Updated State of Knowledge Report of the West Kitikmeot and Slave Geological Province

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1. INTRODUCTION TO STATE OF KNOWLEDGE FOR WEST KITIKMEOT AND SLAVE GEOLOGICAL PROVINCE

1.1. Purpose

This is the second *State of Knowledge Report* prepared for the West Kitikmeot/Slave Study Society (WKSSS). The first *State of Knowledge Report* (Sly *et al.*, 1999) brought together and interpreted written knowledge on the study area up to the beginning of April 1, 1996. This revised report extends the knowledge base to that existing at the end of December, 2000. The term "WKSS area" is used throughout this report to refer to the West Kitikmeot and Slave geological province and the surrounding area that includes the Bear geological province and part of the Mackenzie Valley. The focus, however, is strongly directed to the West Kitikmeot and Slave geological province. With the WKSSS completing its research program on March 31st, 2001, this report will be the last update on the state of knowledge about the region. It is hoped that some other mechanism for updating the state of knowledge will continue this valuable process.

A considerable amount of new information has become available since completion of the first report, and the text, figures and tables have been revised and added to, accordingly. Nearly 300 new references have been added, and both citations and references are now provided in standard scientific format. In this revision, additions and changes have been made throughout the report. In particular, new information has given greater depth to our discussions of climate change and its potential effects, contaminants and traditional foods, exploration and development. Recent studies on flora and fauna and traditional knowledge have also added to many aspects of the report. Socio-economic data have been updated and the products of community monitoring work have provided a broader appreciation of the changing situation of Aboriginal people in the study region.

Although this revised report contains few major new insights, improved understandings have given greater depth to many of the previous discussions. The report has been considerably enriched by the products of many studies sponsored by the WKSSS (since April,1996). To the extent that new information from them has become available, it has also advanced consideration of some of the information needs previously defined by the WKSSS board. Information about climate change and how it may affect the study area, contaminants and diet, exploration and development, and social and societal change have also helped to strengthen the focus of discussion of sustainable development, as it relates to the WKSS area.

The objective of this report remains the same as the first report. It is intended to help readers to develop a "big picture" of the area and its people, and to provide an understanding of what and how change is taking place. Readers are encouraged to consult the references provided for more specific information. The report also highlights areas where understandings are incomplete and more research is needed. The authors are greatly indebted to staff and assistants of the WKSSS for help in collecting and providing copies of journal and report materials identified for the preparation of this revision. Without this support it would not have been possible to update the *State of Knowledge Report* within the time available.

1.2. Description of Study Area

The WKSS area extends across the northern boreal forest and deep into the tundra, from Great Slave Lake north to the coast of the Arctic Ocean. It covers a vast area of land and water in and around the West Kitikmeot sub-region of Nunavut, and the Slave geological province that extends into both Nunavut and the Northwest Territories (NWT) of Canada (Fig. 1). The WKSS area has been occupied and used by Aboriginal peoples for thousands of years but until little more than 200 years ago, the presence of Europeans was negligible. The earliest forms of European influence were related to the fur trade and the establishment of trading posts. In more recent times religious institutions, governments and the mineral industry have shaped development in the area. In particular, this has been through the establishment of churches and schools, fixed communities, roads, operating mines, hydroelectric dams and other forms of infrastructure. There are 12 communities in the WKSS area, with populations that range from less than 100 people to more than 17, 000 (Yellowknife).

1.2.1. Human Environment

Inuit, Dene and Métis of the area continue to travel widely over the land, and traditional place names reflect Aboriginal use and habitation of this area over a very long period of time. There is no part of the land that has been outside the experience of Aboriginal peoples and, as they have said, *"our footprints are everywhere."* Hunting, trapping, fishing and other on-the-land activities are widely practiced by most Aboriginal residents. Snowmobiles, aircraft, vehicles and boats are now used more often than the more traditional dog teams, canoes and foot travel. Non-aboriginal residents, most of whom live in Yellowknife, also participate in many of the same activities. Aboriginal people using the area include the Dogrib people of Rae-Edzo, Wha Ti, Rae Lakes (Gameti) and Wekwetì (Snare Lake), the Yellowknives of Dettah and Yellowknife (including Ndilo), the Chipewyan of Lutselk'e, and the Inuit of Kugluktuk, Umingmaktuk, Bathurst Inlet and Cambridge Bay.

All of the WKSS area is subject to Aboriginal land claims, some of which remain unresolved or under negotiation. The largest of these claims has been completed, and under the Nunavut Final

Agreement the territory of Nunavut was officially established on April 1, 1999. This has divided the study area roughly in two. The Nunavut boundary largely follows the tree line with some areas of overlap defined with other claimant groups. The Dogrib Treaty 11 Council has reached an agreement-in-principle for a claim over much of the southwest portion of the area, and claims by the Chipewyan and Yellowknives covering the southeast of the study area are at an earlier stage of negotiation.

1.2.2. Physical Environment

The WKSS area includes large parts of two of Canada's major ecozones: the Taiga Shield and the Southern Arctic, with the tree line running northwest to southeast between them. Permafrost underlies most of the area. Although tree cover is extensive in the southern part of the region, there has been little commercial forestry other than some small firewood operations and local sawmills. The density of roads is relatively light. More than half of these are ice roads over frozen lakes and land that are usable for less than a third of the year .

Barren-ground Caribou are present throughout the WKSS area and most belong to the Bathurst Caribou herd that roams freely, calving, migrating and wintering throughout the area and beyond. In addition, there are Grizzly Bears, Muskoxen, Gray Wolves, Moose and a variety of furbearers. Huge populations of migratory waterfowl, shorebirds and songbirds spend the summer months throughout the Canadian North. Many of them are found in the WKSS area, part or all of that time. Many of the lakes and rivers also support significant fisheries. The largely pristine environment and abundance of wildlife have attracted tourists and sportsmen. These visitors support an important tourism and outfitting industry, and the "Northern Lights" have become a special attraction.

There are no large protected areas within the WKSS area, although the Thelon Game Sanctuary and Queen Maud Gulf Migratory Bird Sanctuary adjoin its eastern edge. The area has a few small Territorial Parks and several campgrounds. Various organizations have defined special areas within the WKSS area as being worthy of consideration for protection. Most are to be considered in the process of land claim agreements. The NWT Protected Areas Strategy involves most stakeholders in the NWT. It is intended to provide a means for coordinating and evaluating proposals for protected areas.

1.3. Potential Development

By comparison with central and southern Canada, the WKSS area is largely undeveloped. However potential for development is high, particularly for minerals. Gold mining has been a major factor, particularly in southern parts of the WKSS area where there have been a number of producing gold mines. Numerous mineral deposits occur throughout the WKSS area, chiefly gold, diamonds and base metals. There are a few existing small hydroelectric developments and other potential sites have been identified. With the discovery of diamonds in the WKSS area at Lac de Gras in the early 1990's, one of the World's largest staking bonanzas began. Within a few years, virtually the entire area was subject to mineral claims. Mineral exploration activity has been high, and a number of sites are in production or the advanced stages of development. The Ekati Diamond mine, owned by BHP Diamonds and Dia Met Minerals, began production in 1998. A second mine, the Diavik project, is under construction and it is expected to begin production in 2003. De Beers is seeking permits and licenses for the construction and operation of an open-pit and underground mine at their Snap Lake project, and has initiated the environmental assessment process. Tahera Corporation's Jericho diamond site is also in the permitting and licensing phase. Active exploration is still occurring over much of the area. Claims in good standing covered an area of just under 3.65 million hectares, as of March 31st, 2001. This is an increase of more than 50% since April 1st, 1996.

During early stages of the diamond staking rush, concerns were voiced by many organizations and individuals, especially Aboriginal and environmental groups. The concerns were about the pace of exploration and possible effects of a series of projects occurring over a relatively short time period in this large and relatively pristine area. As the extent of exploration and possible development have become clearer, all parties, including industry and governments, have recognized the need for an improved information base. This is needed to help minimize environmental problems and to maximize community benefits, and to forecast likely future changes. This need is particularly evident for information about the effects of multiple developments on the environment and the people in the area. Many people have felt that the *cumulative effects* of development have not been addressed in a comprehensive way.

1.4. Role of the West Kitikmeot/Slave Study

The West Kitikmeot/Slave Study was jointly announced by the Federal Minister of Indian Affairs and Northern Development, and the Minister of (then) Renewable Resources, GNWT on December 9th, 1994. The study was to examine the potential effects of development in the area of the West Kitikmeot and Slave geological province. It was to last five years, with funding provided by the federal and territorial governments. Government funding would match the combined contributions of industry, Aboriginal and environmental partners (to a maximum of $750,000 each). The five year study ended its research program on March 31st, 2001.

At the same time that the West Kitikmeot/Slave Study was announced, the Minister of Indian Affairs and Northern Development formally appointed an environmental assessment panel for BHP's *NWT Diamonds Project*. The panel heard many concerns from a broad range of individuals and organizations, including all the communities potentially affected by the project. Some of these concerns related to the possible effects of the BHP project in combination with a number of other mineral-related developments proceeding in the area. In its final report, the panel made numerous recommendations regarding the project, and several related to the study of cumulative effects of the project in combination with other developments. The panel also directed an eight-part recommendation to the WKSSS about studies related to the cumulative effects of development in the study area.

1.4.1. Partnership Approach

A partnership approach to research was strongly supported by all the founding partners of the WKSSS.

Dogrib Treaty 11 Council
Inuit Organizations
Lutselk'e Dene Council*
Métis Nation of the NWT
Nunavut Co-Management Organizations
Environmental Organizations
Government of Canada
Government of the Northwest Territories
The NWT Chamber of Mines (representing industry)
Government of Nunavut (this body became a WKSSS partner in 2000).

* (The GNWT official spelling for the name of this community is "Lutselk'e. However, the Community and DIAND publications use the spelling "Lutsel K'e". Both spellings are used in this report).

1.4.2. Vision and Objectives of the West Kitikmeot/Slave Study Society

Wishing to ensure their independence, the partners incorporated themselves as a registered society (WKSSS) dedicated to achieving a common vision:

> *".. to achieve sustainable development in the WKSS area which represents aboriginal cultural values, so that the land is protected, culture is preserved, and community self-sufficiency/reliance is enhanced."*

Using this vision as a basis, the partners set the WKSSS goal:

> *".. to collect and provide information for the West Kitikmeot/Slave area to assist informed decision making by the Partners, and to facilitate sustainable development."*

and objectives:

> - *"provide a basis for the identification and assessment of cumulative effects for planning and development purposes.*
>
> - *provide a forum in which to share information on issues, while respecting the diversity of interests: aboriginal, industry, environmental organizations, governments, and the public.*
>
> - *provide the information necessary to enhance the understanding of potential impacts of exploration and development on ecological processes and communities.*
>
> - *support a central role for both traditional knowledge and scientific knowledge, and facilitate the linkage of research carried out in these systems.*
>
> - *ensure the accessibility of study research results and information to all Partners and the public, while respecting the confidentiality of certain information.*
> - *"provide an information base necessary for study partners to make sound resource management decisions.*
>
> - *maximize community research training opportunities and the use of community resources in all study research."*

1.4.3. Research Agenda

The partners set an agenda for the West Kitikmeot/Slave Study and defined a set of research questions they wished to be able to answer by the end of the study (see Section 7). This has been a major task. Because of its continually changing nature, the board of the society built in flexibility for the questions to evolve over time as new information came to light and priorities changed.

In the process of developing the research questions, the board felt that it would be helpful to knit together all the information collected on the study area. This revised *State of Knowledge Report* brings the knowledge base up to date, and like the first report it is intended as an aid to the partners and to any organizations or individuals interested in a holistic picture of the study area.

1.5. State of Knowledge Report: West Kitikmeot and Slave Geological Province

In planning this *State of Knowledge Report* the partners set a number of objectives:

> ***Holistic*** - The report should provide a complete overview of the natural and socio-economic environment of the area of the West Kitikmeot/Slave Study, and the stresses that are affecting it. Many people have knowledge about the land and the people of some part of the study area, or knowledge about some specific conditions. But it has not been easy to get a "big picture"
>
> ***Comprehensive*** - Review as much of the material written about the study area as possible. This material covers the natural and socio-economic environment from both scientific and traditional knowledge bases.
>
> ***Accessible*** - As far as practical, the jargon associated with science and research would be translated into words understandable by the average reader.
>
> ***Integrate knowledge*** - Traditional and scientific knowledge would be presented together in the report, to provide a greater understanding of each of the areas discussed.
>
> ***Research questions*** - The report should assess the WKSSS research questions in relation to any data gaps identified. It would make recommendations to the board regarding changes and additions to the current set of questions based on the synthesis of existing information.

Opportunities for learning more - The report should be accompanied by a comprehensive bibliography. This would list as many as possible of the sources of the written knowledge about the region.

The partners believe that information and knowledge about the region are a very important part of achieving sustainable development. The better everyone understands the environment and the complexity of pressures acting on it, the better the decisions they will make. This *State of Knowledge Report* is intended to support the role of the WKSSS in communicating knowledge and adding to understanding of the region.

As with the first report, the outline and content has been reviewed by the study's partners to ensure that it covered all major areas of concern. Also, that would be useful to people living in the area as well as to the broader public. The report is based on a review of many hundreds of documents, of which about 800 have been used as citations. The intention has been to update the first report and to draw from published and documentary materials as late as possible, within the period of the West Kitikmeot/Slave Study. The first draft of this report was completed at the end of March, 2001.

Unfortunately, there are still topics covered by this final report for which little or no information is available from the WKSS area. Where information was available about other areas or situations that could help to fill in these gaps, it has been used. Only information that is appropriate to the WKSS area has been included. The report makes clear where information has been drawn from sources outside the WKSS area. Because of environmental and cultural differences, very little traditional knowledge from outside the WKSS area has been used.

1.6. Traditional Knowledge

A wealth of information on the WKSS area is held within traditional knowledge of the Aboriginal people who inhabit it. This knowledge has been formed through the need to adapt to the social and physical environments in which people live. The Partners felt it was important for the entire study that they set out their support and expectations, as they relate to traditional knowledge of Aboriginal people of the study area. This is a relatively new field of research that has only recently been applied in the WKSS area.

The Partners agreed that scientific and traditional knowledge have equal value and should be linked where possible to provide a broader understanding of any research question. This vision has influenced the research conducted in the study area. Over the past five years, several diverse projects have been conducted within the WKSS area. These include comparison of Dogrib Elder's knowledge of caribou migration with scientifically gathered satellite radio collar data (Gon *et al*, 1997); the integration of scientific and traditional ecological knowledge on the health of wildlife in the Kugluktuk (Coppermine) area (Elkin *et al.*, 1999a); and the health of people in the community of Lutselk'e (Lutsel K'e Dene First Nation, 1998).

The Traditional Knowledge Steering Committee (TKSC) was appointed by the WKSSS Board in 1996. It comprised representatives of each of the Aboriginal Partners and has continued to monitor and encourage the use of Traditional Knowledge in all research conducted in the WKSS area.

1.6.1. Definition and Ownership of Traditional Knowledge

There are many definitions of traditional knowledge and other similar terms (Johnson, 1992; Legat, 1991; Stevenson, 1996). One of the first tasks undertaken by the TKSC was to develop a definition of traditional knowledge for use in the study and to set out guidelines for this research. The TKSC definition of traditional knowledge used in this report is as follows:

> *"Traditional knowledge is knowledge that elders hold from experience and is passed down to them through the generations. It is continuous and grows. Interpretation of knowledge is important. Traditional knowledge is not just the past, but the future combined with the past"* (WKSSS. 1996)**.**

The Committee also stressed the importance of community control over traditional knowledge research and the data collected. This is reflected throughout the guidelines developed for the West Kitikmeot/Slave Study traditional knowledge researchers.

1.6.2. Sources and Limitations of Traditional Knowledge Used in This Report

One of the objectives of the West Kitikmeot/Slave Study has been to collect traditional knowledge related to the research priorities set by the Partners, and to link it with western scientific knowledge. The review for the first *State of Knowledge Report* covered traditional knowledge documentation up to 1996 (Jenness, 1922; 1924; 1946; Helm, 1961; 1994), as well as older work that included ethnological research and land use studies in the WKSS area (Freeman, 1976; NPC, 1997; Riewe, 1992; Spacial Data Systems, undated).

An additional 21 published documents have been used in the preparation of this revised *State of Knowledge Report,* (Andrews, 1998a; 1998b; Berkes, 1997; Bussey, 1998; 2000; Cluff, 1997; Cournoyea, 1997; Elkin *et al.*, 1999a; Fitzpatrick, 1999; Gon *et al.*, 1997; Gunn *et al.*, 1997; Legat, 1998a; 1998b; Lutsel K'e Dene First Nation, 1998; Parlee, 1997; Stevenson, 1997; 2000; Thorpe, 1997, 1998a; 1998b; Thomson, 1999; 2000). These documents report on traditional knowledge research in the WKSS area, and were produced after 1996. Of this total body of work, comprising more than 30 published sources, only those reporting on research projects conducted during the past 20 years or less were found to be relevant to the revised *State of Knowledge Report*.

Traditional knowledge research continues to evolve and change, and only recently have projects focused on documenting specific aspects of traditional knowledge. Prior to this, researchers tended to gather general information and their projects lacked clear goals and objectives. Current studies are almost exclusively community-based and are conducted by Aboriginal cultural organizations or Band Councils. Some are collaborative and involve research partnerships between communities and outside organizations such as governments or universities. Many of these projects are conducted with the assistance of a trained researcher using the *Participatory Action Research Method* which is designed to ensure that the community maintains control of all aspects of the project (Johnson, 1993; Legat, 1997; Ryan, 1993; 1995). Issues of intellectual property and ethical standards for collecting information are a significant part of any research design.

Traditional knowledge projects have been conducted in a number of Dene and Inuit communities outside the WKSS area, but cultural and linguistic differences among communities make information from these studies of uncertain value to the West Kitikmeot/Slave Study. For the purpose of this report, the focus is on projects conducted in communities within the WKSS area. This focus has helped to better assess data gaps within the region.

A number of organizations have conducted traditional knowledge research that relates to the WKSS area. However, the use of some of this material is restricted due to concerns for intellectual property rights. Permission was requested to use these resources but if approval was not granted, the material has not been included.

Invaluable knowledge is contained within many audio and video recordings housed in various archives in the NWT, Nunavut, and other provinces. Some recordings are also held by community groups. Many of these have not been transcribed, or the results reported cover only a portion of the topics discussed on the tapes. Some collections are also restricted. No attempt has been made to access such original material but where documents based on research were available the results have been included in this report. Fortunately, a number of recent projects are transcribing, translating and integrating archived information. It is hoped that all the information will someday be available.

The Internet is quickly becoming a convenient means by which both traditional and scientific knowledge can be shared. Preparation of the *State of Knowledge Report* has included review of source information on the *"world wide web* (*www*)*"*. This has been an important source of information for reports, project summaries, and the invaluable data contained in both government and non government databases pertaining to the WKSS area. Researchers wishing to directly access some of this information should visit the West Kitikmeot/Slave Study site at:

http://www.wkss.nt.ca
and the Prince of Wales Northern Heritage Centre web site at:

http://www.pwnhc.learnnet.nt.ca.

In the course of the West Kitikmeot/Slave Study, researchers have been able to make some important additions to documented traditional knowledge of the WKSS area. Their work will also contribute to the identification of data gaps in traditional knowledge. The contribution of the West Kitikmeot/Slave Study to the written body of traditional knowledge is important. Although it is small, relative to the huge amount of information still held only through the oral tradition. An enormous amount of work and time will be required before any significant amount of the traditional knowledge of the study area is written down.

1.7. Learning More

It is never possible to have complete information, and interpretation of what is available will vary depending on one's perspective. This report is intended to provide a comprehensive and, as far as it is possible, an unbiased view of the study area for readers. However, the amount of written material reviewed comes to many thousands of pages. Condensing it into such a brief description can only be done by keeping the information compact, simplifying, making choices and leaving many things out. Many tables provide simplified data in the form of mean, range or example values, and the concentrations of some contaminants are expressed in ng/g rather than the more usual μg/g, to keep the tables as compact as possible. For readers wishing to know more about any of the information presented, source materials are cited and referenced. The details lie in these other documents. This report sets the scene and, hopefully, it can strike the spark to fire each reader's personal interest to discover more about this rich land and its people.

1.8. Report Structure

Following this introduction, Section 2 provides a description of the environment and ecosystems of the study area. These include freshwater and marine environments, the terrestrial environment and human elements of the study area. Section 3 gives a descriptive summary of factors that act to stress the environment and people of the study area. These factors may be external or internal to the WKSS area. Section 4 describes in more detail the effects that result from various forms of stress. Many effects occur as a result of multiple rather than singular forms of stress. Section 5 discusses our evolving understanding of the concept of sustainable development. It points to the role that this concept can play in guiding future decision-making which will affect the region. Section 6 outlines additional information that may be required in support of present and near future decision making. It builds on the summary of research needs summarized in Section 7 and prepared in 1996 by the WKSSS. Cross-references are provided within the text and other parts of the report. Sections 8, 9 and 10 provide a glossary terms and abbreviations, an explanation of symbols and notations, and a list of the common and scientific names used in the text. Sources of both scientific and traditional knowledge are listed at the end of the report. Source references are provided separately in support of the text and figures and tables.

2. ECOSYSTEMS AND THE ENVIRONMENT OF WEST KITIKMEOT AND SLAVE GEOLOGICAL PROVINCE

2.1. Introduction

2.1.1. Science and Traditional Knowledge

Much of science and traditional knowledge can be thought of as “two sides of the same coin”. The term "knowledge" (both scientific and traditional) embraces not only information but an understanding of it and an ability to use it. Science seeks to develop understandings of cause and effect. It is often thought of as an exploration of information that occurs in ever more detail, and follows a path that splits into smaller and smaller components (analysis). However, understanding is also gained as different pieces of information are brought together to construct a greater whole (synthesis). The difference between science and traditional knowledge lies not in these two approaches. Both can explore information from the “top-down” or “bottom up”. Rather, it lies in the types of information that are used. Both scientific and traditional knowledge contribute to an understanding of the environment in the WKSS area.

Science tries to gather specific and measurable information (data), and to limit external influences so that experiments can be repeated and ideas demonstrated by replication of results. These forms of objective information provide the basis for most of science. Science usually tries to demonstrate that ideas are false. General acceptance is gained only when ideas can no longer be proven wrong (Gunn *et al*., 1988; Sly, 1995; Zamparo, 1996). Scientific knowledge is almost always published in scientific journals where it can be reviewed, critiqued and tested by other scientists, around the world. In traditional knowledge, on the other hand, more of the information is qualitative (not in numeric form). Although it is also derived from experience, observations, and experiments by trial and error (Gunn *et al*., 1988; Sly, 1995; Zamparo, 1996). Traditional knowledge grows and evolves as information is handed down by people, from generation to generation. Each generation may contribute to its enrichment, and contributions are usually characterized by general acceptance in a community. Scientific knowledge also grows and evolves over time as experiments are carried out and data are collected, and new hypotheses are developed and tested. Both traditional knowledge and scientific knowledge must be shown to be valid over time before they are accepted.

In science, it is usual that only part of the "puzzle" is known to an observer and it is not until information is shared between different minds that a larger and a clearer picture can emerge. The scientific record is often brief or non-existent at many places in the north, and little or no scientific research may be available to show how various parts of the ecosystem link together. Many aspects of traditional knowledge have potential to reflect past conditions (before scientific record), to fill some of the vast gaps (spatial) in the present scientific record, and to contribute collectively to knowledge of the WKSS area environment. For example, very little has been published about the coastal ecosystems of the Coronation Gulf and almost nothing is known about freshwater contributions to this marine environment.

Traditional knowledge has untold value to a people's heritage. It has value both as an understanding of self sustained living (in the study area), and in a variety of other ways that it may contribute to understanding of the environment. Likewise, science can contribute to sustainable development and to further understanding of the environment and its use. There are also points of overlap in the information available from both science and traditional knowledge. Most traditional knowledge still remains in oral form. The transfer between generations is therefore dependent on Aboriginal language and its continuity within a community. There are many factors that threaten this continuity. In some communities there is a communication barrier between elders and youth, as few young people speak their traditional language. In other communities there is no longer a dependency on the resources of the land, and the young people no longer need to learn land-based traditional knowledge.

2.1.2. Concepts of Scale

Concepts of scale in space and time are important for perspective. The WKSS area is large and about half of it lies north of the tree line. It extends south from the Coronation Gulf to Great Slave Lake, a distance of about 800 km. It extends eastward from near the eastern shore of Great Bear Lake to the Queen Maud Gulf on the Kent Peninsula, a distance of about 600 km (Fig. 1). This roughly rectangular area covers more than 300,000 km^2 of the western mainland of the NWT and Nunavut. For comparison, this area is nearly two-thirds of the size of the province of Alberta.

From a geological perspective, the area is both remarkable and unique for what is preserved in the rocks of this part of the Earth's surface. Also, for what may be interpreted as a record of the Earth's history over an immensely long period of time, of more than 4 Ga (Skinner & Porter, 1992).

2.1.3. Life and the Environment

In many other ways, however, the area is not greatly different from the regions that surround it. The major seasonal migrations of animals and people into and out of the area indicate that the web of life is closely knit throughout the WKSS area. Thus, while our attention remains focussed on the

WKSS area, care has been taken to set this within appropriate regional and, or, global contexts.

The land, freshwater (lakes and rivers), marine coast (Coronation Gulf), snow and ice cover, and even the air may each be considered as separate environments within the WKSS area. They are also parts of a larger whole to which they are intimately connected (such as the continental land mass or Arctic Ocean). Because plants grow in one place, they may be thought of as being associated with only one environment. But processes that enable them to spread to new areas, such as dispersals of seeds or living material by wind, water or the movements of animals, often extend parts of their life cycle through different environments. As with most living things, it is usual that one form of environment is dominant in their existence. It is usual to associate various animal and plant communities with a dominant environment. Biological environments can also exist at very small scales. For example, some small organisms may live almost an entire life time on a single plant or animal host. As a matter of convenience, most environments may be described by their chemical and physical characteristics. For each species, however, there is a set of temporal, physical, chemical and biological characteristics that collectively define its position or niche within the environment. No two species occupy the same niche when both are present in the same environment, although one may be replaced in its absence, by another.

Habitat describes something more specific than environment, both in time and space. It usually describes a place where the characteristics of the environment support special needs associated with particular animal activity. Survival of a species may depend on the existence of precisely the right conditions at a specific time and, often, in a specific place. Denning habitat for wolves, calving habitat for caribou, and spawning habitat for fish may each be considered critical habitat. Other forms of habitat may be considered less critical. For example, there may be plenty of space or time is less restricted for a required activity, such as a moulting or staging area for geese, or grazing area for Muskoxen.

Ecosystems characterize functional relations among and between organisms (both plants and animals) and the environment. For convenience, marine aquatic, freshwater aquatic, and terrestrial ecosystems can be used to distinguish between major differences in such relations. Although many species of animals do not fit neatly into such groupings. Birds, for example, are mostly described as members of aquatic or terrestrial ecosystems. Humans are considered a terrestrial species although, very definitely, we are part of most ecosystems and our presence is global. Between ecosystems, there are widely differing degrees of connectedness both in space and time. After snow forms in the atmosphere and falls onto the land and melts, it runs off into rivers and lakes; after black-flies and mosquitoes emerge from their aquatic larval stages they become the torment of many animals in terrestrial ecosystems; yet the life cycles of many fish species remain entirely within freshwater ecosystems. Nevertheless, over time, all are interconnected globally as an integrated whole.

Ecosystems are dynamic and, in many of them, cyclical change is a common feature. Some of the changes occur at more or less regular intervals, such as the cycles of Lynx and Snowshoe Hare that repeat at intervals of about 8 to 11 years. Other, less regular and less frequent population fluctuations also occur in many other terrestrial animals. Fire and periods of glacial advance and retreat provide examples of even more dramatic changes in the environment that occur over much longer time intervals. Over thousands of years, ecosystems naturally evolve, perhaps in response to slow and continual genetic change or to events such as species introductions and environmental catastrophes. The response of ecosystems to various forms of change is often unpredictable.

Ecosystems vary greatly in complexity. Most ecosystems depend on the growth of plants. Primary production is the process that converts carbon dioxide and water into organic matter in the presence of sunlight and plant growth is sustained by the availability of nutrients (Cunningham & Saigo, 1992). Because northern ecosystems are greatly influenced by low levels of annual received solar radiation and low nutrient availability, they are often characterized by relatively small numbers (low diversity) of highly specialized plants and animals. The carrying capacity of northern environments is therefore much less than those in more southerly parts of Canada. Migration is practiced by caribou and many other species, especially birds. It enables relatively large groups of animals to maintain an adequate diet throughout the year, even though food supplies may not be continuously available in the same place. Humans used to migrate as well but now much of their dietary requirement is met by the import of food supplies to resident populations. This is expensive (both in terms of the energy required to move food and the monetary cost of doing this). Because of economic and cultural considerations and preferences, a substantial part of human food requirements is still met from the local harvest of country food.

Ecosystems can be characterized by the environment with which they are associated and by the biological communities that comprise them. The food web describes patterns of energy flow that occur within ecosystems and which involve all stages in the life and death of plant and animal communities. Within the food web there are many food chains, each of which links the flow of energy between important members of a community. As some animals eat other animals and some animals eat plants, the energy from organic matter in many small organisms becomes progressively concentrated in fewer but larger organisms. Most of the energy is stored in plant and animal material (biomass). Some is also used by organisms as they consume food and convert organic matter from lower to higher levels (trophic levels) in the pyramid-like structure of the food web.

Microbial populations exist in vast numbers but little is known about their contributions to northern food chains (in the WKSS area or globally). In simple aquatic ecosystems, phytoplankton are the primary producers (floating microscopic plants) and they occur at the base of most food chains. At the next level, zooplankton (including small crustacea) are the grazers that consume phytoplankton. At a higher level, fish exist as predators (small fish eating the zooplankton and big fish eating small fish). Detritivores (such as worms and larvae) consume decaying organic matter and are themselves consumed by larger forms. These relationships ensure a highly efficient use of all available food material. In simple terrestrial ecosystems, green plants are again the primary producers. These are grazed by herbivores that in turn support various predators. Bacteria and fungi are major contributors to processes of decay in both aquatic and terrestrial ecosystems. Several species of insects, birds and mammals consume decaying organic matter (including carrion). They effectively use all available food material and return nutrients to the land and, or, water. In this way, much of the energy and nutrients that are stored in organic matter are converted by detritus feeders into forms suitable for use by plants. Humans are the top predator in many food chains.

The food chains in many northern ecosystems are short. For example, the dependence of Lynx on Snowshoe Hare or wolves on caribou. With short food chains and many species that are highly specialized, the extent to which northern ecosystems seem to have a built-in redundancy appears to be very limited. Thus, could the Lynx survive without the Snowshoe Hare and what would happen to the vegetation without the Snowshoe Hare? Conversely, also, what would happen without the Lynx?

Both in terms of the environment and its related ecosystems, much of what we experience at the present has been influenced by what has happened in the past (*e. g.* the effects of glaciation). Much of what happens now will affect the future (*e. g.* developments associated with human activities). The resilience (ability to remain whole) of ecosystems under the influence of human activities are difficult to assess. A good understanding of both systems and their components are required for management to ensure continuity and integrity of the environment.

2.2. Physical and Climatic Aspects of the WKSS Area

2.2.1. Climate

Weather describes the day-to-day experience of atmospheric conditions (wet-dry, warm-cold, cloudy-sunny, windy-still) that may vary over distances of only a few tens of kilometres. Climate describes weather and its seasonal variations over larger areas and for time frames extending over several years. Climate is driven mostly by solar heating (Lockwood, 1979; Smith, 1981) and the

Arctic air mass is the dominant feature of Arctic and sub-Arctic regions of North America. There is an additional but lesser influence from the Pacific air mass in the western Arctic and sub-Arctic (Rouse *et al.,* 1997). In the WKSS area, climate is dominated by the persistence of large scale atmospheric structures, particularly the Arctic High Pressure Cell. This is centred north of Alaska and its clockwise circulation generates a northerly air flow across the region (Mysak, 1993). During winter, the formation of ice cover stops much of the moisture exchange between the ocean and atmosphere. Cold temperatures also reduce atmospheric humidity by lowering the condensation point. During the summer, the air warms and can contain much more moisture. More moisture also evaporates from the open waters of the Arctic Ocean and Beaufort Sea and is carried south. This results in a summer precipitation peak throughout the WKSS area. As the air is forced to rise with the increasing height of land south of Coronation Gulf, it cools and condensation occurs. This causes a modest increase in precipitation.

Unfortunately, climate records from locations within the WKSS area are relatively short. Often they are of differing length, some lack continuity, and some are not directly comparable. Most of the information presented in Table 1 is based on data provided by EC (climate normals). Because of inherent limitations in available data, both measured and estimated values from several sources have been included to provide an overall representation of climate across the WKSS area (AES., 2000; Acres Consult., 1982; Aston, 1977; BHP & Dia Met, 1995; Kalin, 1987; Milburn *et al*., 1994; Zoltai *et al*., 1980). By using all available data, it is possible to make general comparisons. There is a distinct temperature gradient across the WKSS area (Table 1) which generally moderates towards the southwest (CCELC., 1989). Three climatic zones are represented. Kugluktuk lies near the southern edge of Low Arctic climatic conditions (Fig. 2). To the south of it, sub-Arctic climate extends to an imaginary line extending between Rae and Reliance. Boreal climate extends further south from this narrow band along the north shore of Great Slave Lake.

The average winter temperature (November - March) increases from -31^{o} C at Cambridge Bay to -22^{o} C at Yellowknife. The average summer temperature (June - August) increases from 6^{o} C at Cambridge Bay to 14^{o} C at Yellowknife. Due, possibly to some influence from Pacific air masses, the January temperature at Kugluktuk is slightly warmer than most other areas north of Yellowknife. July temperatures are warmest at Yellowknife. July temperatures at Bathurst Inlet are warmer than surrounding areas and these support more varied plant and animal communities (Hancock, 1979; PC., 1978; Zoltai *et al*., 1980). Annual total precipitation is low throughout the region, increasing from about 141 mm at Cambridge Bay to about 267 mm at Yellowknife. Typically, 50 to 60% of the total annual precipitation is in the form of rain (mostly between June and October). About one quarter of the WKSS area lies above the Arctic Circle and from Bathurst

Inlet, north, the region experiences 24 hr sunlight in June but 0 hr in December. Yellowknife receives 20 hr of sunlight on the longest day in June but only 6.5 hr on the shortest day in December.

Because Great Bear and Great Slave lakes are very large, they can influence local weather conditions and, to some extent, the climate of surrounding areas. Lake effects are most noticeable as delayed warming in the spring. Then, air passing over the still-frozen lake surface may be significantly colder than over inland areas. Because of vegetation and irregular ground, most inland surfaces have a lower reflectance and warm more quickly. In the fall, the reverse happens. Air passing over open water may keep areas near the shoreline warmer than areas away from the lakes. Lake effects may also include occasional local summer thunderstorm activity and a slight increase in precipitation, due to greater moisture content in the atmosphere over the lakes.

