The Northern Climate ExChange
Gap Analysis Project

State of Knowledge
Impacts of Climate Change on Biophysical Systems

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Background and Context

For the past decade it has been apparent that the greatest impacts of climate change will be most evident in northern Canada and other arctic regions. Nevertheless, there is still a great deal of uncertainty about the magnitude of these effects in different northern regions. These aspects of climate change science have been described in detail in the most recent report of the Intergovernmental Panel on Climate Change (IPCC, 2001) and are the subject of ongoing investigation by the Arctic Climate Impact Assessment (ACIA) [www.acia.uaf.edu]. Other international organizations, including the Arctic Monitoring and Assessment Program (AMAP), Conservation of Arctic Flora and Fauna (CAFF), World Wildlife Fund (WWF), and the International Arctic Science Committee (IASC), among others, are also actively engaged in assessments of climate change impacts in the Arctic.

In Canada, a comprehensive attempt to synthesize the potential effects of climate change on the people, economy and natural resources of northern Canada was published as part of the Canada Country Study on Climate Impacts and Adaptation in 1997. The federal Climate Change Action Fund (CCAF) has also provided several recent assessments of climate change impacts in northern Canada.

The Northern Climate ExChange (NCE) Gap Analysis Project should be viewed as another contribution to these ongoing northern climate change initiatives. More specifically however, the NCE undertook to provide an assessment that will be directly useful for northern communities concerned about climate change impacts. Traditional, community and scientific sources of information were all considered. Since the people of small and remote communities characteristic of northern Canada hold considerable knowledge about climate change, the inclusion of this information in the NCE knowledge gap assessment will help to build a strong link between scientists, communities, First Nations, governments and industry.

This gap analysis is built around the consideration of five main factors including the identification of:

1. climate variability resulting from natural processes and human activity (such as greenhouse gas emissions);
2. ecological and physical impacts of these changes in the north;
3. vulnerability of natural, social and economic resources to the consequences of climate variability;
4. potential adaptation and mitigation strategies that might alter the consequences of climate change; and
5. possible changes in the nature of human activities that generate changes in climate.

This review and assessment will focus primarily on the first three factors, based on the information available in the NCE Infosources database. In the past decade, research efforts towards understanding, preventing and mitigating climate change impacts have greatly increased, but an overall vision of where to allocate limited resources is lacking. Consequently, the overall objective of this assessment was to identify knowledge gaps and to provide reliable information to governments, organizations and peoples of the Arctic. This is expected to lead to the development of a coherent strategy for ensuring that the required information is collected in order to sustain the environments, resources and peoples of northern Canada.

This report provides an overview and assessment of over 450 items, contained in the NCE database, on climate change and its effects on the physical and natural resources that affect human activity in northern Canada. The following issues were addressed:

Issue 1. Is the NCE database representative of the available information?
Issue 2. To what extent do the references in the database provide information needed for assessing specific climate change impacts on physical and human systems?
Issue 3. Are the information sources regionally representative?
Issue 4. Recommendations based on the Gap Analysis:
  1. NCE facilitation of monitoring programs at the community level
  2. Options for maintaining a current database.

Description of the Matrices

The matrices (or tables) developed as part of the NCE gap analysis are the primary method used to organize and compile the information about the state of knowledge of climate change impacts in northern Canada. Each matrix applies to a system relevant to northern Canada. Ten of the seventeen matrices were assessed in this summary, including:

Baseline Climate Data
Boreal Forest and Taiga Ecosystems
Coastal Ecosystems
Tundra Ecosystems
Fresh Water Ecosystems
Marine Ecosystems
Fisheries
Forestry
Hunting and Trapping
Agriculture

Projected scenarios of climate change, including seasonal temperature changes; precipitation changes (rain and snow); and other climate impacts (storms, floods, cloudiness, or increased levels of atmospheric greenhouse gases), were assessed for each system for both baseline data (without taking climate change into account) and potential climate change scenarios.

Table 1: References in each System Matrix (updated Jan. 2002)

Matrix	**No. References**
Baseline Climate Data	47
Physical Systems	
Boreal Forest/Taiga	64
Coast	32
Tundra	85
Fresh Water	58
Marine	53
Human Systems	
Fisheries	33
Forestry	35
Hunting/Trapping	40
Agriculture	17

The matrices are only a tool to detect the current state of knowledge about climate change impacts on the various systems operating in northern Canada, and this information does not answer the question of what the effects of climate change on these systems will be. Therefore, if the state of knowledge of "precipitation changes" on marine mammals is deemed to be poor, this does not necessarily imply that the impacts of more rain or snow will be negative for these species (although this might be true).

