean a northward expansion of their distributions and an increase in their prevalence in Arctic waters.

The distribution of polar bears (*Ursus maritimus*) is partly a function of the ice conditions that allow them to most efficiently hunt and travel. This relationship is particularly strong in areas of moving ice, between foraging grounds and where they give birth to and rear their young (Learmonth et al., 2006). As polar bears feed almost exclusively on ringed seals, changes in ice distribution and extent that impact seal populations will also affect polar bear distribution and foraging success. A significant decline in the numbers and condition of southern populations of adult bears has been documented in western Hudson Bay, and is associated with changes in sea-ice conditions and seal populations (Stirling et al., 1999; Ferguson et al., 2005). Such changes require bears to travel longer distances in search of seals, and to diversify their diet when possible, expending more energy and depleting adipose stores. Ultimately, this can lead to reproductive impairment in females and decreased health of cubs, as mothers have less fat stores during winter months (Derocher et al., 2004). Changes in the proportions of different seal species in the diet of polar bears in Hudson Bay are further evidence of the cascading effects that changing climate and other stressors are likely having on bears in this region (Stirling, 2005). It has also been suggested that changes in ice conditions, as well as specific intraspecies and interspecies competition, have resulted in some bear mortalities in the Beaufort Sea (Amstrup et al., 2006; Monnett and Gleason, 2006).

Projected climate change is likely to lead to improved habitat conditions for both seals and bears at higher latitudes in the near future, as multi-year ice is replaced with annual ice and more leads and pressure ridges are created. In the longer term, however, it is likely that impacts similar to those currently seen in Hudson Bay will also be experienced in high-latitude areas (Derocher et al., 2004).

The iconic nature of the polar bear as a symbol of the Canadian North has elevated discussion of its fate. Not only are polar bears an important component of the Arctic ecosystem, but they are also a key attraction for many visitors to the North each year, and play a significant role in the culture and economies of many Aboriginal communities. Their economic value in regions where high success is achieved in sport hunts, such as western Hudson Bay and Lancaster Sound, is significant for Nunavut communities, where a tag alone can attract as much as $20 000 from a non-resident hunter, with additional income obtained from guiding and outfitting fees garnered by residents in the community (Wenzel, 2005; Freeman and Wenzel, 2006). Thus, the impacts on bears of shifting climate regimes also have implications for tourism, culture and local economies in many regions.

The potential effects of climate change on Arctic whale species are less well understood than for other large marine mammals (Loeng et al., 2005). It is expected that changes in the distribution and extent of ice cover, and the formation and location of polynyas will influence prey species, and thus affect the distribution and range of many northern cetaceans. In general, warming will cause shifts in species composition, with a tendency for northward movement in community structures and the potential loss of some polar species (Tynan and DeMaster, 1997). For example, Moshenko et al. (2003) ranked climate change as a 'high' threat to bowhead whales (*Balaena mysticetus*).

Bird Species

Many sea birds and other migratory avian species are consumed by Aboriginal residents of the North and provide local-scale economic resources in some regions (e.g. eider down). Warming waters and changes in ice distribution and prey productivity are already impacting some northern bird species. The ivory gull (*Pagophila eburnea*), whose distribution is linked to sea ice, has undergone population reductions and further reductions are projected in the future (Mallory et al., 2003). Studies of Brunnich's guillemot (*Uria lomvia*) have shown changes in the timing of breeding at both the northern and southern limits of its range and an advancement of egg-laying dates, yet lower chick growth rates and adult body mass at its southern limits and reduced reproductive success in years of late freeze-up in the north. Gilchrist and Robertson (2000) showed the importance of small recurring polynyas and ice floe edges as wintering habitat for species such as old squaw (*Clangula hyemalus*) and king eider ducks (*Somateria spectabilis*) in Hudson Bay. Throughout the North, Aboriginal hunters have reported changes in migration routes, timing, breeding and reproductive behaviour of birds, as well as the appearance of previously unseen species (e.g. Huntington et al., 2005; Nuttall et al., 2005; Nickels et al., 2006). Together, these results show that warming in the Canadian Arctic in the near future should continue to positively affect some bird species at their northern limits, while having negative impacts at their southern extremes (Gaston et al., 2005).

Conservation and protection of migratory bird resources in the face of changing climate will be challenging in the Arctic, particularly in areas where industrial activity, tourism and increases in local human population provide additional stressors. Protecting key marine areas could play an important role in maintaining ecosystem integrity and thus protecting sea bird populations (Dickson and Gilchrist, 2002). Management strategies involving resource users (Aboriginal residents and others) and industry representatives will have to consider the many stresses on bird populations.

Contaminants and Wildlife

Climate-related changes that have already been observed in the North also influence wildlife exposure to, and intake of, environmental contaminants (Macdonald, 2005; Macdonald et al., 2005). Many environmental contaminants are transported towards polar regions via air and water currents, and changing climate is altering these contaminant pathways (Arctic Monitoring and Assessment Programme, 2003b). For the metals lead, cadmium and zinc, the Arctic is likely to become a more effective 'sink' because of projected increases in precipitation. Mercury appears to be increasing in some northern aquatic systems, related partly to changes in ice cover and permafrost melting. Migratory species represent a form of biotransport, changing the distribution of contaminants they contain. Areas seeing the appearance of new species are most vulnerable to negative changes in contaminant loads in the future. Finally, hydrocarbons will be affected by changes in sea-ice distribution and drift tracks (Macdonald et al., 2005). The largest change in contaminant movement into or within the Arctic may occur as the Arctic Ocean becomes increasingly open to transportation, tourism and mineral exploration.

Changes in contaminant composition and levels in key wildlife species that are consumed by northern residents are significant for human heath and well-being (Kraemer et al., 2005; *see* Section 5). To more accurately track trends of contaminants in key wildlife species in the future, and ascertain the effects of climate on their levels, there is a need to concurrently collect data in both biotic and abiotic media (Macdonald et al., 2005).

Biodiversity and Protected Areas

Climate change is expected to affect Arctic biodiversity through changes in the distribution of ranges and habitats of species, the abundance of species, the genetic diversity and behaviour of migratory species, and the introduction of non-native species (Usher et al., 2005). Current plans for parks and protected areas adopt a natural region or ecoregion representation approach, designed to protect specific natural features, species and communities of a site. These plans generally do not consider the landscape-level shifts in ecosystem distribution and structure that are likely to result from changing climate (Lemieux and Scott, 2005).

Using two global vegetation models and a number of climate models, Lemieux and Scott (2005) projected a decline of more than 50% in conservation lands from each of the three northern biomes (tundra, taiga/tundra, boreal) under a scenario of doubled atmospheric concentrations of carbon dioxide. Such projections raise concerns about the adequacy of existing plans to continue protecting representative samples of Canadian Arctic ecosystems, and ultimately Arctic biodiversity. Usher et al. (2005) concluded that there is an immediate need to develop and adopt new approaches to managing Arctic biodiversity. Adaptive conservation and protected area plans should consider projected changes in phenology and the movements of individual species in response to changing climate, as well as potential changes in biological communities. Disruption of competitive or predator-prey interactions could jeopardize sustainability of ecosystem services on which humans rely (e.g. Root and Schneider 1993; Millennium Ecosystem Assessment, 2005). This is particularly important for species in areas projected to incur cumulative stresses related to climate change, increased development and other human activities.