There is considerable year-to-year variability in precipitation at many sites. For example, limited records of precipitation at Kugluktuk indicate that annual precipitation has ranged from a minimum of about 105 mm to a maximum of about 390 mm (records between 1935 and 1980). Further, it is also recognized that significant errors may exist in measurements of cold season precipitation (Spence, 1995). All locations are characterized by substantial variations in temperature. Winter temperature extremes range from about -5^{o} C to more than -50^{o} C at Cambridge Bay, and from about 3^{o} C to -50^{o} C at Yellowknife. During summer, extremes range from about -2^{o} C to nearly 29^{o} C at Cambridge Bay, and from near freezing to about 32^{o} C at Yellowknife. Information prepared for the Contwoyto Lake area (records between 1956 and 1981) indicate that maximum and minimum January averages lie between -27.9 and -35.1^{o} C; that maximum and minimum July averages lies between 14.9 and 4.8^{o} C; and the maximum and minimum average annual temperatures range between -7.8 and -15.8^{o} C (AES., 2000; Tahera Corp., 2000). Climatic conditions at Bathurst Inlet, Contwoyto Lake and Kugluktuk are generally similar to those at Cambridge Bay. Those at Yellowknife are significantly different. Winds at Cambridge Bay are most frequently northerly throughout the year, except in July when they are westerly. At Yellowknife, winds are most frequently northerly in January, March and May, southerly between June and September, and easterly at other times.

Some of the WKSS area climate data also suggest that a slight annual warming may have occurred over the period of record. Assessments of regional climatic variation in the Mackenzie Valley (Skinner & Majorowicz, 1999) and Shield areas (Schindler, 1997) are consistent with this. Over a larger area, records suggest that most recent warming appears to be greatest during winter and spring over northwest North America, and during spring and summer over the Arctic Ocean (Serreze *et al.*, 2000). The latter suggestion is also supported by reports of changing sea ice conditions, from Inuit at Sachs Harbour, Banks Island (IISD., 2000).

Variations in climate are a major factor affecting the availability of food supplies for many northern species. Stock survival may be threatened by extreme or prolonged unfavourable conditions. Climate records, therefore, provide some of the most valuable information that can be used to characterize large scale changes in the environment.

2.2.2. Geology

2.2.2.1. Formation of the Crust

Rocks of the WKSS area are very old, relative to the age of the Earth (about 4.6 Ga (Smith, 1981). They provide special insight into early evolution of the crust. Interpretations gained from studies of the rocks, their age (Table 2) and distributions, have led to a greater understanding of mineral occurrences and potential for resource development. These include, associations of gold and base metals with volcanic rocks, rare earth minerals with some granitic intrusions, and diamonds with kimberlites.

The Earth is made up of a series of rock layers of different physical and chemical compositions, and the outermost layer, the crust, is composed of massive plates. The thickness of rock forming oceanic crust is about 8 km (basic or basaltic rock), and that of less dense continental rock is typically 30 to 70 km (acidic or granitic rock). The plates “float” on an underlying layer known as the mantle (Skinner & Porter, 1992; Smith, 1981). Over immense periods of time, the plates move, sometimes fusing together and at other times pulling apart. Cratons are the oldest and most geologically stable parts of continents, and the Slave craton is the most ancient part of the Canadian Shield (Percival, 1996).

Geological provinces characterize regions of the Shield that have different geological histories (Percival, 1996). The WKSS area (Fig. 3) includes Slave Province, Bear Province, and small parts of Rae Province. These geological provinces lie close to the western margin of the Canadian Shield where heatflow measurements (Majorowicz, 1996) suggest increased mantle upflow under the western edge of the North American continental plate. Slave Province (Card & King, 1992; Clowes, 1996; Percival, 1996; St-Onge & Lucas, 1996) is composed mostly of late Archean rocks, with small exposures of early Archean rock such as the Acasta granitic gneiss (4.0 Ga). This gneiss formed within the crust. It is remarkable because it suggests that formation of the crust and its differentiation into acidic and basic igneous rocks occurred early in the Earth's history (Skinner & Porter, 1992). Archean rocks are also present in Rae Province (south of the McDonald fault and Great Slave Lake shear zone, Fig. 3),but they have been subject to greater deformation during the Proterozoic. Bear Province consists of early Proterozoic sedimentary and volcanic rocks, and where these younger rocks overlie the western part of Slave Province they were folded into a ancient mountain chain and later eroded. Elsewhere in Bear Province, the rocks are relatively flat lying.

Rocks of the Slave Province cover an area of nearly 200,000 km^2 and comprise fragments of old continental crust that were welded together by late Archean time (Relf *et al.*, the eastern part (Bleeker & Davis 1999). During Archean time, crustal movements (pull-apart) occurred within Slave Province. While igneous rocks were eroded and their debris laid down as new sediments, rifting influenced the process of reworking. Many rock structures have a northerly alignment (Padgham, 1990). The Pb and Nd isotope lines (Fig. 3) indicate large scale differences in igneous source materials. The Pb geochemical signature is the stronger (Bleeker *et al.*, 1999a; Yamashita *et al.*, 1999). The radiogenic Pb ($^{238}U/^{204}Pb$) and non-radiogenic Nd signatures (Northrup *et al.*, 1999) indicate the extent to which early mantle material was mixed with juvenile crust. West of the Pb isotope line, Archean mantle material is a significant contributor to the crustal granites.

The Slave craton became a core onto which other parts of the crust later became attached and bound together. About 2.0 Ga, this plate moved eastward to collide and fuse with another part of the crust, the remnants of which form the western part of Rae Province. During collision, the eastern edge of Slave craton moved downward. Heat and compression changed the then existing igneous and sedimentary rocks into metamorphic rocks. This occurred along the collision boundary of the Taltson-Thelon front (Fig. 3) and caused the plates to fuse together (Gibb *et al.*, 1980: St-Onge & Lucas, 1996).

Fig. 4 provides a summary of some of the complex events in crustal evolution of the south-central part of Slave Province ("terranes" are just large pieces of crust). Associated but not necessarily similar events also occur in different parts of the province at slightly different times.

Bear Province is the remnant of another part of the crust which moved eastward towards the Slave craton. As that collision began, the western margin of the Slave craton is thought to have been subducted (drawn down) beneath the advancing "Bear plate". The western margin of the "Bear plate" is, itself buried beneath accretion of yet younger crustal material (Halls, 1982; Stockwell *et al.*, 1970). Movements of the Earth's crust associated with this collision and later deformation in the Wopmay orogen also caused massive faulting along the eastern boundary of Slave Province

(Bathurst and McDonald faults). Compression (roughly northwest-southeast) and elongation (roughly northeast-southwest) affected many rocks of the Slave Province (Padgham, 1990). The presence of massive dyke swarms that intrude into it probably reflect deep-seated and long term effects of these same crustal stresses (Halls, 1982; St-Onge & Lucas, 1996).

2.2.2.2. Igneous, Sedimentary and Metamorphic Rocks of Slave Province

Little is known about the early history of the crust, but granitoid rocks (*e. g.* Acasta gneiss and the Eokuk Uplift area (Emon *et al*., 1999)) formed part of the Earth's surface before 3.0 Ga. As rifting and stretching of the crust occurred, volcanic sequences and sedimentary basins developed over the granitoid rocks (Padgham, 1990; Bleeker *et al.,* 1999b). Sediments of the Yellowknife Supergroup are about 2.7 Ga and occur in five large and several smaller sedimentary basins that are partly bounded by volcanics. Sediments include coarse conglomerates, sandstones (typical of rapid erosion) and finer materials, and coarse to fine grading sequences deposited under water. Some volcanics are interbedded with the sediments and have features typical of both underwater formation (*e. g.* pillow lavas) and subaerial exposure (*e. g.* tuffs and ashes).

A great variety of rock types are present in the WKSS area and, based on mineral content, some deposits may have formed under oxic conditions. Stromatolites occur in some formations and these probable fossil lifeforms suggest biochemical photosynthetic activity (Cunningham & Saigo, 1992; Skinner & Porter, 1992). Other rock types are more consistent with an early atmosphere that is thought to have had lower levels of oxygen than at present. In some, there is evidence of intense chemical weathering by high levels of atmospheric CO_2 (Corcoran *et al*., 1998).

The Yellowknife Supergroup is intruded by several younger granites, and rare earth pegmatites (Davis & Bleeker, 1999). Post-Yellowknife Supergroup sedimentary rocks also occur. In these, there are fragments of material from both the Yellowknife Supergroup and later granites (Padgham, 1990). Dyke swarms of basic igneous rock tend to be of much younger age. Many are likely associated with effects of various "plate" movements and development of the Great Slave Lake shear zone and McDonald fault. The Blatchford, Indin and Hearne intrusives age between 2.2 and 2.0 Ga (Bethune *et al*., 1999), Contwoyto, Lac de Gras and Beechey swarms age between 2.0 and 1.8 Ga, the Mackenzie dyke swarm dates at about 1.2 Ga, and some dykes are as young as 0.8 Ga (Padgham, 1990; St-Onge & Lucas, 1996; Stockwell *et al*., 1970).

2.2.2.3. Igneous, Sedimentary and Metamorphic Rocks of Bear Province

Bear Province forms a wedge shaped area along the northwest margin of Slave Province (DEMPR., 1995). It also includes a small area of rock immediately west of the southern part of Bathurst Inlet. Bear Province covers an area of about 65,000 km^2. Along the eastern margin, quartzites, dolomites, and siltstones of the northward trending Snare and Epworth groups are interbedded with andesite volcanics (including tuffs, surface flows and pillow lavas). These rocks are typical of accumulations in a crustal trough. The trough is thought to have developed in response to subduction, about 2.0 Ga. Sediments were faulted and folded as the trough closed, and the mountain building processes continued in the Wopmay orogen. Under increasing heat and pressure, these rocks became metamorphosed and intruded by granitic material (Hepburn metamorphic and pluton belt). Some of this material may have originated as a result of melting of parts of the subducted margin of Slave Province. Further west, rocks of the Great Bear magmatic zone, including the McTavish volcanics and plutons of the Great Bear batholith (about 1.8 Ga in age), may be characteristic of a magmatic arc (*e. g.* the present Aleutian Island chain). In the northern part of Bear Province (outside the orogen) and following these events, land became elevated and subject to subaerial weathering. Derived materials were deposited under largely marine conditions and include conglomerates and quartzites, and later dolomites and siltstones of the Hornby Bay group. Later still, thick basalt flows formed at the base of the Coppermine group (which may date as late 1.0 Ga). Afterwards, red sandstones were deposited. The basic rocks of the Muskox intrusion (south of Kugluktuk) and the Mackenzie dyke swarm are likely of similar age (Halls, 1982; Stockwell *et al.*, 1970).

2.2.2.4. From the Cambrian to the Start of Glaciation

Almost all of the rocks that occur in the WKSS area are of Precambrian age (greater than about 0.6 Ga). It is likely that this part of the Earth's crust has been relatively stable since well before the beginning of the Cambrian period (0.6 Ga). Shallow seas existed at the northern and western edges of the WKSS area. Mainly marine sediments of Cambrian to upper Devonian age (dolomites, shales and sandstones) and lower Cretaceous age (shales and sandstones) occur over much of the Mackenzie River valley (DEMPR., 1995; Douglas *et al*., 1970). Lower Palaeozoic sediments, mostly Ordovician and Silurian dolomites with some shales and sandstones, cover much of Victoria Island. Precambrian quartzites in Wellington Bay may, however, indicate that the Slave Province extends beneath the southern part of the island. Shallow marine conditions have occasionally extended over parts of Slave and Bear provinces since the Precambrian, but most of the deposited sediments were removed by subsequent erosion (DEMPR., 1995; Douglas *et al*., 1970). For the most part, only Quaternary sediments, remain. These are of late glacial to recent in age and overlie previously existing erosion surfaces that date to the late Tertiary period (perhaps as little as 30 Ma). Recently, fossil materials of continental origin (pollen, wood, fish and micro-fossils of Cretaceous to early Tertiary age, about 50 to 120 Ma) have been found. The fossil materials occur in fragments of rock that fell back into the kimberlite pipes as they were intruded into the Lac de Gras area (Nassichuk & McIntyre, 1996). These kimberlites were intruded into a continental environment during the early Tertiary (about 52 Ma). Kimberlites intruded in the Contwoyto area appear to be older and have an age of about 172 Ma (Kerr, 1998).

2.2.2.5. Metals Mineralization

Mineralization in Slave Province (Fig. 5) is mostly associated with major crustal deformations that occurred during the oldest part of the Precambrian period (Archean, 2.5 to 4.0 Ga) and the later part of the Precambrian (Proterozoic, less than 2.1 Ga). In the WKSS area, this approximates the time period before and after plate collision with the Rae Province. Understanding geological evolution of the region, therefore, contributes significantly to the success of resource exploration.

Archean mineral occurrences include gold, base metal-silver, and rare earth elements (Brophy 1991; 1993; DEMPR., 1995; Goff 1990; 1994; Igboji, 1996; Igboji *et al*.,1997; INAC., 1998; 1999a; 2000a; Kusick & Goff, 1995; Padgham, 1990). Many gold occurrences formed early and before emplacement of the late granitoides. Gold may occur as lode deposits in shear zones in volcanics (*e. g*. Boston, Giant, and Con), with sulphide replacement in stratiform iron formations (*e. g*. George Lake) or uniformly distributed in stratiform iron deposits (*e. g*. Lupin), in quartz veins associated with volcanic sequences (*e. g*. Discovery and Colomac), and in smaller quantities in other associations. Gold is typically alloyed with small quantities of silver.

Occurrences of volcanogenic massive sulphide (Atkinson, 1990; Brophy 1991; 1993; DEMPR., 1995; Goff 1990; 1994; Igboji, 1996; Igboji *et al*.,1997; INAC., 1998; 1999a; 2000a; Kusick & Goff, 1995; Padgham, 1990) are widespread. They are generally rich in zinc, lead and silver but poor in copper and gold (*e. g*. Gondor, Hackett River, Izok and Musk). The deposits are often associated with calc-alkaline volcanics but no zoning is apparent. Metal contents, suggest these volcanics are closely linked to the granites that intrude the Yellowknife Supergroup.

Rare earth element-rich pegmatites were intruded at a late stage and contain lithium minerals, ferromanganoan phosphates, niobium-tantalum and beryllium minerals (Yellowknife basin, Mackay-Aylmer basin, and Torp Lake basin) (Brophy 1991; 1993; DEMPR., 1995; Goff 1990; 1994; Igboji, 1996; Igboji *et al*.,1997; INAC., 1998; 1999a; 2000a; Kusick & Goff, 1995).

Proterozoic mineralization is largely associated with deep crustal fracturing that extended into the Earth's mantle, and often with extremely basic intrusive rocks of hyperalkaline to mafic or ultramafic composition (Brophy 1991; 1993; DEMPR., 1995; Goff 1990; 1994; Igboji, 1996; Igboji *et al*.,1997; INAC., 1998; 1999a; 2000a; Kusick & Goff, 1995; Padgham, 1990). Fracture filling by copper sulphide occurs in the Coppermine basalt (Wreck Lake). Diabase dykes host small amounts of native silver (Hope Bay) and diabase dykes and carbonatites host nickel-copper-cobalt (Copper Pass). Polymetallic vein deposits occur at Contact Lake, Echo Bay, and Eldorado (arsenic, bismuth, cobalt, copper, nickel, silver and uranium). An extensive suite of rare earth mineral occurs at the Blatchford intrusive complex and at Thor Lake. Layered ultramafic rocks of the Muskox intrusion host chromite-sulphide seams and some copper, nickel, platinum and palladium. Uranium (as pitchblende and with hematite) was mined at Rayrock (south of Rae Lakes) but does not appear to be present within the Slave Province.

Over long periods of time, the movements of water within rock may result in dissolution, migration and redeposition (precipitation) of metals. Some of the copper from the Coppermine River may have been derived from underlying basalts. However, unlike some mineral deposits in the younger Palaeozoic formations south of Great Slave Lake (*e. g.* Pine Point, (Anderson & Macqueen, 1982; Gibbins, 1988)), few if any remobilized metals in the Slave Province appear to occur in economic quantities.

Oil and gas deposits are unlikely to occur in Slave or Bear Province (Fig. 5) but several important deposits are in production or under development in the Mackenzie Valley, where considerably more development is expected (DT., 2000; INAC., 1998; 1999a; 2000a; 2000c).

2.2.2.6. Kimberlites

Kimberlites are a very special kind of rock (DEMPR., 1995; Kjarsgaard, 1996a; 1996b. Pell, 1997). They appear to be restricted to areas of the crust that are older than 1.5 Ga,. They contain diamonds only in areas where the crust is relatively thick (thicknesses of more than 40 km have been reported from the Slave Province). A west to east cross section of the Earth's crust near Yellowknife is shown in Fig. 4. This has been inferred from deep seismic reflection and teleseimic data (Bank *et al*., 2000; Bostock, 1998; Cook *et al*., 1999; Griffin *et al*., 1999).

Palaeozoic materials provide surface cover over the western part of the section. Within the upper and lower crust (UC and LC), strong reflectors indicate the presence of low-dipping fragments of subducted, wedged and underthrust plate materials. Because of temperature-pressure effects, most seismic reflectors become indistinct below the Mohorovic discontinuity (Moho) which marks the upper boundary of the mantle (Cook *et al.*, 2000). The base of the keel-like structure within the mantle (of fragmented mantle material), reaches its maximum depth of about 200 km, somewhat to the east of the Pb isotope line (Fig. 3). This corresponds, in general, with the most extensive distribution of kimberlite intrusions in the Slave Province (Fig. 5). It is not known if this keel extends northward beneath Victoria Island where kimberlite pipes also occur. The Lac de Gras area is underlain by a well defined low seismic velocity anomaly at depths of 350 to 600 km. Genetic relations between an inferred mantle plume and kimberlites are not resolved (Bank *et al*., 2000). Anomalous rock and mineral fragments present in some kimberlites confirm that parts of the mantle underlying the Slave Province lie within the diamond stability field. For example, Jericho diamonds are likely derived from reservoir rocks at a depth of 130 to 190 km (Kopylova *et al*., 1998). The kimberlite pipes of Slave Province likely belong to several generations (Griffin *et al*., 1999). Dates from Lac de Gras give ages of 47-52 Ma (Eocene), 73-75 Ma (Cretaceous), the Jericho site is dated at 172 Ma (Jurassic), and Drybones and Cross pipes at 440 and 450 Ma (Silurian-Ordovician boundary).

Diamonds are a form of pure carbon. They do not form in kimberlite but in peridotite or eclogite (mantle rocks) and at depths of about 150 km below the Earth's surface. Internal "plumes" move these mantle rocks upwards so that fragments of them may be held in kimberlite "reservoirs" beneath the crust. Depending on temperature and pressure, carbon may be present in mineral form as either graphite or diamond. The right conditions to retain carbon as diamonds exist only beneath areas of thick crust. Kimberlite reservoirs are rich in CO_2 and H_2O that fluidize and help to carry fragments of both mantle and crustal material to the surface. Generally, in the process of transport, the mantle fragments break into small pieces and the diamonds are released into the matrix of kimberlite. Exactly what triggers the explosive release of kimberlite to the surface is not known. But, when it happens, the event occurs extremely rapidly (otherwise the diamonds would be destroyed by oxidation during this upward movement). The kimberlite moves upward as a mixture of gaseous CO_2, water vapour and rock fragments. Near the surface, where confining pressures drop rapidly, the exploding mixture blasts out an inverted cone (diatreme). At depth, kimberlites probably move upwards at velocities of 10 to 30 $km \cdot hr^{-1}$. Near the surface they may reach velocities of a few hundred $km \cdot hr^{-1}$. The pipes connect kimberlite reservoirs directly with the surface. Unlike most volcanic eruptions, however, the explosive release appears to be a one-time event and of short duration. Kimberlite pipes are thought to be aligned with deep seated structures. The pipes do not appear to be randomly distributed but neither are they closely related to surface geology.

2.2.2.7. Quaternary Deposits

The Quaternary is the most recent period of geological time (beginning about 2 million years ago) and it has been marked by strong and periodic changes in global climate. Four major glaciations occurred during this period. Each time, advancing ice scoured the surface so that, over most of the WKSS area, evidence remains only of the last Wisconsinan glaciation and its retreat.

Wisconsinan ice spread westward from the Keewatin area across the WKSS area, as part of a much larger mass covering the entire Shield (Dyke & Dredge, 1989; Prest, 1970). It spread in a generally radial pattern from a regional dome centred in the headwaters of the Thelon River drainage (Prest, 1970) and covered all of the WKSS area. Glacial ice probably reached its maximum extent about 20,000 BP. By 11,000 BP, the high ground in west Victoria Island was largely free of ice, as was much of the mainland west of Dismal lakes and north of Hottah Lake (Vincent, 1989). Ice retreated eastward across the region and by 10,000 BP areas west of a line between the Tree River and Yellowknife were ice free. The region was completely ice-free by about 8,500 BP. During glacial retreat, water levels rose in the Great Bear Lake basin.

Rapid melting, downward from the surface of the glacial ice, may have begun as early as 15,000 BP. Marginal retreat of the ice edge, however, did not accelerate until about 12,000 BP. By about 12,000 BP, a huge lake extended north along the ice front from Lake Athabasca to Great Bear Lake (Craig, 1965; Klassen, 1989; Prest, 1970). Lacustrine sediments from this glacial lake (glacial Lake McConnell, Fig. 2) extend to elevations of about 260 m. Surface drainage patterns were more or less established in their present form by 8,500 BP. As the thickness of ice cover decreased, the land surface, long depressed by the weight of ice, began to rise. At first, sea level rose relative to the land because the rate of melt was so rapid, and lowland areas on both Victoria Island and the mainland surrounding Coronation Gulf were inundated by marine waters (Craig, 1965; Prest, 1970). The marine incursion extended far into Bathurst Inlet and reached locations that are now as much as 225 m above sea level. Evidence for this persists in thin layers of marine silt and clay which lie directly on bedrock or on thin layers of glacial till which also overlie bedrock. Evidence is also present in the form of raised glaciomarine and marine deltas, and as raised sand and gravel beaches. After glaciation, isostatic recovery (uplift of the land) was very rapid. For example, at Bathurst Inlet the rate of uplift was about 10 m per century for the first 1 to 2,000 years after ice-free conditions. The rate of uplift has slowed and is presently about 0.5 m per century in the southern Bathurst Inlet area (Prest, 1970). Even at its maximum extent during the Wisconsinan glaciation, glacial ice became progressively thinner west of Bathurst Inlet. Because of this, the amount of surface depression and later isostatic recovery also decreased west of the inlet.

Many smaller glacial lakes formed temporarily (St-Onge, 1980) as ice fronts partially dammed the rapidly expanding melt waters, including those in the basins of the Richardson, Coppermine, Burnside, Back, and Thelon rivers. High level beach deposits of sand and gravel exist in many lake basins and marine coastal areas. Both thin lacustrine silty clays and river terraces of silty sands and gravels mark episodes of previously higher postglacial water level.

Although glacial ice has scoured and eroded the pre-existing Shield landscape, it is thought that only a few metres of bedrock may have been removed (Prest, 1970). Preservation of much of the original vent structure of many kimberlite pipes in the Lac de Gras area supports this view (Nassichuk & McIntyre, 1996). Glacial till is an unsorted mixture of coarse angular to sub-angular rock fragments in a finer matrix of sandy or silty-clayey material. It developed at the base of the glacial ice sheet and has a thin and patchy distribution over most of the WKSS area. It is occasionally overlain by glaciomarine and glaciolacustrine materials. Areas of fluted and drumlinized till are also common throughout the WKSS area. They are thought to have been caused by the movement of ice over till material and may be several metres thick. Hummocky moraine is thought to have been formed under “dead ice”. It covers a large area east of Bluenose Lake, and smaller areas north of the Rae River and around Aylmer Lake, Contwoyto Lake and Lac de Gras (Kerr, 1998; Map 1253A; Prest, 1970).

The most significant glacial features of the region are the presence of numerous and extensive esker and kame complexes. Many of these are continuous over several tens of kilometres (Map 1253A; Prest, 1970). These deposits, of generally sandy material, were formed by under-ice meltwater streams or marginal pondings, and now occur as prominent ridges over bedrock (or thin glacial till). North of a line between Kugluktuk and Clinton-Colden Lake, these features trend southeast-northwest. South of this line but north of a line from Hottah Lake and Clinton-Colden Lake, the trend is more nearly ESE-WNW. Further south again, the trend is more nearly east-west (Map 1253A). Near the ice margin where the ice was relatively thin, and roughly following the east shore of glacial Lake McConnell (Fig. 2), eskers are rare or poorly developed. Likewise in the area midway between the south end of Bathurst Inlet and the east end of Mcleod Bay (Great Slave Lake), where under-ice drainage diverged beneath the middle of the melting ice dome, eskers and kames are poorly developed (Map 1253A; Prest, 1970).

Different types of Quaternary sediment can give rise to a variety of landforms and these, in turn, may provide different forms of habitat for use by a wide range of plant and animal species. This is most evident in the well-drained eskers which overlie bedrock or poorly drained glacial till. Geochemical differences can also exist between glaciolacustrine, glaciomarine and other till materials, and these may be reflected by differences in vegetation.

2.2.3. Physiography (landform)

The WKSS area is characterized by mostly low to moderate relief and large areas of exposed or thinly covered bedrock (BHP & Dia Met, 1995; Bostock, 1970; Dyke *et al.*, 1989). Although glacial erosion and deposition have strongly influenced formation of the present landscape, some bedrock surfaces may reflect the effects of much earlier erosion. The oldest erosion surfaces may be of Precambrian age (Bostock, 1970; Dyke *et al*., 1989).

The Victoria Lowlands extend over all of the southern part of Victoria Island (Fig. 6). Here, the sedimentary bedrock is nearly flat lying. It is generally masked by a thin cover of glacial or postglacial sediment, and the lowlands are characterized by numerous small lakes and low relief. Elevations are generally less than 300 m except on the Wollaston Peninsula where they reach a maximum of about 500 m (Bostock, 1970).

On the northern part of the mainland, the Horton Plain rises to greater elevations. The Melville Hills (formed by an inlier of Precambrian rock) reach more than 850 m, west of Bluenose Lake. Although the bedrock geology suggests continuity with that of Victoria Island, the landscape is different. There is little surface ponding on the plain and drainage is more strongly developed. The Horton Plain is separated from the Victoria Lowlands by Dolphin and Union Strait (Bostock, 1970).

The Coronation Hills have a lower elevation (generally less than 500 m). They cover a smaller area between the northeast shore of Great Bear Lake and the mouth of the Coppermine River (Bostock, 1970). Here, the presence of different sedimentary and igneous Precambrian rocks with variable resistance to erosion provides locally complex relief. Channels in the lower reaches of some rivers may be unstable where they cross early postglacial deposits, such as the valley terraces and delta area of the Coppermine River. Falls or rapids may be formed over resistant bedrock (Ellis, 1962; Raffan, 1979; Wedel *et al*., 1988) and may limit flood plain development to a short distance south from the present coastline, such as on the Tree River (Robertson & Dowler, undated). East of this area, the Coronation Gulf has formed in what may be a submerged river valley that previously drained west into Amundsen Gulf. Glacial scour has deeply channelled parts of the floor of the gulf. From the mainland, many low islands extend eastwards along the shore as expressions of resistant bedrock (including the Coppermine sills). Depths in the gulf are typically 70 to 130 m and they reach a maximum of about 220 m. Extensive areas of shallow water extend between many islands and along the south coast.

Elevations over the eastern parts of the Great Bear Plain and the Great Slave Plain are generally less than 300 m. However, along the north shore of the McVicar Arm (Great Bear Lake) they reach a maximum of 700 m, and to the southwest of Hottah Lake they reach about 450 m. Both regions were covered by glacial Lake McConnell (Klassen, 1989; Prest, 1970). At present, Great Bear and Great Slave lakes have separate drainage. Both drain into the Mackenzie River but the level of the two lakes (about 156 m) differs by less than 0.5 m. The Precambrian Shield is exposed along the east shore of both lakes. Elsewhere, generally flat-lying or gently dipping sedimentary rocks of much younger age are present.

The deeply indented shoreline of Bathurst Inlet and the strong relief of this area reflects glacial scour along the Bathurst fault. It also reflects the distributions of many different types of Precambrian sedimentary and igneous rocks, and other structural controls (PC., 1978; Zoltai *et al*., 1980). High falls occur where drainage crosses resistant rock formations and fault lines. The most extensive area of high ground (rising to about 500 m) forms the divide between the Hood and the Burnside rivers.

The Bear-Slave Upland conforms, mostly, to the remaining areas of the Bear and Slave geological provinces (Bostock, 1970). Elevations rise to 300 m over a distance of 40 to 60 km inland from the coast and to greater heights along the western boundary of Slave Province. Most of the region is above 300 m, and elevations locally exceed 650 m around the northeast shore of Contwoyto Lake. Numerous lakes cover 10 to 30 percent, or more, of the surface in this area of moderate bedrock relief. Rounded hills are formed by resistant bedrock such as granitoids and metamorphosed sandstones. Lakes and rivers develop along jointing and fault lines, and over softer bedrock that includes some volcanic material and kimberlites. Low ridges of exposed bedrock occur over intrusive dykes that are often aligned in a northerly direction. Eskers of glacial sand and gravel also occur as long ridges, and these trend more nearly northwest-southeast.

Glacial scour along the faulted and sheared southeast boundary of Slave Province has produced dramatic erosional features in the area of the East Arm Hills of Great Slave Lake (Mondor, 1982). Although many of the southwest - northeast trending islands have strong relief, the underwater features are even more pronounced and depths reach nearly 300 m in McLeod Bay and more than 600 m in Christie Bay.

The Kazan Upland (Bostock, 1970) is generally similar in appearance to the Bear-Slave Upland and has formed over Shield rocks of Rae Province. The Back Lowland (Bostock, 1970) is also formed over Precambrian rocks of Rae Province but this region has significantly lower elevations (less than 300 m). Postglacial marine inundation of the Back Lowland was more extensive than over the Bear-Slave Uplands. It typically extends 130 to 150 km south from the present coastline over a gently undulating surface.

2.2.4. Hydrology, Ice Cover and Coastal Conditions

The major drainage basins of the WKSS area are shown in Fig. 7. Most of the rivers draining to the Arctic coast are relatively short, as are those entering Great Bear Lake. The Coppermine River has the longest drainage. It flows northwest across the Bear-Slave Upland and passes through numerous lakes and across a great variety of bedrock types. The Burnside River dominates the drainage of Bathurst Inlet. Most of the water entering Great Slave Lake is derived from areas to the south of the lake, in the Slave River drainage (with headwaters in the Rocky Mountains). The Lockhart River, with headwaters above Mackay Lake, is the most important source of water entering the East Arm of Great Slave Lake. The North Arm is fed by drainage from Lac Grandin and Lac la Martre, and from the Snare River and Lake system. The Camsell River which flows north through Rae, Hardisty and Hottah lakes provides the largest input to Great Bear Lake.

Water quality (McNeely *et al*., 1979) is generally good throughout the WKSS area (HBT-Agra, 1993; Puznicki, 1996). Although monitoring at Snare Rapids has shown a slight increase in concentrations of sulphate and nitrate ions since 1994, sulphate in precipitation is only one-fifth of the guideline level for sensitive environments (7 kg $SO_4 \cdot ha^{-1} \cdot a^{-1}$). At Snare Rapids, the 1996 average annual pH of precipitation was about 5.1 and typical of unpolluted background conditions (DRWED., 1998). Over many areas of the Shield, surface waters are slightly acidic but over areas of carbonate rock, alkalinity and calcium concentrations may increase. For example, pH values increase from 6.6 to 8.0 in the Coppermine River where high values are associated with dolomitic rocks in the northern part of the drainage. Seasonal increases in alkalinity may naturally occur during the July-September period. These are associated both with biological productivity and the influence of bedrock (Wedel *et al*., 1988). Sediment loads, both bed and suspended sediment loads, increase dramatically with surface and bank erosion during spring runoff. They may temporarily limit supplies for potable water, as at Kugluktuk on the Coppermine River. Concentrations of some forms of contaminants, including several heavy metals and PAHs are also known to be associated with fine sediments and their quantities may increase, seasonally, with the load of suspended sediments (Section 4.2.3.1). Movement of bed materials may also significantly alter channel forms and affect water transport, such as on the Mackenzie River. In most areas, conductivity, nutrient concentrations, and trace metal concentrations are low (Puznicki, 1996; Wedel *et al*., 1988).

Based on a SW to NE survey of 24 shallow (less than 25m), small to medium size lakes (50-500 ha), summer surface water temperatures decrease latitudinally from about 14.5º C near Yellowknife to about 11.5º C at the tree line (near Beniah and Lockhart lakes), and to about 7.5º C near Contwoyto Lake (Pienitz *et al.*, 1997). Summer transparency is generally high except where lakes receive coloured waters from surrounding forested areas or peatlands. Conductivity is low in most lakes of the WKSS area and declines to very low values north of the tree line (Pienitz *et al.*, 1997; Puznicki, 1996). Most lakes in the WKSS area have very little buffering capacity, and pH tends to be quite variable and within the range of pH 6 to 9 (Pienitz *et al.*, 1997).

As in the rivers, concentrations of major ions strongly reflect geology and vegetation. On a relative basis, Ca > Na > K. Values of Ca are very low in areas of granitic rock but increase in areas of carbonate-rich sedimentary rock and some volcanics and mafic intrusions (Pienitz *et al.*, 1997). Concentrations of dissolved nutrients (N, P, Si and inorganic C) are low in lakes throughout the WKSS area and extremely low in most tundra lakes. Locally, hot-spots of nutrients and pathogens may be associated with seepage or discharge of sewage materials from some communities, camps and resorts (Sections, 4.2.4, 4.2.6). Dissolved organic C in tundra lakes increases slowly towards the tree line, from minimum values of less than 2 $mg \cdot l^{-1}$. There is a significant increase southward from the tree line, where DOC values rise from about 5 to more than 9 $mg\ l^{-1}$ near Yellowknife (Pienitz *et al.*, 1997). Most DOC is derived from decaying vegetation and brown acidic run off from forested and peatland areas may also carry relatively high concentrations of dissolved Fe. On a regional basis, lake alkalinities tend to rise with increasing temperature but dissolved nutrients decrease due to biological processes of removal (Schindler, 1997).