The overall Gap Analysis Project involved the identification of information sources and the subsequent synthesis of this information with respect to the impacts of climate change on northern Canada. Information sources included documented scientific, local and traditional knowledge from journal articles, conference proceedings, research licences, databases, and consultation with local experts and researchers. The number of information sources available for each matrix evaluated is indicated below. There were 464 references in total, although there is some duplication of records among the different systems.

Limitations of the NCE Database

The NCE Infosources database and the matrices provide information about the state of knowledge, with a critical assessment of what information is still required. Being able to see where these knowledge gaps are will provide both confidence in current decision-making processes, and identification of directions for future studies.

This assessment of the possible trends and consequences of climate change will allow users to determine independently possible responses in other regions, but it is not a substitute for local information and research. If comparisons of responses are made between regions, they must be undertaken carefully, recognizing the tremendous variability in conditions across northern Canada. Most importantly, this gap analysis may provide opportunities to identify research and monitoring needs, and allow communities, governments and researchers the opportunity to coordinate their efforts.

There are several sources of uncertainty that apply to this gap analysis. First, many of the overview studies included in the database are highly speculative and are based on limited details. Similarly, many of the detailed, technical studies were conducted at a specific site and cannot be easily extrapolated to a larger scale. Second, the database provides a representative (rather than exhaustive) collection of information sources, so that the state of knowledge is more likely to be under-interpreted than over-interpreted. Third, the range of possible climate change scenarios is not well understood, and potential responses of biological and physical systems remain rather tentative. For all of these reasons, this assessment of knowledge gaps is generally conservative. However this limitation should be interpreted as a virtue rather than as a liability.

Issue 1: Is the NCE database representative of the available information?

There is a vast body of scientific literature available on the topic of northern climate change. The current NCE Infosources database contains several hundred documents from various sources, but no database is ever complete. However, the NCE database provides a representative, if not entirely comprehensive, overview of the northern climate change literature.

This assessment is based, in part, on a comparison with two other research databases, the ISI Web of Science Database and the Arctic Science and Technology Information System database.

A search of the ISI Web of Science Database (www.isinet.com) using the keywords “Arctic” and “climate change” identified more than 450 references to scientific papers published in the technical journals between 1975 and 2001. No papers using these key words were published before1989, but there has been a steady increase in these publications over the last decade (Table 2).

A similar search of the Arctic Science and Technology Information System (ASTIS - www.aina.ucalgary.ca/astis) using the key word "climate change" identified a total of 286 publications for the period 1990-2001, 58 during the 1980s, 17 during the 1970s, and only 5 prior to 1970. This database emphasizes reports from government agencies, industry, First Nations, and universities in addition to some journal articles, conference papers, graduate student theses and books.

Most of the references in the NCE database are from 1990 or later, and therefore should provide a reasonable perspective on the available information, and are likely

Table 2: Number of papers published in scientific journals identified in a search of the ISI Database using the keywords ‘Arctic’ and ‘climate change’ (updated Jan. 2002).

Year	Number of Papers	Year	Number of Papers
2001	75	1994	26
2000	60	1993	26
1999	68	1992	12
1998	49	1991	10
1997	63	1990	2
1996	17	1989	1
1995	48	<1989	0

sufficient to assess the knowledge gaps for northern Canada, recognizing that other information may be available in some areas. This additional information will be particularly important to provide additional information about "baseline" conditions for some systems in different regions, and this could include almost any information about each of these systems from earlier decades.

In this sense the NCE database is incomplete, but there is probably little value in adding additional general references. Current information about climate change impacts is more relevant to assessing potential risks, as well as the development of strategies for adaptation and mitigation at a local level.

Issue 2: To what extent do the references in the database provide information needed for assessing specific climate change impacts on physical and human systems?

For each of the systems listed in Table 1, a matrix was constructed to identify the state of knowledge (good, fair, poor) for baseline conditions of various system components and climate change projections, as described in the project methodology. In general, baseline knowledge is rated "good" to "fair", whereas climate change projections are rated "poor" to "not rated' because of data deficiencies. A number of general observations can be made from the available information sources.