4.9 TOURISM

The Arctic has seen increased interest and visitation by tourists in recent years (Stewart et al., 2005). Although standardized tourism statistics are lacking for the region as a whole (Pagnan, 2003), some indicators of the level of visitation and the importance of these visitors to local and regional economies are available. The Yukon sees the greatest economic benefits from tourism, with approximately 32 000 tourists in 2002 generating approximately $164 million in economic value (Pagan, 2003). Although hunting and fishing visitors account for only 14% of all visits in the Northwest Territories, they generate approximately 45% of annual spending by tourists in the territory. Tourism is the fourth largest economic sector in Nunavut, with 18 000 visitors entering Canada's newest territory in 2003.

Economic development has long been the driving force behind tourism in the North (Stewart et al., 2005). Although there are obvious benefits to economic diversification, there are also concerns regarding the impacts of tourism on northern communities and local businesses. Inuit in Clyde River, NU, for example, have expressed interest in opportunities associated with tourism as long as the development of these activities is gradual and the community maintains control (Nickels et al., 1991; Stewart et al., 2005).

Challenges facing the tourism industry in the Arctic include a short travel season, transportation difficulties, costs of infrastructure and dependence on nature. Potential positive impacts of changing climate for the tourism industry are associated with increased access and longer travel seasons. An increasingly navigable Northwest Passage could increase tourism opportunities for cruise ships through this relatively unseen wilderness (Stewart et al., 2005), although ice hazards are likely to remain high for several decades (*see* Sections 3.1 and 4.5.1).

5 COMMUNITIES, HEALTH AND WELL-BEING

Communities throughout the North are already reporting impacts and challenges associated with climate change and variability (e.g. Krupnik and Jolly, 2002; Canadian Climate Impacts and Adaptation Research Network (C-CIARN) North, 2006a–c; Ford et al., 2006b; Nickels et al., 2006). The distribution of economic, health, cultural and social impacts associated with changing climate will vary across regions and among segments of the population (Arctic Climate Impact Assessment, 2004, 2005). Furthermore, climate is only one of several factors whose changes are influencing the nature of settlements and populations in the three Canadian territories (*see* Section 2.2). It is the interactions and effects of ongoing changes in human, economic and biophysical systems, exacerbated by changes in regional and local climate, that are disproportionately influencing the health and well-being of northern residents (Chapin et al., 2005).

The majority of research conducted to date on climate impacts in Arctic human systems has been focused on the individual or subpopulation (e.g. hunters within a community) scale. Community case studies, such as those conducted by Ford et al. (2006b), have focused primarily on small remote Aboriginal populations and provide insights into the vulnerability of some northern residents. The challenge in understanding vulnerability throughout the North is complicated by the diversity of community types and their dynamic nature. The factors that influence community vulnerability (*see* Chapter 2) vary significantly between small, remote, predominantly Aboriginal communities, regional centres and larger northern municipalities.

Workshops (e.g. Council of Yukon First Nations and Arctic Athabaskan Council, 2003; Anonymous, 2006; Nickels et al., 2006) have identified a series of local impacts and future concerns throughout the northern territories. At one of the few workshops focused on larger municipalities, impacts and concerns raised by Yellowknife residents included, but were not limited to, municipal water and sanitation, municipal roads and related infrastructure, power sources, and adaptation strategies and planning (Anonymous, 2006). Although there has been little study on how climate change is being considered or integrated in municipal- and regional-level planning and other decision-making processes, some Northwest Territories communities have developed integrated planning processes that consider both the reduction of greenhouse gases and the development of long-term adaptive capacity (Bromley et al., 2004). In Nunavut, one regional workshop has taken place and others are planned that focus on adaptation planning for climate change, and specific community-based projects have begun as a result of this initial meeting (Government of Nunavut, 2006). Concerns shared by small, more remote settlements, in addition to effects on infrastructure from melting permafrost and coastal erosion, include the impacts that changing climate is already having on their relationship with the local environment, the services it provides (e.g. country/traditional foods, raw water, aspects of health and well-being) and the environment's place in local culture, tradition and identity (e.g. Council of Yukon First Nations and Arctic Athabaskan Council, 2003; Nickels et al., 2006).

The effects of climate change on northern biophysical and economic systems (*see* Sections 3 and 4), interacting with non-climatic stressors, have both direct and indirect influences on residents, their health and well-being. The distribution and significance of these impacts is a function of existing vulnerabilities and the characteristics of adaptive capacity at individual and collective scales (Ford and Smit, 2004).

5.1 DIRECT IMPACTS ON HEALTH AND WELL-BEING

The direct influences of climate on human health and well-being in northern communities are primarily related to extreme weather and temperatures, and natural hazards (Table 15). A more detailed discussion of human health vulnerabilities to climate in the Canadian North is provided in Furgal et al. (in press). The effects on northern residents of changes in levels of ultraviolet-B exposure are discussed elsewhere (e.g. Berner et al., 2005).

Residents of small, predominantly Aboriginal communities in all regions of the Canadian Arctic have reported that the weather has become less predictable and, in some cases, that storm events progress more quickly today than in previous memory (e.g. Huntington et al., 2005; Ford et al., 2006b; Nickels et al., 2006). This unpredictability limits participation in land-based and subsistence activities and travel, and increases the risks of being stranded or involved in accidents on the land (Ford and Smit, 2004; Ford et al., 2006b; Nickels et al., 2006). Residents of Arctic Bay, NU have reported that "increased storminess" increases the danger of summer boating and decreases access to some hunting grounds (Ford et al., 2006b). These changes have economic implications for individuals and households in terms of damage to equipment and decreased or lost country/traditional food catches. Extremes of temperature, both cold and heat, influence health directly. The Council of Yukon First Nations has reported that 7% of injuries among youth are cold related, such as hypothermia and frostbite (Council of Yukon First Nations, 2006), and reports of heat-related stress are being recorded, predominantly among elderly residents, in a number of regions (e.g. Communities of Labrador et al., 2005; Communities of the Inuvialuit Settlement Region et al., 2005). Qualitative data suggest that the incidence of accident-related injuries attributable to weather conditions is increasing in smaller coastal communities throughout the North (Nickels et al., 2006). Although preliminary analysis (Noonan et al., 2005) shows increased daily variability of weather in Nunavut, and climate models project an increase in the frequency and severity of extreme events (storms, floods, icing of snow layers, drought), the impacts of such events on health remain difficult to project (Berner et al., 2005).

In response to changing weather conditions, northern residents identified the need for improved infrastructure to communicate weather information, including cellular and improved citizens band radio (CB) service, and the need to construct more permanent shelters on the land as refuges from storms (Communities of the Inuvialuit Settlement Region et al., 2005). In the Nunavut communities of Repulse Bay and Arctic Bay, residents reported taking more supplies than has typically been the norm, such as additional warm clothing, lighters and extra food, when going hunting or travelling on the land, in order to be better prepared for uncharacteristic weather events (Community

TABLE 15: Summary of potential, direct, climate related health impacts in northern regions (*adapted from* Furgal et al., 2002).