Metal concentrations in lake sediments strongly reflect local geology and natural occurrence. Most fall within the range typical of freshwater sediments (Puznicki, 1997). Relatively high concentrations of As, Cd, Cu, Fe, Mn and Ni exist in some lake sediments and other metal anomalies have been detected in a few lakes (Puznicki, 1997). In the lower Slave River, As, Cu, and Zn and some other metals have been detected at concentrations above guidelines for LEL. These are also thought to be mostly of natural origin and adapted to by biota McCarthy *et al.*, 1997a). Some concentrations of PAHs (from both natural and anthropogenic sources) in suspended sediments also exceed LEL (Ontario) but remain well below SEL (Ontario). Overall, the Slave River at Fort Smith and below is considered to be of near pristine water quality (McCarthy *et al.*, 1997a). The biological availability of metals in sediments depends on many factors and total metal concentrations are of limited value in estimating potential health hazard. However, on a site-specific basis and where there is human use of food or water from lakes containing high metal concentrations in sediment, further assessment of metal availability may be needed. Hot-spots of heavy metal contamination may exist as a result mining and other industrial activities (Section

4.2.4).

There are major differences in the seasonal flow of most rivers in the WKSS area. Near zero flow occurs during late winter in many water courses (Acres Consult., 1982; HBT-Agra, 1993). This is partly because precipitation is lowest during winter but, also, because thick ice forms and freezing may take place to the bottom of some channels. Evaporation is also a significant factor across much of the WKSS area, accounting for 25% or more of the total precipitation in areas north of the tree line and where permafrost restricts seepage to a minimum. Over much of the region, lake evaporation may be as much as 50% of total precipitation (Acres Consult., 1982; BHP & Dia Met, 1995). Because ground remains frozen for much of the year and because large areas of bedrock are exposed, surface runoff is high, typically 50 to 75% of total precipitation (Acres Consult., 1982). Lake storage (Acres Consult., 1982; HBT-Agra, 1993; Wedel *et al*., 1988) provides an extremely important natural buffer that reduces variations in flow throughout the region, especially on the Coppermine, Camsell, Snare, and Lockhart rivers. However there is also considerable year-to-year flow variability, even on rivers well buffered by lake storage. For example, since 1966, maximum flow conditions on the Coppermine River have ranged from about 120 to 535 $m^{-3} \cdot sec^{-1}$ (July period), and low flow conditions from about 25 to 45 $m^{-3} \cdot sec^{-1}$ (Acres Consult., 1982; Wedel *et al*., 1988). Hydro development has occurred on the Snare, Taltson, and Yellowknife River systems. Potential for additional development has been identified on other rivers, including the Barnston, Coppermine, Hoarfrost, and Lockhart systems (HBT-Agra, 1993; Glacier Power Ltd, 1997; UMA Group, 1979; Wedel *et al*., 1988). Additional hydraulic resources in the WKSS area (based on dependable flow, Fig. 7) are relatively small, and land withdraw by Parks Canada, has limited availability of sites on the lower Lockhart River.

Although most of the WKSS area lies within cold climate regimes (Section 2.2.1), precipitation is light and evaporation can be a major influence on the availability of surface water. Catchment studies in the Yellowknife River basin show that seasonal energy budgets differ from sites in the eastern sub-Arctic where there is more precipitation (Spence, 2000; Spence *et al*., 2000). Exposed rock keeps water at the surface and allows high evaporation rates during late spring and early summer. In normal years, this may produce a moisture deficit by early July. Rock fractures enhance infiltration (few large fractures provide greater infiltration than many small fractures). Soil cover increases infiltration and retention. Collectively these conditions decrease runoff and down slope availability of water. The drying of soil-bedrock contact zones, as water is drawn to the centre of soil covered areas, causes further disconnect in the hydraulic system (Spence *et al*., 2000). Thus the annual moisture deficit of soil-covered hillslopes has a major influence on runoff response during summer and fall.

Lake storage deficits influence the volume and time of upstream discharge into mainstream flow (Spence, 2000). In the Yellowknife area, snowmelt occurs during mid-April to mid-May. Rates of evaporation increase to early summer. Moisture levels in peatlands begin to fall in late June and water tables reach their lowest levels in August. With thin soils, there is little storage buffer (Spence, 1995; 2000). With light summer rains, evaporation is high and evaporation rates do not begin to decrease until August. Because of this, the storage deficit only begins to recover after mid to late August. In upland areas, evaporation accounts for about 16% of available snowmelt, and only 70% goes into runoff. Of this, more than 50% goes to replace the storage deficit in receiving areas. Less than 10% of the meltwater is carried into mainstream flow. Some headwater lakes do not outflow every year and some flow only for a few days a year. Thus the previous year's storage deficit has a large influence on mainstream discharge in the following year. High discharge may occur only for a short period, and estimates of evaporation are a crucial component of water budgets (Spence, 2000; Spence *et al.*, 2000). Also, and as with precipitation estimates (Spence, 1995), there are concerns that generally applied measurements of evaportation (Gibson *et al*., 1998) may fall short of requirements of water budgets for the WKSS area.

Small inland lakes and sheltered points of inflow to larger lakes are the first to become ice-free and break-up begins about mid-May in the most southerly part of the WKSS area. The last frost is about May 30th and a general date for break up in the western part of Great Slave Lake is about June 1st. Break up near Yellowknife occurs about June 15th (Sirois *et al*., 1995). The last frost in the McLeod Bay area is about June 20th and ice may persist there until early July (Sirois *et al*., 1995). Ice may also persist into July in parts of Great Bear Lake. The first frost in the Great Slave Lake area occurs about September 10th (Sirois *et al*., 1995) and ice cover develops first on small inland lakes. It begins in early October near the Arctic coast. Lac de Gras is usually frozen by mid-October and the large bays of Great Slave Lake are usually ice covered by early November. The lake is completely covered by mid-December. The process of freezing on Great Bear Lake is similar and occurs a little earlier.

Surface and near surface flow in Dolphin and Union Strait is generally from west to east but reversals occur after periods of strong wind (Can Arctic, 1989). Queen Maud Gulf also receives cold water drifting south along the east coast of Victoria Island. At the eastern end of Dolphin and Union Strait, tidal streams produce polynya in June. These areas of open water expand slowly and ice fracturing begins in early July. The strait is largely ice free by late July or early August. In the Coronation Gulf, break-up starts in the west and progresses eastward. Extensive surface ponding occurs and much of the sea ice melts in-place. Once started, disintegration becomes rapid and is assisted by inflow from the Coppermine River. The gulf is usually ice-free by late July. Most ice also melts in position in Dease Strait which becomes generally ice-free by late July or early August

(Can Arctic, 1989).

Ice re-forms in October, beginning in the east (Can Arctic, 1989). Freezing begins about October 1st on the Kent Peninsula. The mean date of freeze-up is October 10th at Cambridge Bay and October 24th at Coppermine (1930 to 1985 record). The ice pack remains mobile in Amundsen Gulf most of the winter and, in mild winters, polynya may persist off the western part of the Wollaston Peninsula. At the east end of Dease Strait, the ice is frequently rough and ridged but over most of Coronation Gulf it is relatively smooth (Can Arctic, 1989).

2.2.5. Permafrost and Massive Ground Ice

Permafrost occurs in soil and rock that remains at or below freezing for a long period of time, at least for two winters and the intervening summer. Most permafrost has existed for much longer. Permafrost continues to develop when winter heat loss at the ground surface exceeds summer heat gain. It can move downward to a depth at which heat loss in the frozen ground is balanced by heat flow from the ground beneath. Where the mean annual ground surface temperature has remained generally less than -5^{o} C over periods of thousands of years, permafrost may be several hundred metres thick (Brown, 1970; French, 1989; Harris, 1987; Map 1246A). In the continuous permafrost zone (Fig. 2), thick and cold permafrost exists almost everywhere. Ground temperatures generally increase from north to south and the northern limit of discontinuous permafrost corresponds with a mean annual air temperature of about -6 to -8^{o} C (Brown, 1970; French, 1989). Within regions of discontinuous permafrost, there may be both large and small areas without permafrost or lenses of unfrozen ground between layers of frozen ground.

The distribution of permafrost can be influenced by several factors (Brown, 1970; French, 1989; Harris, 1987; Map 1246A). Permafrost is often found beneath peatlands, because of their insulating effect. It is also found on north-facing slopes, or in areas where vegetation cover increases shade and reduces the insulation effects of winter snow cover. However, where heat from unfrozen surface water is sufficient, it can prevent formation of permafrost in the underlying ground. Permafrost is usually absent beneath large lakes and rivers, even within areas of otherwise continuous permafrost. Soil moisture in permafrost exists in the form of ground ice that is often present in excess amounts (*i. e.* more than the soil would normally contain when thawed). Melting of this ice, as a result of some form of disturbance, can lead to soil instabilities and thus to a concern for terrain stability and infrastructure integrity. The quantity and distribution of ground ice depends largely on soil texture, environmental conditions and glacial history (Burgess, 1988).

Massive ground ice can occur in association with both glaciolacustrine and glaciomarine sediments (Dredge *et al.*, 1999). It is a relict feature formed in late glacial or early postglacial times. Massive ground ice, up to 10m thick occurs in hummocky tills, eskers and some outwash deposits where it may directly overlie bedrock or be separated from it by a thin layer of sediment (1 to 2m thick). It may also be present as (frozen) slightly saline saturated sediment of marine origin. Massive ground ice can originate as glacial ground ice that was buried in-place. If the sediment cover coarsens-upward it may indicate a shallowing of water cover, over time. The ice may also originate as glacial meltwater that subsequently froze in place in eskers or kettle holes. Wedges may be present as remnant casts of early postglacial ice-wedge forms (Dredge *et al.*, 1999). Massive ground ice of freshwater origin has very low electrical conductivity and low concentrations of most major ions (especially Al, Fe and Si). These characteristics suggest that no significant enrichment has occurred by subsequent downward percolation of surface water (Wolf, 1998). For the most part, the presence of massive ground ice is not a cause of developing thermokarst features. Massive ground ice has been reported in hummocky till from the Contwoyto Lake and Lac de Gras areas (Dredge *et al.*, 1999; Wolf, 1998). It is likely present in other parts of the WKSS area where late glacial conditions allowed rapid cover of residual forms of glacial ice and frozen meltwater. Massive ground ice is best preserved in areas of permanently frozen ground. Table 3 provides a summary of weathering and thermokarst features associated with most of the materials and geological landforms present in the WKSS area. It also indicates forms of ground ice that may be present and the sensitivity of the terrain to permafrost degradation.

All of the WKSS area lies within the permafrost zone (Brown, 1970; French, 1989; Map 1246A). Continuous permafrost exists north of a line extending generally southeast-northwest from Artillery Lake to the Dease Arm of Great Bear Lake. Permafrost extends to depths of as much as 90 m at Yellowknife, and to more than 100 m at the site of the Eldorado mine on the east shore of Great Bear Lake. Near Lac de Gras, it occurs to depths of more than 270 m (BHP & Dia Met, 1995; Map 1246A) and near Contwoyto Lake it is estimated to occur to a depth of about 540 m (Tahera Corp., 2000).

2.2.6. Soil Development

Soil development is influenced by the characteristics of source material, climate and hydrology. Source materials in the WKSS area include bedrock, till (mostly silty sand with rock fragments), and glaciolacustrine and marine clays (Acton, 1989a; 1989b; Map 1253A). Till geochemistry is highly variable throughout the WKSS area and it often reflects the composition of underlying bedrock. Granitic bedrock is usually poor in nutrient elements and gives rise to more acidic conditions than basic rocks such as basalt. Where tills contain materials from several different sources, they may give rise to less acidic soils but these generally remain nutrient poor. Glaciolacustrine sediments are usually rich in clay minerals that contain more nutrient elements (exchangeable cations such as Ca, Mg, K and Na). Contents of Ca and Mg are often highest in marine clays (Zoltai *et al*., 1980).

Soils develop in the active layer in which seasonal thaw occurs. This thin layer at the ground surface is often only a few tens of centimetres thick, although local conditions make this highly variable. Dredge *et al.* (2000) cite a range between 15 and 120 cm, with the greater depth occurring in areas devoid of vegetation cover. Generally, the thickness of the active layer decreases northwards (Brown, 1970; French, 1989; Map 1246A). Soils that develop within regions of permafrost are collectively termed Cryosolic (CSSC., 1978). Turbic Cryosols (TCs) are strongly affected by the physical movements of the ground, caused by annual freeze-thaw cycles. Orthic TCs describe soils which frequently develop over well drained till or hummocky till (Zoltai *et al*., 1980). They are characterized by a thin layer of granular material of slowly decomposing rock fragments, just below the more organic-rich surface layer. Brunisol TCs lack this thin granular layer but often show evidence of soil movement due to frost heave. They form over less well-drained till. Regosol TCs occur where there is strong soil movement. Typically, this carries organic material to depths within the soil and fresh mineral and rock fragments are brought to the surface (*e. g.* “mudboils”). Peatlands (CCELC., 1988; Tarnocai, 1989) generally occur in areas of poor drainage where plant matter accumulates to form organic soils. These are often more than 0.5 m thick and overlie permafrost. The organic matter is usually derived from *Sphagnum* moss on the more elevated parts of a peatland and from sedge meadows in the lower parts. Decomposition tends to be least complete in the raised *Sphagnum* areas. Peat soils are strongly acidic (pH 3 to 5). Where soils develop on well drained sand or gravel (*e. g.* kames, eskers, and some river terrace deposits), there may be little evidence of cryoturbation. Soil horizons become well differentiated (Zoltai *et al*., 1980).

Rates of soil development relate to the physical and chemical breakdown of rock and mineral particles and release of nutrient elements, and to the accumulation of decomposed organic matter. They are closely associated with both vegetative growth and decomposition by communities of soil biota (Nadelhoffer *et al*., 1992), particularly bacteria and fungi. However, information is limited about species diversity and population size of these Arctic and sub-Arctic communities. Rates of soil development are therefore also related to the combined effects of both temperature and soil moisture regimes (CSSC.,1978; CCELC., 1988; Tarnocai, 1989; Zoltai *et al*., 1980). Layers of decomposed rock material tend to be best developed in moist but well drained soils. In these soils, the thickness of surface organic matter tends to be least because this is where recycling of organic matter and nutrients is most rapid. Rates of soil development throughout the WKSS area are very slow, typically in the order of a few millimetres per century, but peat materials may accumulate much more quickly. Soil development and nutrient availability are significant factors that influence the distribution and growth of higher plants.

2.3. Biological Aspects of the WKSS Area

2.3.1. Biomes and Ecozones

Ecozones (Maxwell *et al*., 1995; Wilken, 1986) are large units of the ecosystem that contain distinctive sets of biological and non-biological resources which are related as a system. They are closely similar to biomes that characterize large and distinctive communities of plants and animals. In the WKSS area, climate is a dominant factor and tundra, taiga and boreal conditions characterize both ecozones and biomes (CCELC., 1989). Within each of these climatic zones, local conditions are very important. General comparisons of terrestrial plant production with received solar radiation (*e. g*. temperature) may be meaningful only when other conditions are also similar (*e. g.* soil nutrients and moisture (Wielgolaski *et al*., 1981)). As latitude increases, relief, slope and aspect become particularly important components of local microclimate (Zoltai *et al*., 1980; Jacobson 1979**)**. The variability of plant species can be as great or greater within-sites than between-sites (Wielgolaski *et al*., 1981). As a result, distributions of plant dependent species (*e. g.* some insects) may exhibit similar diversities over short distances and larger browsing animals may be continually moving from site to site because sources of food are limited at each location.

River valleys provide shelter from wind but summer temperatures at the base of slopes may be much colder than on surrounding flat lands. North and south facing slopes receive significantly different amounts of solar radiation. This is equivalent to as much as 10 to 100 km of latitudinal distance. Well drained soils, as on eskers and kames, warm quickly and may support “islands” of dwarf tree and shrub growth. Poorly drained wetlands with cold and acidic soils severely limit plant root development (CCELC., 1988; Damman & French, 1987; Glaser, 1987), but cold dry soils tend to be most limiting (Wielgolaski *et al*., 1981). Local “shading effects” can occur around individual trees or shrubs, or small rock outcrops. Patterns in the landscape reflect these and other physical characteristics that, in turn, influence the distributions of vegetation cover and animal communities (Geurts, 1983).

Figure 8 shows the distribution of ecozones in the WSK&R, in which ecosystem units have been defined by the ecological land classification system for land areas in Canada (EC., 1991). Ecozones are the largest units. They are subdivided into progressively smaller units based upon similarities or dissimilarities in ecological characteristics, such as climate, soil or water properties, and wildlife.

Each ecozone is subdivided into ecoprovinces, each ecoprovince into ecoregions, and each ecoregion into ecodistricts. Previously, the regional-scale features of climate, vegetation and physical landform have been presented separately (Figs 2 & 6). While the distinctive NW-SE trends in landscape patterns remain, several of the zones defined in Fig. 8 are distinctly different. Indeed, although the climatic and physical characteristics of WKSS area are easily observable, the more complex integrations represented in Fig. 8 may not be so obvious. For example, the tree line of vegetation is closely associated with long term average position of the Arctic frontal zone of climate, but conforms with few of the ecoregion boundaries (Fig. 8). Further, and as discussed in Section 2.3.4.6, regional wildlife distributions may be most easily represented by their direct associations with broadly defined zones of vegetation.

Although Figs. 2, 6 & 8 present information in forms that are suitable for general characterization of the WKSS area at a regional scale, much of the information is not adequate to meet the needs of either direct observation or site-specific assessment of environmental impact. In particular, more sensitive information is required in support of resource inventory, planning and development, and comparisons of environmental change over time. Table 4 provides an example of the types of detail that are required in order to characterize the environment at a more local scale in the WKSS area. This table presents a summary of information that can be collected by ground observation and from both qualitative and quantitative aerial and remotely sensed images (Atkinson, 1999; BHP & Dia Met, 1995; Epp *et al*., 2000; Fitzpatrick, 1999; Tahera Corp., 2000; Traynor, 1998). More detailed information referred to later in this report is also be linked to Table 4.

Connections between plant and animal communities in time and space, both within and between marine, freshwater and terrestrial environments support a complex food web of plants, insects, fish, birds and other animals, and summaries of these are shown in Figs. 9, 10, and 11.

Total production, the mass of living organisms supported in each of these ecozones, depends largely on the amount of energy that can be fixed annually by plant matter (Hare & Thomas, 1974). Net annual production of terrestrial plant organic matter increases from less than 200 $g{\cdot}m^{-2}$ in tundra areas to 300 to 500 $g{\cdot}m^{-2}$ in taiga, and to 500 to 1000 $g{\cdot}m^{-2}$ in boreal areas (Fig. 2). Much of this occurs in the form of underground rhizomes, stems and root material (Bliss & Matveyeva, 1992). Net annual primary production (plant production) in nearshore Arctic marine waters is probably similar to terrestrial tundra areas, or a little less, but in offshore areas it may be substantially less than 100 $g{\cdot}m^{-2}$. In very large lakes (*e. g*. Great Bear and Great Slave lakes) and largely because nutrient concentrations are very low, net annual primary production may be only a quarter, or less, of that in Arctic marine waters. It may be less than a fiftieth of that in equatorial lake systems (Bodaly *et al.*, 1989; Brylinsky & Mann, 1973; Ryder, 1972). Small lakes and streams are usually more productive than large lakes and rivers.

In some of the following parts of Section 2.3, numerical estimates of population densities, mortalities, range areas and migratory distances have been provided for a few species. Unless otherwise indicated, these values should not be taken to be widely representative of the WKSS area. Most of the values have been derived from limited surveys in specific areas and reference should be made to the original citations to ensure that information provided is correctly applied. The values are presented in this report only as statements of available information and as a guide to some of the more direct implications that may be drawn from them.

2.3.2. Marine Ecosystem

2.3.2.1. Nutrients and Primary Production in Marine Areas

Between Victoria Island and the mainland, cold and nutrient poor Arctic water supports only low biological productivity. Tidal ranges and flows are small and there is probably little movement of deep oceanic water or the exchange of associated nutrients into the surface waters of Coronation Gulf. Nutrient levels in runoff from the Shield are generally very low but some marine upwelling may occur in response to the outflow of a few larger rivers (Sly, 1995). This could locally increase nutrients and biomass in surface waters. However, any upwelling that is generated by the offshore movement of a plume of freshwater is likely to be greatly limited by the short period of high river discharge which is typical of many river basins in the WKSS area (Section 2.2.4). In most of the coastal rivers, winter discharge is negligible and runoff is small relative to the volume of receiving water, but the seasonal meltwater discharge may be sufficient to locally depress salinities. Although detailed information is lacking, particulate organic matter from land drainage may be an important addition to some estuaries such as the Coppermine River (Ellis, 1962; Wedel *et al.*, 1988). Based on evidence from other areas in the Arctic, atmospheric fluxes may be an important source of nitrate, nitrite and phosphate nutrients (Sly, 1995). Almost certainly, surface and near surface concentrations of nutrients remain low throughout the growing season, and levels of nitrate are probably very low at the end of summer.

Water clarity varies considerably (Bodaly *et al.*, 1989; Ryder, 1972; Coronation Gulf Air Photo Coverage, various dates). River plumes, particularly during the spring melt, and wave erosion can greatly increase nearshore turbidity and limit primary production in surface waters. Water clarity may be high in other areas, thus allowing light penetration to considerable depth. Chlorophyll *a* is a green pigment that can be used to indicate the presence of plant growth. In very clear water it is possible for light intensity to be greater than the optimum for aquatic plant growth. It is not known if there is a related chlorophyll *a* maximum at depth, as there is in some other parts of the Arctic and sub-Arctic. In some areas, light intensity rather than nutrient availability may limit the growth of aquatic plants (Sly, 1995).

Although quantitative data are not known from this area, ice algae are likely an important part of marine productivity, as in other parts of the Arctic (Sly, 1995). Ice algae start growing as ice begins to form but stop as light levels decrease below critical values during the early part of winter. In the spring, ice algae resume growth. Ice algae are concentrated at the base of the floating ice where salt rejection and ice formation create a thin layer of nutrient enrichment. Ice algae include both pelagic and benthic forms, and benthic forms may become dominant as spring advances and ice break-up begins.

As sea ice melts in place, airborne introductions may produce early blooms of freshwater algae in shallow ponds that form on the surface of the sea ice. However, melting ice also reduces the salinity of near surface water and increasing density stratification may cut off the upward supply of nutrients to surface waters. The nutrient supply for the spring bloom of surface phytoplankton is probably quickly exhausted. Light is a major factor controlling productivity, and ice algae are likely an important part of the total primary production.

Primary production is strongly pulsed in response to light. In comparable areas of the Arctic, partial cropping by pelagic species allows more than 40% of the energy from phytoplankton to enter food chains through benthic components of the food web (Sly, 1995). Partial cropping can occur in the water column if populations of browsing and grazing organisms do not increase rapidly enough to consume all the available food. Unconsumed plant material then settles to the bottom. Little is known about this part of the Arctic food web which is often reflected in the abundance of benthic organisms on both rocky and sandy bottoms (*e. g.* mussels, clams, Brown Sea cucumbers and sea urchins (Bright *et al.*, 1995; Stewart *et al.*, 1993; Zoltai *et al.*, 1980).

2.3.2.2. Structure of the Marine Food Web

The general structure of the food web present in the area between Victoria Island and the mainland is shown in Fig. 9 (EC., 1991; Jensen *et al.*, 1997; Sly, 1995). It is greatly simplified and may exclude components that have special but, as yet, little understood significance. For example, ciliates may be an important link in the energy flow between nanoplankton and microphyto-plankton (including: bacteria, organic detritus, small diatoms and small flagellates) and larger omnivorous zooplankton (*e. g.* amphipods). Locally, contributions of organic matter from terrestrial sources may be significant in coastal areas such as Cambridge Bay (Bright *et al.*, 1995). Structures in benthic components of the food web are not shown because information is lacking. Benthic omnivores such as the Four-horned Sculpin occur throughout the area and are an important species in some coastal areas (Bright *et al*., 1995, Zoltai *et al*., 1980). Primary production at the base of the food web is likely supported both by ice algae that provide a crucial early pulse in the production cycle, and by phytoplankton (Sly, 1995). The ingestion of algal material by large numbers of copepods likely triggers an early start in their reproductive cycle. Copepod eggs and nauplii are a key component in the diet of many larval fish, in particular, the larvae of Sand Lance and Arctic Cod. Indirectly, survival of fish at these early stages may be more dependent on availability of ice algae than the spring phytoplankton bloom. Amphipods, a major group of consumers, also feed on ice algae and on phytoplankton. The Sand Lance uses both planktonic and benthic sources of food. In turn, it is an important source of food for Arctic Cod which also feeds extensively on pelagic crustaceans. Arctic Cod and Capelin support many top predators, including Greenland Cod and Ringed Seals (Klohn-Crippen, 1993).

Estuarine and nearshore environments are important for anadromous fish such as Arctic Char that are tolerant of a wide range of salinities, and semi-anadromous fish such as Arctic Cisco, Least Cisco, Lake Whitefish and Broad Whitefish (Bodaly *et al*., 1989; Ellis, 1962; McCart, 1986; McCart & Den Beste, 1979). During the ice-free season, these fish benefit from higher primary production of these environments. Arctic Char (McCart, 1986; McCart & Den Beste, 1979; Robertson & Dowler, undated; Sirois *et al*., 1995; Stewart *et al*., 1993) are a key species in the coastal rivers of both Victoria Island and the mainland. In summer, stocks of Arctic Char may mingle together at sea where a high proportion of their diet consists of amphipods and small fish. Anadromous fish return annually to over-winter and spawn in accessible freshwaters. These waters remain slightly warmer than salt water and provide thermal protection (McCart, 1986; McCart & Den Beste, 1979; Sly, 1995; Stewart *et al*., 1993). For some anadromous species, the rising spring discharge is used to assist passive migration of juvenile forms from upstream to downstream sites. The juvenile forms may depend upon the availability of early life stages of zooplankton for first feeding at downstream sites.

2.3.2.3. Distributions of Marine Fish and Mammals

Very little is known about the size of populations or distributions of fish and marine mammals between Victoria Island and the mainland. Anadromous fish are present in several rivers entering these waters, including the Coppermine and Tree rivers, rivers entering the Wellington Bay and Cambridge Bay areas of Victoria Island, and rivers entering Bathurst Inlet (Bodaly *et al*., 1989; Bright *et al*., 1995; Ellis 1962; McCart, 1986; McCart & Den Beste, 1979; Robertson & Dowler, undated; Zoltai *et al.*, 1980). Sand Lance, Capelin and Arctic Cod are more widespread. At the mouth of the Coppermine River, water temperatures are about 10^{o} C from late June to late July and may reach a maximum of about 18^{o} C, but conditions are not stable and freshets of warm water may kill fish in the delta. Anadromous fish move out of the river as soon as ice conditions permit and most populations are greatest in the delta after July. Capelin spawn on sandy beaches in the delta in mid-July and are important in the diet of several anadromous species. Return migrations begin in September. Boreal Smelt are known to spawn in several rivers and streams entering Coronation Gulf (Zoltai *et al*., 1980).

Arctic Flounder (feeding on isopods and gastropods), Starry Flounder (feeding on smaller fish such as Capelin) and Saffron Cod have also been caught at Kugluktuk (Ellis, 1962). Several species of sculpin (including Four-horned Sculpin), Eelblenny and Eelpout are present in Coronation Gulf, and small numbers of Bering Flounder and Starry Flounder have been reported from Bathurst Inlet (Zoltai *et al*., 1980). Both of these flounders are thought to be relict species which became separated from parent stocks about 5000 BP when climate change resulted in regional cooling of Arctic waters. Survival of these relict populations may depend on special marine conditions caused by the influence of a shallow sill at the north end of Bathurst Inlet (Zoltai *et al*., 1980). Greenland and Toothed Cod, and Pacific Herring have also been reported west of Coronation Gulf (Stewart *et al.*, 1993).

The Ringed Seal is present in Bathurst Inlet, in Cambridge Bay, and along the south shore of Coronation Gulf, and the Bearded Seal is also occasionally present (Bright *et al.*, 1995; NPC., 1997; Zoltai *et al*., 1980). Mollusc (bivalve) populations, however, may be too small to support Walrus. Although relations between Polar Bear distributions and habitat in this area are not known, this animal is present in both the Amundsen Gulf (Thorpe & Kadlun, 2000) and Queen Maud Gulf areas (NPC., 1997) but generally absent from Coronation Gulf and Dease Strait. The extensive development of thick and continuous ice in Coronation Gulf may restrict winter access to much of the area by seals (and whales) and, hence, the gulf may lack suitable food resources for Polar Bears. The lack of snow cover also restricts potential Polar Bear denning habitat.

2.3.2.4. Birds of the Coastal Region

Coastal-marine bird species are present for only a few months of the year, during the open-water season, and the most diverse community probably occurs around Bathurst Inlet (Zoltai *et al*., 1980). Yellow-billed Loons are widely distributed (Godfrey, 1986; Kalin, 1987). They are present in large tundra lakes and coastal marine waters. These loons nest on freshwater lakes from the tree line north to the coast, and feed mostly in the marine nearshore. King Eider (Barry, 1986) occur on small islands in Bathurst Inlet, inland on grassy tundra (without shrubs and where predators are easily visible), and on some of the islands in Coronation Gulf. Both solitary and semi-colonial nesting occurs (Bromley, 1998). It is thought that King Eider males tend to leave the region (migrating east to west) before ice formation but late leaving females and young may be trapped in an early freeze-up. Colonies of Common Eider (Pacific race (NPC., 1997)) nest on small sand and gravel islands (isolated from Arctic Foxes) in ice-free areas of Dolphin and Union Strait, Coronation Gulf, Bathurst Inlet and in Elu Inlet (Barry, 1986; Bromley, 1998). They also migrate westward before freeze-up. Glaucous Gulls often nest close to Common Eiders and are an important predator on young Eider Ducks (Bromley, 1998). Red-breasted Mergansers are more common than the Yellow-billed Loons. Near the coast, they share similar habitat and may be present in rivers, as well (Zoltai *et al*., 1980). Small numbers of Herring Gulls and Glaucous Gulls occur throughout the region. Both nest in coastal areas and Herring Gulls also nest inland. Small colonies of Arctic Terns are present in a few areas (Bromley, 1998). Loons, mergansers, and Arctic Terns feed extensively on small fish and invertebrates in shallow coastal waters. In the marine environment, many species of sea ducks also feed on invertebrates in the water column and eiders feed on bivalve molluscs (Blue Mussel and clams).

Several species of wading birds (shorebirds), including phalaropes, plovers, and sandpipers (Godfrey, 1986; Zoltai *et al*., 1980) are present where mud flats and marshlands provide a sufficient source of small invertebrate foods, including molluscs, gastropods and dipteran larvae.

2.3.3. Freshwater Ecosystem

2.3.3.1. Nutrients and Production in Freshwater

The freshwater ecosystem includes species adapted to a wide range of aquatic environments. These range from extremely large deep lakes (*e. g*. Great Bear Lake (Johnson, 1975) and Great Slave Lake (Rawson, 1950)) to many smaller and more shallow lakes, ponds and marshes, and to rivers and streams with great seasonal variations in flow and water level. As in the marine environment, nutrient concentrations are low or very low throughout the growing season and net annual production is generally less than in Arctic marine waters.

Most of the primary production in large deep lakes comes from phytoplankton. Annual primary production values range from less than 4 g $C \cdot m^{-2}$ in the East Arm of Great Bear Lake, 15 g $C \cdot m^{-2}$ in McLeod and Christie bays (East Arm of Great Slave Lake), 30 g $C \cdot m^{-2}$ in the western basin of

Great Slave Lake, to about 40 g C·m^{-2} in Yellowknife Bay (Fee *et al.*, 1985; Johnson, 1975). Nutrient concentrations in Canadian Shield drainage are generally low and primary production from phytoplankton is also low in many small lakes. There may be significant variations in year to year primary production. This is particularly so in bays and deltas that are influenced both by variations in run-off and nutrient contributions from surrounding watersheds, and by climatic variations. Rawson (1956) noted greater phytoplankton growth in Great Slave Lake during years with warm springs and a larger inflow from the Slave River. Seasonal distributions of phytoplankton in Yellowknife Bay reflect the relative influence of water from the main lake and the Yellowknife River (which contains effluent discharge from Yellowknife ((Fee *et al.*, 1985; Moore, 1980)).

In clear shallow lakes more light can penetrate to the bottom and a significant part of the bed may be covered by benthic algae. In clear lakes and streams, some algae (periphyton) may also be attached to hard surfaces. Primary production from both of these algal forms may be equal to or greater than that of phytoplankton (Johnson, 1975). *Chrysophyta* are the most important phytoplankton in turbid lakes. In addition, in very shallow lakes, primary production from rooted aquatic plants (macrophytes) can be several times greater than that of phytoplankton (Johnson, 1975).

The biomass of fish is low in most streams, rivers, ponds and lakes of the WKSS area. In natural systems (not subject to heavy fishing pressures), it tends to be concentrated in relatively small numbers of large old fish. These represent the conversion and storage of many years of primary production (Johnson, 1973; McCart, 1986; McCart & Den Beste, 1979; Ryder, 1972). Terrigenous inputs of organic matter and nutrients are very important, and so are atmospheric inputs of nutrients (Sly, 1995). Latitude ranges from about 62^{o} N to nearly 70^{o} N across the WKSS area and this results in additional differences in growth potential related to temperature, light, and ice cover (Brylinsky & Mann, 1973; Pienitz *et al.*, 1997; Ryder *et al.*, 1974; Schlesinger & Regier, 1982). Except in large lakes, the effects of nearshore ice scour are much less than in marine coastal areas. This allows rooted aquatic vegetation to become established, except in areas of high turbidity (mostly due to suspended sediment). Because concentrations of all forms of plankton are low, water clarity is generally very high. Secchi depths range from about 13.7 m in Great Bear Lake, to 10.7 m in Great Slave Lake, and to 4.5 m in Lac la Ronge. These values are typical of large boreal lakes (Ryder, 1972).

Also, as in the marine environment, partial cropping allows a significant amount of the primary production to pass into the food web through its benthic components. This occurs when secondary feeders such as zooplankton grazers under utilize primary production. Under utilization in the water column can occur over large areas if phytoplankton densities are too low or too patchy to support significant assemblages of zooplankton. Locally, it may occur if warming or an influx of nutrient-rich waters creates a brief pulse in primary production. In general and across regions of broadly similar climate, most variabilities in productivities of aquatic ecosystems are linked to nutrient availability and feeding efficiencies in different parts of the food web (Brylinsky & Mann, 1973). Climatic factors, and differences in late glacial and postglacial development of the region have probably influenced the distributions of some species (Brylinsky & Mann, 1973; McCart, 1986; McCart & Den Beste, 1979**)**.

2.3.3.2. Freshwater Food Web and Fish Distributions

Figure 10 provides a greatly simplified summary of the structure of the region's freshwater food web. Phytoplankton include drifting green and blue-green algae, and diatoms (Fee *et al.*, 1985; Johnson, 1975; Moore, 1978; Rawson, 1956). Algae also may be present as benthic and attached forms (Bodaly *et al.*, 1989). Larger floating plants include Chickweed, and rooted aquatic plants (macrophytes) include Yellow Pond-Lily and Water Milfoil. Emergent and wetland species include bulrushes, cattails, rushes, and horsetails (BHP & Dia Met, 1995; Zoltai *et al.*, 1980).