1. The state of knowledge of baseline conditions and the potential impacts of climate change are regionally highly variable. This is a function of past research efforts, which tend to be focused in smaller areas (for example, Mackenzie Basin, Kluane Lake, Mayo, Churchill), but which are poorly distributed in the rest of the North. Baseline data provides good site-specific coverage in some cases, but regional coverage is generally limited. Extrapolation from highly localized studies to a larger scale is often problematic.

2. Information about climatological, physical and biological processes is poorly integrated with socio-economic aspects of the Northern environment. As a consequence, even where potential climate change impacts are reasonably well understood, the implications for human activities and well-being are not obvious. Thus, in all systems there is great uncertainty about the impacts of climate change on complex interactions.

1. Climate Data

Climate data in northern Canada is available from relatively few stations considering the large area of this region. Most climate stations are located near communities and consequently there is poor coverage in other areas. Most records are less than 50 years in duration, and there is a worrying trend of shutting down many weather stations, further reducing the ability of climatologists to monitor and predict changes in climate. Since weather data is essential for determining subsequent impacts on natural and physical resources, this trend must be reversed.

Nevertheless, the NCE database indicates that there is a reasonable state of knowledge for basic temperature and precipitation data in northern Canada. However, other climate data, such as effects of storms, extreme events and UV- radiation, is relatively poor. Recent predictions suggest that the future arctic climate will be characterized by a 5-7°C warming in winter over the mainland and much of the Arctic Islands, with modest cooling in the extreme eastern Arctic. In summer, warming of up to 5°C is predicted for the mainland NWT, but only 1-2°C over marine areas. Annual precipitation may increase by 25%, with increases in the frequency of rain in early autumn or spring. Only by monitoring these changes and the outcomes will it be possible to really assess the implications of climate change.

One gap that needs attention is the extent to which ongoing community and scientific monitoring will be prepared to detect these changes. In addition, baseline climate data for temperature is generally better than for precipitation or extreme weather events, and this trend is reflected in our state of knowledge of the various potential climate change impacts on a particular system.

2. Boreal Forest/Taiga

In general, the state of knowledge about the boreal forest is good. The distribution of trees and other plants in the boreal forest, along with historical changes at treeline, are quite well known in northern Canada. Understanding the impacts of climate change on boreal forest vegetation is less certain, particularly if physical processes such as permafrost and forest fires are considered.

Also, there are still some difficulties in predicting effects of climate change on forest growth. For example, measurements of tree-ring width and maximum late-wood density of white spruce in North America (representing growth from 1700 to 1990) show increased net tree productivity from 1760-1950. However, this increase has leveled off since 1940, perhaps due to other confounding factors such as increasing UV-B. This decreased sensitivity of responses of tree growth to temperature change is problematic because of the importance of tree-ring data in reconstructing past climate. (Briffa et al. 1998).

Changes in animal populations are known from a number of long-term experimental studies. For example, in the Yukon the 10-year snowshoe hare cycle and its effects on other boreal species are well known (Krebs et al. 2001). Similarly, an analysis of lynx population cycles across Canada based on 21 time series from 1821 onward showing that lynx population dynamics are associated with winter climatic conditions. The mechanisms behind this association are not known, but the influence of snow on hunting efficiency needs to be addressed (Stenseth et al. 1999). These relationships can be largely extrapolated across northern Canada.

In northern Quebec, trampling scars on roots and low branches of conifers were used to index caribou numbers within the Rivière George caribou herd from 1868-1992. The index shows a negative trend in population growth from about 1900 to 1950, with positive growth from 50s to 80s. There was also a small increase in numbers during the 20s to 30s that is not well documented in the historical record (Morneau and Payette 2000).

Overall the largest gaps are for invertebrate pest species and the relationships between physical (permafrost, hydrology, fire) and biological processes in the boreal forest. Potential effects of climate change will not be the same in all regions, and more work needs to be done to integrate existing datasets.

3. Coast

Baseline information and projected impacts of climate change in coastal regions are generally poor. *There is some urgency in addressing these gaps* because thermal expansion of the ocean coupled with melting glaciers and ice sheets is projected to raise mean sea levels about 20 cm in the Arctic Ocean from 2000-2049, and 50 cm by 2100. Such changes in sea level are expected to have significant effects on the Arctic's coastal settlements, and costly measures may be needed to protect them from flood damage, if indeed they can be protected.