Identified climate-related change	Potential direct health impacts
Increase in temperature extremes (magnitude and frequency)	Increased heat- and cold-related morbidity and mortality
Increase in frequency and intensity of extreme weather events (e.g. storms, etc.) Increase in uncharacteristic weather patterns	Increased frequency and severity of accidents while hunting and travelling, resulting in injuries, death and psychosocial stress
Increase in ultraviolet-B exposure	Increased risk of skin cancers, burns, infectious diseases, eye damage (cataracts), immunosuppression

of Repulse Bay et al., 2005; Ford et al., 2006b). People are also becoming more risk averse, with some residents curtailing hunting and travelling activities to avoid storms. Increased use of global positioning systems (GPS) for navigation, and of larger or faster vehicles, was reported among hunters in several communities to compensate for unpredictable or challenging weather. However, these adaptations can also increase exposure to risk by raising the sense of security among hunters and increasing the amount of travel in dangerous circumstances.

Documentation of experience with weather-related natural hazards, such as avalanches, is limited in northern regions. Fatal avalanches and property damage have been recorded in Nunavik (Arctic Quebec), Nunavut, the Northwest Territories and the Yukon, but they are far less common than in British Columbia and Alberta. Events such as the avalanche in Kangiqsualujjuaq, Nunavik in 1999, which killed 9 and injured 25, demonstrate local northern vulnerability. Increased frequency of midwinter thaw-freeze events, creating conditions conducive to snow slides and avalanches, have been reported by residents mainly in eastern Arctic regions in recent years (Nickels et al., 2006). Parts of the western Arctic (e.g. communities within the mountainous regions of the Yukon), where significant winter warming has already been recorded, are particularly vulnerable to avalanche hazards. Landslides associated with heavy rainfall and/or permafrost melt represent another climate-related natural hazard. Communities in the Inuvialuit Settlement Region and in Arctic Bay, NU have reported observations of such events for the first time in recent decades (Ford et al., 2006b; Nickels et al., 2006), and a resulting increase in dangerous travelling conditions (Ford and Smit, 2004; Community of Arctic Bay et al., 2006).

There has been little research that considers the risks associated with changing climate on hazard zonation and adaptation for northern communities (Lied and Domaas, 2000). Newton et al. (2005) recommended that such applied research be conducted in co-operation with northern communities and Aboriginal groups, in order to include local understanding and knowledge of such conditions. Some northern communities in mountainous regions have noted the increasing importance of adequate staffing and training of search-and-rescue personnel because of the increasing possibility of weather-related natural hazards (e.g. Communities of Labrador et al., 2005).

5.2 INDIRECT IMPACTS ON HEALTH AND WELL-BEING

Indirect influences of changing climate on northern communities and residents' health and well-being result from shifts in ice conditions, changes in exposure to emerging diseases, changes and impacts to aspects of food security, implications of permafrost melting for community infrastructure, and the combined effects of environmental and other forms of change on northern residents. Furgal et al. (in press) have provided a detailed discussion of human health vulnerabilities associated with indirect relationships to climate (Table 16). The following is a general discussion of human impacts associated with climate-related changes in northern territories.

Ice Conditions and Safety

Scientific studies and local Aboriginal observations have reported an increasing length of the ice-free season and decreasing ice thickness and extent of sea-ice cover (*see* Section 3.1; Huntington et al., 2005; Walsh et al., 2005; Ford et al., 2006b; Gearheard et al., 2006; Nickels et al., 2006). Models project a continuation of these recent trends through the twenty-first century, with summer sea-ice loss expected to be greatest in the Beaufort Sea (Walsh et al., 2005). Flato and Brown (1996) estimated that continued warming will decrease landfast ice thickness and duration of cover by approximately 0.06 m and 7.5 days/°C, respectively. This would translate into a decrease in thickness of 50 cm and duration of coverage by 2 months by 2080–2100 for a community such as Arctic Bay, NU (Ford et al., 2006b).

In addition to the implications of changes in ice conditions reported in Sections 3 and 4, such changes are also important for many traditional and subsistence activities. Sea-ice provides a stable travelling and hunting platform for northern residents and is critical to the reproduction and survival of several Arctic marine species (*see* Section 4.8). Inuit residents have reported recent changes in ice characteristics, increasing danger and decreasing access to hunting areas and country/traditional foods throughout the territories (Riedlinger and Berkes, 2001; Huntington et al., 2005; Ford et al., 2006b; Nickels et al., 2006). A perceived increase in the number of accidents and drownings associated with ice conditions (Lafortune et al., 2004; Barron,

TABLE 16: Summary of potential indirect climate-related health impacts in northern regions (*adapted from* Furgal et al., 2002).

Identified climate related change	Potential indirect health impacts
Increase in temperature extremes (magnitude and frequency)	Increased incidence and transmission of infectious disease, psychosocial disruption
Decrease in ice distribution, stability and duration of coverage	Increased frequency and severity of accidents while hunting and traveling, resulting in injuries, death and psychosocial stress Decreased access to country food items, decreased food security, erosion of social and cultural values associated with country foods preparation, sharing and consumption
Change in snow composition (decrease in quality of snow for igloo construction with increased humidity)	Challenges to building shelters (igloo) for safety while on the land
Increase in range and activity of existing and new infective agents (e.g. biting flies)	Increased exposure to existing and new vector-borne diseases
Change in local ecology of water and food-borne infective agents (introduction of new parasites and perceived decrease in quality of natural sources)	Increased incidence of diarrheal and other infectious diseases Emergence of new diseases
Increase in permafrost melting, decrease in land surface stability	Negative impacts on stability of public health, housing and transportation infrastructure Psychosocial disruption associated with community relocation (partial or complete)
Sea-level rise	Psychosocial disruption associated with infrastructure damage and community relocation (partial or complete)
Changes in air pollution (contaminants, pollens and spores)	Increased incidence of respiratory and cardiovascular diseases, increased exposure to environmental contaminants and subsequent impacts

2006) may be reflected in statistics showing a higher incidence of accidental deaths and injuries in smaller settlements of the Northwest Territories (Government of the Northwest Territories, 2004). Increased velocity and volume of spring run-off from melting ice and snow create hazardous conditions for young children in northern communities. Economic impacts arising from changes in ice conditions include lost earnings from reduced seal or narwhal harvests, damage to equipment and loss of access to wildlife food resources (Ford et al., 2006b). These changes also have a negative impact on social cohesion and mental well-being by disrupting the traditional cycle of land-based practices (e.g. Furgal et al., 2002; Berner et al., 2005). Similar changes have been reported for freshwater ice and access to fish resources that are important for many Aboriginal and non-Aboriginal populations across the North (*see* Section 4.7).

Adaptation to changes in ice conditions has involved shifts in individual behaviours and the adoption of new technologies. Shifts in hunting activities in response to changes in sea-, lake- or river-ice conditions have been reported by many communities. In Arctic Bay, NU, a portion of the narwhal quota for that community has been shifted from the spring to summer hunt to reduce safety risks associated with earlier and less predictable break-up conditions, and to increase chances of hunting success (Armitage, 2005; Community of Arctic Bay et al., 2006). Some hunters now take small boats with them in case they are stranded on drifting ice (Ford et al., 2006b). Inuit hunters in coastal communities report using new land-based or nearshore routes to access areas previously reached via sea-ice trails (Tremblay et al., 2006). Some residents now consult Internet-based satellite imagery of sea-ice conditions prior to travelling to the floe edge, and many carry GPS units to increase travel and hunting efficacy and decrease risks (Communities of Nunavut et al., 2005; Ford et al., 2006b; Gearheard et al., 2006).