Zooplankton include a great variety of small organisms that derive most of their food from living or dead phytoplankton, or other zooplankton (Fee *et al.*, 1985; Healey & Woodall, 1973; Moore, 1977). In tundra streams, larval drift is comprised mostly of insects (Diptera) and small crustaceans (Sections 9.4 and 9.5 (BHP & Dia Met, 1995)). Species composition increases significantly in boreal areas of the WKSS area. Many of the same species of cladocerans, cyclopoids, and calanoids occur widely across northern Canada. Shrimp-like amphipods (*e. g. Gammarus* and *Pontoporeia*) and mysids are also typical of larger lakes (Fee *et al.*, 1985; Healey & Woodall, 1973; Johnson, 1973; 1975; Rawson, 1950; 1956). Chironomids (dipteran larvae), oligocheate worms, sphaeriid bivalves, and small gastropods (snails) are typical benthic feeders (BHP & Dia Met, 1995; Fee *et al.*, 1985; Healey & Woodall, 1973; Rawson, 1956). The larval and nymph stages of many aquatic insects are also adapted to stream habitats (*e. g.* blackfly, mayfly and stonefly) and pond habitats (*e. g.* caddisfly and mosquito). The insects feed on detritus including fungi and bacteria and other organisms including diatoms (Moon, 1970; Moore, 1977; 1979). Frogs can provide an important link between insects and higher parts of the food web but they are only present in streams and wetlands south of the tree line (*e. g.* Boreal Frog and Wood Frog). Many species of aquatic invertebrates are environmentally sensitive and their abundance can be a useful indicator of changing conditions. Climate and habitat naturally limit the number of species and their distributions in the WKSS area, including those in the aquatic environment. Because of this, measures of density rather than diversity or the use of indicator species are most appropriate as indicators of stress, (*e. g.* pollution (Moore, 1977)).

Away from the effects of postglacial marine inundation along the Arctic coast, the structure of fish communities is somewhat unpredictable (Bodaly *et al*., 1989; McCart, 1986; McCart & Den Beste, 1979). A number of small fish species provide a key link between upper and lower parts of the food web (BHP & Dia Met, 1995; Scott & Crossman, 1973). Troutperch is common in the warmer waters of streams and shallow lakes where it feeds on insects and zooplankton. Ninespine Sticklebacks occur in similar areas and feed on insects and crustaceans. Lake Chub has a similar diet but also feeds on algae (BHP & Dia Met, 1995; Scott & Crossman, 1973). Goldeye grows to larger size, its diet includes other small fish and it is adapted to turbid conditions in warmer and shallow water. It is an important species along the south shore of Great Slave Lake (McCart, 1986; McCart & Den Beste, 1979). Yellow Perch has a similar diet and is also limited to warmer but less turbid lake waters in the upper part of the Mackenzie basin where it occurs in small numbers (its range also coincides with more abundant populations of Walleye). Slimy Sculpins are adapted to colder waters and occur in streams and in lakes to depths of 30 m or more. The Four-horned Sculpin is a widely distributed glacial relict species and may be present to depths greater than 350 m. It is also widespread in the marine environment but it is not migratory. Both sculpins are bottom feeders (McCart, 1986; McCart & Den Beste, 1979). Longnose Suckers are larger bottom feeders. They are present to moderate depths and widely distributed in most of the WKSS area.

The juveniles of many fish species feed on zooplankton of various sizes but they are also subject to cannibalistic feeding by adults of their own species. Juveniles tend to be distributed peripherally, especially in large lakes, where mergansers and terns may be important predators. However, survivors grow rapidly to join the population of adult fish.

Boreal Smelt and ciscoes are key plankton feeders in many lakes and rivers (Zoltai *et al*., 1980). The Arctic Cisco is is widely distributed in the lower parts of many rivers, along the coast between the Mackenzie River and the Kent Peninsula, and along much of the southern part of Victoria Island (McCart, 1986; McCart & Den Beste, 1979). The Least Cisco is present in mainland rivers and lakes, and extends south to Point Lake in the Coppermine River drainage and to Contwoyto Lake in the Burnside River drainage (BHP & Dia Met, 1995; Ellis, 1962; McCart, 1986; McCart & Den Beste, 1979). The Lake Cisco occurs throughout the WKSS area, except in the coastal areas north of Contwoyto and Dismal lakes and north of the Great Bear Lake drainage. Some populations of ciscoes may migrate within drainage basins and spawning tends to occur on sand or gravel in tributary areas. In some shallow lakes, benthic algae and periphyton may also provide a significant part of the diet for migratory coregonids, particularly anadromous ciscoes (Bodaly *et al*., 1989).

The Inconnu is a major predator of smaller fish and is present in much of the Mackenzie River drainage, including Great Bear Lake and Great Slave Lake. This species is anadromous in the lower reaches of the Mackenzie River and both freshwater and anadromous forms are migratory (Bodaly *et al*., 1989; Howland *et al*., 2000; McCart, 1986; McCart & Den Beste, 1979). Inconnu are relatively fast growing and spawn in areas of fast flowing water. In the lower Mackenzie drainage, spawning may be 6 weeks earlier than at the southern limit of it range (Howland *et al.*, 2000). Inconnu from the lower Mackenzie make extensive use of the delta for feeding and overwintering but there is little mixing with upstream stocks. Few Inconnu in the Lower Mackenzie move above Norman Wells and those in the Liard River remain below Great Slave Lake (Howland *et al*., 2000). Inconnu that feed and overwinter in Great Slave Lake, move into the Slave River during late August and September. They spawn in the Fort Smith area during October and return to the lake in November. Inconnu also migrate into the Buffalo, Little Buffalo, and Taltson rivers, and some upstream migrations may be barrier-limited (Howland *et al.*, 2000).

Walleye is another predatory species. Its preference for warmer (and more turbid) waters restricts it to areas south of the tree line. Its abundance generally increases within the Boreal climate zone (Scott & Crossman, 1973). Walleye are present throughout much of the Mackenzie drainage basin but abundance is low in Great Bear Lake and to the north of it. The most significant populations of this species are present in Great Slave Lake (excluding McLeod Bay and Christie Bay), Lac Grandin, Lac la Martre, Kakisa Lake, Tathlina Lake and in the Taltson River (Bodaly *et al*., 1989; McCart, 1986; McCart & Den Beste, 1979). Walleyes spawn on coarse bottom sediment soon after ice break-up. Northern Pike occur throughout the mainland. They also prefer warmer and shallower lake waters, and their diet consists mostly of small fish. Northern Pike spawn after ice break-up, in weedy nearshore areas. Arctic Graylings are generally slow growing and spawn in small tributaries shortly after break-up. They are present in many mainland rivers and streams, and some lakes. Their diet includes small fish, stream drift and surface insects. In Great Slave Lake, Arctic Graylings are present mostly along the rocky northern shore.

Three species of whitefish are present (Bodaly *et al*., 1989; Healey, 1975; Healey, 1980; McCart, 1986; McCart & Den Beste, 1979; Muth, 1969). The Broad Whitefish is present in the Mackenzie River, north from Fort Simpson and in the coastal drainage of mainland streams, but it is not present on Victoria Island. Round Whitefish and Lake Whitefish occur throughout most of the region, but the Round Whitefish is absent on Victoria Island. All of these whitefish species are cold-adapted but Lake Whitefish and Round Whitefish tend to be separated, within lakes, by their preferences for feeding on different benthic communities. Though both species include small molluscs and benthic invertebrates in their diet. Round whitefish occur mostly at shallow depths. Lake Whitefish are dominant in large lakes and optimum growth rates occur in areas with a climate equivalent of about 890 to 1220° C degree days. Whitefish spawn on coarse bottom materials in cooling near-surface waters before ice begins to form.

Lake Trout is the most widespread fish species in the region (Bodaly *et al*., 1989; Johnson, 1973; 1976; McCart, 1986; McCart & Den Beste, 1979; Rawson, 1951; Scott & Crossman, 1973). It is long-lived (to 60 years or more) and can grow to be one of the largest fish (to 0.5 m or more) in the WKSS area. The species takes longer to mature with increasing latitude. For example, first spawning may not occur until 12-14 years old, as in Great Bear Lake (McCart & Den Beste, 1979). It uses a wide variety of food sources, with preference for amphipods and mysids, and small fish, and prey size increases as the fish gets bigger. Where available, ciscoes may form much of its diet. Lake Trout disperse widely to overwinter, and may move 100 km or more in some river-lake systems (McCart & Den Beste, 1979). At break-up, they may concentrate to feed in surface waters. Lake Trout move to deep water as surface waters warm (above 10° C). Spawning occurs on coarse material in shallow water, usually in late September or during October.

Arctic Chars (Ellis, 1962; McCart, 1986; McCart & Den Beste, 1979; Muth, 1969; Robertson & Dowler, undated; Scott & Crossman, 1973) occur both as landlocked populations (*e. g.* Keyhole Lake, Victoria Island) and as anadromous populations (*e. g.* Nauyuk Lake, Kent Peninsula). Anadromous populations grow faster because their diet is enriched with marine organisms. Arctic Chars are particularly adapted to severely changing stream conditions and, in freshwater, their diet is composed mostly of insects and crustaceans. The anadromous habitat of Arctic Chars may be limited in parts of Coronation Gulf and Bathurst Inlet, by physical constraints such as falls or rapids (*e. g.* Tree River (Robertson & Dowler, undated)). Arctic Char spawn in shallow water on coarse bottom materials shortly before ice begins to form.

Burbot is a cold water species that occurs to depths of 100 m or more and is an important predator in most large lakes and rivers in the region (McCart, 1986; McCart & Den Beste, 1979; Scott & Crossman, 1973). Burbot feed on whitefish, ciscoes, sculpins, sticklebacks, mysids, amphipods and small molluscs).

Because of energetic constraints, populations of some fish species may not spawn every year or spawning may not occur in the same year as an anadromous return. This reflects limited food supply and an inability to convert sufficient energy into reproductive materials (McCart, 1986; McCart & Den Beste, 1979). For example, Arctic Char and Lake Trout may spawn every other year or once in every three years at some high latitude sites. In addition and across much of the WKSS area, constraints in food supply may be reflected by seasonal variations in diet and trophic relationships (Little *et al.*, 1998). Many species of fish are opportunistic feeders. For example and in place of their preferred diet or dominant food source, some invertebrate feeders consume small fish and some plant material. Northern Pike may include rodents, snakes and small birds in their diet (Little *et al*., 1998). In the Lower Slave River, there are some dietary overlaps between Walleye and invertebrate feeders during the spring, and between Walleye and northern Pike during the summer. Several benthic invertebrate feeders also have dietary overlap during the spring and summer but, in most species, feeding declines rapidly during the fall. Shallow water prey species include Emerald Shiner, Ninespine Stickleback, Troutperch, and y-o-y (young of the year) Lake Chub, Goldeye, Lake Whitefish, Longnose Sucker, Northern Pike and Walleye. Deepwater prey species (particularly during the spring) include Arctic Lamprey, Burbot and Lake Chub (Little *et al.*, 1998).

In terms of human use, the most important fish species are Northern Pike, Broad Whitefish, Lake Whitefish, Round Whitefish, Lake Trout and Arctic Char. Arctic Graylings have been a part of the domestic fishery (McCart, 1986; McCart & Den Beste, 1979).

Unlike the marine environment, most mammals (excluding humans) are not significant top predators in lakes and rivers, and otters and muskrats are largely limited to areas south of the tree line.

2.3.3.3. Birds of the Freshwater Areas

Open water is crucial for staging ducks, and many lakes provide an important migratory corridor north to the shores of Coronation Gulf and Bathurst Inlet, and across to Victoria Island (Alexander *et al*., 1991; BHP & Dia Met, 1995; Bromley & Buckland, 1995; Bromley & Stenhouse, 1994; McCormick & Bromley, 1990). During the spring migration, between mid-May and early June, a total of 65,000 birds of 34 species have been reported south from Yellowknife to the Beaulieu River (Alexander *et al*., 1991; Bromley & Buckland, 1995; Sirois & Cameron, 1989). These include Greater Scaup and Lesser Scaup and Canada Goose which, together, make up nearly half of all the birds observed; Mallard and Tundra Swan, each about 10% or more of the birds present; Surf Scoter, American Widgeon, Northern Pintail and Lesser Snow Goose, each about 5% or more of the birds present; and small numbers of Red-breasted Merganser, Common Loon, White-winged Scoter, and Bufflehead. The north shore of Great Slave Lake is also a major stop-over for spring migrants, with 90,000 birds of 29 species recorded in some years (Alexander *et al*., 1991; Bromley & Buckland, 1995). Inland, in the Artillery Lake area (Alexander *et al*., 1991; Sirois & McCormick, 1991), surveys have reported 39,000 to 49,000 waterfowl (70% geese, but with large numbers of ducks and tundra swans). Other important staging areas include the Slave River delta, the Mackenzie River near Fort Providence, and the Snowdrift and Thelon rivers (Alexander *et al.*, 1991; McCormick *et al*., 1990). At these sites, geese and many ducks feed on over-winter berries and the green shoots of sedges. Berries on exposed hilltops and south-facing slopes of upland tundra provide particularly important spring feeding sites for geese. Diving ducks feed on insects, crustaceans, molluscs, and small fish.

Fewer waterbirds nest on Great Slave Lake than in nearby small lakes and marshes. Most waterbirds nest near productive wetlands and shallows along the North Arm of Great Slave Lake, where about 100 bird species have been recorded (Alexander *et al*., 1991). Some waterbirds are near the northern and some near the southern extremities of their range, and although there is no shortage of nesting habitat, populations are likely limited by the low net production of the environment. Migrant arrivals coincide with snow- and ice-melt, and include Red-necked Grebes, Horned Grebes, Canvasbacks, Hooded-Mergansers and Harlequin ducks.

Red-necked Grebes are widely distributed in the southern part of the WKSS area where breeding pairs select nesting sites on emergent vegetation away from shore (Cattail, horsetail and sedges) in large ponds. Pair densities are about 1.6 $\cdot km^{-2}$ and the WKSS area probably supports much of the Canadian population of this species (Fournier & Hines, 1998a). Horned Grebes are present in the same general area from mid-May to early September. They nest on shoreline and nearshore emergent vegetation, in small ponds but breeding success is more variable and strongly influenced by predation from Raven, Mink, Herring Gull, California Gull and, occasionally, Great Horned Owls. The density of breeding pairs (2.2 $\cdot km^{-2}$) is higher than for Red-necked Grebes (Fournier & Hines, 1999). Canvasbacks are widely distributed in ponded areas of open woodland in the northern boreal forest. However breeding success in the WKSS area is lower than in boreal areas of the Canadian Prairie provinces. A ten-fold population increase of Canvasbacks in the Yellowknife area between the mid-1960's and mid-1980's is thought to be due mostly to in-migration (Fournier, 1998b). Hooded Mergansers are an occasional summer transient in the forested wetlands around Yellowknife, but recently increasing numbers may indicate population expansion or dispersal caused by deforestation within their normal range (likely in Alberta). Hooded Mergansers are thought to be present for staging or moulting but breeding is unlikely in the WKSS area (Fournier, & Hines, 1996). Harlequin ducks feed mostly on insects in fast flowing streams and rivers and a few breeding pairs may be widely dispersed over the WKSS area (Fournier & Bromley, 1996). Breeding populations of Common Loon, Mallard, American Widgeon and Surf Scoter are thought to have become established since surveys of the Thelon River valley in the 1930's. They may reflect range expansion in response to warming (Norment *et al*., 1999).

Gulls arrive in mid-April, and terns in late May after shore areas become free of ice. Gulls are a major nest predator and they feed on the eggs and young of other birds. The emergence of insects and the presence of small fish in late June and early July provide a major source of food for terns. Early frosts quickly reduce the abundance of insects, and terns leave shortly afterwards. Gulls leave as freeze-up begins. In decreasing abundance, species breeding in Great Slave Lake include: California Gull, Herring Gull, Common Tern, Mew Gull, Arctic Tern, Ring-billed Gull, Caspian Tern, Parasitic Jaeger, and Boneparte's Gull (McCormick & Sirois, 1988; Sirois *et al.*, 1995). Small numbers of White Pelican, Franklin's Gull and Glaucous Gull also nest in the lake. Black Terns breed in nearby marshes.

Overall, the number of bird species present generally decreases northwards but in some groups, such as shorebirds, the number of species may actually increase. Abundance surveys made for environmental assessments of mine developments in the WKSS area (*e. g.* BHP & Dia Met, 1995) indicate that, where present, numbers of these summer migrants are generally less than 10 birds per km of shoreline. Typical shorebird habitat includes marshes, beaches and mudflats, but these are of limited occurrence over most of the WKSS area. Greater abundance would be expected in some marine coastal areas with better and more extensive habitat. In the Lac de Gras area, shorebirds include American Golden-Plover, Least Sandpiper, Stilt Sandpiper and Red-necked Phalarope (*e. g.* BHP & Dia Met, 1995).

2.3.4. Terrestrial Ecosystem

Climatic conditions are most extreme in the terrestrial environment and adaptations in terrestrial ecosystems also tend to be more pronounced than those in marine and freshwater ecosystems. Many plant and animal species are not present over all of the WKSS area, and several plants are unique in their adaptation to low temperature and an extremely short growing season (Billings, 1992). Often plants are present only in dwarf form at the northern part of their range. Figure 11 provides a general summary of the terrestrial food web in which insects (many with early life stages in aquatic forms), mammals, and birds are the dominant groups. Many food chains are short and link plants, insects and birds, or plants and different groups of mammals.

2.3.4.1. Nutrients and Plant Growth

Plant growth occurs within the active layer of soil, in which some seasonal decomposition occurs. Climate has a strong effect on below-ground tundra soil respiration and CO_2 release during both winter and summer, but vegetation type is of greatest influence during the summer (Grogan & Chapin, 1999). In winter, most litter degradation occurs at the beginning and at the end of the season when soil temperatures are -5^{o} C or warmer. This is enhanced by early snowfall (providing moisture and thermal insulation). Vegetation type affects the quality of litter. Depending on soil and vegetation type, 25 to 50% of annual CO_2 production from soil degradation may occur during the winter period (Grogan & Chapin, 1999). Simple models of C and N interactions between plants and soils with a closed N-cycle show convergence. That is, rapid plant growth with highly efficient N-use results in litter with a high C:N ratio but a low rate of mineralization. Slow plant growth with poor N-use efficiency results in litter with a low C:N ratio but high mineralization rate (Tateno & Chapin, 1997). Seasonal dynamics of tundra litter and soil are similar and N availability to plants is likely greatest at snowmelt. However, if soil temperatures are too low for active root growth or microbial activity, much of the available N is probably lost in runoff to aquatic systems. This is consistent with N-limitation observed in tussock tundra (Hobbie & Chapin, 1996).

Growth is nutrient limited in most high latitude areas, especially by the availability of nitrogen (Billings, 1992). Generally, about half of the nitrogen requirements are met by N-fixation from the atmosphere and precipitation provides an important additional source. Cyanobacter are major N-fixers. They are present both as free living bacteria at the soil surface and as symbionts in lichen (Chapin & Bledsoe, 1992). Lichens appear to be little specialized for temperature. Although optimum conditions for N-fixation are 15 to 25^{o} C, some nitrogenase activity can occur at temperatures just below freezing (Chapin & Bledsoe, 1992). Snow Fleas can be an important consumer of vegetation and soil fungi, contributing to soil formation in woodland areas (Bastedo, 1999). However, most decomposition occurs as a result of bacterial action and, relative to soils in more temperate climates, other forms of soil biota are mostly lacking.

Decomposition rates are slow and nutrient turn-over times are long. In wetter soils considerable quantities of nutrients are held in only partly decomposed organic matter and may become lost in permafrost. Although microbial respiration is measurable below freezing, cellulose degradation occurs mostly above 10^{o} C (Nadelhoffer *et al*., 1992). Rates of litter decomposition are greatest for deciduous shrubs and grasses, lower in evergreens, and they are least in mosses, lichens and woody tissues. Symbiotic relations exist between some fungi and the roots of higher plants. In mycorrhizal networks of Arctic soils, fungal activity in the roots of plants produces compounds of nitrogen and phosphorus that can be used as nutrients by the host plant. Carbohydrates produced by the host plant are used by the fungi. *Sphagnum* moss derives much of its nutrient requirement from percolating water (Tenhunen *et al*., 1992). As Arctic soils age and thicken, the distance from the mineral horizon may become critical, especially for the availability of phosphorus. Coastal salt marshes occur rarely along the Arctic shoreline (particularly because of ice-scour) but, where present, phosphorus is more available and plant productivity may be much greater than on the surrounding land area (Chapin & Bledsoe, 1992).

Plants place a heavy demand on nutrient availability early in the season, and phosphorus supplies can be severely depleted within the first two weeks of plant growth (Kielland & Chapin, 1992). Phosphorus cycling may occur as much as 200 times and nitrogen cycling as much as 10 times in a growing season (Nadelhoffer *et al*., 1992). High nutrient demands at the start of the growing season and frequent nutrient cycling are not peculiar to Arctic and sub-Arctic plants. However, he conditions under which they occur (short growing season and very limited nutrient supply) present special difficulties, and adaptations occur in several species of plants. For example, extensive surface or near-surface root mats allow plants to absorb nutrients from large areas and to avoid root saturation in wet soil. Adventitious rooting, such as from the roots or stem in Black Spruce (Candelabrum Spruce), can also compensate for root death due to increased soil saturation (*e. g.* rising water level) or nutrient and moisture competition from surrounding ground cover (*e. g. Sphagnum*).

Over most of the WKSS area, plant production is dependent on conditions during at least two growing seasons. The number of buds that form depend on conditions in one season and their growth depends on conditions in the following season (Wielgolaski *et al*., 1981). At the end of each growing season, deciduous plants move carbon and nutrient resources from leaves to storage in stems and roots, or swollen leaf-bases (Berendse & Jonasson, 1992). These reserves provide a key source of energy to support rapid development at the very start of the next growing season (Kielland & Chapin, 1992). Evergreens store carbon and nutrients in leaves and shoots above ground. They continually remobilize them from senescing tissue throughout the growing season. Winter tissue loss may be critical to the survival of evergreens. Carbon is stored mostly as polysaccharides (such as starch) in lichens and mosses, and as sugars in shrubs.

2.3.4.2. Plant Distributions

Globally, climate is the dominant control on what and where plants can grow, and both physical and chemical conditions greatly influence vegetation type and form (Bliss & Matveyeva, 1992; Kielland & Chapin, 1992; Wielgolaski, 1981; Wielgolaski *et al.*, 1981). The seasonal time available when temperatures are sufficient to support plant growth is particularly important. There is a general relationship between mean annual temperature and the number of species of vascular plants. Based on general latitudinal relationships, diversities of about 100 plant species (per 10,000 km^{-2}) may be present in the Cambridge Bay area and more than twice this number around Yellowknife (Billings, 1992). At high latitudes, vascular plants become progressively less important in plant communities. The proportion of below-ground to above-ground plant tissue increases with the severity of climate

(Wielgolaski, 1981; Wielgolaski *et al*., 1981). Underground rhizomes provide plant storage and vegetative propagation in monocotyledons. Their erect and blade-like leaves are well suited to capture low-angle solar radiation in the tundra environment. Tap roots, as in some species of forbs, provide another means of plant storage. Low spreading cushion-plants (*e. g. Dryas* sp.) are typical of more windy and exposed tundra locations. Above the tree line, dwarfism occurs in several species of vascular plants (Wielgolaski, 1981; Wielgolaski *et al*., 1981).

Deciduous plants have higher photosynthetic rates than evergreens and maximize growth above ground, and are therefore more sensitive to light shading (Sveinbjornsson, 1992). Soil temperature is usually more important than air temperature, especially for deciduous plants. Moisture is very important for both deciduous and evergreen plants. It may restrict the number of species capable of establishing themselves in a given area. Saturated and acidic soils generally favour the growth of *Sphagnum* moss, and tussock sedge develops in moist but less saturated conditions (CCELC., 1988; Nadelhoffer *et al*., 1992; Wielgolaski, 1981; Wielgolaski *et al*., 1981). Lichens are more competitive in areas where soil moisture contents are low, such as in rocky or well drained areas. They are also competitive where conditions are windy and summer drought occurs, or where most of the biomass of vascular plants is below the ground surface (Wielgolaski, 1981; Wielgolaski *et al*., 1981). Crustose lichens colonize many forms of bare substrate, often as a thin film of brightly coloured organic matter on bare rock. Under more favourable conditions, foliose lichens form thicker and slab-like forms. Fruticose lichens are more plant-like in appearance and may grow to a height of several centimetres. Several species of this form provide important grazing for caribou. In northern boreal forest areas, trees may also provide a substrate for hanging lichens (bearded lichens). Nutrient availability can be an additional influence that favours selected species. Evergreens have lower absorption rates and Black Spruce are tolerant of nutrient-poor and light-shaded conditions. White Spruce are more competitive where nutrients and shade are less limiting.

Vegetation differs in each of the three major climatic zones (CCELC., 1989) within the WKSS area (Fig. 2). The Low Arctic climatic zone (CCELC., 1989) is characterized by treeless tundra. This zone covers the area north of a line running from the headwaters of the Lockhart drainage to the mouth of the Coppermine River, then generally westwards towards the northern limit of the Great Bear Lake drainage. Wet meadows of cottongrass, sedge and grass are typical of sedge tundra, and tussock tundra forms in areas where standing water may occur early in the growing season. Organic soils develop in poorly drained areas of sedge and tussock tundra. Elsewhere, Bilberry (Bog Blueberry), Labrador Tea and Lingonberry (Mountain Cranberry or Cowberry) are typical of areas with moist and acidic soil. Shrub tundra is typical of sheltered sites with both good drainage and sufficient moisture. Where protected from the wind, as on esker slopes and river banks, Green Alder, birch and willow may grow to as much as 2 m in height. Dwarf shrub tundra occurs over well drained but exposed upland areas where vegetation is typically comprised of Dwarf Birch, Crowberry (Curlewberry), Bilberry and Labrador Tea. Mountain Avens occurs on thin gritty and generally non-acidic soils where winter snow cover is minimal or absent. Herbaceous tundra vegetation is more limited in extent and is characteristic of warm but often frequently disturbed sites. For example, where soil movements are due to slope failures and creep or animal denning, as occur along stream banks and the south slopes of eskers. There, plant communities may be enriched with a variety of species including River Beauty, Tundra Wormwood, Liquorice-root, Prickly Saxifrage and Variegated Horsetail.

South of this climatic zone, and to a line extending between the most easterly and northerly points of Great Slave Lake, and then generally westwards, the sub-Arctic climatic zone supports taiga vegetation (CCELC., 1989). This typically includes open conifer stands of Black Spruce, Tamarack and White Spruce. At lower levels, ground cover includes Dwarf Birch and willow, Labrador Tea, cottongrass, moss and lichen. Drier sites favour White Spruce and low covers of Lingonberry, Bearberry, Crowberry, Dwarf Birch, moss and lichen. Sedge tussock and *Sphagnum* moss predominate in poorly drained areas. Balsam Poplar, White Spruce and Paper Birch occur in more sheltered river valleys. To the west of Great Slave Lake, slightly warmer winter temperatures and increased precipitation favour increasing tree size and vegetation cover. The tree line (Fig. 5) approximates much of the taiga-tundra boundary north of the Lockhart River drainage.

The rest of the region lies within the Boreal climate zone (CCELC., 1989) in which forest cover is generally closed and where the dominant tree species are Black Spruce, Jack Pine (over rocky and sandy soils), and some Paper Birch. The lower cover is comprised of feather moss, Bilberry, Labrador Tea, Lingonberry and lichen. White Spruce, and Balsam Fir are climax species but they may be poorly represented where there is frequent reoccurrence of fire. Balsam Poplar, and Trembling Aspen are characteristic of warmer but moist sites. Over poorly drained areas, Black Spruce, Labrador Tea, Bilberry, Bog Rosemary, and Cloudberry predominate.

Northern ponds age over very long periods of time, in part by the addition of sediment but mostly by the accumulation of dead and partly decayed plant material. Slowly, the processes of accumulation begin to form a bog or fen. Tundra bogs and fens lack trees and may consist mostly of mosses, sedges, and low shrubs. Boreal bogs and fens, however, are characterized by large carpeted areas of wet and spongy *Sphagnum*, sedges, and conifers (CCELC., 1988; 1989). Black Spruce is common in more southerly areas. Bogs are more lacking in nutrients than fens. Sedge and Black Spruce associations are typical of areas at the outer edge of a bog, where inflowing water carries some mineral-derived nutrient from the surrounding areas (CCELC., 1988; Damann & French, 1987; Glaser, 1987). *Sphagnum* and Black Spruce associations are typical of the more central parts of a bog, remote from nutrient inputs. Both bogs and fens change over time. For example, as plant materials accumulate and if precipitation exceeds evaporation, the central part may rise relative to the edge. This forms a raised bog and, sometimes, it encloses areas of open water. In large part, this is because *Sphagnum* has a great capacity to absorb and hold moisture. Palsa bogs are also raised but they are usually without water-filled openings. They develop where the accumulation of plant fibre provides enough insulation to accelerate permafrost formation beneath the bog (CCELC., 1988). Over most of the WKSS area, the cover of peatland (both bogs and fens) is less than 5%. But, between Great Slave Lake and Great Bear Lake this may increase to as much as much as 25% (Tarnocai, 1989).

2.3.4.3. Insects in the Terrestrial Food Web

Almost all animals consume plant material in at least part of their diet. Most prefer live material high in nutritive value. For example, chemical energy stored as carbohydrates in leaf-base, roots, berries and seeds, or specific nutrients like protein in plant enzymes (Jefferies *et al.*, 1992). Some insects also feed on living green plant tissue and others derive most of their food from decomposing plant material and associated fungi and bacteria. Many insects prefer deciduous trees and shrubs because they are less protected by natural plant chemicals than evergreen plants (Bryant & Reichardt, 1992). However, some insects like the Spruce Budworm have adapted to evergreen plant defense.

The number of insect species declines northwards across the WKSS area, particularly north of the tree line. About 20,000 insect species are estimated to be present in boreal areas, half that number at the tree line, about 1,000 species at the northern edge of the taiga, and 300 or less in the tundra (Moon, 1970). Many insects spend much of their life-cycle in water which provides a temperature-moderated environment for over-winter survival of eggs and larvae. More than 60 species of blackfly occur in the boreal forest ecozone where most are associated with well oxygenated, clear, and cold stream waters. The blackfly "season" for the adult stage may extend from April to October. Although the number of blackfly species decreases northwards, they are one of the most abundant insects throughout the WKSS area. Mosquito larvae are more typical of pond and slow moving waters. Many insects have special adaptive behaviours. For example, in extreme northern areas, mosquito larvae may bunch together and "follow the sun" to maximize heat-gain (Moon, 1970). In their larval forms, the widespread distributions of stonefly and caddisfly are important in the food chains of many fish species. As adults, they are important in the food chains of several birds. Caterpillars are an important component of some terrestrial food chains, and boreal forest areas support many species of beetles, butterflies and moths, bees and wasps, and flies. North of the tree line, however, there are no dragonflies or ants, few butterflies, and only one species of bee.

Species of the order *Diptera* are the most abundant insects in taiga and tundra areas (Moon, 1970).

2.3.4.4. Small Mammals in the Terrestrial Food Web

Small mammals are another key component of northern ecosystems and they are widely distributed. Distributions of lemmings, mice, shrews and voles are summarized in Table 5. These are based on summer night trap data from many sites in the WKSS area between 1990 and 1998 (Carrierè, 1999). Data are consistent with previous collections (Shank, 1993). As with many plants and animals, several species have developed unique physical and, or, behavioural adaptations to increase survival under the harsh conditions of their environment. For example, the Collared Lemming (Victoria Collared Lemming) is the only rodent to moult (having different summer and winter coats) and the claws on their front feet become modified for winter digging (Engstrom, 1997). Insects (as larval grubs in soil or as adults) form a major part of the diet of shrews. Shrews remain active all year (including Arctic Shrew and Common Shrew). The diet of White-footed Deer Mice and Arctic Ground Squirrels (both of which hibernate in winter), and Northern Red-backed Voles also includes some insects (Engstrom, 1997; Fuller, 1984). Voles (including Meadow Voles, Northern Red-backed Voles, Chestnut-cheeked Voles and Rock Voles, and Tundra Voles north of the taiga) and lemmings (Brown Lemming, Victoria Collared Lemming, and Northern Bog Lemming) are largely vegetarians. They feed mostly on roots, seeds, willow bark, and sedges. Seeds and nuts provide much of the diet of Red Squirrels that occur throughout most forested areas (Collins, 1959; Moon, 1970; Wilkinson, 1970).

Both Snowshoe Hares (Varying Hares) and Arctic Hares are vegetarian. They feed mostly on grasses, twigs, shrubs and bark. The Snowshoe Hare extends north to the edge of the taiga, and the Arctic Hare is limited to areas north of the tree line (Fig. 6). The caloric value of different plant food sources to rodents and hares varies among species. In general, flowering plants are about twice as nutritious as grasses and sedges, and nearly three times more nutritious than mosses (Jeffries *et al*., 1992). Many rodent and hare populations seem to increase with the availability of plant food but may "crash" with its depletion. However, food supply may not be the only factor influencing these fluctuations and their cause or causes remain uncertain. For example, densities of Victoria Collared Lemmings may vary from less than $100 \cdot km^{-2}$ to more than $5,000 \cdot km^{-2}$ during a "cycle" (Engstrom, 1997). Populations of small rodents such as voles and lemmings frequently follow a 3 to 5 year "cycle". Their cycles may have a 10-times to 50-times range in abundance (Shank, 1993). Fluctuations in the peak of small mammal populations seem to occur at the same time in several locations. Population highs occurred during 1994-95 and 1998, and lows in 1991-92 and 1996 across the taiga plains (Fort Liard, Fort Simpson, Inuvik and Norman Wells). Taiga Shield (Yellowknife) and boreal plain sites (Fort Smith) shared a common population low in 1996.

Arctic coastal sites (Hope Bay, Kugluktuk and Melville Sound) shared similar peaks in 1996 (Carrierè, 1999).

Populations of Snowshoe Hares follow a longer "cycle" of about 8 to 10 years (in which there may be some coincidence with sunspot cycles). In some parts of the WKSS area, densities of Snowshoe Hare have been estimated to exceed 100·km^{-2}, 2 to 3 years after a population minimum (Krebs *et al*., 1987; Poole, 1989; 1992; Poole & Boag, 1988). However, from more recent studies on hares in the Mackenzie Bison Sanctuary, populations ranged from a peak of 5.3 - 6.2.km-2 (1988-1990) to a low of 0.6 - 1.0.km-2 during 1992-93 (Poole, 1997).