Obviously these predictions are based on assumptions applied to global circulation models, but many of these projections appear to be quite reasonable. In this case the model is based on 1950-1990 greenhouse gas emissions compounded by a 0.5% annual increase after 1990, and the projections are compared with simulation using control greenhouse gas emissions from 1950 (Miller & Russell 2000).

There is a clear need to develop better parameterized models using data from local coastal monitoring sites, since models will continue to play a large role in predicting the fate of coastal regions.

4. Tundra

There is good baseline information for a number of tundra sites in the Arctic due to long-term research efforts sustained over many decades at a number of sites including Devon Island, Ellesmere Island, Bylot Island, among many others. Recent experiments conducted by the International Tundra Experiment (ITEX) have also provided considerable insight into the ecology and effects of climate change on tundra environments.

There is some concern that taiga/tundra ecosystems may be reduced by as much as two-thirds of their present size if climate warming shifts the southern boundary of the tundra north. Indeed, the southern Arctic Ecozone may completely disappear from the mainland. Similarly, the northern distributions of 25 mammal species are bounded by the Arctic Ocean. Of those, the collared lemming (*Dicrostonyx groenlandicus*), which is a keystone herbivore, is expected to lose 60% of its habitat (Kerr & Packer 1998).

From 1950 to 1995, trends in both total accumulation of precipitation and daily precipitation intensity at climate stations have increased significantly in the Arctic, particularly in the Arctic Islands. Heavy event precipitation has increased most during the winter months and less so during the summer (Stone et al. 2000). The implications for tundra species are still speculative, but under these conditions mainland caribou would probably lose weight because of heavier snow cover and the increase in insects harassing the herd. High Arctic Peary caribou and muskoxen may become extinct.

More information is needed about the effects of extreme conditions on the survival and condition of large and small herbivores in tundra environments. There is also a gap in our understanding of the hydrology of tundra environments.

5. Freshwater

The state of knowledge about freshwater environments in northern Canada is fair to poor, and potential impacts of climate change are also poorly understood. Among the possible consequences of a warmer atmosphere and longer thaw period is increased evaporation resulting in decreased river flows and levels. The river-ice season may be reduced by up to a month by 2050, and the season for large lakes by up to two weeks. Many alpine glaciers are retreating rapidly, with resulting changes in stream flow and sediment loading.

Species in lakes and streams are predicted to shift northward by about 150 km for every degree of increase in air temperature. If this were to occur, Arctic charr would have to compete with the expansion of southern species such as brook trout. In general, the consequences of these range expansions are unknown. There are also concerns that increased UV-B may lead to changes in species composition and productivity, since UV-B can interact with heavy metals to reduce nutrient uptake, enzyme activity, carbon fixation, and oxygen evolution in some phytoplankton species.

Overall, there are significant gaps at all levels in understanding of freshwater environments.

6. Marine

With the exception of baseline information about marine mammals, the state of knowledge about arctic marine environments is generally poor. The primary concern in the Arctic Ocean is the potential loss of sea ice. Microwave satellite remote sensing indicates a 14% reduction in multiyear ice in winter (1978-1998), a rate of 7% per decade (Johannessen et al. 1999).

Marine mammals such as polar bears, ringed seals, and bearded seals are totally dependent on the sea ice environment, and all three species are sensitive to likely impacts of climate change and are predicted to decline. In contrast, the range and numbers of beluga and bowhead whales may increase. Reduction in sea ice extent, duration, thickness and concentration, as well as displacement of the marginal ice zone, can adversely affect reproductive success, foraging success, migration patterns and survival of marine species.

There is a need to identify critical habitat for marine mammals relative to sea ice characteristics. This will require close integration of physical and biological researchers, and the close involvement of communities dependent on these resources.

7. Fisheries

Baseline knowledge of fisheries is rated as only fair. This is in large part because most of the available information relates only to distribution of species. There is little known about fish habitat, food chains in northern waters, parasites, or harvest levels. For example, of the 29 species in the by-catch of the commercial turbot fishery in the eastern Arctic, there is almost no information on the age to maturity, growth rates, food consumed, parasites, or general habitat use of these species.

In addition, most subsistence fisheries in the North are difficult to manage using traditional fisheries science models developed for large-scale commercial fisheries. Increases in community size and fishing effort using new fishing gear have made it difficult to set harvest levels based on historic consumption estimates. As well, the variable life histories and isolated locations of different fish stocks make estimating population size by direct counts very inefficient and expensive.