Warming Temperatures and Emerging Diseases

Many zoonotic diseases currently exist in Arctic host species (e.g. *trichinella* in walrus and polar bear, and *cryptosporidium* in both marine and terrestrial mammals), and some regions have reported significant cases of zoonotic diseases in humans in the past (Proulx et al., 2000). A relationship between zoonotic diseases and temperature is evidenced by increased illness and parasitic infection in terrestrial mammals, marine mammals, birds, fish and shellfish in Arctic regions associated with past warm years related to El Niño Southern Oscillation events (Kutz et al., 2004). It is likely that longer warm seasons resulting from changing climate will be associated with a change in the type and incidence of disease in these species, which can be transmitted to northern residents (Bradley et al., 2005). Changes in the spatial occurrence of these diseases is also likely.

The most common forms of food- and water-borne diseases in the Northwest Territories are giardia (from drinking contaminated water), and *salmonella* and *campylobacter* (from eating typically raw or poorly cooked contaminated foods; Government of the Northwest Territories, 2005). Despite the consumption of some foods that are traditionally eaten raw in Aboriginal communities, the rates for *campylobacter* and *salmonella* have declined in recent years in the Northwest Territories (Government of the Northwest Territories, 2005). Communities in the central and eastern Arctic, however, have identified an increase in parasites in caribou over recent years, an observation that has been corroborated by studies of muskox

(Kutz et al., 2004), and have expressed concerns about whether this meat is safe for consumption (Nickels et al., 2006).

Overwintering survival and distribution of some insect species are positively impacted by warming temperatures, leading to increased risk from human and animal vector-borne diseases already present in the region, as well as opportunities for the introduction of new diseases into Arctic regions (Parkinson and Butler, 2005). In the western Arctic, Inuvialuit residents have reported seeing increased numbers of insects and species not observed there previously, including biting flies and bees (Communities of the Inuvialuit Settlement Region, 2005).

Food Security

The diet of many northern residents is a combination of imported foodstuffs and locally harvested foods (country/traditional foods). These foods from the land and sea, including animal and plant species, contribute significant amounts of energy and protein to the total diet, help individuals meet or exceed daily requirements for several vitamins and essential elements, and provide protection from some forms of cardiovascular disease and, potentially, contaminant toxicity (Blanchet et al., 2000; Kuhnlein et al., 2000; Van Oostdam et al., 2005). The proportion of the total diet consisting of country/traditional foods is significantly higher among Aboriginal residents and older age groups (Kuhnlein et al., 2000; Van Oostdam et al., 2005).

Hunting, fishing and gathering also figure prominently in the cash economy of northern communities, and are important for maintaining social relationships and cultural identity among Aboriginal populations (Nuttall et al., 2005). The dependence on country/traditional foods is greater in more remote communities, where access to affordable, fresh market foods is significantly less (*see* Section 2.2, Table 7). Despite their importance, there has been a shift away from country/traditional foods and an increase in the amount of store-bought foodstuffs in the diet of northern populations, especially among younger ages and residents of those communities with greater access to store foods (Receveur et al., 1997).

Shifts in animal distributions and local ecology, and changes in northerners' access to country/traditional food species as a result of changing climate have significant implications for food security (Furgal et al., 2002; Ford et al, 2006b; Guyot et al., 2006; Pratley, 2006). Climate-related changes in terrestrial and marine species, as outlined in Section 4.8, are reported to be affecting harvests of wildlife in some regions. For example, Inuvialuit residents have reported changes in fish and wildlife distributions in addition to the severe storms and changes in sea-ice and permafrost stability, all of which make harvesting more difficult (Riedlinger, 2001). Many other northern communities have also reported impacts on country/traditional food security as a result of changing environmental conditions (e.g. Berkes and Jolly, 2002; Huntington et al., 2005; Ford et al., 2006b; Nickels et al., 2006). These challenges are not limited to coastal communities. For example, residents in Beaver Creek, YT and the Deh Gah Got'ie First Nation in Fort Providence, NT have also witnessed changes in climate that are affecting aspects of their country food harvest (Guyot et al., 2006). The discussion of the impact of climate change on livelihoods of Aboriginal peoples is about sustaining relationships between humans and their food resources, as well as being aware that this impact poses the threat of irreversible social change (Nuttall et al., 2005).

Country/traditional food items are also the largest source of exposure to environmental contaminants for northern residents (Van Oostdam et al., 2005). Climate change will likely enhance transport, deposition and uptake into Arctic wildlife of contaminants, thereby influencing human exposures (*see* Section 4.8; Kraemer et al., 2005). These chemicals are known to adversely affect immune and neuromotor functioning in children (Arctic Monitoring and Assessment Program, 2003a; Després et al., 2005). Current levels of exposure to mercury and organochlorine contaminants among some segments of the population in Nunavut already exceed recommended safety guidelines (Van Oostdam et al., 2005).

Increased temperatures and lengthening growing seasons present opportunities for the development and enhancement of small-scale northern agriculture, particularly in the western Arctic. Such opportunities would create additional and more cost-effective local sources of some food items. Increased warming will also lengthen the ice-free seasons and increase navigability of northern waters (see Section 4.5), and could therefore increase the frequency of transport to communities and reduce costs associated with some market items.

Individual adaptations to changes in country/traditional food access have included shifting times of hunting activities and the use of different forms of transportation (e.g. all-terrain vehicles rather than snowmobiles) to access some hunting and fishing grounds. Residents in all northern regions have reported species that are more difficult to locate and catch today, and are replacing them in the regular hunting schedule with species that are more readily accessible. In the community of Kugaaruk, NU, residents reported that, when the ice is dangerous for travel, people have started to go fishing instead of travelling on the ice to go seal hunting. Some regions have reported a greater need for the community freezer program (Communities of Nunavik et al., 2005; Communities of the Inuvialuit Settlement Region et al., 2005) or the development of intercommunity trade programs (e.g. Communities of Nunavik et al., 2005; Community of Arctic Bay et al., 2006). Increased costs associated with some responses (e.g. purchase of larger boats, use of more fuel to travel farther and access caribou whose migration route has changed) have implications for household budgets, but have not yet been evaluated.

Water Quality

There are significant concerns about access to, and quality of, freshwater resources in many northern communities (Box 1). In the Yukon, 25% of First Nations residents reported that their water was unsafe for consumption (Council of Yukon First Nations, 2006). Approximately 2% of Yukon First Nations residents use untreated water directly from a natural source for daily household use (Council of Yukon First Nations, 2006). Climate-related impacts on the quantity, quality and accessibility of drinking water resources are expected to affect mainly smaller, remote northern communities, some of which face challenges in effectively utilizing municipal treatment systems (Moquin, 2005). Increasing temperatures in the western Arctic have resulted in increased algal and plant growth, making untreated water sources less desirable.