Porcupine occur in the most southerly part of the region. They feed on leaves, twigs and buds in summer, and the inner bark of conifers and poplars in winter (Moon, 1970). Beavers build lodges and dams on ponds and small lakes, or den along the banks of slow flowing streams. They have a preferred diet of deciduous bark. In favourable habitat, their range extends north of the tree line. Dene note in addition to the bark and twigs of willow, poplar and birch, that leaves and stems of a variety of aquatic plants are eaten and food is either eaten on the spot or cached (Johnson & Ruttan, 1993). “Starvation food” for beaver is the inner bark of Tamarack and spruce.

South of the tree line, a number of weasel-like mammals act as key predators of small rodents, the young of small and large rodents and hares, small birds, and the eggs and young of birds. Their diet may also include insects and small quantities of plant material, particularly seeds, berries, and willow (CCELC., 1988; Collins, 1959; Jenness, 1924; Moon, 1970; Wilkinson, 1970)). Marten (American Sable) occurs in wooded areas where voles, mice and hares, and carrion form most of their diet (densities may be about one Marten·2 km^{-2} or greater). Marten eat fish killed by other animals or that they can catch in shallow water (Johnson & Ruttan, 1993). The occasional squirrel is eaten and so are lemmings. Eggs, berries and roots are also eaten, and Marten are known to cache food (Johnson & Ruttan, 1993). Populations of Marten tend to rise and fall with the availability of hare (Johnson & Ruttan, 1993). Mink are important predators on mice, Muskrats and fish. They are usually found near streams and marshes (densities about two Mink·km^{-2}). The small Least Weasel is present in open woodlands below the tree line. Ermine (Short-tailed Weasel) is present throughout the region. All are active year-round but population densities are generally low (typically some tens of animals per km^{-2} in good habitat).

As with some species of aquatic birds (Section 2.3.3.3), there seems to be evidence for range expansion in small mammals. For example and based on comparison of survey records from the Thelon River valley since the mid-1930's, Beaver, Porcupine, Red Squirrel and River Otter appear to be colonizing new areas (Norment *et al.*, 1999). Likely, “northward” range expansion is occurring in many plant and animal communities, in response to improved climatic conditions.

2.3.4.5. Birds in the Terrestrial Food Web

Tree and shrub insects are an essential food for many migratory woodland birds. These include several species of warblers, and also woodpeckers, flycatchers, Boreal Chickadee and Ruby-crowned Kinglet. Insects and seeds from grasses, sedges and shrubs in taiga and tundra areas provide summer food for several species of finches and sparrows. These include American Tree Sparrow, Harris’ Sparrow, Savannah Sparrow, White-crowned Sparrow. Horned Larks and Lapland Longspurs are often the most common migrant birds in northern taiga and tundra (BHP & Dia Met, 1995; Collins, 1959; Moon, 1970; Wilkinson, 1970). Several other species of perching birds are present in the WKSS area. Recent environmental studies for mine developments are providing information about abundance and habitat use of many species at selected sites (*e. g.* BHP & Dia Met, 1995; Diavik, 1997). Traditional knowledge studies are further expanding the information base, and recently American Robins and Barn Swallows have been reported as far north as Banks Island (IISD., 2000).

Arctic browsing birds feed extensively on woody and herbaceous matter (Wakelyn *et al.*, 1999). The Spruce Grouse and Ruffed Grouse have a similar diet of berries, spruce and and pine needles, poplar buds, and insects (Collins, 1959; Moon, 1970, Wilkinson, 1970). The Spruce Grouse occurs in areas of generally close (spruce) forest cover. Small numbers of Ruffed Grouse are present in areas of more open deciduous cover. Willow Ptarmigan and Rock Ptarmigan include sedge, shrub flowers and berries, willow and birch leaves, buds and seeds, and insects in their diet (Wakelyn *et al.*, 1999). These birds are present year round. In summer, the range of Willow Ptarmigan extends north into the tundra. The Rock Ptarmigan is present in the tundra and barren areas north of the taiga. Typically, ptarmigan densities are a few birds·km^{-2} (Poole & Boag, 1988).

In spring, most geese pass north through the WKSS area and there is little nesting in the region. The North Arm (Great Slave Lake) - Lac la Martre - Hottah Lake area may be a corridor for limited migration through Great Bear Lake. Except where staging or moulting, the population densities of geese are low. In the southern part of the region, river valleys and inland lakes with early break-up are important sites for staging and moulting (Bromley & Buckland, 1995; McCormick & Bromley, 1990; McCormick *et al.*, 1990; Sirois & McCormick, 1991). In the north, shrubless tundra provides geese with habitat that is generally isolated from most predators during the seasonal moult. Hilltops and south facing slopes provide sites of early snow melt and opportunities to crop over-winter berries and sedge shoots (Bromley & Buckland, 1995). A few species nest in coastal parts of the WKSS area and the Kent Peninsula (Fig. 1) is an important summer ground for geese (Table 6). However, populations are very much larger to the east (Bromley & Stenhouse, 1994). More than a million geese may be present in the Queen Maud Bird Sanctuary and east along this coastal region (Gunn *et al.*, 2000). There, postglacial marine sediments (relatively Ca-rich) support vast areas of tussock vegetation. Geese begin to arrive in the southern part of the WKSS area about mid-May (Aniskowicz, 1993), and in Coronation Gulf area by about May 20th (Bromley, 1998). Departures begin from the gulf by about August 15th, and from the north and east shores of Great Slave Lake by the end of September (Aniskowicz, 1993). They feed mostly on sedges and grasses (Bromley & Buckland, 1995; Jefferies *et al.*, 1992). Canada Geese nest throughout the region. Tundra Swans, Greater White-fronted Geese, Lesser Snow Geese, Ross' Geese and Brant Geese (Pacific race) are present along both shores of Coronation Gulf.

Several species of large predatory birds are present in the region, and most are migrants (BHP & Dia Met, 1995). Osprey, Great Horned Owl and, occasionally, Northern Goshawk, Sharp-shinned Hawk and Red-tailed Hawk all occur south of the tree line (Bromley & Buckland, 1995). Bald Eagles, Northern Harriers, Merlins and American Kestrels are present in both boreal and taiga areas. Peregrine Falcons, Golden Eagles, Rough-legged Hawks and Gyrfalcons occur throughout the WKSS area (Bromley & Buckland, 1995). Great horned Owls feed on a wide range of small mammals and birds. Red-tailed Hawks prefer areas of woodland cover and Rough-legged Hawks are present over much of the tundra. Both feed extensively on voles, mice, and lemmings (Bromley & Buckland, 1995). Rough-legged Hawks and other nomadic avian predators locate nesting sites in areas of prey abundance, such as voles (Bromley & McLean, 1986; Krebs *et al.*, 1987; Shank & Poole, 1994). The maximum density of Rough-legged Hawks is about one nest·50 km^{-2} (Bromley & McLean, 1986). Peregrine Falcons feeds on a variety of small birds and occasionally on ptarmigan, grouse, voles, mice, lemmings. They nest on river and coastal cliffs and ledges, and on rock outcrops in upland areas (Anon., 1993; Shank & Poole, 1994). Their territorial requirements are similar to Rough-legged Hawks and nesting density varies, depending on prey availability (maximum of about one nest·50 km^{-2} (Bromley & McLean, 1986)). Gyrfalcons are present year-round, most commonly nesting at low densities (maximum of about one nest·175 km^{-2}) within 20 km of the coast (Anon., 1993; Bromley & McLean, 1989). The distance between Gyrfalcon nests seems to be least in areas of highest mean July temperature. This may reflect the influence of food availability on breeding success. Rock Ptarmigan and Arctic Hare form the main source of food for Gyrfalcons in May and June, and Arctic Ground Squirrels in July and August (Bromley & McLean, 1986; Poole & Boag, 1988). Except under extreme winter conditions (including lack of prey), the Snowy Owl remains mostly within the WKSS area but it moves south from the coast in winter. It also feeds extensively on ptarmigan, voles and lemmings. In many different species, nesting practices may be adapted to take particular advantage of prey availability. Prey switching by generalist predators may also affect the reproductive success of waterfowl.

Population cycles occur in ptarmigan. Although they share much of the same food source as lemmings, fluctuations in the two groups may differ considerably . For example, population changes in Willow Ptarmigan (Bromley, 1998) seem to approximate a 10 rather than the 3 to 5 year "cycle" that is typical of many groups of small mammals (Shank, 1993). Sometimes, the cyclic effect is transferred up the food chain. Snowy Owls are particularly sensitive to such changes because their preferred diet includes both lemming and ptarmigan. Although the staple diet of Gyrfalcons is ptarmigan, cyclic fluctuations in availability of this prey do not seem to have much effect on Gyrfalcon populations which remain fairly stable. Fluctuations in food supply may, however, influence year-to-year reproductive success (Bromley, 1998).

Common Ravens are present throughout the region, year round. As scavengers, they are particularly important consumers of carrion. Ravens and gulls (especially California, Glaucous, Herring and Mew gulls) are extremely adaptive. They are opportunistic feeders and these species increase in numbers near human settlements where organic wastes are easily available.

2.3.4.6. Ungulates in the Terrestrial Food Web

Four major groups of ungulates (hoofed mammals) are present in the WKSS area, and relations between regional vegetation zones and associated wildlife are summarized in Fig. 12. Wood Bison are present in the Mackenzie Bison Sanctuary on the west shore of Great Slave Lake. Plains-wood Bison are present in the Slave River delta and Wood Buffalo National Park (Fig. 1). Conservation programs maintain these herds that are near the northern limit of their present range (Jacobson, 1979). Large areas of sedge prairie (seasonally drained lakes that lack tree growth), between forest stands, provide grazing for the bison. Although these herds presently exist outside the WKSS area, slight changes in climate could extend their range into study area.

Relative to more southerly distributions in Canada, Moose population densities are low in the WKSS area. Moose occur in small family groups or as individuals. In good habitat, Moose require a browsing range of about 12 to 50 km^{-2} per individual (Bromley & Buckland, 1995). They feed on young deciduous vegetation, particularly willow, and semi-aquatic vegetation in ponds and shallow lakes. Moose are present year-round in all forested areas and especially in the Lac Grandin - Lac la Martre - Rae area, south of Yellowknife; and the lower Taltson River, east of the Slave River delta (Figs. 7 and 12). During the summer, individuals may move far into the tundra where they feed on willows in sheltered river valleys (Bromley & Buckland, 1995; Jacobson, 1979).

They tend to move into the bog and forest, and glaciolacustrine wildlife zones during winter (Fig. 12). Moose prefer quiet surroundings (sound is important for sensing the presence of predators such as wolves). They move away from wintering caribou which noisily scrape and crater snow cover to graze on the underlying vegetation (Johnson & Ruttan, 1993). Moose are locally abundant in areas of forest regrowth (after burns) where they feed on new shoots (Bromley & Buckland, 1995; Jacobson, 1979).

In forested areas, Moose prefer different types of habitat at different times of year (Johnson & Ruttan, 1993). In summer, they can be found in cool and wet areas where there are a variety of aquatic plants, grasses and willows to feed on. By remaining in water, they also reduce harassment from insects. At other times and under conditions of light snow cover, Moose may move to higher ground where they feed on Labrador Tea and grasses. In winter, Moose may move to valley areas and to creeks and islands where they feed on a variety of willows. The use of burned areas by Moose appears to be dependent on the intensity and type of burn. For example, crown fires burn the tops of trees, surface fires burn only light ground cover, but severe fires burn everything including organic soil (Johnson & Ruttan, 1993). Moose are attracted first to areas that have had lighter burns and which develop nutrient-rich new growth. Large burned areas may not provide useful habitat if wind-blown snow becomes hardened and Moose can not feed on the underlying vegetation.

The mating season is from mid-September to late October (Johnson & Ruttan, 1993). During the rut, bulls will travel long distances in search of a mate. They are territorial once mating has occurred. Calving takes place from mid-May to early June and a variety of habitats are suitable for this (Johnson & Ruttan, 1993).

Caribou are of critical importance throughout much of the NWT and Nunavut and there are several sub-species (Hall, 1989; Sutherland & Gunn, 1996; Williams, 1990; 1995; Williams & Fournier, 1996). Woodland Caribou (Fig. 12) are present south and west of Great Bear Lake, and east to the edge of the Shield (Jacobson, 1979). They may be widely dispersed in some years (Case, 2001). During winter months, part of their range may be shared with Barren-ground Caribou. Woodland Caribou calve in May. During summer, small groups of females and calves feed in the sedge prairie areas of the Mackenzie Bison Sanctuary. Some bulls also move into these areas during late summer. Woodland Caribou mate in September and the bulls establish a small harem that they stay with during the winter (Johnson & Ruttan, 1993). Males begin to group together at the beginning of the rutting period (Jacobson, 1979) and by mid-September lines of Woodland Caribou move towards upland areas north and west of Lac la Martre (Figs. 1 and 6). In late winter, as snow depth increases, they move south to areas of less precipitation. Some Dene also recognize a "mountain caribou" that is lighter in colour than the Woodland Caribou and which migrates through the mountains, west of the Mackenzie River (Johnson & Ruttan, 1993). The winter diet of Woodland Caribou includes lichens, sedges and deciduous vegetation. In summer, they feed on young grasses and sedges, buds and shoots, willow and birch leaves, and deciduous shrubs.

The Peary Caribou is small and light-coloured (CWS., 1997), and is present in low numbers across much of the high Arctic. The most southerly part of its range includes the northwest part of Victoria Island. The Arctic-island Caribou is similar in appearance to Barren-ground Caribou but a little smaller. It is present over much of Victoria Island (Fig. 13), King William Island and the northern part of the Boothia Peninsula (Gunn, 1998; Hall, 1989; Jacobson, 1979; NPCTT., 1996; NPC., 1997). Many caribou from the Dolphin and Union herd of Arctic-island Caribou migrate across the seasonal ice cover of the Coronation Gulf to a winter range on the northern mainland (NPCTT., 1996; NPC., 1997; Gunn *et al.*, 2000). Northwest of Great Bear Lake, Dene of Fort Good Hope and Colville Lake report two different types of Barren-ground Caribou. One is smaller than the other and it more closely resembles the Peary Caribou (Johnson & Ruttan, 1993).

Barren-ground Caribou are the most numerous and widespread sub-species of caribou in the WKSS area. There are probably ten or more herds of Barren-ground Caribou in the NWT and Nunavut, and these are mostly present on the mainland (Gunn, 1998). In the western part of their range, between Great Slave Lake and Great Bear Lake, and between Great Bear Lake and the Mackenzie River, they mix with Woodland Caribou. Their range extends southward to Lake Athabasca and through northern Saskatchewan and Manitoba to the mouth of the Nelson River on Hudson Bay. Barren-ground Caribou are present throughout all of the eastern mainland except the Boothia Peninsula (north of Spence Bay). They are present on Baffin Island and some of the larger islands in the northern Part of Hudson Bay.

On the mainland, the most westerly herd of Barren-ground Caribou exists around Bluenose Lake (Fig. 13). In 1987 the population of the Bluenose herd was about 115,000. Part of the herd moves into areas west of Kugluktuk during the summer. During the winter migration, part of the herd moves into the Lac la Martre area. Recently, the Bluenose herd has been redefined into three separate herds. The herd that now calves west of Kugluktuk and winters south of Great Bear Lake is defined as the Bluenose East herd (Case, 2001). Some caribou from the Bathurst herd also over-winter in this area (Johnson & Ruttan, 1993).

The Beverly herd is similar in size to the Bathurst herd and its range covers extensive areas south and east of the East Arm of Great Slave Lake (Williams, 1995). Herds are usually distinguished on the basis of their adherence to particular calving grounds. Most recently, the Queen Maud Gulf

Caribou herd has been defined in the area just east of Bathurst Inlet (Gunn *et al.*, 2000). The calving ground of this herd overlaps the traditional ground of the Bathurst herd, on the east side of Bathurst Inlet (but which is not presently used by Bathurst Caribou). Based on calving ground surveys, the estimated population of the Queen Maud Gulf herd increased from about 27,000 in 1986 to about 200,000 in 1996 (Gunn *et al*., 2000). The southern wintering range of the Queen Maud Gulf herd overlaps with the wintering ranges of the Beverly and Bathurst herds. Rutting of Queen Maud Gulf herd occurs mostly within the Thelon Game Sanctuary. The northern "summer" range of this herd appears to overlap with the Dolphin and Union herd's winter mainland range (Gunn *et al*., 2000). It is not uncommon for caribou to shift their range and since the 1980's, for example, wintering caribou from the Dolphin and Union herd have replaced Queen Maud Gulf Caribou on the Kent Peninsula, and Queen Maud Gulf Caribou have replaced Bathurst Caribou on the calving grounds east of Bathurst Inlet (Gunn *et al*., 2000).

The Bathurst herd is of special importance to many communities in the WKSS area (Sutherland & Gunn, 1996; Williams, 1990; 1995; Williams & Fournier, 1996). In 1990, its population was more than 300,000. In 1996, its population was about 350,000 (Lloyd, 1996; Sutherland & Gunn, 1996). The Bathurst herd winters south of the tree line (Figs. 6 & 8) where it is dispersed over a wide area between the Dease Arm of Great Bear Lake and the East Arm of Great Slave Lake (Hall, 1989; Jacobson, 1979). In some recent years, the herd has wintered as far south as northern Saskatchewan (Bromley, 1998; Gunn & Dragon, 1998). Caribou are reported to stay on the tundra during winters with low snowfall and few storms (Johnson & Ruttan, 1993).

Females migrate to calving grounds on the uplands around Bathurst Inlet, to arrive by late May or early June (Sutherland & Gunn, 1996). Surveys between 1974 and 1984 (Sutherland & Gunn, 1996; Urquart, 1981) showed greatest concentrations of calving caribou on tussock tundra east of Bathurst Inlet (between the Ellice and Perry rivers in the Queen Maud Bird Sanctuary , Figs. 1 and 7). In later surveys, however, concentrations of calving caribou were greatest west of Bathurst Inlet. Males generally migrate a shorter distance into the tundra (Sutherland & Gunn, 1996). By July, females and calves move southwest towards Contwoyto Lake, and males and females begin to aggregate at that time. Rutting takes place near the tree line in October. During the winter, males and females disperse and males tend to move further into the tree line. Rates of movement depend on activity and habitat (Gunn & Dragon, 2000). In May and towards the latter part of the spring migration onto the calving grounds, cows may be moving at rates of more than 20 km·d. Rates of movement decrease to about 10 km·d as cows move onto calving grounds, and to a minimum of less than 5 km·d during calving. Rates increase again to about 10 km·d about 10 days after calving (Gunn & Dragon, 1998). Movements of caribou on their winter range are also less than during the rut.

Caribou may follow similar pathways year-after-year, where constrained by geography (*e. g.* Point Lake crossing and locations in Bathurst Inlet). Caribou are thought to use terrain and landscape features as a guide to migration routes. Many routes of spring and fall migration are known (Gunn, 1998). Winter migration routes are well known to Dene hunters and variation is periodically noted (Johnson & Ruttan, 1993). However, year-to-year variations in the use of routes are not well predicted, and different groups of the Bathurst herd follow different paths (Case *et al*., 1996). The survival of animal groups during these migrations may depend very much on the experience of lead caribou (Gunn *et al*., 1988; Jakimchuk & Carruthers, 1983; Johnson & Ruttan, 1993).

Caribou feed selectively to obtain maximum nutrition (Jefferies *et al*., 1992). Seasonal changes and the availability of particular vegetation in sufficient quantity and quality seem to be important factors driving caribou migrations. Caribou avoid recent burns (less than about 15 years old) where lichens, in particular, have not recovered. For example, complete revegetation of lichens may take 40 to 60 years (Case *et al*., 1996; Jefferies *et al*., 1992). Caribou also avoid areas of thick snow cover that makes travel difficult for them and which may also increase the effectiveness of wolf predation (DRR., 1996; Gunn, 1996).

Early nutrition is essential for calving caribou and calving in early June coincides with the availability of high quality protein food (Johnson & Ruttan, 1993; Thorpe & Kadlun, 2000). In winter, caribou use their hooves to dig through snow to feed on easily digestible lichens, and sedges and horsetails (in early winter), and alder, birch and willow (in later winter) as available (Johnson & Ruttan, 1993). Cows of the Bathurst herd make most use of lichen heath and moist shrub vegetation zones as they move onto the calving grounds. They shift to wet-graminoid vegetation after calving (Griffith *et al*., 1999). Fruticose lichens provide early food on the calving grounds, and willow, Dwarf Birch, Green Alder and cottongrass are grazed as new growth emerges. Cottongrass is thought to provide particularly important nutrition for lactating cows. Elsewhere, on summer grounds, grasses and sedges, and other sprouts and buds (rich in minerals and protein) are used early. Later, caribou diet switches to willow, Dwarf Birch, Bilberry and Bearberry, as other plants become less digestible. Bulls and cows have dramatic weight gains in late summer (Case *et al*., 1996). The time spent on the calving grounds is also important for renewing hair and hooves. The caribou also get essential minerals from small soil mounds or ‘licks’ which improve the quality of milk production (Johnson & Ruttan, 1993). Although varying greatly with season and habitat (*e. g.* migration and calving), in very general terms range density is less than two caribou$\cdot km^{-2}$ (Hall, 1989). Caribou may shift their range at densities above $5\cdot km^{-2}$ to find more food (Gunn, 1998). Caribou herds show considerable variation in their distributions from year-to-year, even within large areas (Gunn, 1996).

Severe harassment by insects (particularly mosquitoes, bot flies, and warble flies) may lessen the ability of caribou to maintain body condition into and over the winter months. Harassment may affect calving success in the following year (Mueller & Gunn, 1996). Mosquitoes are sensitive to both wind and temperature, and their activity decreases when wind speed is greater than 22 $km \cdot hr^{-1}$ and when temperature is less than 13º C. Bot flies are light sensitive, and both bot flies and warble flies tend to aggregate on hill-top areas. As a result, many caribou seek shade and lower temperatures and flat sandy areas to avoid insect harassment during warm summer periods (Mueller & Gunn, 1996).

Early means of estimating caribou numbers may not have been reliable and counts may have been influenced by the presence of mixed herds. But, over periods of several years, significant changes are known to have occurred in the population size of caribou herds (Hall, 1989). These changes may be related to a number of factors, including weather and the quality of grazing (Case *et al*., 1996; Hall, 1989). Hunters contend that population fluctuations naturally occur over periods of 60 to 70 years (Gunn *et al*., 1988) and that these are, perhaps, due to the availability of food supplies. Dene also consider that population declines are due to the breaking of traditional law or a lack of respect for caribou (Johnson & Ruttan, 1993; *Parlee et al*., 2000). It is probable that past declines resulted from increased use of caribou for the provisioning of fur trade posts. More recent declines may reflect wastage and over hunting (Gunn *et al*., 1988; Johnson & Ruttan, 1993). At present, the population of the Bathurst herd appears to be relatively stable (Case *et al*., 1996; Sutherland & Gunn, 1996; Williams & Fournier, 1996).

Weather can also affect the survival of Muskoxen but their population was most severely depressed throughout the WKSS area as a result of unregulated hunting for hides during the late 1800's and early 1900's (Barr, 1989; 1995). Overall numbers are low but there has been some recovery since about 1970 (Bromley & Buckland, 1995). The Muskox is now recolonizing its historic range (Barr, 1989; 1991) which probably covered much of the tundra (Figs. 12 and 14). In the mid-1970's, surveys recorded concentrations of Muskoxen on the Horton Plain north of Great Bear Lake and west of Kugluktuk, Fig. 6 (Jacobson, 1979). Later surveys (Graf & Shank, 1989; Gunn, 1995) recorded other groups concentrated in areas around the Back River and Contwoyto Lake. In 1991, about 1,400 Muskoxen were observed between Contwoyto Lake and Bathurst Inlet. Small numbers have been reported, also, in the Lockhart River drainage (above Artillery Lake, Fig. 7). At least 1,000 animals were reported by a 1994 survey in the Thelon Game Sanctuary (Fig. 1). In

1998, 537 Muskoxen were recorded in a stratified aerial survey of an area of about 50,000 km^{-2} east of Great Slave Lake. The data support a population estimate of about 1606 Muskoxen in this area and suggest that their population has increased in this area since 1989, and spread westwards (unpublished data, DRWED, Yellowknife). Recent estimates suggest that as many as 4,250 mainland Muskoxen may be present on their summer range along the Queen Maud Gulf (Gunn *et al*., 2000). Herds are usually small, 5 to 25 animals, though some of 100 or more have been reported. Concentrations reflect local conditions and range from about one Muskox·50 km^{-2} (Artillery Lake), one Muskox·12 km^{-2} (Victoria Island), one Muskox·6 km^{-2} (Queen Maud Bird Sanctuary), to one Muskox·3 km^{-2} (Bank's Island).

Calving occurs in late March or early April and, in some herds, there are migratory patterns. For example, west of Kugluktuk, a mainland herd concentrates in the broad valleys of the Rae and Richardson rivers (Fig. 14), from late October to March. There, snow is less wind-packed and Muskox forage on stands of willow and birch (Gunn & Fournier, 2000). At the end of March, snow becomes crusty and more dense with daytime heating. Muskox leave the valleys to calve on wind blown slopes that are free of snow, and where foraging is less energetically demanding and the herd is better able to protect calves from predator attack. Studies show that the proportion of calves in the herd drops from nearly 17% in July to 8-9% by November (Gunn & Fournier, 2000). Later, the herd moves slowly north to the coast and then begins to slowly return south in August (a round migration of nearly 300 km). West of Bathurst Inlet, Inuit hunters report that Muskoxen migrate to the coast in June and return to higher rocky areas in July. This migration probably follows the availability of willow leaves that open earlier on the coast than inland (Gunn & Fournier, 2000). In the Queen Maud Gulf area, calves represent nearly 15% of the herd in August, and to the west of Bathurst Inlet calves represent about 12% of the herd population. Parasitic lungworms appear to be a particular problem in the Muskox population just west of Kugluktuk (Gunn & Fournier, 2000; Hoberg *et al.*, 1995). In these animals, pregnancy and calf survival rates appear to be low, and Grizzly Bears may cull badly infected Muskox. The valley population near Kugluktuk has varied from about 1,295 in 1983, to 1,800 in 1986, and to 974 in 1994 (Gunn & Fournier, 2000). Further potential for growth of the WKSS area Muskox population, as a whole, is uncertain (Bromley, 1998).

Muskoxen feed on grasses, sedges and willows, and like caribou they maximize nutritional intake by selective feeding (Jefferies *et al.*, 1992). Calves are born several weeks before plant growth begins and cows lose considerable weight during the first 6 weeks of lactation. Both males and females increase weight rapidly after the start of plant growth. During the growing season, Muskoxen spend about half their time feeding. Both males and females reach peak condition by the time of the rut, in August. Muskoxen are adapted to digest the high fibre content of over-winter grasses and sedges. They seek areas where snow has been blown away and where it is relatively easy for them to reach food. Freezing rain or deep snow, however, may severely limit their ability to forage. Their winter diet consists mainly of grass and sedge leaves, and leafless willow twigs. About half as much time is spent foraging in winter as in summer.

Nutrient cycling between plants and animals (by ingestion and excretion) contributes to the growth of forage, for both Muskoxen and caribou. But because caribou retain ammonium by recycling urea (for protein reserves), nutrient feedback may be more significant for Muskoxen that also feed more intensively (and thus fertilize) at one site (Gunn, 1998; Jefferies *et al*., 1992). In addition, excreted materials may directly or indirectly enter the aquatic environment where they also enrich nutrient availability.

2.3.4.7. Intermediate and Top Predators in the Terrestrial Food Web

Lynx are active all year. They are heavily dependent on Snowshoe Hare for their food supply and distributions of the two species are similar. However, they are also known to kill and eat small mammals, grouse, ducks, and even caribou calves (Poole, 1989; 1992). Lynx numbers increase with the abundance of hares but declines abruptly at the end of each hare "cycle" (Fig. 15). At the end of the hare "cycle", Lynx mortality is high (particularly cubs) and this is largely due to starvation. Natural mortality is thought to account for about 75% of long term total mortality in the Lynx population (Poole, 1997). At that time, both male and female Lynx disperse widely over distances of several hundred kilometres. One straight line radio-tracked distance of 930 km has been recorded (Poole, 1997). Some Lynx may move into areas where the hare-Lynx "cycle" is not in-phase with that generally existing over much of the WKSS area (Poole, 1989). Densities vary from a low of about one Lynx·33 km^{-2} to a high of one Lynx·3 km^{-2} (Poole, 1992). The most recent cycle followed the hare population peak of 1988-90 and collapse of 1992-93 (Poole, 1997). Few Lynx occur north of the tree line (Bromley & Buckland, 1995; Jacobson, 1979). They are widespread in the bog and forest, and glaciolacustrine (Lake McConnell) wildlife zones (Fig. 12).

Both Red Fox and Arctic Fox are opportunistic feeders (Bromley & Buckland, 1995). Small rodents form much of their diet but they will also eat berries and other vegetation. They scavenge wolf kills, particularly in winter. In addition, both foxes feed on Willow Ptarmigan and Snowshoe Hare in winter, and waterfowl and their eggs and young in summer. Red Fox also kill Muskrat in the spring. Arctic Foxes are considered a more specialist feeder and much of their diet consists of lemmings. Red Foxes are present year round and in small numbers (typically about one Red

Fox·10 km^{-2}) over most of the WKSS area, including open forest and some of the tundra wildlife zones. They are most abundant in bog and forest, and glaciolacustrine wildlife zones which support substantial growths of willow (Fig. 12). Arctic Foxes may move south from tundra to forest-tundra and open forest wildlife zones in winter. Both foxes prefer to den in sandy ridges and densities vary greatly with the availability of food supply and the time of year. Both foxes range widely (Jacobson, 1979).

Black Bears and Grizzly Bears (Brown Bears) are also opportunistic feeders (Johnson & Ruttan, 1993). In a recent study by Gau & Case (1999), the diet of Grizzly Bears shows a distinct pattern that may reflect both availability and nutritional necessity. The authors studied Grizzly Bears in an area west from Contwoyto and Aylmer lakes to the tree line, during 1995 and 1996. Licorice roots are thought to an important part of early spring diet over much of the range of Grizzly Bears (Fig. 12), shortly after they emerge from their dens (*e. g.* forest-tundra transitional wildlife zone (Jacobson, 1979)). However, Gau & Case (1999) report that this plant was not present in the study area. Instead, early nitrogen requirements were met by prey taken from the Bathurst Caribou herd in the period of the spring migration to its calving grounds. During the first four or five weeks after emergence, the bears also consumed Arctic Ground Squirrels and pre-emergent vegetation. From mid-June to early July, their diet was mostly vegetarian. It comprised a nearly equal mix of emergent and pre-emergent horsetails, sedges and cottongrass. As post-calving Bathurst Caribou began to move back into the study area between early July and early August, prey from the mixed herd formed most of the bears' diet. Berries ripen during the last three weeks of August. At that time, Crowberries, Cranberries and Blueberries became a major component of bear diet. As caribou began to move towards the tree line in September and early October, caribou meat again increased in the diet. Berries continued to be an important food source until the bears began to hibernate.

In the study area, it is thought that caribou provide the Grizzly Bears with their main source of protein and that berries provide a key source of carbohydrates. The berries are essential for the formation of fat reserves which are required to sustain the bears through hibernation. Grizzly Bears in the study area entered hibernation with an average total body fat level of about 25.5%. However, the content of body fat continued to decline after hibernation. It reached an average low of about 10.8 % in mid to late July. Body fat increased rapidly during the "berry period".

Grizzly Bears appear to be adept at killing caribou and they also scavenge wolf kills. Gau & Case (1999) estimate that, during their normal active period, male Grizzly Bears require an average of about 8.2 kg and females about 5.7 kg of caribou meat per day. Males require an average of about 55.1 kg and females 38.4 kg of berries per day during the "berry-period". This implies feeding on berries up to 20 hours a day. Grizzly Bears in the study area are generally smaller than in other parts of their range, they mature later, their breeding intervals are longer, population densities are lower, and they have a long hibernation period. It is likely that Grizzly Bears in the 1995-1996 study area are closely dependent on the availability of the Bathurst Caribou.

In general, both Grizzly Bears and Black Bears will feed on a wide variety of plant materials including roots, sedges and other deciduous vegetation, and berries and nuts. In addition to caribou, animal prey includes Moose and Muskox, small mammals, birds and eggs, and fish (Gau & Case, 1999; Jacobson, 1979; Johnson & Ruttan, 1993). Large male Grizzly Bears are also known to kill and eat female Grizzly Bears and their cubs (Bromley & Buckland, 1995). Gastro-intestinal parasites are common in bears and from studies on Grizzly Bears, the prevalence of these parasites significantly differed between spring and fall. This may suggest that Grizzly Bears void gastro-intestinal parasites before hibernation but it is not known how (Gau *et al.*, 1999). In the WKSS area, both Black Bears and Grizzly Bears hibernate for 7 to 8 months a year. They emerge in early May and den in mid-October (McLoughlin *et al.*, 1999).

Black Bears are widely distributed in the forested areas, particularly around Great Slave Lake and the Mackenzie River (Bromley & Buckland, 1995). Black Bears may move into the forest-tundra transitional zone during the summer and some individuals also range onto the tundra (Jacobson, 1979). Black Bears are most abundant in the bog and forest wildlife zones (Fig. 12), and they den in the forested areas (Jacobson, 1979).

Grizzly Bears are present throughout the WKSS area (Jacobson, 1979; McLoughlin *et al.*, 1999). Most of their dens occur in heath tundra, with and without boulders (McLoughlin et al., 1999). Recent satellite radio collar tracking studies have shown that there are significant seasonal and gender preferences for different types of habitat. Male Grizzly Bears occur over a wide range of habitat types. Females prefer esker habitat year-round and also riparian tall shrub and birch seep habitat. Except during spring mating, females avoid using habitat where males are present (McLoughlin *et al.*, 1999). In spring, both males and females showed high preference for tussock and, or, hummock successional tundra. In summer, males continued this preference but females showed highest preference for tall shrub riparian and esker habitat. Males also showed a preference for tall shrub, and females for birch seep; males tended to avoid birch seep. In late summer, eskers were preferred by both males and females but females also had a preference for birch seep and boulder field habitat. In the fall, males were found in tall shrub, heath tundra, heath boulder and birch seep. Females mostly preferred esker habitat, but they were also present in tall shrub and heath tundra (McLoughlin *et al.*, 1999).

About 41% of Grizzly Bear dens were found in heath tundra habitat, 21% in heath tundra with boulders (> 30% boulders), 13% in eskers, 9% in birch seep and 9% in spruce forest. A few dens occurred in tall shrub riparian and river embankment habitat. Vegetation root structure frequently provided den roof support and most bedding material was comprised of Crowberry mats (McLoughlin *et al.*, 1999). Adult densities in the Kugluktuk and Bathurst Inlet areas vary between about one Grizzly Bear·200 km^{-2} and one Grizzly Bear·400 km^{-2}. Sub-adults may range extensively before hibernation, over distances of 500 to 700 km (Bromley & Buckland, 1995; Gunn, 1991). Barren-ground Grizzly Bears are the most carnivorous and their annual and seasonal ranges are some of the largest recorded in North America (annual range 6700 km^{-2} for males, and about 2100 km^{-2} for females (McLoughlin *et al.*, 1999)).