Overall there is very little information about northern fisheries, and the state of knowledge is poor to nonexistent in most regions. The impacts of climate change on both freshwater and marine fisheries remain largely speculative.

8. Forestry

The state of knowledge about forestry in northern Canada is fair, but there is great uncertainty about the effects of climate change. Forest fires and northward shifts in species habitats could affect human use of forests. Climate change could exacerbate current development pressures in more accessible areas, especially where there is potential for competition from agriculture.

The geopolitical and economic context is important in assessing the impact of climate change on the use of forests. There is a good sense of potential land-use shifts, and a general understanding of possible physical changes to land-use, but it is not clear how political and economic factors may play into actual land-use changes.

Much more work is needed on cumulative effects of forestry in the North. Studies in northern Alberta and Quebec indicate that corridors, industrial activity and climate change will all impact the future viability of forestry in the North. The experience in the Yukon suggests that forestry activities will not remain a sustainable part of the economy in the long term, given the slow rates of forest regrowth following harvesting. Considerably more work on this topic, especially in the context of climate change, is required.

9. Hunting and Trapping

Northern subsistence economies are intimately linked to wildlife resources. Although the state of knowledge is generally good for most species, there have been few detailed studies relating harvesting to climate change. There are a few communities where information is available (e.g. Old Crow), but these experiences are not easily applied to other situations with different environments, traditional practices, and climate impacts. Much of the information about traditional hunting and trapping in communities was originally collected to support land claims and for harvesting data in community economic studies, and consequently is not generally available.

There may be a gap in knowledge in this area, and an assessment of the implications of climate change on the long-term availability of country foods should be undertaken. For example, the loss of local waterfowl and fish populations could have serious implications because these resources are not likely be replaced by other wild food sources. In a broader context there are gaps in understanding the relationship between food quality, human health and resource management in northern communities.

10. Agriculture

For the most part, agricultural activity in northern Canada is not viable on a large scale. The short growing season and poor soils limit the types of crops that could be grown, although there has been serious investigation of this potential by government agencies over several decades in Yukon and the Mackenzie valley. In some areas wheat production may be possible with expanded irrigation, but a lack of suitable markets and high transportation costs may limit its viability.

Game ranching has been discouraged, but the potential for more extensive livestock operations in the Yukon and NWT has not received as much attention, and this is a knowledge gap.

Issue 3. Are the information sources regionally representative?

This issue was the most difficult one to assess because Northern Canada is a vast region and considerable variability in local responses to climate change is anticipated. However, many of the references in the database represent analyses conducted at a large geographical scale, often for the entire arctic region. All northern regions will be susceptible, in different ways, to the impacts of climate change and variability, affecting all natural resources and every major human activity in the Arctic. While some changes may bring economic benefits, the benefits are likely to be offset by new problems.

Given that both geography and community settings vary widely in the North, providing information on probable regional or local impacts of climate change is critical. There are references in the NCE database from all northern regions, but these tend to be clustered from sites of more intensive research activity, rather than being representative of an entire region. In some cases it is possible to extrapolate from small scales to larger scales, but in general this approach is probably not very helpful.

Table 3 indicates the number of references that apply to each region in northern Canada. However, many of the references in the database are not specific to a single region, therefore they are often cross-referenced to several regions. When these references are divided into the various categories for climate, biological and human systems, it is apparent that many knowledge gaps remain.

One significant pattern emerges from the assessment of regional gaps. In general, regions with a longer history of access from southern Canada tend to have a more complete set of baseline information that can

Table 3: Geographic Focus of Database References

Location	No. Records
Yukon*	93
Northern Yukon	72
Central Yukon	15
SW Yukon	44
SE Yukon	10
NWT	169
Nunavut	101
Hudson Bay	49
Northern Quebec/Labrador	64
Arctic Ocean	114
Northern Provinces	80

*In the Yukon, many references apply to more than one region; consequently total Yukon records are fewer than the sum of all Yukon regions.

be used to assess potential effects of climate change. In most cases these sustained research efforts have been facilitated by the presence of research infrastructure, especially field stations. This pattern was apparent in the past, and is also evident today. Most of the regional knowledge gaps are in areas that are either difficult to access, or where no research infrastructure is present. The high costs associated with northern research appear to be a significant barrier to more extensive studies in many areas.