BOX 1

Local observations of changing water resources

"Freshwater is not as good anymore. It tastes swampy because it is not moving as it should. The water flow in creeks is much less now…Some drinking water sources are not there now." (Tuktoyaktuk resident; Community of Tuktoyaktuk et al., 2005)

"The glaciers, which used to reach right into the sea, have all receded, some to the point that you can no longer see them. Permanent snow, which used to remain in the shady areas have started to melt and are no longer available for water in the summer…the Inuit really depend on this water for their tea." (Pijamini; Nunavut Tunngavik Incorporated Elders Conference, 2001)

Decreases in water quality and accessibility have resulted in northern residents becoming increasingly reliant on bottled water when hunting and fishing away from the community (Nickels et al., 2006). Several communities have reported the need for more frequent water-quality testing of both municipal systems and untreated water sources to ensure safety and confidence in drinking water.

Community Infrastructure

Changes in permafrost may have significant implications for a variety of public infrastructure in northern settlements, including waste-water treatment and distribution, water distribution systems relying on pipes, housing and other buildings, and transportation access routes (Warren et al., 2005). Current issues of overcrowding and the quality and affordability of housing faced by many northern residents complicate these challenges. As of 2001, 54% of residents in Nunavut, 35% in the Inuvialuit Settlement Region of the Northwest Territories and 43% in the Yukon lived in overcrowded homes (Statistics Canada, 2001; Council of Yukon First Nations, 2006). Moreover, 16% of homes in the Northwest Territories and 33% of those in the Yukon required major repairs, as compared with the national average of 8% (Statistics Canada, 2001; Government of the Northwest Territories, 2005; Council of Yukon First Nations, 2006). These issues are of greatest concern in small communities (Government of the Northwest Territories, 2005).

Low-lying coastal communities in areas of high risk of permafrost melting (i.e. areas with significant massive ground ice) are most vulnerable to infrastructure damage (cf. Smith and Burgess, 2004). Some communities in these regions are already reporting damage to community buildings from the combined forces of coastal erosion and permafrost degradation (Community of Aklavik et al., 2005; Community of Tuktoyaktuk et al., 2005; *see* also Section 3.7).

Permafrost degradation and coastal erosion are also damaging important cultural sites (Colette, 2007), and may mean partial or complete relocation of communities in the future (Barrow et al., 2004). Although the shoreline in some communities, such as Tuktoyaktuk, has been reinforced to reduce coastal erosion associated with increased storm surges, decreasing sea-ice cover and increasing water levels, this is only a temporary solution. In Tuktoyaktuk, the community has undertaken consultations on potential relocation plans for portions of the community (Community of Tuktoyaktuk et al., 2005). In many communities, residents are moving buildings back from the shoreline in response to erosion (Communities of the Inuvialuit Settlement Region et al., 2005).

In one of the few studies to estimate costs of infrastructure adaptation, Hoeve et al. (2006) developed an inventory of building foundations in six Northwest Territories communities and conducted a scenario-based approach to estimating costs of adaptation for the territory. Assuming these communities were representative of others in the Northwest Territories, preliminary cost estimates of adaptation could be up to $420 million ('worst case' scenario if all foundations require rehabilitation).

Multiple Stressors and Impacts

Changes in environmental conditions also influence the mental health and well-being of many northern residents whose livelihood and ways of life are strongly connected to the local environment. This is especially the case for the approximately half of Arctic residents whose culture, language and identity are tied inextricably to the land and sea via their Aboriginal heritage and identity (*see* Boxes 2–4). Disruption of traditional hunting cycles and patterns (Ford et al., 2006b; Nickels et al., 2006), reduced ability of elders to predict weather and provide information to others in the community, and concern over losses of cemeteries and homes due to coastal erosion (Community of Tuktoyaktuk et al., 2005) all represent forms of social disruption in communities already undergoing significant change as a result of both internal and external forces. The stresses resulting from these multiple changes have been associated with symptoms of psychosocial, mental and social distress, such as alcohol abuse, violence and suicide (Berner et al., 2005; Curtis et al., 2005).

Each region in Northern Canada is unique with regards to the environmental, social, cultural, economic and political forces that influence change at the local and regional scales. This is very important for regions or communities undergoing various forms of rapid change in many sectors at the same time (Chapin et al., 2005). For example, the increased growth of the wage economy in many regions has reduced both the necessity for, and time available for, hunting, fishing and gathering. This, in turn, has reduced the generation and transmission of traditional knowledge and environmental respect to younger generations, as well as diminishing the health benefits from the consumption of local foods. However, access to the cash economy provides resources for adaptation via the purchase of hunting equipment (e.g. boats, ATVs, snowmobiles) that, in turn, permits individuals to hunt more species over a larger geographic area. Dominant driving forces of change in any one community or region may be enhanced, reduced or altered by aspects of a changing climate (McCarthy et al., 2005). After reviewing key forces and their interactions, Chapin et al. (2005) reported that the deterioration of cultural ties to traditional and subsistence activities, and all they represent, is the most serious cause of decline in well-being among Aboriginal people in circumpolar Arctic regions today (Chapin et al., 2005).

5.3 ADAPTIVE CAPACITY

Adaptation occurs at the individual, collective or systems level, and at local, regional or national scales (Government of Canada, 2001, *see* Chapter 10). For many issues, adaptations will be most effective and sustainable when they are developed at the local

BOX 2

Aboriginal perspectives on climate change impacts and adaptation: Inuit concerns and priorities (prepared by Inuit Tapiriit Kanatami)

The Inuit of Canada are approximately 53 400 in number, inhabiting the Inuvialuit Settlement Region on the Beaufort Sea; the Kitikmeot, Kivalliq and Qikiqtani regions in Nunavut; Nunavik, in northern Quebec; and Nunatsiavut, in northern Labrador (Statistics Canada, 2001). Inuit communities have several common characteristics that make them distinct from other northern Aboriginal populations and southern populations within Canada and strongly influence their vulnerability to changing climate.

Nearly all Inuit communities were established in the last 50 to 60 years, are located on the Arctic or Atlantic coasts, have no road access and depend upon the health and management of the land and oceans to support and sustain a way of life that is based largely on marine activities and resources. Prior to the formation of communities, Inuit were largely nomadic, living throughout the Arctic in dispersed hunting camps and following migratory wildlife. Today, communities are trying to find ways to provide adequate infrastructure and services to meet existing needs, while anticipating further pressures on a young and rapidly growing population. Like other Aboriginal peoples in Canada, Inuit have experienced fundamental and rapid change to their society, language and culture since contact, and these changes continue today. Significant gaps exist between Inuit and other Canadians in areas such as human health, level of secondary and post-secondary education, housing needs, access to early childhood development initiatives, rates of incarceration, and employment rates and income.

Innovative political and administrative institutions established by Inuit, in the form of the four land claim agreements for traditional Inuit territories, play a key role in addressing the challenges and opportunities associated with climate change. Inuit Nunaat (Inuit homelands encompassed by the four agreements) make up approximately 40% of Canada's land mass and an even larger proportion of Canada's total land and marine areas. It includes nearly half of Canada's coastlines and forms virtually all of one territory (Nunavut) and portions of two other territories (Northwest Territories and Yukon) and two provinces (Quebec and Newfoundland and Labrador). As land owners of some of the most sensitive and vulnerable regions in the country to the impacts of climate change, Inuit play a key role in addressing this very important issue.