Wolverines are present throughout the WKSS area and range widely in undisturbed wilderness. They are usually solitary animals (Bromley & Buckland, 1995). Wolverines are primarily predators and scavengers, although berries and other vegetation may be included in their diet. Their diet usually includes Beaver, caribou, waterfowl, ptarmigan and grouse (Lee, 1994; Lee & Niptanatiak, 1993). Additional foods include small mammals, Muskox, fox, Ermine and even seal (Mulders, 2000). They are active throughout the year, they cache food, and it is likely that they are able to digest and extract nutrients from bone. This ability may be extremely important to their survival when food is scarce. Densities range from about one Wolverine·130 km^{-2} to one Wolverine·500 km^{-2} (Lee & Niptanatiak, 1993; Mulders, 2000). The home range for males (> 200 km^{-2}) is much greater than that of females (about 100 km^{-2}). The young are born in March and April, and dispersing juvenile males may travel more than 300 km to establish a new home range (Mulders, 2000). It is probable that there are important links in the ecology of caribou, wolverines and wolves but information is limited.

The Gray Wolf is present throughout the WKSS area. South of the tree line, members of this species (boreal wolves) are generally darker in colour than those living on the tundra where they may be almost white (tundra wolves). Wolves are closely associated with caribou and sometimes with Moose or Muskoxen. Like foxes, the wolves may include vegetation in their diet, as well as rodents, hares, birds (including both Willow Ptarmigan and Rock Ptarmigan), eggs, and fish. The primary source of their food is caribou (often older or less healthy animals, or young). Most Moose are killed by wolves during the spring when crusty snow supports the weight of a wolf but not a Moose (Johnson & Ruttan, 1993). Gray Wolves range widely. They are not territorial and they may hunt as groups to minimize the expenditure of energy (Bromley & Buckland, 1995).

In winter, Gray Wolves are most abundant in the mossy forest wildlife zone (with both Woodland

Caribou and Barren-ground Caribou), in the glaciolacustrine zone (with Moose), and with Barren-ground Caribou in the open forest zone (mid-winter) and transition zone (late winter). These zones are shown in Fig. 12. Light coloured wolves (tundra wolves) remain on the tundra year-round and follow caribou into the taiga but do not move much below the tree line. These wolves are closely associated with the Barren-ground caribou. The darker boreal wolves also move into the taiga but generally remain below the tree line. Wolves den extensively in the forest-tundra transition wildlife zone (Desjarlais, 1999; Jacobson, 1979; Mueller, 1995). Their dens are often located in smaller sandy side eskers rather than on the main esker complex. Plant roots often provide roof support (Desjarlais, 1999). At the extreme northern extent of their range, wolves may produce a litter of only 2 or 3 pups or 4-6 pups in alternate years. This contrasts with annual litters of 5-6 in areas of the southern boreal forest (Meech, 1995). Food supplies for females and pups denning near the tree line are often critical by July when most caribou are far out on the tundra (Heard & Williams, 1992). Wolves have been reported to range up to 400 km from dens at that time of year but such distances are well beyond their ability to return with a kill. In some years, survival of wolf pups at the tree line may be very low. Small numbers of tundra wolf dens occur nearer the calving areas of the Bathurst Caribou herd, mostly east of Bathurst Inlet. The total number of Gray Wolves on the range of this herd is estimated to be between 1,400 and 3,000. On average, each wolf probably kills 15 or more caribou per year (Bromley & Buckland, 1995; Case *et al*., 1996). Some of this range is also shared by Muskoxen but the extent to which wolves prey on them remains uncertain.

As a predator, wolves may cull many of the weaker and elderly members of prey groups. By this means they contribute to maintaining population health in caribou, Moose, Muskoxen and other prey species ("survival of the fittest"). However, wolves are also opportunistic hunters and depending on circumstance they may or may not be selective. Wolves will kill whatever they can when prey are few (Johnson & Ruttan, 1993). Often, wolves do not, or can not, make full use of their kill and carcass materials remain available to support the needs of other predators and carrion eaters. In this way, wolf-kills also provide an extremely important supplement to the diet of many other species, particularly when food supplies are short or not accessible.

Timing is often of critical importance in the life-cycles of many species that comprise the food web of tundra, taiga and northern boreal regions (Sly, 1995; Stewart *et al*., 1991). Both transients and migrants within the WKSS area are critically dependent on appropriate space and time linkages for passage and reproduction. Many species are highly adapted. There is a very high degree of interdependence among and between many species and feed-back between animals and plants is also very significant. All of these relationships are of great significance in relation to human development in the WKSS area.

2.4. Human Elements

Each of the three sub-regions of the WKSS area has been used and occupied for thousands of years (Fig 16). The WKSS area is the traditional homeland of various Aboriginal peoples and is the new homeland of several non-Aboriginal peoples who have come from many parts of the world. The Aboriginal groups of the WKSS area describe themselves and, or, are identified by Euro-Canadians as: (traditional or formerly official names appear in brackets)

1) *The Copper Inuit* who live in Kugluktuk (Coppermine), Cambridge Bay (Ikaluktutiak), Bathurst Inlet and Umingmaktok (a.k.a. Bay Chimo) in the West Kitikmeot sub-region, Nunavut Territory.

2) The *Dogrib Dene* of Rae Lakes (Gahmìtì), Wekwetì (Snare Lake), Wha Ti (Lac La Martre) and Rae-Edzo (Behchok'ò) in the Treaty 11 sub-region, NWT.

3) The *Chipewyan Dene* of Lutselk'e (Snowdrift) and "Yellowknives Dene" of Ndilo and Detah in the Treaty 8 sub-region (an area that also includes Yellowknife (Sombak'e), the capital of the NWT).

2.4.1. A Long Time Ago

"No person's sense of himself has to do only with the present, not with only his own people.... The past - even the remote past - enters the present, becomes part of it in stories, in myths, and in what is gathered together in the word 'culture'" (Brody, 1976).

The earliest known archaeological evidence of people in the WKSS area dates back to about 10,000 BP. The first people likely came to this area from the south, having followed the retreating ice-sheets of the last glaciation (Section 2.2.2.7). About 7,000 BP, bison-hunting people from the western plains moved north to inhabit areas in the vicinity of Great Slave Lake. These bison-hunters adapted to a new environment and came to rely on caribou for survival (Crowe, 1974). However, there is no evidence that these early hunting cultures are related to Dene cultures which have used and occupied the area in more recent times.

Between 4,000 and 5,000 BP when the climate became cooler, the first people from the west, known as the pre-Dorset culture, began to arrive in northern parts of the WKSS area. These people were followed about 3,000 BP, by an early Inuit culture known as the Dorset culture. "*Modern Inuit know of the Dorset people through stories passed down by their ancestors, who met and were* *absorbed or eliminated by the older culture. In the stories, the Dorset people are called Toonit, and while some of the tales have become fanciful over the years, many of the facts agree with the evidence of archaeology*" (Crowe, 1974). The Dorset culture was replaced by a whale hunting culture, the Thule Inuit, who came from the north coast of Alaska. These people arrived in northern Canada about 1,000 BP. The Thule people quickly spread across the Arctic. *"There is no certain time when the Thule way of life became the Inuit way, only a gradual change, greater in some places than others. Most people agree that by about A.D. 1700* (300 BP) *the true Thule culture had become that of the modern Eskimo, the Inuit."* (Crowe, 1974). Today, several Inuit sub-groups live throughout the circumpolar world. One of the many Canadian sub-groups is the Copper Inuit who live in the west Kitikmeot sub-region of the Nunavut Territory.

Archaeological evidence found near the tree line, from the lower Coppermine River east to Hudson Bay, indicates that the ancestors of the modern Dene of the Treaty 8 and 11 sub-regions may have arrived in the WKSS area about 2,500 BP. The early Dene came from the south and were members of the Athapaskan language group, one of the largest indigenous linguistic families in North America. Today, the Dogrib, Chipewyan and Yellowknives people of WKSS area are among the most northerly of Athapaskan-speaking peoples. Other closely related members of this language group live along the Pacific coast and in the southwestern United States (McFadyen, 1974).

2.4.2. Before the Europeans

In 1789, Alexander Mackenzie was told by some Chipewyan that *"in ancient times their ancestors lived till their feet were worn out from walking"* (Mackenzie, 1801). The mobility and extensive travels of early Dene and Inuit are recurring themes in the oral histories of Aboriginal northerners. The Dene tell stories of the movements of their people from one area to another, and about the divisions that occurred in their populations. One Dogrib story tells of two brothers who separated after their childhood, one traveling north to the Arctic coast and the other going south into the forests (Helm, 1966). The Inuit tell of the epic journeys that their ancestors made to distant lands (Freeman, 1976). The nomadic and highly mobile lifestyles of the ancestors of modern day Dene and Inuit required a strong ability to adapt, both to different climatic conditions and to the availability and distribution of food sources. They used tools made from stone, bone and wood, and they harvested a variety of fish, bird, large and small game, and flora resources. Caribou were a particularly important source of food, and many archaeological sites have been found at locations where migrating caribou could be intercepted (Arnold, 1989).

The northern Athapaskan people were not a homogeneous population. The largest most widely distributed group was the Denesoline or Chipewyan (Fig. 16). The latter name is derived from a

Cree word meaning “pointed skins”. It describes the clothing once worn by these people (Smith, 1981). Sub-divisions of the Chipewyan are the Yellowknives or *T’atsaot’ine* (also known among early European traders as the Copper Indians) and the eastern *Ethen-eldeli* people (at one time known as the Caribou Eaters). The Chipewyan were present over much of the Canadian Shield, from Coronation Gulf east to Hudson Bay (Gillespie, 1981). They occupied the northern transitional zone of boreal forest (taiga) and adjacent barren grounds (tundra). The Dogrib (*Tlicho*), another northern Athapaskan sub-group, were present between Great Slave and Great Bear lakes, and from the lowlands on the east side of the Mackenzie River to Contwoyto, Aylmer and Artillery lakes (Helm, 1981). While each Dene band used well defined areas, land use was not exclusive.

Many distinct sub-groups of Inuit inhabit the Arctic regions. The Copper Inuit of the West Kitikmeot sub-region are neighbours of the Mackenzie Inuit (to the west) and the Netsilik Inuit (to the east). The range of the Copper Inuit traditionally covered much of Victoria Island and southern Banks Island (Fig. 16). On the mainland they extended south to Great Bear Lake, Contwoyto Lake and Beechy Lake (Back River), and east to the Perry River (Damas, 1984; Farquharson, 1976). Within the range of the Copper Inuit, there were many small, dispersed and mobile groups. Eight groups lived in the areas known today as Kugluktuk, the Dolphin and Union Straits, and Coronation Gulf. The groups were located near an important crossing for migrating caribou between the mainland and Victoria Island, and productive seal, waterfowl and fish populations (Farquharson, 1976). The Copper Inuit followed a seasonal cycle. Towards the end of May, they left snow house villages on the sea ice and moved to the land. The harvesting cycle involved hunting seals and fish jigging in spring; caribou hunting and fishing inland during the summer; fishing during the runs of Arctic Char and hunting during the fall migration of caribou; and winter sealing from camps on the sea ice (Damas, 1984).

The various Dene and Inuit sub-groups were recognized or described by the land or territory they used, their clothing, the resources harvested or other prominent lifestyle features. The various sub-groups shared a common interest in the Barren-ground Caribou (Fig. 13). These caribou were central to the lifestyle of the Dene and an integral part of the seasonal cycle of the Copper Inuit. Caribou were the primary source of food, clothing and shelter. Estimates of usage for clothing, alone, numbered as many as twenty skins a year for each person (Arnold, 1989). The Chipewyan structured their seasonal cycle, movements, technology and socio-territorial organization around the Barren-ground Caribou. Caribou were the basis of many beliefs, stories and traditions among the Chipewyan (Smith, 1981). The central role of caribou in the lives of the Dene is a theme in many stories and legends. As typified by the beginning of this story from The Book of Dene: “*At one time there was a famine from the barrens to the ocean. In vain we looked for caribou but there* *was none. It was a hard time"* (DE., 1976).

Aboriginal people of the WKSS area have relied mainly on the Qaminurjuaq, Beverly and Bathurst herds of Barren-ground Caribou (Section 2.3.4.4). These herds seem to have been large enough to feed sizable populations of people for a long time (Abel, 1993). In the hunting grounds, the Dene were closely tied to the ranges and migration routes of caribou (Arnold, 1989). Several methods were used to harvest caribou and one method, the caribou pound, yielded, when successful, enough meat to enable the Dene to live relatively sedentary lives for a time (Hearne, 1958).

The movements and distribution of the Dene varied according to activity, time of year and available food supply. To a large degree the movements mirrored those of the caribou herds on which they were dependent (Smith, 1981). Movements and distribution also shaped the size and composition of each Dene group. The family was the basic social unit around which Dene bands were organized (Abel, 1993; Ryan, 1995). A man, his wife and unmarried children usually constituted the family. Other wives, married children and one or two older people may also have been considered as members, depending on the season and availability of food (McFadyen, 1974). Group associations reflected ties through blood and marriage. Men hunted, built shelters, made tools and weapons, and were responsible for the means of travel for hunting and seasonal migrations. Women were responsible for almost every other task, including the preparation of food and clothing and maintenance of shelter (Abel, 1993).

The families of the northern Athapaskans have been described by size and composition as a "local group" (or closely related families) and the "regional band" (or families related by blood or through marriage). Local groups worked and lived cooperatively in the same household or in proximity to each other, for much of the time. They identified with the larger regional band which gathered infrequently. Relationships with others were fostered through marriage and adoption (Abel, 1993; Helm, 1981). Large gatherings usually did not extend beyond the regional band, possibly due to the potential for conflict.

Traditionally, the Copper Inuit had restricted and customary areas of land use although individuals might travel extensively for social and trading purposes (Farquharson, 1976). Copper Inuit groups were organized around the family unit and the size of groups also varied with the season and availability of food. When food was scarce or limited to fishing in lakes and hunting small game, groups may have been made-up of only one family. Typically, groupings of Copper Inuit numbered a dozen or more people but when caribou or Arctic Char were plentiful, groupings may have been as large as 50 people (Damas, 1984).

The Copper Inuit were unique among central Inuit populations in that they were organized by independent, nuclear families. They placed little importance on the extended family and kinship beyond the nuclear family. This independence was absolute in all seasons. The Copper Inuit practiced a system of mutual reciprocity where a gift was immediately repaid with a gift of equal value. Voluntary reciprocal relationships between families were established primarily through spousal exchange and singing and, or, dancing partnerships. The Copper Inuit were creative dancers, songwriters and poets and the communal dance house was central to Copper Inuit social life (Stevenson, 1997).

Within most Aboriginal families of the WKSS area, individuals were in a general sense, free to make their own choices and follow their own convictions (Jenness, 1922; McFadyen, 1974). Decisions pertaining to Aboriginal groups were made through a consensus of the individuals directly involved. Criticism, gossip and ostracism served to maintain social order and harmony. Disputes between individuals were often settled through compensation, vengeance or combat. Leaders were male. Leadership was established through consensual recognition that the individual was a superior producer-provider, and generous and committed to the welfare of the group (Helm, 1981). *"A man acquires influence by his force of character, his energy and success in hunting or his skill in magic. As long as these last him, age but increases his influence, but when they fail his prestige and authority vanish"* (Jenness, 1922).

Children among the Dene and the Inuit of the WKSS area were valued and their presence heightened the status of women and the family. Children were rarely disciplined or treated harshly. The main role of elders was one of advisors and educators. During times of extreme hardship when food was scarce, members of the family unit, particularly the male hunters, were subject to tremendous stress. Mobility and strength were essential in the search for food. Family members unable to keep up may have been considered a liability, and left behind to die (Abel, 1993). Female infanticide was practiced among northern Athapaskans (Abel, 1993). It may have been practiced among the Copper Inuit until the 1940's (Damas, 1984).

2.4.3. Arrival of the Europeans

The northern Athapaskans and the Copper Inuit came into contact with Europeans at different times. In 1670, a British royal charter authorized the Governor and Company of Adventurers of England (Hudson Bay Company - HBC) to trade furs in the Hudson Bay region. The Chipewyan were the first of the northern Athapaskans to come into contact with these European traders. Contact between the Chipewyan and European traders in the late 1600's began the longest, continuous, Dene-European relationship in northern history (Smith, 1981). In 1717, the Prince of

Wales Fort was established at Churchill to facilitate trade with the Chipewyan. Chipewyan trappers traded with the Europeans, supplied food to the traders and served as intermediaries between the HBC and other northern Athapaskans (Hearne, 1958). At the time of contact, the Chipewyan peoples including the Yellowknives and *Ethen-eldeli* sub-groups, may have numbered about 4,000 (430 Yellowknives, 2,250 Chipewyan and 1,250 *Ethen-eldeli* (Smith, 1981)).

At the urging of HBC traders who had learned of copper deposits and of the existence of the "Copper Indians" (the Yellowknives) in the interior, the Chipewyan were encouraged to bring copper or the people associated with it, to Fort Churchill for trade (Abel, 1993). The Yellowknives did visit this fort (Gillespie, 1981) but they seem to have had infrequent contacts with the traders. Intermittent contacts may have been due to many factors such as distance of the HBC fort from their traditional range and tenuous Yellowknives-Chipewyan relationships. There may have been fear about harvesting copper from lands bordering those of the Inuit, a protectionist view of the copper that was known to be a source of power and prestige, and, or, avoidance of trader pressures to bring copper to Churchill (Abel, 1993; Gillespie, 1981). Traders made contact with the Dogrib around 1740 (Osgood, 1936).

From 1769 to 1772, the eastern Chipewyan leader, Matonabbee, guided Samuel Hearne of HBC overland to the Arctic coast. Hearne was the first European to travel overland, to describe Great Slave Lake, and to document contact with the Copper Inuit. Throughout the 1800's, the Copper Inuit, estimated to number some 1,000 at that time, were intermittently exposed to European traders and explorers (Crowe, 1974). During the latter half of the 19th century, however, there was little contact between the Copper Inuit and outsiders.

Between 1818 and 1855, in excess of 50 expeditions made-up primarily of Europeans, traversed the Canadian Arctic. Expeditions expanded European knowledge of the Inuit but a lack of documentation would suggest that few, if any, lasting relationships were established. Sir John Franklin, who visited the site of present day Bathurst Inlet in 1821 and 1826 made little contact with the Copper Inuit (Stevenson, 1997). In the 1830's, Chief Factor Warren Dease and Thomas Simpson of the HBC traveled down the Coppermine River and explored the coast to the east of the Kent Peninsula. They encountered small groups of Copper Inuit, the largest being a group of 30 people. The search for the Franklin expedition in the late 1840's and early 1850's created numerous opportunities for European and Inuit contact. In 1848, Rae explored the south and west coasts of Victoria Island. In his search for the Franklin expedition, Collinson wintered in Walker Bay, Victoria Island in 1851/52 and in Cambridge Bay among 200 and 300 Inuit the following year.

By the late 1700's, the Chipewyan's role in the Athapaskan fur trade had diminished. Competitive traders (later known as the North West Company - NWC) were establishing posts in the interior and trading directly with various groups of northern Athapaskans. In 1789, Alexander Mackenzie of the NWC met Dogrib and Slavey on the Mackenzie River, near the mouth of the Great Bear River. The Dogrib may have numbered close to 2,000 at that time (Crowe, 1974). A year later, the NWC established Old Fort Providence on the North Arm of Great Slave Lake to serve as a meat provisioning post and to facilitate trade with the Yellowknives and Dogrib (Helm, 1981).

The range of the Yellowknives at the beginning of the 1800's was closely linked to the Bathurst Caribou herd. The Yellowknives had a "warlike reputation" among European traders and their Dene neighbours, the Slavey and the Dogrib (Gillespie, 1981). Akaitcho was an important Yellowknives leader and had been involved in Sir John Franklin's first expedition between 1819 and 1822. Tensions between the Dogrib and the Yellowknives continued, and in 1823 the Dogrib made a revenge attack. They killed an encampment of 34 people, estimated at one-fifth of the Yellowknives population (Gillespie, 1981). Dogrib oral history attributes subsequent amity between Yellowknives and Dogrib solely to Dogrib Edze (Edzo). He, by his oratory, shamed and terrified Akaitcho and the Yellowknives into peace (Helm, 1981). The historical record of this exchange is undocumented, from the Yellowknives perspective. After 1823, the Dogrib occupied areas that the Yellowknives had once dominated. By the 1830's, the Yellowknives were no longer the power they had once been (Abel, 1993). The Yellowknives gradually retreated from areas around the Yellowknife and Coppermine rivers to occupy the eastern end of Great Slave Lake (Gillespie, 1981).

In 1821, the two rival trading companies (HBC and NWC) merged to create a fur trade monopoly in the north. The trading post at Old Fort Providence was closed, leaving the Dogrib and the Yellowknives without a point of trade within their areas. The post at Fort Resolution, established in 1784 by the NWC, began to draw these Dene into a common range for trade. By the 1850's, trade posts were located at or near the site of many present day communities in the Treaty 8 and 11 areas (Hall, 1986). The prominence of trade posts began to grow in the latter part of the 19th century. The missionaries who arrived in the 1850's, contributed substantially to this expanded role. For example, the Fort Rae post, established in 1852 on an island in the North Arm of Great Slave Lake, became a meeting place for the Dogrib people and an important caribou meat provisioning centre for traders. Later, it also became a source of medical services, communications, and religious teachings. Between 1876 and 1902, the Fort Rae post became a major station in the trade of Muskox robes (Helm, 1981).

Men of French and, or, Cree descent (Métis) who worked for the trading companies formed alliances with Dene families by marrying Dene women. These men and their families acted as interpreters and middlemen between the Dene and the European traders. Relationships between the Dene and traders in the 1800's had a high level of inter-dependence. The survival of traders was dependent on country foods and furs provided by the Dene. In turn the Dene became dependent on European trade goods such as guns, ammunition, tobacco, tea, flour, axes, files, other tools, household utensils, and woollen clothes. The Dene found that some European trade goods were more durable, efficient and, or, easier to use than handmade items. This often made time available for other pursuits. "Free time" made it possible for art and craft activities to develop among the Dene. *"The nineteenth century was a time of a literal cultural flowering. Exquisite bead and quill work was produced in quantities apparently unknown in the past … the skills of women producing these beautiful items became highly valued … "* (Abel, 1993).

The Dene and European traders had differing ideas about their trade relationships. For example, European traders advanced credit to the Dene for winter supplies, based on a trapper's skills and previous successes. This system of credit required a trapper to return to the post to repay his debt. Among the Dene, a large debt was considered quite prestigious and not necessarily something that should or needed to be paid off at the end of each season. The European traders did not share such views (Hall, 1986). Another example is provided by the high value and importance that European traders accorded to the accumulation of material goods, a value and importance which was not shared by the Dene. The Dene *"recognized the dangers of devoting too much time to fur trapping (to trade for material goods), for if game suddenly became scarce and there were no provisions in store, the possibility of starvation was very real indeed"* (Abel, 1993). Starvation was not the only concern. In the 1850's, scarlet fever ravaged a Yellowknives band at Lac de la Mort. A decade or so later, influenza decimated about 30% of the Copper Inuit (Crowe, 1974).

Missionaries came into the WKSS area in the 1850's. Their main purpose was to convert the Dene to Christianity. Missions were established, and the missionaries traveled to Dene camps and to large Dene gatherings. In subsequent decades, the roles of the missionaries expanded to include both education and care giving. Initially, the missionaries were drawn to the trade posts that enabled them to establish contact with Aboriginal people, to access supplies and to secure transport. In some parts of the WKSS area, the intent of the missionaries was quickly accomplished. For example, the Roman Catholic missionaries arrived at Fort Rae in 1859 and the first Dogrib was baptized into that faith in the same year. Within five years, 600 Dogrib people had been baptized (Helm, 1981).

Records indicate that the seasonal cycle of the Dene was not substantially altered by early traders or missionaries (Abel, 1993; Helm, 1981; Ryan, 1995). Rather, trapping for trade and travel to the trade posts were integrated into this cycle. For example, the annual cycle of the Dogrib in the latter part of the 1800's involved trading Beaver and Muskrat in June and July, drying fish and caribou hunting in late July and early August, stockpiling fish in September-October, trapping fine furs in November and December, seeking game in January and February, caribou hunting in March, and trading in April and May. By the latter decades of the 1800's, the Dogrib were visiting the Fort Rae post at Christmas and Easter, and in June after the spring Beaver hunt. The regularity of these visits by Dogrib families resulted in large tribal gatherings at these times (Helm, 1981).

Unlike the Dene, the Copper Inuit had no significant contact with European travelers, traders or missionaries in the 1800's. Possibly, the only group who may have had some exposure to the Europeans would have been the people of the area known today as Bathurst Inlet and Umingmaktuk. This group made more use of inland areas than other groups of Copper Inuit (Farquharson, 1976). Nevertheless, tons of valuable materials (copper, iron and wood) and manufactured goods entered Copper Inuit society from the British ship, *Investigator*, which was abandoned at Mercy Bay, Banks Island, by M'Clure (Stevenson, 1997).

In the latter decades of the 1800's, a series of events took place which set the stage for the tremendous changes which would occur in the WKSS area in the 20th century. The most significant of these events occurred between 1867 and 1870. They included the founding of the Dominion of Canada (1867), establishment of the first mission school in the NWT at Fort Providence (1867), and the transfer of title to Ruperts Land (the entire Northwest Territory) from the HBC to the new Government of Canada (1870). These events spawned an era of nation building, and the development and passage of legislation and policies to define the jurisdiction and authorities of the new government.

Among the new legislation and of particular relevance to the people of the WKSS area was the *Indian Act* (1876). The act defined Aboriginal people and the responsibilities of the Canadian Government. The *Northwest Territory Act* (1875) established administrative districts throughout the Northwest Territory. The District of Keewatin was established in 1876, the Districts of Assiniboia, Saskatchewan, Alberta and Athabaska in 1882, and the Districts of Mackenzie and Franklin in 1895. In 1898, Yukon became a separate territory and in 1905, the provinces of Saskatchewan and Alberta were formed. The *Northwest Territory Act* was amended in 1905 to give the Federal Government full responsibility for the remaining districts of the Mackenzie, Keewatin and Franklin. It also provided for the appointment of a Commissioner and a Council (of not more than four members (Carney, 1971)).

The economy and lifestyles of the Dene of the WKSS area underwent significant changes as the 20th century approached. These changes brought hardships and seriously threatened the survival of the Dene well into the new century. The Dene experienced game shortages, a declining fur trade, more competitive resource pressures and less amicable relationships with non-Aboriginal people. Dene also experienced uncertain relationships with the Government of Canada (Abel, 1993; Fumoleau, 1973). Little assistance was available to deal with these hardships. Annual visits by a medical doctor did not begin in the Dogrib region until 1900 (Ryan, 1995). Appeals by missionaries to the Canadian Government to assist the Dene, were unsuccessful (Fumoleau, 1973). *"The Hudson's Bay Company had always helped the Indians in time of famine. However, after 1870 it argued that the Canadian Government must assume responsibility for the NWT and its native people … The Canadian Government did not feel any obligation toward people with whom it did not have a formal agreement"* (Fumoleau, 1973). The policy of the Canadian Government in the late 1800's has been described as "no-treaty-no-help" (Fumoleau, 1973). The Canadian Government seemed to have little interest in the north or in its people. It was not interested in entering into a treaty north of the 60th parallel.

The Canadian Government's approach to northern administration, and to the people of the northern districts, finally changed with the discovery of oil in the Mackenzie River Valley and the discovery of gold in Yukon (Fumoleau, 1973). The resource potential of the northern districts caused the government to actively pursue treaties with the northern Athapaskans and in 1899, Treaty 8 was signed.

2.4.4. The 20th Century

At the beginning of the 20th century, the business of building a new nation greatly influenced the WKSS area, as did other economic and political events occurring elsewhere in Canada and in the world. The gold rush in northern British Columbia and Yukon, mineral and oil exploration in the Mackenzie Valley, the growing presence of the Canadian Government in the northwest, and World War I were among these events. They brought an influx of non-Aboriginal traders, mineral explorers, scientists, law enforcement officers, missionaries and federal government agents into the region. With the newcomers came new social, economic and political pressures, and new expectations, systems and laws. The Canadian Government gave the North West Mounted Police (RCMP after 1921) the job of asserting Canadian sovereignty in the northern districts, establishing law and order, and enforcing government policy. The first RCMP detachment was established in the NWT at Fort McPherson in 1903. By 1921, there were six detachments, 12 by 1937 and 15 by 1944 (Barnaby, 1991).

In 1905, following the *NWT Amendment Act,* the Canadian Government appointed a non-resident council to guide development and express the nation's interests in the Districts of Mackenzie, Keewatin and Franklin. The Government also pursued treaties as a means of furthering national interests and in 1921, Treaty 11 was signed. The Government viewed treaties as a mechanism for extinguishing land claims. Treaties also provided a cheap form of relief payment to Aboriginal people and facilitated the implementation of law and order, and government policies (Abel, 1993). Dene oral history may provide a more accurate version of the treaties. The Dene viewed treaties as international agreements that established relationships between themselves and the Crown. Treaties acknowledged Dene sovereignty and underlying title, while allowing Euro-Canadians access to the land. *"Dene were to retain control of themselves, their land, economy and political life; in return they promised to live in peace.....In return for living in peace, Dene would receive gifts of medical and relief aid for the sick, elderly, and destitute and emergency assistance."* (Smith, 1999).

Treaties were expressions of good will whereby the Government promised to protect the land-based economy from outside pressures brought by settlers, trappers, and prospectors and to assist in times of hardship or sickness (Abel, 1993). For the Dene, ensuring continued access to hunting, fishing and trapping territories was the main motivation for entering into a treaty with the Government. In ensuing years, however, the Dene saw access to land and resources being threatened by government and non-Aboriginal interpretations of the treaties. The implementation of legislation also restricted or limited resource harvesting activities. The first legislation, the *Game Act*, came into force in 1896 and this was followed by the *Migratory Birds Convention Act* in 1917, and the *NWT Game Act* in 1929 (Abel, 1993; Fumoleau, 1973). The Dene began to voice concerns to the first Indian agent, who was appointed to the northern districts in 1901. Lack of satisfactory resolution of concerns respecting resource harvesting eventually led to boycotts of Treaty 8 in Fort Resolution in 1920 and 1937. There were numerous other complaints and protests (Abel, 1993). In 1947, all Dene bands in the NWT lodged complaints to the Government about the *NWT Game Act* (Dene Nation, 1983).

While treaties were being signed and new Canadian laws implemented, the Dene of the WKSS area continued to be ravaged by starvation, sickness and disease. Epidemics and death from famine frequently followed diseases. Effects were to destroy families and profoundly undermine the skill and knowledge base of the people as well as their self-sufficiency and hopes for the future (Abel, 1993). Starvation and sickness drove Dene throughout the WKSS area to the trade posts in search of help. Little if any help was available. *"The complete inadequacy of northern medical services was demonstrated tragically in 1928. A severe strain of influenza was imported to Fort Smith that spring and developed into a full-blown epidemic reminiscent of the disastrous scarlet fever epidemic of 1865. The spring boats carried the virus from post to post down the Mackenzie; both Natives and non-Natives were snared in the same trap of contagion"* (Abel, 1993).

The early decades of the 20th century also brought Euro-Canadians scientists, adventurers, traders, missionaries and government agents into the west Kitikmeot subregion. The Canadian Arctic Expedition brought researchers and scientists to the lands of the Copper Inuit to investigate the people, flora, fauna and resources. The documents produced by the Expedition and others recorded during this time provided important insights into Copper Inuit society. *"The exploratory journey of Stefansson in 1910 to 1911 and the presence of the Canadian Arctic Expedition 1914 to 1917 were important factors, but the influx of goods brought by trading ships from the west and the establishment of a number of trading posts in the Coronation Gulf area during the early 1920's were the chief determinants of changes in material culture, economy, and social organization. "* (Damas, 1984).

After 1916, new trade posts sprung up in the Arctic coastal region to capitalize on the demand for Arctic Fox. In an attempt to maximize profits, many of these traders exploited Inuit trappers (Condon, 1994). The missionaries arrived about the same time, although the work of the churches was likely slowed by the murder of a Roman Catholic priest near Bloody Falls in 1913 (Damas, 1984). In the 1920's, mineral prospecting by aircraft began in the Arctic. The first settlement of Bathurst Inlet evolved from a mining exploration camp established there in 1929 (Pierce, 1994). The RCMP arrived in Cambridge Bay in 1926. A six-bed hospital operated at Kugluktuk between 1929 and 1931. This was undoubtedly influenced by a severe epidemic in 1928, that drove over half of the surviving population of Bernard Harbour to Kugluktuk. Bernard Harbour was situated on the south shore of Dolphin and Union Strait, almost due north of Kugluktuk (Farquharson, 1976).

After only a short period of use, trade goods, particularly the rifle, steel trap and fish net, had begun to alter the seasonal cycle, land use and migration patterns of the Copper Inuit (Damas, 1984). By the mid-1920's many families were leaving sealing camps in early spring to remain inland until late fall. Jenness (1922) noted the rapid rate at which dogs became a major means of transportation. The dependance upon of dogs put greater pressure on caribou and fish resources and led to local shortages of caribou (Stevenson, 1997).

Traditional Copper Inuit society began to change as a result of contact with Euro-Canadians. *"The fur trade, the rifle and the fish net not only undermined traditional reciprocal rights and obligations, but they began to turn families into self-sufficient production units. Thus, the traditional foundation for sharing began to erode and socio-economic relationships became more inwardly focused."* (Stevenson, 1997). Around the same time, missionaries outlawed spousal exchange and dance and, or, song partnerships. These actions severely reduced traditional co-operative and reciprocal activities, and eventually extended family units began to replace voluntary partnerships.

Much of the literature about the WKSS area in the early to mid-20th century focuses on the interaction and the influence of the Anglican and Roman Catholic churches, Federal Government agents and the RCMP with the Aboriginal peoples. Mission-run schools were established early in the 20th century at central trade posts such as Fort Resolution (1903), Fort Smith (1915), and Fort Simpson (1918) in the western NWT, and at Chesterfield Inlet (Nunavut) and Churchill (Manitoba). These schools generally evolved from mission-run day schools to residential or boarding schools. They took young children far away from their families, in some cases, for years at a time. A major expansion of Canadian Government funding of mission schools was introduced in 1898. Possibly, this was in anticipation of the signing of Treaty 8. It was not until 1910 that a major revision of government policy was undertaken to address mounting complaints about the viability, efficacy and appropriateness of the church-run "Native boarding schools" (Abel, 1993). The policy gave the government a clear role in determining the curriculum, reducing the previous emphasis on religion. Schools were to provide *"an English education; to teach calisthenics, physical drill; fire drill; to teach the effects of alcoholic drinks and narcotics on the human system, and how to live in a healthy manner; to instruct the older advanced pupils in the duties and privileges of British citizenship, explaining to them the fundamental principles of the Government of Canada, and to train them in such knowledge and appreciation of Canada as will inspire them with respect and affection for our country and its laws."* (Abel, 1993).