1. Yukon

There is reasonably good information available for both baseline conditions and climate change impact assessments in most parts of the Yukon.

In the southwest Yukon this is largely a result of more than 40 years of intensive scientific investigation based out of the Arctic Institute of North America's Kluane Lake Research Station. Over 1000 scientific publications on physical and biological processes and climate impacts have been published, providing a large body of knowledge. Many of the "gaps" in this region are for more specific information about detailed responses of physical and biological systems to climate variability, and better integration with consequences of human activities such as forestry and mining.

In the central Yukon, 20 years of work on permafrost in the Mayo region have provided a sound basis for assessing the effects of climate change on forests, lakes, hydrology and infrastructure.

In the northern Yukon, the Arctic Borderlands Ecological Knowledge Co-op, in conjunction with other agencies such as the Wildlife Management Advisory Council (North Slope), has taken a leadership role in facilitating and developing ecological monitoring projects.

Only in the southeast Yukon are more basic assessments of baseline information and potential climate change impacts lacking. It is worth noting however, that there are sufficient differences between the ecology and climate of this region compared to other Yukon regions that the absence of local information is a significant gap.

2. NWT

The greatest body of information about potential climate change impacts in the NWT comes from the Mackenzie Basin Impact Study, completed in 1997. Physical and ecological processes in other parts of this region are not as well studied, although some monitoring programs have been initiated at sites such as Daring Lake.

Ongoing studies in the Inuvialuit Region also have a long and ongoing history of scientific investigation that supplements traditional knowledge. For example, recent observations from Banks Island suggest that (1) late freeze-ups (3-4 weeks) and early spring breakups of sea ice are interfering with caribou migrations; (2) there is a deepening of permafrost layers; (3) storage caches dug into permafrost are more unreliable; (4) there is an increase in the frequency of severe thunderstorms; (5) ice floes are now absent in summer; (6) muskoxen are born earlier and polar bears are emerging earlier; and (7) fishermen are catching Pacific sockeye and pink salmon in nets (Riedlinger 1999).

3. Nunavut

There have been a number of long-term studies of physical and biological processes in Nunavut, including long-term mass balance studies of icecaps and glaciers, and biophysical studies of tundra environments at Truelove Lowland (Devon Island), Alexandra Fiord (Ellesmere Island) and Bylot Island. *Specific knowledge gaps in Nunavut are related to changes in the sea ice environment, and potential effects of climate change on marine mammals*.

4. Hudson Bay

The environment of western Hudson Bay is reasonably well known as a result of detailed research efforts conducted for several decades out of the Churchill Northern Studies Centre. Changes in sea ice, permafrost, hydrology, treeline dynamics, polar bears, plant-herbivore interactions and climate variability have been studied extensively, and provide a very useful baseline for determining climate change impacts. There has been considerable work on the eastern coastline as well. Overall, there are many opportunities for further research in the Hudson Bay region, but there are no significant gaps in comparison to some other regions in northern Canada. *This region would be a good place to establish integrated multidisciplinary research programs.*

5. Northern Quebec/Labrador

The availability of baseline data in northern Quebec is very good as a result of several decades of long-term research by university scientists based out of research stations maintained by McGill University and Laval University. In addition, hydroelectric developments since the 1960s have ensured increased monitoring activity in the region. *There is less information available for Labrador, and this region is certainly a large gap.*

6. Arctic Ocean

Issues related to the Arctic Ocean are described under the Marine Systems summary above. *Overall, there are still many gaps in knowledge with respect to both the physical and biological environment of the Arctic Ocean*. Factors that influence high-latitude energy fluxes need to be addressed, including attempts to link global climate models with models of ocean dynamics. At a more regional scale, patterns of spatial variability of sea ice cover are poorly documented. Variability in sea ice will have a strong influence on both the rate and magnitude of climate change in the Arctic and globally, and this should be a priority area for research.

7. Northern Provinces

Information from the northern provinces is highly variable, reflecting in part the lack of focus on this region in the database. Since these sub-arctic areas are also experiencing the greatest increase in industrial activity (forestry, oil and gas exploration and development, agricultural expansion) the potential effects of climate change need to be urgently considered. Overall there are several initiatives focused on cumulative effects assessment in these regions (e.g. the Sustainable Forests Network at the University of Alberta), and these studies should provide useful information for assessing risks in the northern provinces.