Through their regional, national and international organizations, Inuit have taken steps to identify the impacts of climate variability and change that are of particular significance for their populations; these priorities are outlined in Table 17. A Partnership Accord, signed by the Inuit of Canada and the federal government on May 31, 2005, includes an Inuit Action Plan that identifies activities and initiatives to be conducted over a three-year period. One of the most important issues in this plan is climate variability and change. In this regard, the plan calls for: 1) a policy process that involves Inuit knowledge alongside science; 2) establishment of an Inuit-driven process to deal with Inuit-specific concerns; 3) increasing Inuit involvement with the Government of Canada to address climate change mitigation and adaptation, both domestically and internationally; 4) a process to follow up on the recommendations of the Arctic Climate Impact Assessment; 5) development of sustainable capacity-building tools supporting Inuit efforts in impacts and adaptations research and planning; and 6) the establishment of a Canadian Arctic Climate Change Strategy that addresses both mitigation and adaptation. The Action Plan also stresses the need for co-operation on key international activities related to climate change, such as those under the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), the North American Commission for Environmental Co-operation, and the Arctic Council.

BOX 2 *Continued*

TABLE 17: Priority issues around climate change impacts and adaptation for the Inuit of Canada.

Key issue	Importance for Inuit
Wildlife	Wildlife is more than subsistence and nutrition to Inuit. It plays a role in preservation and promotion of language, culture and traditional knowledge. Hunting is a social process of learning and knowledge transmission in communities, even today. Some key species (e.g. polar bear) require attention to balance interests between conservation and management for wise use by Inuit in the future.
Infrastructure	Inuit communities are located in predominantly low-lying coastal zones, and many are already having to take actions to protect shorelines and buildings, and to consider future relocation as a result of encroaching erosion and existing damage.
Human health	Health impacts of climate change are already reported in many Inuit communities today. Inuit health status is already challenged and climate will influence existing vulnerabilities (social, physical and mental). Ability to adapt is limited by such things as access to medical and emergency services, which are already significantly less in Inuit communities than in other parts of the country.
Food security and contaminants	Reports of impacts on Inuit food security already exist and will combine with the influence of contaminants currently recognized in country foods. Adaptation in response to contaminants is dependent on outside information delivery and education. Current monitoring and research capacity to support informed decision-making is limited. Current economic access to alternatives (healthy market foods) is limited.
Traditional knowledge	Traditional knowledge of the environment (seasonal rhythms, weather prediction, animal migration, and quality and quantity of sea ice) is an important part of Inuit culture. Inuit knowledge plays an important role in development of northern policy, and wildlife management and endangered species regulations. Climate change, along with other forms of change in communities, is threatening and eroding Inuit traditional knowledge. However, its role in adaptive capacity is raising awareness of its value and importance for the future.
Economies	Changing climate is impacting the ability of Inuit to earn income and, at the same time, increasing their expenditures. Inuit have already started to adapt, with individual households bearing the brunt of economic impacts, which are expected to rise.
Emergency management	Emergency preparedness is most critical for small remote communities, such as those in which many Inuit live. Increasing and changing environmental hazards are putting more young Inuit at risk while on the land. Search-and-rescue efforts are becoming more frequent and also more dangerous. Increasing potential risks to health call for enhanced emergency response capability, plans and disaster recovery strategies.
Security and sovereignty	Inuit traditional lands include extensive Arctic coastline, and nearly all communities are coastal. Increased shipping and the opening of Arctic ports will mean significant changes for Inuit communities, including potential risks associated with environmental disasters (spills) and sociocultural change, and benefits (increased opportunities for wage employment).

BOX 3

Aboriginal perspectives on climate change impacts and adaptation: Yukon First Nation communities (prepared by Council of Yukon First Nations)

The Council of Yukon First Nations (CYFN) represents 11 of the 14 First Nations in the Yukon, as well as four Gwich'in First Nations in the Mackenzie Delta region. The CYFN is committed to the promotion of responsible management of the human and natural resources within all its member First Nation traditional territories. The effects of a changing climate on ecosystems are already evident, having been reported by elders and other First Nation members. They include such things as altered seasonal river discharges, insect infestations and changes in forest composition. In partnership with the Arctic Athabaskan Council, CYFN participated in the development of the Arctic Climate Impact Assessment and supports the implementation of its central recommendations. The CYFN has built its own climate change strategy around these objectives. The organization's response is organized around three primary themes:

- core capacity to co-ordinate and manage Yukon First Nation responses to climate change impacts
- support for directed community research
- communication, public education and partnership development

Community-based research and monitoring are viewed as important for developing an overall understanding of potential adaptation. The CYFN argues that such research and monitoring would illustrate the importance of accumulating detailed knowledge of local perspectives and understanding of climate change, and the need for the exchange of information among a diverse group of individuals, including communities, scientists and policy makers. The concerns and priorities of the communities have been documented through workshops and conferences undertaken by CYFN over the past few years. They identify community concerns about the potential impacts of climate change on traditional and non-traditional aspects of society; community social and cultural interactions; and local- and regional-scale economic activities. They describe the problems communities believe they are either already dealing with or are likely to face in the future, and how they might organize themselves to take advantage of opportunities through effective adaptation. Key research themes identified in consultation with First Nations communities are presented in Table 18.

The focus of the CYFN's approach to enhancing adaptive capacity of communities is to provide the right information to the right people at the appropriate time. Drawing upon the findings of the latest research and assessments, it is argued that the promotion of, and support for, sustaining the livelihoods and cultural traditions of Aboriginal peoples and communities requires getting this information out to decision-makers at various levels to support the proactive development and implementation of policies and actions. Yukon First Nation elders have established the Elders Panel on Climate Change and have participated and assisted in directing the work for CYFN on climate change issues. The elders believe that sharing their knowledge will break new ground in contributing an understanding needed to formulate national and circumpolar strategies to investigate and address the issue. Engaging CYFN communities and assisting them in understanding and developing their own adaptive capacities and addressing conflicts in the face of climate change impacts is the primary goal of CYFN efforts in the near term.

TABLE 18: Priority themes for research related to climate change, identified by the Council of Yukon First Nations in consultation with Yukon First Nation communities.

Key issue	Importance for Council of Yukon First Nations communities
Food security	Traditional resource practices of hunting, herding, fishing and gathering remain critically important for local economies, cultures and health of Yukon First Nation members. Characteristic environmental conditions over centuries have enabled communities and peoples to develop skills and knowledge and pass these down between generations. Conditions are changing, and impacts on resource practices are already occurring. Access and legal right to harvest fish and wildlife are protected for Yukon First Nations under existing agreements, yet these institutions may be challenged by changes in climate. Thus, there are political implications for food security that require better understanding to protect these resources for First Nations members.
Community health and well-being	The potential introduction of new diseases into the Yukon is a direct threat to First Nation communities. The combined effects of the biophysical (climate), social, economic and cultural change taking place have significant potential to negatively impact health, which is already stressed on many fronts. Potential impacts on the sustainability of traditional Yukon economies and indirect influences on health and well-being are significant but poorly understood.
Resource-use conflicts	Because of strong involvement in both wage and traditional economies, and potential impacts to both via climate change, there is a need to better understand conflicts arising as a result of impacts and competition between economic sectors (traditional and wage based). There is a need to understand cumulative impacts, including climate, associated with large-scale developments in the Yukon.
Emergency preparedness	There is currently a lack of understanding of the level of First Nations community emergency preparedness in the Yukon to deal with increased risks of extreme weather events and variability and associated natural disasters, such as forest fires, and the potential impacts of climate on remote communities.