In recent years, the church-run residential schools have been more thoroughly documented in light of allegations of abuse (Barnaby, 1991; Chrisjohn, 1994; Peterson,1994). Much of the evidence is similar regardless of the origin of the child or the location of the school. *"Native schooling was not designed to enable graduates to assume positions of power, as these were reserved for hierarchies within the church, the company, and the government, all of whom were autocratic, conservative and fundamentally racist in character … (Thus the Dene) never having been consulted about schooling, had nothing to say about the substitution of one paternalism for another, thereby leaving sectarian controversy which accompanied the rise of the federal system to the missionaries to resolve."* This author's research was based on historical documents and education policies pertinent to the NWT (Carney, 1971).

In the early decades of the 20th century, day to day influence of federal agents on the lives of Aboriginal people in the WKSS area seems to have been less than that of other Euro-Canadians. The reasons for this are attributed to the wide range of their functions from health and education inspectors to treaty officials, and the extensive areas and widely dispersed populations for which they were responsible (Barnaby, 1991). The RCMP were regionally based, and played a significant role in the daily lives of northern people. The presence of the RCMP is described in the literature as a “mixed blessing” not only to Aboriginal people but also to the traders and the missionaries. The RCMP assisted in providing relief to those in need, enforced game laws (Section 4.2.5), and protected the interests of Canada in the north. These responsibilities often brought the RCMP into conflict with northern people, both Aboriginal and non-Aboriginal (Abel, 1993).

World War II (WW II) stimulated additional and more rapid changes in the north. The discovery of silver at Great Bear Lake, oil at Norman Wells, and gold on the shores of Yellowknife Bay in the 1930's, fueled greater interest in northern resources. Within the context of WW II, northern resources were viewed as critical to future national security (Abel, 1993). Gold discoveries at Yellowknife created a boom town by 1936 and four years later, it was a thriving community of about 1,000 people with the first municipal government in the district. Advances in communication and transportation technologies, a growing industrialization of the northern economy, falling fur prices and game shortages, and continued sickness and diseases particularly among the Aboriginal populations, posed new challenges for the people and the Government. *“The 1930's and 1940's saw the development of two northern solitudes: two independent economies, two very different societies and a significant power imbalance."* (Abel, 1993). The solitudes separated those involved in the Aboriginal land-based harvesting economy and the non-Aboriginal wage-based economy. These differences continued to be reflected in the marginal involvement of the Dene in the industrial economy, in decision making and perhaps, most importantly in the regulation of game and fish resources. *“Game regulations became the intersection at which Dene interests and value-systems collided most dramatically with outsider interests.”* (Abel, 1993).

Despite the rapid changes occurring in the WKSS area, the seasonal activities of the Dene during and after WW II were reminiscent of those of previous generations. The Dene continued to be migratory. After spring break-up, they moved to traditional fishing sites for the summer. They gathered and dried foods for winter in late summer, and moved to traditional hunting grounds for the fall hunt. In December, they moved to the nearest post to trade furs and, after, they returned to winter camps until spring (Helm, 1981). Within this economic cycle, the general health of Aboriginal peoples continued to be poor. Between 1937 and 1941, the incidence of tuberculosis among Dene of the Mackenzie District was 14 times greater than the national average. The occurrence of pneumonia was more than double the national rate (Wherrett & Moore, 1945). In 1950, one in every five Inuit suffered from tuberculosis (Crowe, 1974).

The post-war years brought a recommitment from the Canadian Government to asserting sovereignty north of the 60th parallel, and to developing the north’s non-renewable resources. Increases in government expenditures provide evidence of this commitment. In 1945, the Canadian

Government's budget for the NWT was $0.5 million and in 1961 it was $41 million (Carney, 1971). In the 1980's and 1990's Federal Government allocations to the GNWT exceeded $1 billion annually, prior to the creation of Nunavut Territory. The 2001/2002 fiscal year budget for the new, smaller NWT stands at just over $750,000,000. The budget for Nunavut Territory, for the same fiscal year, is $667,000,000 (GNWT., 2000a).

In the post-war years, new national social programs became available in the WKSS area. In 1946, the Northern Health Service of the Department of National Health was established. It was to provide medical services and to address abysmal northern health conditions, particularly among Aboriginal peoples. Other forms of support such as food vouchers, social (financial) assistance, the family allowance (1945) and the old age pension (1948) were introduced or became more readily available. These forms of support quickly became incorporated into the northern economy and were eagerly used by the Dene and Inuit. Support was viewed as an economic resource, and one that was complementary to land-based harvesting practices (Ross, 1986). In 1956, Commissioner Gordon Robertson expressed concern about the wide-spread dependency on social support among Aboriginal people in the north (Abel, 1993). The wide-spread dependence on income support and social programs remains a concern throughout the NWT (DECE *et al.*,1995; Lutra, 1998).

In 1953, the Canadian Government restructured its administration of the northern districts. A Northern Administration Branch was created, in which the Territorial Division and the Lands Division were relevant to the Dene. The Arctic Division was relevant to the Inuit. Northern education was reorganized in 1955. Church run schools were phased-out, allowing government schools to refocus education. This provided an opportunity to reflect current social and economic circumstances and northern development policies of the Canadian Government (Abel, 1993). The new northern education program was designed to transform hunters into wage-earners. It was also intended to assimilate northern Aboriginal people into main stream Canadian society (Kakfwi, 1977). Family allowance supports became one of the instruments for encouraging the participation of Dene, Métis and Inuit children in education programs. To receive desperately needed cash, families sent their children to school. Some children attended schools near their family but many others went to residential schools in distant communities (Asch,1986; Barnaby, 1991; Carney, 1971). Dene and Inuit children of the post-war period were the first of their people to have the opportunity to achieve a high school education and pursue other post-secondary education. The parents of these children were the first to adopt a sedentary, community-based lifestyle, a trend that emerged in support of their children's education. It was also a trend that fundamentally altered the lifestyle of the Dene (Abel, 1993; Barnaby, 1991; Helm, 1981; Smith, 1981).

By the early 1960's, the effects of the Canadian Government's new northern policies were evident in the lifestyles of people throughout the WKSS area (Abel, 1993; Barnaby, 1991; Helm, 1981; Smith, 1981). Government nursing stations and elementary schools had been constructed near churches, trading posts, RCMP detachments and government staff housing. "Stick-built" housing was also replacing the tents and, or, log dwellings of Aboriginal people. In the Dogrib region, some Dene families began to live year-round at the present town site, rather than gathering at Rae once or twice a year and spending the winter on the land (Ryan, 1995). Electricity arrived in Rae in the 1950's and a connector road to the Mackenzie Highway opened in 1960. In 1965, concerns about the water supply and health of Rae residents spurred the Canadian Government to establish the new town site of Edzo and a new school was opened there in 1971. The Dogrib community of Wha Ti (Lac La Martre), formerly a NWC trading post (1793 to 1817), began to form with the construction of a school in 1955. Rae Lakes (Gahmìtì) and Wekwetì (Snare Lake) remained outpost hunting camps until government services and infrastructure began to arrive, respectively, in 1970's and 1980's. Lutselk'e (Snowdrift) began developing as a Chipewyan community when government services and permanent housing became available there in 1954. The Canadian Government designated the name "Yellowknives A Band" to Chipewyans in the Lutselk'e area in the 1960's and "Yellowknives B Band" to the Dogrib residing in and near the town of Yellowknife (Gillespie, 1981).

The impacts of increased Canadian Government investment and new social policies were also felt by Copper Inuit of the west Kitikmeot subregion. In 1951, the Canadian Government took over the LORAN infrastructure for communication purposes and the Royal Canadian Air Force established a survival school at Cambridge Bay. Military and other government personnel arrived with the DEW-line, and a school was built in 1958. By 1955, Cambridge Bay had become a major supply and transportation centre for 12 DEW-line sites being constructed across the north. *"At the peak of this construction, some 200 Inuit were employed along this section, and Cambridge Bay became a focus of immigration from other settlements."* (Farquharson, 1976). The construction of a DEW-line site at Kugluktuk in the 1960's attracted Inuit to settle in the developing community. *"The extent of land use during the 1950's and early 1960's decreased, for most people lived in or near Coppermine at the time, and they still used dogs to travel. The numbers of caribou and other game taken were not especially large. Then the snowmobile was introduced, and it changed the lifestyle and patterns of land use altogether. The necessity of maintaining a camp 20 to 30 miles out of town to be nearer good hunting territory became much less, so more people moved into the settlement. They are now able to travel farther and faster with the snowmobile and, despite the more concentrated settlement pattern, have returned to exploit most of the hunting area they left in the late 1950's."* (Farquharson, 1976).

The Copper Inuit population settled in the new communities in part because of the availability of wage employment and social services, but also because of declines in caribou populations and the uncertainties of the Arctic Fox fur trade (Damas, 1984). Bathurst Inlet did not develop into a central settlement like Kugluktuk (Coppermine) and Cambridge Bay. The people of that area continued to live on the land year round. Bathurst Inlet has remained, until very recently, an outpost camp with few services (Farquharson, 1976).

The growth of permanent communities together with the movement of land-based peoples into settlements, contributed to the development of cooperatives across the Canadian Arctic in the late 1950's. Cooperatives were an effort to link the land-based and the wage economies (Crowe, 1974). The Cambridge Bay fisheries and Kugluktuk arts and crafts cooperatives were established in 1961 and 1969, respectively. Regional economic surveys in the 1950's and 1960's showed that few northern Aboriginal people held year-round or permanent wage jobs. The economic circumstances of Aboriginal peoples were very poor compared to those of non-Aboriginal people. Low participation of Aboriginal people in the wage economy was also influenced by limited opportunity, personal circumstance and lifestyle choice (Abel, 1993; DIAND., 1958-1969).

Governance in the NWT evolved with the development of the new communities. The first territorial council was appointed in 1905 but the first resident did not join the council until 1947. It was 1951 before the first members were elected. Fifteen years after Aboriginal people were allowed to vote in federal elections (1960), the first fully elected territorial council took office. This first fully elected council had a majority of Inuit, Dene and Métis members. It followed a consensus style of decision-making which is not found in any other legislative assembly in Canada. Since the 1960's, the Dene and Inuit have been working toward self-government. In response to grievances and growing concerns in and about the north, the Canadian Government sponsored the Carrother's Commission to inquire into the political future of the NWT. In 1966, following this report, the seat of government was moved to Yellowknife. This begin the devolution of power from Ottawa to the north.

In 1967, the Federal Government installed a Commissioner and administrative staff at the new capital of Yellowknife. Two years later, administrative responsibilities were transferred from the Government of Canada to the newly created GNWT. In the following decades, responsibilities for education, health, forestry, and some aspects of wildlife management and housing have been passed from the federal to the territorial government. Today, the Federal Government retains or shares responsibility with the GNWT and, or, Aboriginal organizations for non-renewable resources, fisheries and much of the regulatory processes related to the natural environment in the north. The institutions, structures and payroll of the GNWT bureaucracy grew steadily from its inception until the mid-1990's. In 1974, the GNWT employed 2,700 people (DP-GNWT., undated) and in 1995, this number was 6,128 (FMS-GNWT., 1995). After the creation of Nunavut, the GNWT employed only 3,351 people while Government of Nunavut employed 4,298.

Amidst the devolution of Federal Government responsibilities and the creation of the GNWT, Aboriginal peoples across Canada and in the NWT were evolving active political organizations. The establishment of the GNWT, concerns for Aboriginal participation in northern decision making, and the Federal Government’s 1969 White Paper outlining the future of Aboriginal peoples in Canada were among the issues that lead to the formation of new Aboriginal political organizations. These included the Indian Brotherhood of the NWT in 1970 (now known as the Dene Nation), the Committee for Original Peoples Entitlement (COPE), the Métis Association of the NWT, and the Inuit Tapirisat of Canada (Abel, 1993). These political organizations worked to gain recognition of Aboriginal land rights, to regain control of resources, and to address issues of governance. Their efforts were manifested in a growing public awareness of Aboriginal peoples and of the north. Three years after the formation of the Indian Brotherhood, the Dene sought legal recognition of their prior interest in 450,000 square miles of traditional lands in the Mackenzie Valley. The initially positive response to the Dene's claim rendered by Judge William G. Morrow of the Supreme court of the NWT provided the basis for the Dene to pursue legal claim and recognition of Aboriginal rights to traditional lands, resources and governance. They were also successful in influencing the outcome of the 1975 Mackenzie Valley Pipeline Inquiry (Berger Inquiry) which recommended a moratorium for ten years on the first proposed oil pipeline, in light of unresolved rights and land disputes (Berger, 1977).

The 1970's and 1980's were decades of socio-cultural and political revitalization among northern Aboriginal peoples, and of the evolution of northern governments and institutions. The GNWT promoted establishment of municipal governments and today, locally elected councils function in virtually every community in the WKSS area. Dene communities also maintain a Chief and Council as established by the Federal *Indian Act.* Education, health and social services begun in the WKSS area were expanded to include programs and services related to housing, municipal transportation, communications, and economic development. Many of these activities were driven by a need to catch-up and to introduce modern health care, recreation, schooling, transportation and jobs to the north (GNWT., 1991). Among Aboriginal peoples and their organizations, the need for self-determination again within their homelands was recognized. This encouraged greater use of Aboriginal languages and other expressions of Aboriginal cultures in the business of northern institutions, and supported the involvement of more Aboriginal people in the affairs of the state. In 1984, the *Official Languages Act* recognized Aboriginal languages along with French and English, as official languages of the NWT.

Throughout the 1970's and 1980's, Federal and Territorial Government investment and policies supported the development and expansion of community governments, public infrastructure, communication and education facilities and services and Aboriginal political organizations. They also supported community-based economic development in the form of renewable resource and tourism industries, and small businesses (SCNE., 1989). In these decades, four new mines opened in the NWT, adding to the three mines operating since the 1930's and 1940's. The mining industry continues to be the largest private sector employer and largest single influence on GDP (NWT-CM *et al*., 1993). Throughout the 1970's and 80's, national and international resource developers continued to look north to exploit rich oil and gas deposits. In 1985, the first oil pipeline was built from Norman Wells to Alberta. Industrialization of the north has continued and in 1998, after almost a decade of intense exploration and development, the first diamond mine in Canada, the BHP Ekati mine, opened in the traditional range of the Dene (Sections 3.3.3.3 to 3.4). Two additional mines are expected to open within the next few years.

The last two decades of the 20th century have been ones of tremendous political change in the WKSS area and NWT. To some extent, traditional land and resource uses of some Dene groups and the right to self-governance have been recognized in federal and territorial government legislation and policies. The first Aboriginal land claim agreement in the NWT was signed in 1984, between the Inuvialuit and the Government of Canada (*Inuvialuit Land Settlement Act*). The Federal Government began negotiating with the Dene and Métis in 1981 toward a comprehensive land claim settlement for the whole of the Mackenzie Valley. Nine years later, the Dene Nation rejected the proposed claim, partly due to the federal land claims ‘policy-of-the-day’ to extinguish Aboriginal rights. In 1990, the Gwich'in of the Mackenzie Delta and the North Slavey of the Sahtu Region withdrew their negotiating mandate from the Dene Nation. Each group requested that the Canadian Government negotiate regional land claim settlements. These claims were concluded in the Gwich'in area in 1992 and in the Sahtu Region in 1993 (Fig. 16). The Gwich'in and Sahtu agreements extinguished the Aboriginal rights of these Dene but provided certainty to the use and ownership of land. The agreements included a commitment for the Federal and Territorial governments to negotiate Aboriginal self government agreements with these regional Aboriginal organizations (CWG., 1998). Some negotiations are nearing completion and others are in progress.

The failure to reach a comprehensive settlement in 1990 and maintain unity among northern Athapaskan peoples, has weakened the political strength and fragmented the organizational force of the Dene and Métis, but resource and governance issues continue to be pursued. Formal negotiations began with the Dogrib in January 1994, the third regional land claim to be accepted for negotiation in the Mackenzie Valley. Interim agreements provide the Dogrib with opportunities to participate on government bodies which assess and review development activities and regulate land and water uses in the North Slave region. In August 1996, the Dogrib, the Canadian Government and the GNWT were signatories to a framework agreement that outlined the issues and time frames for concluding a land claim and self-government agreement. In January 2000, the Dogrib, the Canadian Federal Government and the GNWT were signatories to an agreement-in-principle, which forms the basis for concluding a land claim and self-government agreement. The Treaty 8 Chipewyan and Yellowknives are also pursuing treaty entitlement and self-government discussions with the Federal Government. The thrust of these discussions is to achieve co-existence among Aboriginal and non-Aboriginal people in the Treaty 8 area. Co-existence is a philosophy based on the understanding that *"nothing will be done or allowed to interfere with their (Dene) way of living as they were accustomed to, and as their antecedents had done"* (NWT Treaty 8 Tribal Council, 1994).

Residents of the West Kitikmeot sub-region participated in a 1982 plebiscite which showed that 70% of eligible voters in Nunavut wished to divide the NWT into two parts (generally along the tree line), and to create a politically and culturally distinct territory for the Inuit. Five years later, the *Iqaluit Agreement* set out the principles by which an eastern and a western territory would be established. In 1990, the Tungavik Federation of Nunavut, representing Inuit throughout the NWT, reached an agreement-in-principle with the Government of Canada respecting Inuit land rights and governance. Four years later, the Nunavut land claim was legislated, recognizing traditional lands of the Inuit and the creation of the new territory of Nunavut on April 1, 1999. The West Kitikmeot sub-region is part of this new Inuit territory.

2.4.5. Toward the 21st Century

"One factor of overriding importance is the rate of change in the North, especially since World War II. Each successive generation of Native people has grown up in very different circumstances. For example, elders alive today remember a childhood in which very occasional wage labour and the fur trade were the only significant sources of cash income, while most people made their living mainly from the land. The next generation - people who are in their thirties and forties now - remember being taken from their communities to residential schools for long periods of time and trying to learn the language and skills of their parents despite this. The children of the 1980's attend school (at least until high school) in their own communities, or they may be growing up in cities and large towns. They watch television, listen to popular music and face many different obstacles to learning about their heritage. The contrasts among the childhood experiences of these three generations illustrate the pace of change." (Abele, 1989).

As the 21st century begins, the prospect of change is a certainty shared by Aboriginal and non-Aboriginal residents of the WKSS area. New governance regimes are evolving in the two new territories, with the implementation of Aboriginal land claim settlements and self-government agreements. The wage or industrial economy is changing in response to reductions in government investment and proposed mineral, hydrocarbon, hydroelectric and infrastructure developments. Competing interests and changes in the natural environment influence both subsistence and land-based economies. Environmental and climatic change, new technologies, global market conditions, and changing harvester skills and interests pose complex questions and challenges for the future of resource harvesting. Amidst these changing conditions, many of the issues that existed at the turn of the 20th century persist today. These include access to and management of resources, equal participation in decision making, and ensuring the health and well-being of individuals and families. In the WKSS area, these concerns are made more urgent by the growing population, half of which is under 25 years of age.

The population of the NWT was 42,600 in 1976 and 64,402 in 1996. After division the total NWT and Nunavut population exceeded 70,000 (42,154 to NWT and 27,892 for Nunavut) The rate of population growth in the NWT in the year 2000 was 1.9%. This was second only to Nunavut's rate of growth, the highest in Canada, of 2.8%. More than 25,000 people live in the WKSS area (Table 7). In the Treaty 8 and 11 and West Kitikmeot sub-regions, Dene and Inuit remain the majority in all communities except the capital of Yellowknife.

The people of the WKSS area are confronted with several unique and complex challenges. The population lives in a world of change and contrast, of new and old. Aboriginal and non-Aboriginal residents of the WKSS area have access to global communications and mass media, but also to elders who speak in forms of the Dene and Inuktitut languages that are spoken by few other people. There is a rapidly growing and mainly immobile labour force that lacks skills and education to compete for work opportunities. This labour force is growing faster than the number of new jobs. At the same time, governments lack a significant tax base from which to provide the wide range of programs and services that people in WKSS area communities have come to expect. The challenge of these issues is compounded by disturbingly high incidences of alcohol and drug abuse, illiteracy, boredom, unemployment, family violence, suicide and disease. For the large numbers of young people now growing up in WKSS area communities, these circumstances are disquieting. The creation of greater social, political and economic stabilities are among the greatest challenges now facing residents of the region (GNWT., 1991).

2.4.6. Land and Heritage Sites: An Example of the Importance of Land to Aboriginal Peoples

Aboriginal people often refer to the important role that the land plays in their culture and survival, and non-Aboriginal people will likely relate to these statements from their own cultural perspective. They may think of the importance of wildlife used for food, the aesthetic qualities of land and the attachment that is felt to familiar country, or country occupied for generations. However, the depth of meaning of the statement may be lost on most non-Aboriginal people unless they know more about the integral nature of land to Aboriginal culture.

Among the Dene and Inuit the content of stories, songs or other forms of narratives are essential components of culture. Spirituality, values, history, governance, justice, and practical information needed for obtaining resources are examples of information contained within narratives. These are passed from one generation to the next through the oral tradition (Andrews, 1997; Legat, 1995; 1997).

Examples from recent Dene research show that many place names and associated narratives reflect the values and knowledge of Dene people. Knowledge of these narratives, that accumulate over a life time are essential to being or becoming a true and knowledgeable Dene (Andrews, 1990; 1997). Examples of the fundamental importance of places and place names are reflected in the legend of the culture hero Yamoria (Blondin, 1990). Through a series of heroic actions Yamoria brought order to the world, in part by separating animals and humans, and by ridding the land of giant animals that were harmful to people. The specific locations where these actions took place are remembered through place names assigned to each of them. When people travel past or camp at these places the stories associated with the place names are recounted and provide a time to reflect on or be taught the cultural values they convey. Some places are associated with particular stories that outline appropriate cultural behavior. Those who are not behaving accordingly are reminded of this when they travel to or past these places. When away from them and acting inappropriately, the individual will think of the story and the place (Andrews, 1990).

Place names also provide practical descriptions for the location of resources such as caribou crossings, good fish lakes, places where a particular type of rock can be quarried for tools, or birch bark suitable for canoes. Some names simply provide a description of geographical features. For the Dene, traveling and living on the land is as important as it is to visit places where cultural narratives are expressed and knowledge imparted (Legat *et al.*, 2000).

Given the importance that the land holds for the Dene, only those who are truly knowledgeable of the land are thought qualified to speak about it (Zoe, 1995). Before doing so, elders establish their credibility to others in telling of their experience on the land, their knowledge of the rules set down by important historical leaders, and of key spiritual and, or, mythical events. In doing so, they demonstrate that they are true holders of important knowledge which has been passed down through the generations. The land plays a role in the lives of Aboriginal people that is quite different from the experience of most non-Aboriginal peoples.

2.4.6.1. Heritage Sites

Given the importance of land to Aboriginal people, there are innumerable places within the WKSS area that are significant to Dene, Inuit, and Métis culture and history. Collectively, these are referred to as heritage sites. The use of the word heritage does not mean that the sites are only significant in an historical context. Many of these places continue to be used in some manner, as they have been over hundreds if not thousands of years.

Heritage sites are often named places and are documented through place names research. Such sites may be landmarks, sites associated with mythological or legendary events, or traditionally used places that also have archaeological remains. Place names research, archaeological surveys, oral traditions interviews, and a combination of all of these are the ways in which heritage sites can be documented within the WKSS area.

2.4.6.2. Aboriginal Place Names

Information on the place names of the NWT is held at the Prince of Wales Northern Heritage Centre (PWNHC) in Yellowknife. In the NWT, the importance of using Aboriginal place names to Aboriginal peoples can be seen in the recent change of many community names from Euro-Canadian ones to those that were traditionally used. For the past fifteen years the PWNHC has been gathering and promoting the recording of traditional names for all geographic features (lakes, mountains, rivers, islands,) throughout the north. Over the years traditional community names, many of which predate the community itself as they were used for nearby geographic features, have been recognized as official by the GNWT. Examples (DECE., 2000) include Tsiigehtchic (Arctic Red River), Tulita (Norman Wells), Kugluktuk (Coppermine), Wha Tí (Lac La Martre), and Iqaluit (Frobisher Bay).

Traditional place names reflect the use of the land by Aboriginal peoples and are places of importance to them. Most non-Aboriginal people are unaware of the large number of named places that exist in the NWT. In the past, many Aboriginal names were not included on official maps and this resulted in a perception of under representation of the area's use by Aboriginal peoples. Documentation of traditional place names in the NWT, some of which are within the WKSS area, is taking on a new impetus (Andrews, 1997; 1998; Blondin, 1990; *Dene Mapping Project*, 1986). Not only do people want to see the names appear on maps but they also want to document the knowledge related to them. The GNWT recognized the importance of documenting and preserving traditional names and has sponsored more than 40 place name projects over the past 15 years. As well, several non government projects have also taken place. More than 15,000 traditional place names have been documented through recent place names projects (Freeman, 2000).

2.4.6.3. Archaeological Sites

Archaeological sites in the NWT are protected by three laws. The *NWT Archaeological Sites Regulations* state that excavation or investigation of sites or collection and removal of artifacts cannot be undertaken without a permit. The *Territorial Land Use Regulations* state that land use permit holders shall not conduct land use operations within 30 metres of a known or suspected archaeological site or burial ground. Permit holders are to suspend operations if a site is found while working in an area and to report the find. The *Historic Resources Act* protects sites on Commissioner's Lands of the GNWT. Developments thought to threaten historic remains on such lands are subject to the Commissioner calling for the developer to undertake a study and, or, salvage of the remains. The importance of archaeological sites to Aboriginal peoples is clearly stated within most land claims agreements or negotiation documents (DECE., 1996).

The Archaeological Survey of Canada Sites Database is administered and maintained by the Canadian Museum of Civilization in Hull, Quèbec. It contains information on all sites reported in the NWT. The PWNHC in Yellowknife accesses this database and also maintains a file of sites reported by non-archaeologists. Within the WKSS area, the Archaeological Sites Database lists 1,041 known archaeological sites (Fig. 18). This is thought to represent only a small fraction of the actual number of sites in the area (Andrews, 1998). The sites represent occupation of the area over as long as 7,000 years (Section 2.2.2.7). Among the types of sites listed are burials, campsites, hunting localities, hunting blinds, lookouts, quarry sites, workshops, and forts.

There are numerous examples of the importance of using traditional knowledge in identifying and interpreting archaeological sites (Andrews, 1998; Blondin, 1990; NPC., 1997). The value alone in identifying numbers of sites through traditional and, or, local indigenous knowledge can be seen in the report of the West Kitikmeot Land Use Plan (Greer, 1997). Seven hundred archaeological sites were identified within the region. Of these, 61% were known sites obtained from the Archaeological Sites Database and the remaining 39% were identified by Inuit who knew of these sites from living and traveling in the area.

Recent archaeological surveys undertaken by the Dogrib Treaty 11 Council and the PWNHC show the importance of archaeological sites and the information they contain on culture and history. During a survey of the Idaà trail (linking Great Slave to Great Bear Lake), Dogrib elders and project researchers recorded 286 sites as well as 350 named places (Fig. 18) (Andrews, 1997; 1998).

2.4.6.4. Graves

The Dene, Inuit, and Métis share concerns for the protection of graves. In the past, graves have been destroyed or damaged through development (Beilawski, 1993). Concerns that more graves may be destroyed was voiced by many Aboriginal people attending the Environmental Hearings for the BHP Ekati mine (Legat, 1995). Graves are widely scattered across the land in areas where people lived and traveled. However, no systematic documentation of grave sites has been undertaken and very few graves have been recorded. Only graves that are sometimes recorded during archaeological surveys come under the protection of laws which pertain to archaeology. Graves in cemeteries are protected, but those found elsewhere, and not considered archaeological, are not protected. New legislation proposed by the PWNHC seeks to protect graves on Commissioner's Land (DECE., 1996).

The attitude towards, and treatment of, burials differs between cultures, particularly between Euro-Canadian and Aboriginal groups. For example, although graves are treated with respect in both cultures, Dene consider them more sacred and their graves may serve a number of functions specific to the needs of local and regional inhabitants. Dene graves, with a cross and surrounded with a picket fence are carefully maintained by people traveling past them. Offerings are presented to the dead and assistance may be asked for in hunting or some other activity. Graves may also be used as a meeting place for travelers and as a place where ceremonies are held to ensure safe travel.

It is important to Aboriginal people to identify grave sites so that they are not destroyed. Graves are present over a very large area and reflect the extensive land base on which people have lived and traveled. A recent survey of a portion of the traditional trail between Great Slave and Great Bear lakes yielded 189 graves (Andrews, 1998). Even though far away from present communities, graves are still a concern to people as the following statement of elder Laiza Koyina attests *"All the land over there is where the dead bodies are laid. Kôk'etibà is where grandmother had died and they had to bring her across the lake and over by Kôk'etibà. They carried her there and buried her. And so my younger brother, Johnny is buried there … We have a lot of relatives who are buried in the barren land* ."(Legat, 1995).

3. THE DYNAMIC WKSS AREA ECOSYSTEM

3.1. Introduction

In terms of the environment, a stress is something that causes change. It may take the form of a sudden large event or an accumulation of many very small "happenings" which occur over time. Cumulative impact occurs when many stresses act together to cause change. Often their combined effects are greater than if each stress were to act separately. When stress exceeds some form of threshold, it alters the balance of life. Stress occurs naturally, such as when a wildlife population grows to exceed the carrying capacity of its range (*e. g.* caribou or geese). It also occurs when human development substantially alters the natural system (*e. g.* by contamination or exploitation). Stress has the potential to affect any part or all of the ecosystem and to be a major part of human experience.

Throughout the WKSS area, both natural and man-made stresses, and global and local stresses interact to cause change in many parts of the whole ecosystem (Fig. 19). Relative to most parts of southern Canada, the WKSS area is much less disturbed or developed, but such comparison can be misleading. Even a small amount of development has the potential to affect sensitive environments of the WKSS area and their freshwater, marine and terrestrial ecosystems. Many of the resources of this region have already reached a moderate state of development and a few are at an advanced state.

The mining industry is an example of development associated with a non-renewable resource. Many mines operate for less than 10 years although there are a few exceptions like Con (opened in 1938) and Giant (opened in 1948) that will have had lifetimes of more than half a century. Mineral resources of the WKSS area are extremely valuable. Based on known reserves, existing and new mining activities in the WKSS area are expected to continue for many years to come. However, these resources have a limited lifetime and their rates of exploitation are largely determined by decisions made far outside the region. Some renewable resources, such as fish and caribou, are relatively large but they are also significantly developed in terms of their potential long term yield. Other resources may support only very light use. For example, the number of Muskoxen is known to have been heavily depleted by past exploitation. For the foreseeable future, renewable resources are likely to remain a crucial part of Aboriginal and some domestic economies. They can only become more important in the future as non-renewable resources eventually become depleted.

Multiple forms of stress affect the WKSS area and many of them result in cumulative impact, but management of effect often requires that each form of stress be considered separately. Thus, in the following discussions, distinction is made between stress, its causes, and the effects of stress. It is also recognized that social and economic forces which drive development can not be divorced from its effects. They are often the source although they may not be the immediate cause of environmental change. As we have done throughout this report, social, economic and environmental factors need to be addressed together because people are an integral part of the environment. Stress does not affect all people equally or in the same way. There are obvious differences such as those depending on employment, education and economic standing. There are also cultural differences that exist among Aboriginal and non-Aboriginal communities and which can be equally significant in ways that give rise to different effects.

3.2. A Mixed Economy

For centuries, family and group economies in the WKSS area have been influenced by the availability of and demand for resources, access to technologies and other circumstances such as climatic conditions. In the 20th century, these influences became more national and global in nature. For example, the influences of both World War I and II, the "cold war", the assertion of sovereignty in northern Canada, and increased mineral and hydrocarbon exploration and development activity. They spurred the establishment of DEW-line sites and transportation infrastructure throughout northern Canada (Section 2.4.4). New economic circumstances (cash economy) created opportunities to take up seasonal construction work, and to supplement scarce game and low demand and, or, poor return from fur trapping. Health, education and social and government services that expanded in the WKSS area after WW II also offered opportunities to supplement intermittent wage employment and harvesting activities. To respond to new economic opportunities, some families abandoned the nomadic lifestyle and seasonal camps in favour of a community base. Social, health and education services encouraged a more sedentary lifestyle among Aboriginal people (Ryan, 1995). New technologies enabled harvesters to pursue traditional activities from a community base. Snow machines replaced dog teams, enabling harvesters to travel further and faster, and radio communications allowed harvesters to remain in contact with their families in the community. As new costs were incurred to support harvesting activities, wage employment became increasingly more vital as a means by which ties to the land and traditional activities could be retained (Usher, 1971). Government transfer payments were readily integrated into the wage and, or, harvesting economy of fledgling communities. Transfer payments were used by governments and recipients alike to respond to gaps in the economy whether as a result of depressed fur markets, poor harvesting conditions, inadequate housing or lack of employment (Abele, 1989). By the time the WKSS area communities were taking shape in the 1960's, wage employment and social and, or, transfer payments, like trapping in earlier decades, had been fully integrated into the economic cycle of the Dene, Inuit and Métis (Abel ,1993).

Today, the economy of the WKSS area has three elements. These are traditional activities, wage employment and government transfer payments. The combination of these three components is generally known as a “mixed economy”. It is an economy which combines cash and non-cash inputs (Usher, 1989). A mixed economy combines cash inputs from wages with subsistence harvesting (mainly for food) and transfer payments (mainly as cost of living subsidies). While components of the mixed economy of the WKSS area typically function as integrated and intertwined elements, each community has its own economic cycle (Abele, 1989). For example, a truly mixed economy might generate cash inputs from seasonal wage employment in the construction, transportation or forestry sectors during the summer months. Cash inputs from trapping may be generated in the fall and winter. Both non-cash inputs from harvesting activities and cash inputs from transfer payments may occur throughout the year. Hunting, fishing, trapping and arts and crafts are known as traditional "activities". Traditional activities typically form part of the mixed economy of Dene, Inuit, and Métis, particularly those living in small communities in the WKSS area (Hall, 1986). The relative importance of each component of the mixed economy varies among the 12 WKSS area communities. This is as a result of the availability and capacity of natural, human and physical resources.

The capital of the NWT, Yellowknife, has a wide range of full, part-time and seasonal jobs in mining, government and secondary services industries. It is the staging point for industrial developments in the WKSS area and for the supply and servicing of communities throughout the western NWT and the Kitikmeot sub-region of Nunavut. It has the largest and most diverse non-Aboriginal and Aboriginal populations in the NWT. Wage employment dominates the City’s economy. Hunting and fishing are pursued by segments of the population for mainly recreation purposes. In 1999, the unemployment rate in Yellowknife was 7.9%, as a whole. It was 17.5% among Aboriginal people (BS., 1999). Government and quasi-government corporations provide 38% of employment; 15% is provided by the transportation, communication and construction sectors; 14% is in each of the resource and retail and wholesale sectors; and 5% is in the restaurant and accommodation sector (Diavik, 1997).