Issue 4: Recommendations Based on the Gap Analysis

1. NCE facilitation of monitoring programs at the community level

This analysis of the NCE Infosources database indicates that the regions with the most complete baseline information and potential to assess climate change impacts are those with established and ongoing scientific and community-based monitoring and research programs in place. There is a critical need for interdisciplinary studies combining traditional, community and scientific knowledge. All partners are essential to the success of these programs.

Monitoring is required to obtain a description of the long-term processes that drive ecosystems, and to assess the ecological integrity or the health of ecosystems. Some monitoring activities can be conducted over the short term, but because many processes occur over longer periods (for example, the 10-year snowshoe hare cycle, fluctuations in caribou numbers over many decades, and climate patterns associated with 30-50 year oscillations in oceanic regimes such as the Pacific Decadal Oscillation), commitments to monitoring programs must be long-term. Monitoring programs based out of communities could provide much of the required information and sustain these efforts over time.

In northern Canada, the impacts of global change are an issue of high priority for decision makers in the public and private sector, for scientists, and for communities and the public. There is increasing awareness and concern about the possible extent and nature of changes related to climate variability and impacts on daily life. The answers to these questions are complex and require an assessment of possible impacts of global changes on environmental and socio-economic systems in a comprehensive and integrated manner. These assessments also need to be focused on a regional scale in order to derive meaningful and reliable results. This approach is known as an Integrated Regional Impact Study (IRIS).

Perhaps the best example of such a program is the Mackenzie Basin Impact Study (MBIS) that functioned from 1989-1997. The MBIS integrated studies of the physical and biological environment with human activities that depend upon these natural resources. The overall research program provided an integrated analysis of climate change impacts within the entire Mackenzie watershed. Other examples of Integrated Regional Impact Studies, at different scales, include the Wolf Creek study (Yukon) and the proposed Hudson Bay ecosystem study (Nunavut, Manitoba). All of these projects engage multiple partners including communities, government agencies, and research organizations.

There is an urgent need for more geographically specific data collection throughout the North. Integrated Regional Impact Studies provide a framework for conducting multidisciplinary, long-term research. Emphasis on building partnerships to establish a network of IRIS programs in northern Canada is essential, and would ensure that many of the identified knowledge gaps would be addressed in a systematic manner.

The NCE is not in a strong position to maintain global or national summaries of climate change impacts, and much of this work is being undertaken by other agencies such as IASC, IPCC and ACIA. However, clear knowledge gaps have emerged from the NCE database at the scale of communities. Integrated studies need to be conducted at regional scales in all of northern Canada. Areas with fairly good coverage at present include Yukon, Mackenzie Basin, Hudson Bay and Northern Quebec. Regions lacking attention in the necessary monitoring and research include the eastern Arctic, Labrador, central NWT, and the Arctic Islands. Priorities for monitoring include atmospheric, oceanographic, and biological systems. Greater utilization of Traditional Ecological Knowledge and the active involvement of northerners in climate impact research is essential. The NCE could play an important role in facilitating the establishment and development of *Integrated Regional Impact Studies.*

2. Options for maintaining a current database

One problem with this gap analysis project is that new information is becoming available on a daily basis. While older references are relevant to establishing baseline information, only more recent items deal explicitly with climate change and the implications of climate change. Consequently, the pool of references with a specific analysis of climate change impacts is relatively small at this time.

It is possible that the NCE database will become outdated as other assessments (e.g. ACIA) become available. The ACIA program in particular is well funded and a part of larger international programs. However, the NCE database should remain a very important place for communities to find and share information, particularly information that is relevant at the local and regional levels, scales that are often overlooked by larger-scale assessments such as ACIA.

Rather than attempting to maintain a "global" database, it would likely be most efficient to identify information at the level of individual communities or local regions. This has been attempted with the current references; however, many of them cannot be identified at a more precise geographic scale. Where possible it would be useful to identify references to the scale of a community. *A community-focused database will provide useful information that is unlikely to be widely available otherwise*.

The assessment of potential impacts of climate change would benefit from close integration with specific community concerns. For example, research on water resources could be integrated with applications to fisheries, development of hydroelectric power, commercial navigation, and water supply and waste management. As noted earlier, the NCE could play a valuable role in matching researchers to communities, and communities to researchers. In addition, it is essential that community-specific databases be established so that knowledge of climate change impacts can be readily adopted in decision-making processes related to adaptation and mitigation.

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