BOX 4

Aboriginal perspectives on climate change impacts and adaptation: the Dene Nation (*from* Paci et al., 2005)

The Dene Nation is the Aboriginal political organization mandated to represent the interests and beliefs in Denendeh, which includes more than 25 000 residents living in 29 communities across five culturally and geographically distinct areas. As in other Arctic regions, Dene are experiencing and reporting changes in climate and the environment that are unique to the people of that land. The Denendeh Environmental Working Group (DEWG) brings together Dene and invited guests from government, universities and non-governmental organizations, and has held workshops on climate change knowledge and observations. Workshops have discussed the themes of climate change and impacts on forests, water and fish. Four central questions have shaped much of the DEWG discussion on climate to date (Paci et al., 2005, p. 80):

- Is there a difference today in Denendeh and is climate change having a role in these changes? What else might be causing it?
- What climate change programs are there, and how can our communities be more involved in research and communication about these changes?
- If it is important to document Dene climate change views/knowledge, how should we communicate this knowledge with each other and policy-makers, governments and others outside the North?
- Is the DEWG a good mechanism to discuss climate change? What should we be talking about and what else do we need to do?

A more comprehensive description of Dene observations of climate change and climate impacts in Denendeh is reported in the Arctic Climate Impact Assessment (Paci et al., 2005).

scale and directly involve the individuals affected (Clark, 2006; Furgal and Seguin, 2006). Institutions that facilitate connections across scales help to enhance resilience to change (Berkes et al., 2005). With respect to Northern Canada, studies to date on adaptation have focused mainly on remote communities made up of predominantly Aboriginal residents (e.g. Berkes and Jolly, 2002, and chapters contained therein; Nickels et al., 2002; Ford et al., 2006b). Comparatively less attention has been given in the academic literature to impacts of changing climate on non-Aboriginal residents or adaptation in large municipalities. However, issues such as impacts and vulnerabilities of municipal infrastructure and transportation have been recognized for their significance, and some governments have been working to address them in recent years (e.g. Government of Nunavut, 2006).

Workshops and research projects conducted throughout the North have reported that individuals are already adapting to reduce the impacts of climate change on aspects of their lives and livelihoods, primarily in a reactive manner (*see* examples in previous sections of this chapter). The ability to adapt is influenced by factors such as access to economic resources, technology, information and skills, institutional arrangements, equity among members of a group, risk perception and health status (*see* Chapter 2; e.g. Kovats et al., 2003; Smit and Pilifosova, 2003). As outlined in Section 2.2, many of these factors vary significantly between regions and also within regions between smaller remote communities and larger regional centres and municipalities. Consequently, the adaptive capacity and resilience of individuals and communities to climate and other forms of change vary by geography, sociodemography, economic status and culture. Nonetheless, it is possible to identify some sources of social and economic resilience and vulnerability, and associated opportunities for adaptation, that are common to many Arctic societies (Table 19; Chapin et al., 2006).

Erosion of Traditional Capacities

The Arctic has experienced significant climate change in the past. The archeological record, ethnohistorical accounts and memories of Aboriginal elders provide detailed accounts of how periodic, irregular and often dramatic ecosystem changes, triggered by periods of warming or cooling and extreme weather events, have been a dominating influence on human life in the Arctic. The successful long-term habitation of the Arctic by Aboriginal peoples has been possible because of the capacity of their social, economic and cultural practices to adjust to climate variation and change. For millennia, Arctic populations adapted to gradual or even rapid environmental change by resettling amid favourable environments and along the paths of animal migration routes (Nuttall et al., 2005). The massive social, cultural and economic changes that have occurred since Aboriginal peoples have settled in permanent communities, predominantly over the last 50 to 60 years, have significantly eroded the traditional aspects of their socioecological resilience and adaptive capacity (Berkes and Jolly, 2002). New economic opportunities that could be presented as a result of climate change should result in increased wage employment. This, in turn, is likely to further reduce opportunities for individuals to gain the land-based skills and traditional knowledge necessary to continue aspects of subsistence and traditional livelihoods.

Economic Resources

Northern communities, however remote or small, are tied economically and politically to the national mainstream. Trade barriers, wildlife management regimes, globalization, and political, legal and conservation interests all affect the abilities of northerners to meet the challenges posed by changing climate. Several northern issues are unique within Canada. For example, even though the Government of Nunavut estimates that it would cost approximately CDN$35 million annually to replace food secured through traditional and subsistence activities, virtually

TABLE 19: Sources of social and economic resilience and vulnerability that characterize many Arctic systems (*from* Chapin et al., 2006).

Arctic characteristics	Sources of resilience	Sources of vulnerability	Opportunities for adaptation
Social and institutional properties	Sharing of resources and risks across kinship networks Multiple jobs and job skills held by an individual ('jack of all trades')	Inadequate educational infrastructure to plan for future change Relatively unskilled labour force	Learning and innovation fostered by high cultural diversity
Land tenure and use rights are regionally variable; where strong there is flexibility for adaptation			
Economic properties	Flexibility to adjust to change in mixed wage-subsistence economy	Decoupling of incentives driving climatic change from economic consequences Non-diverse extractive economy: boom-bust cycles Infrastructure and political barriers to relocation in response to climate change	Substitution of local resources for expensive imports (food, fuel) National wealth sufficient to invest in adaptation
Retention of rents from development are regionally variable; where present, they can build infrastructure and social capital that allow adaptation and diversification			

none of this traditional wealth can be converted into the money needed to purchase, operate and maintain the equipment that hunters use. Abandoning hunting for imported food would not only be less healthy than continued use of country/traditional foods, but would also be immensely costly (Nuttall et al., 2005).

The natural resource extraction economy of many northern regions provides an economic base to support various adaptations to environment change. As a result, some regions have a far greater capacity to adapt in the short term if they are able to benefit from these activities. However, as noted by Justice Berger (Berger, 2006), Inuit (and all northerners, for that matter) must be educated and ready to take part in the economic opportunities that future changes may create in the North, such as enhanced oil and gas exploration and development, intensive development of mineral resources, enhanced navigation, and port and other infrastructure development. Current levels of skilled labour and formal education often limit the abilities of northerners to take advantage of such opportunities.

Information and Technology

Ford et al. (2006b) discussed the importance of traditional skills and knowledge, social networks and flexibility towards resource use in their analyses of vulnerability to climate change, primarily among hunters. Many other studies have noted the importance of combining scientific knowledge and traditional knowledge in the effort to understand aspects of climate change, impacts and local-scale responses (e.g. Parlee et al., 2005; Furgal et al., 2006; Gearheard et al., 2006; Laidler, 2006;). Traditional knowledge systems and skills are central components to many individual responses to environmental change, yet are being challenged and, in some cases, eroded by the combined forces of environmental and social change in northern communities (Nuttall et al., 2005; Ford et al., 2006b; Lacroix, 2006). This erosion is particularly acute among younger Aboriginal residents engaged in full-time wage-earning employment. Nevertheless, at the same time that their adaptive capacity in response to environmental change is diminishing in one respect, it is also enhanced as a result of increased access to economic resources and technology. As a result, it is difficult to project the net impact of all combined forces of change very far into the future.

Policies and Institutional Capacity

Chapin et al. (2006) and Ford et al. (2007) recommended adaptation policies aimed at supporting aspects of resilience in northern communities and sectors. These include such things as ensuring flexibility in resource management regimes (e.g. Adger, 2003), support for formalized teaching of traditional skills and knowledge, and economic support for the pursuit of traditional and subsistence ways of life (e.g. Ford et al., 2007). They also place emphasis on skills training and development so that northerners are better prepared to adapt to, and derive benefits from, the rapidly changing northern social, economic and physical environment (e.g. Berger, 2006).

The development and implementation of such policies requires institutional awareness and vision. Of particular importance is the manner in which organizations and individuals interact — in the public sector, across government and non-governmental organizations, and within society (Adger, 2003; Willems and Baumert, 2003; Berkes et al., 2005). There are some examples of institutional capacity in the North to address climate change. Where government departments and organizations have developed and implemented adaptation plans, or where groups engaging Aboriginal organizations, government representatives and the general public have convened to identify common challenges and how to address them, there is evidence of the effect that mobilizing the existing local, territorial and regional capacity can have. Nevertheless, the effective implementation of policies and measures will require maintenance and strengthening of climate-related expertise and perhaps the creation of new institutional arrangements for a variety of policy areas in the North, particularly related to public safety and economic development. Use of existing institutional capacity to integrate (mainstream) climate concerns into existing policy and program areas is an important goal.

6 CONCLUSIONS

Canada's Arctic has already experienced significant changes to its climate that are producing cascading effects on physical, biological, economic and social systems. The sensitivity of these systems to climate change is relatively high because of their dependence on the predictability and characteristic stability of the cryosphere (snow, glaciers, freshwater/sea ice and permafrost). Current climate trends are likely to continue and intensify, creating unique conditions, challenges and/or opportunities for natural and human adaptation.

Major changes are expected in a variety of resource sectors, including hydroelectric generation, oil and gas, mining, forestry and fisheries. Locally, hydroelectric facilities and operations will need to be adapted to changing flow regimes associated with an altered timing and magnitude of snowmelt runoff. Perhaps more important, however, will be a need to consider the implications of future impoundments as the needs for additional and renewable energy increase, particularly on the northward-flowing Mackenzie River system. Where older infrastructure in the Arctic overlies thaw-sensitive permafrost, some form of structural or operational adaptation may be needed to deal with permafrost thawing, and there is evidence that some adaptive measures are already being undertaken (Section 4.4). An important issue for the mining industry is the containment of wastes. Historically, the industry has relied on the impervious nature of permafrost to ensure long-term storage, but future permafrost thaw could eliminate the option of such surface-storage approaches and require remediation of older storage sites. In the case of the oil and gas industry, changing climate will affect exploration, production and delivery. Projected reductions in sea-ice cover, for example, are likely to be beneficial to exploration and development in both the energy and mining sectors, leading to further economic development.

Reductions in the thickness and seasonal extent of river, lake and sea ice will require adaptation of marine and freshwater transportation activities. These will vary from changes in the types of vessels used and the routes followed to a shift to more barge- and land-based traffic as ice roads and crossings become less viable. For the marine system, increases in navigability also raise important issues about the international use of the Northwest Passage. Expansion of marine and land-based transportation would have synergistic effects on resource exploration, as previously remote resources would become more accessible and economically viable to exploit. These changes will introduce new risks and opportunities for human settlements. The influx of wage employment may enhance adaptive capacity to some climate impacts; however, greater involvement in full time jobs will continue to be associated with current trends of social and cultural erosion.

Changes in habitat quality and quantity in the fisheries and forestry sectors will require adaptation ranging from shifts in management strategies to alterations in the equipment used. For both sectors, there are also concerns about how to deal with invading species and changes in biodiversity. Modified sustainable management plans will be required for both sectors to deal with future changes in climate. Key Arctic wildlife species at their southern limits are already being affected by changing climate, and alterations in management regimes and potential changes in boundaries of protective areas may be required. Actions to better understand and protect genetically unique and sensitive species that have undergone recent significant declines, such as the caribou herds of the central and western Arctic, will help support the health and cultural well-being of Aboriginal Arctic populations.

The direct health impacts of climate extremes and natural disasters are most significant for communities and individuals living in more environmentally exposed locations (e.g. remote, low-lying coastal areas and isolated mountainous regions), which are situated farther from emergency health services and with less developed emergency preparedness plans. Elders and those individuals with an already challenged health status are most vulnerable to temperature extremes. Many of the populations most highly exposed to the indirect impacts of climate change are already under stress from other forms of change, so the specific role of climate is often difficult to isolate. Based on increased exposure to untreated water sources and challenges in the effective use of municipal treatment systems in some small communities, these settlements are more vulnerable to the effects of warming on drinking water quality. However, large communities also face risks to water quality and supply because the access, treatment and distribution of drinking water is generally dependent upon a stable platform of permafrost for pond or lake retention, a situation that is currently changing.

Communities and households most vulnerable to the effects of climate change on food security are those that depend on a limited number of country/traditional food species, are high consumers of country/traditional foods, are located farther from regional centres and have limited access to market foods. Many of these communities also lack the economic resources to purchase new and more powerful hunting and transportation equipment to adapt to changing environmental conditions. Adaptation measures in the form of intercommunity trade programs, community freezers and a variety of individual behavioural changes have been developed by some communities to reduce the impacts already being experienced.

The political, cultural and economic diversity of northern Canada means that communities are affected by, and respond to, environmental change in different ways. For many of the currently identified climate-related impacts, it appears that the larger municipalities and their residents are less vulnerable than smaller, more remote communities. Larger municipalities are generally less exposed to climate risks, and have greater capacity to adapt (e.g. greater access to economic resources, technology, infrastructure and health services). At the same time, however, groups and individuals residing within regional centres are dependent upon municipal infrastructure, which is sensitive to climatic change. Within the smaller, predominantly Aboriginal communities, many other factors influencing adaptive capacity are stronger, including traditional knowledge and skills, social capital, and risk perception and awareness. As vulnerability is a function of exposure and the ability to adapt, and these concepts vary within and between communities for particular climate-related impacts and opportunities, it is not possible to generalize climate change vulnerability across the Canadian North.

It is evident that the Canadian Arctic is already undergoing significant changes in climate, and that these changes are affecting almost every aspect of the northern environment and population. Many communities have already begun adapting. However, knowledge gaps remain regarding the thresholds at which impacts occur, how best to support ongoing adaptation efforts, where adaptation is not possible, and what the limits to adaptation strategies are for various locations and groups. Strengthening understanding in these areas will support more informed decision-making on these issues in future.

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