Cambridge Bay, Kugluktuk and Rae-Edzo are medium-sized communities with populations of 1,000 to 2,000. Most of the residents in these communities have Aboriginal ancestry. These communities have developing business, government and transportation infrastructures that serve the needs of regional residents and industries. Households in these communities typically blend all elements of the mixed economy. For example, in Kugluktuk and Rae-Edzo, 58% and 55% of the working age population, respectively, participated in the wage economy in 1999 (Table 8). In

Cambridge Bay, Kugluktuk and Rae-Edzo about half of all employment is in the government sector (Diavik, 1997). Half or more of the working age population in these communities are involved in traditional activities on a full or part-time basis. In 1996 and 1997, 36% of the Cambridge Bay and 44% of Kugluktuk populations received or were a member of a household receiving income support (formerly social assistance), at some time during the year. In Rae-Edzo, 60% of the population was assisted with income support at some time in 1996 and 1997 (Lutra, 1998).

The remaining communities in the WKSS area are small, traditional communities. Typically, Aboriginal people are the majority population in these communities. Lutselk'e and Rae Lakes are typical of small, traditional WKSS area communities. Due to limited economic and government sector activity, these communities have few opportunities for generating wage income. Community economies are reliant on traditional activities, transfer payments and seasonal employment. For example, in 1996 and 1997, 95% of the Rae Lakes and 78% of Lutselk'e populations received or were a member of a household receiving income support at some time during the year (Lutra, 1998). In 1999, just over one-half (55%) of the working age population in Rae Lakes and 66% of the Lutselk'e population of this age participated in the wage economy (Table 7).

Harvesting of wild game and fish for domestic consumption (subsistence harvesting) has been described as the cornerstone of many community economies. It has also been described as the focal point of social and physical health and well-being throughout the Canadian north (Condon *et al*., 1995; Fast & Berkes, 1994; Parlee, 1998). Annual household harvests of an estimated three to six caribou, together with fish and wild fowl and other available animal resources such as Moose or Muskox, make-up the bulk of the country foods harvested and consumed in WKSS area communities (BHP & Dia Met, 1995). In Lutselk'e, caribou is the most commonly consumed country food. Ducks are consumed in the late summer while more fish are consumed in summer than in winter (Marlowe *et al*., 2000). Virtually all Aboriginal households (91%) in the NWT consume meat and fish harvested from the land (BS., 1991) and all community residents in Lutselk'e consume meat and fish harvested from the land (Marlowe *et al*., 2000). It is assumed that NWT country food harvesting and consumption patterns apply in most Dene, Inuit, and Métis communities of the WKSS area. Other studies conducted in the last decade corroborate these patterns of country food harvesting and consumption (Kuhnlein, 1991; Lawn & Langer, 1994; Rawson Academy, 1990; Receveur *et al*., 1996). In the NWT and, or, Nunavut:

- 65% of Aboriginal households obtain half or more of the meat and fish consumed in the household through harvesting. Reliance on harvested resources is higher among Inuit (59%) households in Nunavut than in Dene and Métis households in the NWT (39%).

- The proportion of meat or fish obtained by hunting or fishing increases with the number of persons living in the household. About 35% of Aboriginal households with one or two members obtain most meat and fish consumed through hunting and fishing. In Aboriginal households with seven or more members, this figure rises to 70%. The average size of Aboriginal households is 3.8 people in Treaty 8 and the West Kitikmeot sub-region, and 5.4 in Treaty 11 communities.

- The consumption of country food is greatest among low income households. Half of the Aboriginal households with incomes of less than $40,000 obtain most or all of their meat and fish through hunting or fishing. This compares to only 34% of households earning $80,000 or more. In small communities such as Rae Lakes, 81% of households have incomes of less than $40,000 (SC., 1991).

- The amount of caribou consumed by Aboriginal people in northern Canada is declining. Data collected in 1989/90, when compared to 1967/68, show a two to fourfold reduction in caribou consumption over this period. The average intake of caribou by males in Rae-Edzo fell from 135 grams per day to 42 grams per day during this same period (Tracy & Kramer, 2000)

Harvesting activities provide food and reduce economic stresses in Aboriginal households. Assigning a monetary value to traditional activities has been the subject of some research and discussion in recent decades. The average annual replacement or the imputed value of wild meat and fish harvesting to Aboriginal households in the NWT and, or, Nunavut (exclusive of added-value country food processing) has been estimated at $10,000 (Usher, 1989). Returns from trapping are generally less than the investment in that activity. For instance, each trapper in Rae-Edzo received an average of $394 (1996) from the sale of furs, as part of the total community income of $50,000 from trapping. Exclusive of personal time and equipment investments, government subsidy of the fur industry in Rae-Edzo for 1996 was $66,000 (DRWED., 1996). Harvesting activities also have cultural significance, as an expression of identity and as a component of life on and connection to the land (Hall, 1986).

Government policies and investment strategies have a significant influence on the mixed economy in the WKSS area. Between the 1950's and the mid-1990's, public sector investment in the north continued to grow. For at least three decades, the federal and territorial governments offered subsidies to encourage and support traditional activities. For example, the *Outpost Camp Program* started in 1976, provided funding for transportation, building materials and fuel to enable families to live on the land for much of the year (Usher, 1989). Over this period, significant Federal

Government funding was invested in economic development strategies and sector-specific initiatives designed to diversify the economy and to create jobs in regional centres and small communities. Government-funded initiatives were designed to stimulate and enhance the viability of local employment in community cooperatives, tourism, arts and crafts, commercial renewable resource and small business ventures. Infrastructure was also funded to encourage industrial and non-renewable developments (DEDT., 1990). In the WKSS area, the results of these investments are evident in the Ekaluktutiak (fisheries) Cooperative in Cambridge Bay that employs about 25 local people (mainly Aboriginal). Kitikmeot Foods Ltd, a country foods processing plant in the same community, provides another 10 full-time jobs and supplements the income of some 125 local suppliers of Muskoxen, caribou, and fish (Lutra, 1996). Several tourism operations based on game and fish resources, such as the sport fishing lodge in Wha Ti and big game hunting outfitting from Wekwetì, developed from these investments (Diavik, 1997). Tourism businesses in Dogrib communities and Yellowknife have created 186 person-years of employment (North Group & Norecon, 1996).

Government investments in public health, social, education and municipal infrastructures and services throughout the NWT and Nunavut continue to create the vast majority of full-time job opportunities in the WKSS area communities. Public investment in services and infrastructure is declining along with the government's role in economic development and job creation. At the beginning of the 21st century, the GNWT estimates that of the 19,920 jobs in the NWT, 10,825 are in the private sector. It also estimates that in the decade ending in 2010, 4,123 of the 6,400 new jobs that will be created will be in the private sector (BS., unpublished). In 1999, approximately 1220 people were employed in mining and oil and gas extraction jobs in the NWT. Non-residents filled 40% of these jobs (BS., unpublished). Approximately one-third of workers at BHP's Ekati Diamond Mine are of Aboriginal descent and 70% are northern residents (BHP & Dia Met, 2000).

The third element of the mixed economy in the WKSS area, government transfer payments, has continued to play a prominent role since being introduced in the post-war years. The GNWT reports that in the 12 years between 1982 and 1993, annual social assistance payments increased from $8.1 million to $30 million and the number of social assistance recipients rose by 63% (DECE., 1995). The use of social assistance in WKSS area communities has followed a similar trend. Dependency on social assistance is greatest among those who are unemployed and have a low level of education. While the demand for income support continues in the absence of income alternatives, fiscal restraint and changing social policies with government are lowering income support payments to to WKSS area communities. (Diavik, 1997; Lutra,1998). However, the percentage of the population in most WKSS area communities that receives income support, continues to be high (Lutra, 1998).

The evolution of the mixed economy has created a variety of stresses for individuals and families in the WKSS area. Today, much of the stress may be a result of the extent to which the three elements of the economy can be blended to ensure viable family and community economies. Not all families or WKSS area communities share the capacity or have access to the resources for economic sustainability.

3.3. Human Pressures on the Environment and Ecosystem

3.3.1. Summary of General Forms of Environmental Stress in the WKSS Area

Stress in the environment is related to both natural and man-made causes, and often it is difficult if not impossible to separate their effects. One or more forms of stress may occur at a single site or many sites, and stresses may be continuous or discontinuous. Some forms of stress are so widespread as to be global in their presence and effect. Without assigning any particular cause, most forms of environmental stress are related to one or more of the following (Fig. 19):

Nutrient stress*:* changes in nutrient availability.

Exploitation stress: disruption of food web structures by the loss or reduction in numbers of top consumers (excluding humans).

Exotic stress*:* disruption of food web structures by the presence of non-native microbes, plants or animals.

Toxic stress: presence of biologically harmful contaminants in significant quantities (including both non-radioactive and radioactive contaminants).

Habitat stress: loss or change of habitats, or connections between habitats (in space and, or, time).

UV radiation stress*:* changes in received UV solar radiation at the Earth's surface (stress is usually associated with an increase in received radiation).

Climatic stress*:* changes in temperature and, or, precipitation.

3.3.2. Examples of Direct Causes of Environmental Stress in the WKSS Area

Even though the WKSS area is distant from most major centres of development, human activities are a cause of many forms of environmental stress (EC., 1991). Based on the previous Section (3.3.1), examples of the causes of stress that may occur in the WKSS area include:

> ***Causes of nutrient stress***: Excess quantities of nutrients may be released from domestic sewage or animal wastes, or from wetland storage due to changes in drainage, or from bank erosion or soil loss. However, decreased recycling from grazing animals such as Muskoxen could result in nutrient depletion.
>
> ***Causes of exploitation stress****:* Advances in equipment may make it easier to hunt and trap wildlife, to store and process this food, and improvements in transportation may make it easier to export product (external demand for country foods is increasing). Exploitation can be exacerbated by poor hunting practices, and by inadequate storage or processing facilities that lead to waste. Fluctuations in demand imposed by cultural fashions or beliefs can also lead to periodic extreme demand for hunting and trapping of some fur-bearers (including poaching).
>
> ***Causes of exotic stress****:* Intentional or accidental introductions of non-native species can modify existing ecosystems in many different ways. For example, an escape of non-native strains of hatchery fish could influence the genetic composition of native stocks. Or, the introduction of microbial disease or non-native parasites could occur at any trophic level and result in significant changes in the food web.
>
> ***Causes of toxic stress****:* Contaminants that are toxic, persistent and which bioaccumulate in the food web include pesticides, PCBs, and methyl mercury. Most of these are carried in the atmosphere and brought into the WKSS area from outside sources. Locally, heavy metals may be released from mining operations, and a wide range of contaminants may be released from municipal and military waste sites and spills. Mine wastes may locally add to the low levels of radiation present in the WKSS area from both human activities and natural sources, within and outside the region.
>
> ***Causes of habitat stress***: Logging removes forest cover and construction causes habitat loss or change and, in particular, increased vehicular access may reduce the availability of many forms of preferred habitat. Fire can be destructive of terrestrial habitats, and manipulation of water levels and flow can affect availability of aquatic habitats (*e. g.* for

hydroelectic power or water supply).

Causes of UV radiation stress: Ozone gas is naturally present in the upper atmosphere but a wide range of manufactured gases react photochemically with it and destroy ozone. The loss of ozone in the upper atmosphere allows greater penetration of UV radiation. Most manufactured gas emissions occur outside the WKSS area but they circulate globally. The process of ozone depletion is greatest at high latitudes.

Causes of climatic stress: Global climate may be influenced by emissions of greenhouse gases if their quantities are sufficient to modify the physics and chemistry of the atmosphere and its circulation. Total combustion in the WKSS area is small relative to industrial areas of similar size in southern Canada, but it does contribute to global emissions and potential climate change. Natural processes could greatly increase greenhouse gas release from peatlands under some conditions of climate change, thereby adding to further climate change.

3.3.3. Development as a Cause of Environmental Stress in the WKSS Area

Human development creates many different forms of stress on the environment and this section considers existing sources of stress in the WKSS area, in more detail. Global emissions may affect all parts of the WKSS area and are a source of two major external causes of stress: global climatic change, and long range transport of atmospheric pollutants (EC., 1991). Within the WKSS area, activities resulting in more localized effects of stress include: mining, settlement and construction of supporting infrastructures, transportation, hydro development, domestic and commercial hunting, fishing and trapping, tourism and recreation. Other forms of development such as pipeline corridors, ranching and aquiculture might affect the region. For the foreseeable future, forestry is likely to be only of local significance and agriculture unlikely to be any significance. The environment is also subject to natural forms of stress, particularly those that are weather or climate related such as fire (mostly from lightning strikes), precipitation, and surface snow and, or, ice conditions.

General relationships exist between various types of activities and environmental effects but site conditions may further influence the extent of stress. Where several activities occur at one site they may cause multiple forms of stress. For example, mine sites usually create local effects but where mines are grouped together there may be cumulative effects. Atmospheric emissions may cause an additional regional stress where mining and smelting occur together. Also, the effects of hydroelectric development may differ greatly, depending on the type and operation, size and environmental setting.

3.3.3.1. External stress - Global Climatic Change

Complex global interactions between oceans and the atmosphere, and large scale changes in land use and increasing quantities of "greenhouse" gas emissions (particularly carbon dioxide and methane), have the potential to influence global climate. The scales and types of interaction may vary between different regions, and it is difficult to differentiate between natural conditions and those caused by human activity. Some of the gases are released by biochemical processes occurring naturally in the environment, and feed-back exists between many of these processes and climate (Cohen *et al*., 1994; Ovenden, 1989; Rudd *et al*., 1993). Thus, the extent to which trends in recorded climate represent early stages in climatic change or fluctuations within the range of natural variation remains uncertain (Allen *et al.*, 2000; Hulme *et al.*, 1999). However, a significant warming of the average annual surface air temperature has occurred over much of the WKSS area during the past several decades (Cohen *et al*., 1994). Model predictions of greenhouse gas emissions indicate that emissions will almost certainly continue to increase over the next 50 years or so (Anon., 2000e), and climate models (CCPB., 1991; Cohen *et al*., 1994; EC., 1991; Maxwell, 1987; 1992) predict that future near surface air temperatures are likely to increase in response to the emissions and that changes are likely to be greatest at high latitudes.

3.3.3.2. External stress - Long Range Transport of Atmospheric Pollutants

Long range transport of atmospheric pollutants is the main contributor to toxic stress in the WKSS area (EC., 1991; Jensen *et al*., 1997; Pfirman *et al*., 1994). Several persistent organic contaminants for which there is no significant regional source of emission have been identified at low concentrations in the food web (EC., 1991). These include DDT and its derivatives, PCBs, and other organochlorines. Other substances, such as mercury, and some radioactive materials occur both as an external source of loading and as a “local” input from within the region. Many contaminants have been identified from distant sources in North America, Asia, and elsewhere (Macdonald *et al*., 2000).

Industrial gas emissions from sources distant to the WKSS area are also of special concern at high latitudes, where loss of naturally occurring ozone in the upper atmosphere results in decreased adsorption of UV radiation and an increase in the amount received at the Earth’s surface (EC., 1991). Reflected radiation from ice, water and snow surfaces may add to the amount of exposure in the terrestrial environment, and the aquatic environment also receives increasing amounts of UV-B radiation.

3.3.3.3. Internal Stress - Mining

Mining has been a major part of development (Section 2.4.4) in the region for more than 50 years (DEMPR., 1995). During the exploratory and staking phase, ground and vegetation disturbance may occur over wide areas and may persist for many decades (Vavrek *et al.*, 1999). Modern mining techniques are less disruptive than in the past but their stress on the environment may last for decades or more (Acres Internat., 1993; Bright *et al*., 1996; Gunn *et al.*, 1998; Klohn Leonoff, 1992). Mine development involves the set-up of heavy equipment, supplies and storage, ore processing, accommodation and transportation facilities, waste disposal, and various forms of decommissioning. There are many abandoned mines in the region (Acres Internat., 1993).

In 1999, there were two producing gold mines (Con and Giant), the Colomac mine was closed by the end of 1997. The Lupin mine stopped production in 1998 but reopened in 2000, and production remains suspended at both the Ptarmigan and Mon gold mines. The BHP Ekati diamond mine (Lac de Gras) began production in 1998 and the proposed Diavik diamond mine (Lac de Gras) is expected to be open by 2003 (Brophy, 1991; 1993; Goff, 1990; 1994; Igboji, 1996; Igboji *et al*., 1997; INAC., 1998; 1999a; 2000a; Kusick & Goff, 1995). Diamond mines at the Jericho site and Snap Lake are also expected to be opened within the next 2 to 3 years (Fig. 5). There are several other potentially viable base metal, gold and silver, and kimberlite deposits in the region, and some of these have been known for two or more decades, but viability and lifetime depend on world commodity prices, and it is difficult to predict when any of these additional resources will become economically worthwhile to develop. Hope Bay site (Fig. 5) appears to have considerable potential and there are concerns for the effects of its development on caribou migration and calving (northeast Bathurst Inlet). Exploration and survey activities are continuing around several previous mine sites to assess the potential for additional resources at these locations, and it is also probable that some recently suspended mining operations will start up again.

Projections suggest that 8 or more new mines (gold, diamonds and base metals) are likely to come into production over the next decade (MRD., 1996), and it is expected that current levels of mining activity will continue, for at least the next two to three decades. Depending on the type of ore, mining may directly create nutrient stress (*e. g.* soil disturbance and presence of organic wastes), toxic stress (*e. g.* metals release, acidification, and low level radioactive waste), and habitat stress. If there is increased access to areas around mine sites, exploitation stress (*e. g.* fish and wildlife) may also be important. Most forms of stress are local but cumulative effects from toxic stress are possible over wide areas.

3.3.3.4. Internal Stress - Hunting, Fishing and Trapping

Most hunting in the WKSS area is for Barren-ground Caribou (Section 2.3.4.4) and the total annual take from the Bathurst Caribou herd was estimated to be between 14,500 and 18,500 in the late 1980's (Aboriginal, resident and non-resident hunters). This is thought to represent less than 6% of the population of the herd (Case *et al*., 1996; D'Hont, 1998). Other frequently killed big game in the WKSS area, include Moose and Woodland Caribou, and lesser numbers of wolves and bears (Chalmers, 1990). For many years it has been illegal to hunt Muskoxen but, recently, a quota of 124 Muskoxen has been set and this covers much of the WKSS area (D'Hont, 1998).

During 1988 and 1989, resident hunters (mostly non-Aboriginal) took about 1,400 Barren-ground Caribou, 140 Moose, 60 Woodland Caribou, 20 Black Bears, and 19 wolves in the WKSS area (Chalmers, 1990). During 1996 and 1997, resident hunters took a similar number Barren-ground Caribou, 60 Moose, 8 Woodland Caribou, 12 Black Bears and 60 wolves (D'Hont, 1998). An additional 684 Barren-ground Caribou and 3 wolves were taken by non-resident hunters. It has been estimated that 5 to 10 Grizzly Bears were also killed annually (for food or because of nuisance) prior to setting a commercial quota of 10 bears, in 1987. In 1997, 8 Grizzly Bears were taken under the quota and an additional 11 were killed in defence of life and property (D'Hont, 1998). About 90 Wolverines were taken during 1992 and 1993 and about 142 during 1997 and 1998, mostly by Aboriginal hunters and trappers in the Kugluktuk and Umingmaktok-Bathurst Inlet areas (D'Hont, 1998; Lee, 1994). Resident hunters took 13 Wolverines and non-resident hunters took 6 Wolverines, during 1996 and 1997 (D'Hont, 1998). Between 600 and 700 Lynx were taken in 1987 and 1988, shortly after the minimum of the hare cycle (Poole, 1992). Other fur-bearers were also taken by trappers.

In 1988 and 1989, resident hunters also took about 860 ducks, 150 geese, and more than 8,500 game birds (grouse and ptarmigan) in the WKSS area. In 1996 and 1997, 1,400 ducks and 6,000 game birds were taken by resident hunters (D'Hont, 1998; Lee, 1994). The total annual take by hunting and trapping is variable relative to the total population of a target species (Section 2.3.3.3), and the size of domestic or subsistence harvests is not known with any certainty. However and as discussed further (Section 4.3.1), traditional foods form an extremely important part of the diet of almost all Aboriginal people in the WKSS area.

Recreational, domestic and commercial fishing activities (Sections 2.3.2.2 and 2.3.3.2) occur throughout the region (McCart & Den Beste, 1979). Lake Trout, Arctic Char, Grayling, and Northern Pike are key species for recreational and tourist fishing, and trophy fish are particularly important for the tourist industry (McCart & Den Beste, 1979). All available species are utilized by the domestic freshwater fishery and this represents a significant part of the Aboriginal economy. Domestic fisheries on Great Bear Lake and Great Slave Lake include whitefish, Lake Trout and other species, and domestic fisheries also exist on many other lakes and rivers. Commercial fishing on Great Slave Lake targets Lake Whitefish (with some by-catch of Lake Trout) and, at various times, there has also been commercial fishing on lakes in the Lockhart and Camsell River, and Lac la Martre drainages. The largest commercial fishery for Arctic Char in Nunavut began as a Federal government test fishery at Cambridge Bay, in the 1960's. The fish plant at Cambridge Bay is supplied by catches of migrating Char in both Victoria Island and mainland rivers. Usually, the Paliryuak, Holovik and Lauchlan rivers are fished for a few days during mid-July and early August, and the Ellice, Ekalluk and Jaco rivers are fished for a few days between mid-August and early September (Stewart *et al.*, 1993). Weather and ice-conditions are a significant factor affecting this fishing activity. Blue Mussels, clams, Green Sea Urchins and Brown Sea Cucumbers occur at low densities in the Coronation Gulf area but are little utilized. Domestic fisheries for Arctic Char occur at Kugluktuk and Bathurst Inlet.

Exploitation stress is also increasing as a result of greater access to fish and wildlife resources. Habitat stress is associated with support facilities (*e. g.* lodges, camps and storage), noise, the increasing network of roads (public, mining and forestry), off-road travel, and accidental fire.

3.3.3.5. Internal Stress - Settlement

Yellowknife is the largest centre in the region (Section 3.2) and had a mixed European and Aboriginal population of about 17,300 in 1996 (DT., 2000). The predominantly Aboriginal communities of Cambridge Bay, Kugluktuk, Dettah, Lutsel K'e, Rae-Edzo, Rae Lakes, Snare Lake, Umingmaktuk (and Bathurst Inlet), and Wha Ti add about another 8,000 people, for a total of more than 25,000. Although there may be a short term decline in the population of Yellowknife (about 2,000 people may leave as a result of the formation of Nunavut, many as government employees), the population of this city is expected to increase to about 25,000 by the year 2010. With expected increases in the other communities, the total population of the region will then be about 32,000; this would be an increase of about 36% over 15 years. Government policy is to encourage non-permanent accommodation at mine sites, and to draw employment from existing communities. However, new settlements might be considered if several mines were to operate close together and for an extended period of time. Yellowknife provides government and major health services for that part of the WKSS area within the NWT. It is also a centre for mining, tourism and trapping. Cambridge Bay provides regional services of government to those parts of the WKSS area (West Kitikmeot) now in Nunavut. Most other communities are heavily dependent on hunting, fishing and trapping, and mining is an additional activity for the communities at Rae-Edzo, Gameti, Kugluktuk, Lutselk'e and Wha Ti.

At each of the communities there will be increasing needs for housing, access roads, supplies and storage, power, water, waste treatment and disposal, and transportation facilities. The most common forms of stress associated with increasing size of settlements include nutrient, toxic, and habitat stress.

3.3.3.6. Internal Stress - Transportation

Much of the region's bulk transportation is centred at Hay River, on the south shore of Great Slave Lake. Hay River is linked by road, rail and air to major centres in Alberta. Air and marine services also connect many locations in the WKSS area with Hay River (DT., 1995). Hay River is also more convenient than Yellowknife as a resupply centre for road transport north into the Mackenzie Valley where oil and gas development is expanding (Fig. 5).

All weather (mostly gravel) and winter roads link many northern Mackenzie Valley communities, and several other communities around Great Slave Lake with Hay River (Fig. 1). All weather roads link Dettah, Yellowknife, Rae-Edzo, and Fort Providence with Hay River. Reconstruction of highway 3 between Rae and Yellowknife and parts of the Ingraham Trail (highway 4) are planned for the near future (DT., 1999; 2000). Winter roads also link Rae-Edzo with Wha Ti and Gameti, and Yellowknife with the Lac de Gras diamond field and the Lupin mine (Contwoyto Lake). Extensions also provide access to the Kennady Lake and Snap Lake diamond sites. Recently, a winter road has reconnected the Colomac mine (Indin Lake) with Yellowknife, for emergency pumping of the tailings pond to avoid overflow during the spring melt. Development of the Jericho diamond mine may extend the winter road beyond the Lupin mine. With the probable opening of a number of future base metal mines north of Yellowknife, additional road development could take place to support bulk transport of ores and mineral concentrates. A new winter road could link the proposed Izok Lake base metal mine and other potential mines in the West Kitikmeot sub-region with a deepwater port near Kugluktuk or Bathurst Inlet (at present, Bathurst Inlet appears to be the preferred location (DT., 1999; 2000)). With additional mine development, parts of transportation route might be upgraded to an all weather road (DT., 1995; 1999). However, the costs of infrastructure requirements can not be financed by the Izok Lake project, alone. Winter roads make it possible to transport heavy mining equipment, fuel and other bulk supplies. For shipments of low volume but high value products (*e. g.* gold and diamond mines), air transport is sufficient to meet many requirements. Numerous potential routes for transportation corridors to service anticipated future development in the WKSS are under consideration (DT., 1999; 2000). Road transport can be subject to various forms of interruption (*e. g.* road bed stability and weather effects). Ferry services, and or, ice bridge access at Fort Providence (linking Hay River and Yellowknife) may be interrupted by ice formation on the Mackenzie River in early winter and by break-up in the spring.

Hay River serves Mackenzie River communities and coastal communities of the western Canadian Arctic with barge supplies of fuel and dry goods, and supply facilities have been upgraded at Cambridge Bay, Kugluktuk, and Fort Providence. Additional improvements are likely at these and other large and inland lake facilities (including Dettah, Lutsel K'e, Rae-Edzo, Rae Lakes and Snare Lake). A new port has been proposed in Coronation Gulf east of Kugluktuk for shipment of base metal ore (DT., 1995) and, most recently, an alternative port site for ore shipment in Bathurst Inlet has been suggested (DT., 1999). Yellowknife, Hay River and Cambridge Bay each handle more than 10,000 tons (annually) of marine supplies. Kugluktuk handles about 6,000 tons and Lutselk'e less than 2,000 tons (annually).

Almost every community in the WKSS area has flight connections with Yellowknife, and most are provided with airstrips and some sort of terminal facility. Float planes also serve many communities in the region (and seasonal lodge operations). Air transport is an essential service throughout much of the region and further upgrades in facilities to improve operations and support larger aircraft have been proposed (DT., 1995). Yellowknife reported nearly 47,000 air movements, Hay River nearly 8,000, Cambridge Bay nearly 5,500, and Kugluktuk more than 2,700 air movements in 1991. Smaller communities such as Lutselk'e, Fort Resolution and Wha Ti reported air movements in the 500 to 1,000 range, and many others had a few hundred air movements a year.

Roads, rail, airport and docking facilities all directly modify habitat; and roads, in particular, make wider areas accessible for hunting and fishing. Noise associated with transportation, fuel spills, and the increased possibility of fire may be additional forms of environmental stress. Increased shipping raises the potential for accidental spills and loss, and disruption of sea ice cover (NPC., 1997; NPCTT., 1996). If manipulations of water level and flow are used to improve road use (DT., 1995), they may add to habitat stress.

3.3.3.7. Internal Stress - Hydroelectric Development

Limited hydro development has occurred on the Snare and Yellowknife rivers, primarily to meet local domestic needs, and on the Taltson River. In future, there is a proposed to raise the level of Indin Lake by 3 m (HBT-Agra, 1993; Lloyd, 1996) and development has been proposed on the Lac la Martre River. However, a recent proposal for upstream diversions, increased storage and hydroelectric development on the lower Barnston River (Glacier Power Ltd, 1997) has not received approval. Other potential hydro developments (Fig. 7) have also been considered on the Back, Burnside, Coppermine and Hood rivers, largely in support of possible mine developments (Goff, 1990; HBT-Agra, 1993; Igboji *et al*., 1997; UMA Group, 1979; Wedel *et al*., 1988). Development of sites on the lower Lockhart River have also been proposed. But, in this area, land has been withdrawn by the Federal Government pending land claim agreements and decisions relating to a proposed National Park on the East Arm of Great Slave Lake (Glacier Power Ltd, 1997; Hamre & Cozzetto, 1999a; 1999b; Mondor, 1982; Seale & Cozzetto, 1998). For most mines, hydro development is not viable on an individual basis but future development might take place if a group of mines could be served together (spaced reasonably close together and operating over a similar time period).

Hydro development may involve regulation of flow, changes in water level (including flooding), diversion, and construction of barriers. It may also cause changes in the natural regime (*e. g.* a shift or spread of peak discharge events). Transmission corridors that carry power from generation sites to user sites also create many of the same environmental stresses that are associated with road transportation. Many changes create stress on both terrestrial and aquatic habitats and their effects are long term, and some are more or less permanent.

3.3.3.8. Internal Stress - Tourism and Recreation

Tourism is the third largest industry in the WKSS area and two-thirds of the 1992 value of $135 million came from non-residents. In total there are about 30 tourist lodges and camps, 25 of which are located around Great Bear Lake and Great Slave Lake. In the WKSS area there are nearly 40 outfitters. In 1994, 6 tourist companies work out of Yellowknife, providing tourist and recreational services to non-resident visitors. More than one hundred other businesses provide accommodation and other tourism-related services ((North Group & Norecon, 1996) Section 3.2). Tourism has grown rapidly in the region (Section 3.2) and, although only a small percentage of visitors travel beyond Yellowknife, wildlife viewing and wilderness travel are locally as important as tourist fishing or hunting. Non-residents are increasingly involved in wilderness trekking and canoeing, and resident use of the Ingraham Trail (Yellowknife) for cabin and lake recreation is also high. Yellowknife received about 30,000 visitors in 1994.

Few park areas exist within the WKSS area(Hamre & Cozzetto, 1999a; 1999b). Existing and proposed parks, reserves and historic sites in Nunavut and the NWT include Mount Pelly (Cambridge Bay), Bloody Falls (Kugluktuk), Hidden Lake (near Yellowknife), Fort Smith Mission, Twin Falls Gorge (near Hay River), and Mills Lake near Fort Providence **(**Hamre & Cozzetto, 1999a; 1999b; NPC., 1997; Seale & Cozzetto, 1997; 1998). The Coppermine River has been proposed as a National Heritage River, and Parks Canada has also considered both the Bathurst Inlet and East Arm (Great Slave Lake) as areas of special interest (Hamre & Cozzetto, 1999a; 1999b; Hancock, 1979; HBT-Agra, 1993; PC., 1978; Seale & Cozzetto, 1997; 1998). Parts of the boundary for the Tuktut Nogait Park (Fig. 1) have been established but discussions between the Federal Government, Nunavut and the Sahtu Dene and Métis continue with regard to its southern and eastern boundaries. At present, there are no national parks within the WKSS study area .

Most recently tourism has been growing at the rate of a little over 1% a year but poor road conditions are a limiting factor for expansion of road-based tourism (many companies do not rent vehicles to tourists wishing to visit the NWT by road). Road improvements will aid tourism and if all weather roads are extended north to Inuvik and other lower Mackenzie valley settlements (DT., 1999; 2000), tourism "to see the Arctic" may increase significantly. Many forms of stress are associated with support facilities and transportation (as with fishing, hunting and trapping), but noise and disturbance add to habitat stress, and local exploitation of fish or wildlife may be a concern (Hamre & Cozzetto, 1999a; 1999b).

3.3.3.9. Projections of Future Development

A study of future development in the WKSS area (1994) presented three scenarios for the year 2010, based on low, moderate, and high levels of activity in the region (Bernard *et al*., 1995; MRD., 1996). The scenarios are largely driven by mining development but since mining is most responsive to international market conditions that are notoriously difficult to predict, it is difficult to know which is most probable. The scenarios are summarized in Table 10.

The underlying characteristics of development during this time period (Section 3.2) appear to be that mine employment is likely to increase rather than decrease, but this may not occur at a steady rate. Mining activities are greatly influenced by fluctuations in international mineral and metal markets. Also, even though opportunities are likely to increase, there may still be more people available for employment than work available. Population increases in Yellowknife and Aboriginal communities in the WKSS appear to differ. Both will increase but increases in Aboriginal communities are likely to be largely independent of employment opportunities (*e. g*. mining, and government administration). More hydroelectric development may occur on the Snare River, but additional developments on other rivers are unlikely unless they are required in support of new mining activities (Figs. 5, 7). Winter roads to the Arctic coast and associated port facilities may be required in support of mine development, particularly of base metal mines (*e. g*. Izok Lake, High Lake and Hackett River (Figs 1, 5)). The availability of high grade of ore at Izok Lake might also justify upgrading to an all weather road. Exploration and development of Arctic oil and gas is not likely to occur in the WKSS area but there may be indirect effects. For example, in relation to transportation and the use of existing or potential road and sea corridors.

It is unlikely that hunting pressure on the Bathurst herd of Barren-ground Caribou will decrease and, as a result of both competing interests and natural variabilities, resource management could become more difficult. Tourism is expected to increase under all scenarios and with greater road access to areas “north” of Yellowknife, it could increase very significantly. Winter tourism for the Aurora Borealis is expected to continue as a special attraction, and wilderness tours and wildlife observation are likely to increase. Overall, more people will spread over larger areas of the WKSS area and this will occur during a greater part of the year.

The Mackenzie Valley Environmental Impact Review Board (MVEIRB) was established in 1998 to provide screening of proposed development in the Mackenzie Valley and adjacent areas (Hamre & Cozzetto, 1999a; 1999b), and most of the WKSS area that lies within the NWT is included under the jurisdiction of this board. Table 11 provides a summary of activities that have been and are currently under review by the MVEIRB (MVEIRB., 2000a; 2000b; 2000c). Of these, North and South Slave and transboundary activities (with Nunavut) account for 40% of the total. They provide a strong indication of the present and near future importance of the WKSS area to the NWT economy, as a whole. Most activities are associated with mine development but, region-wide, there is also considerable activity associated with forest production. Remaining activities are mostly associated with road work and construction of other forms of infrastructure. This summary, together with recent population statistics (DT., 2000), suggests that development is presently occurring at a rate that is at least equivalent to the “Moderate Scenario” of Table 10.

3.4. Activities as a Cause of Human Stress in the WKSS Area

Just as many forms of human activities create stress in the natural environment, such activities may also cause stress within society. These stresses may be produced as a result of the interactions between and among people, and as a result of human interactions with other components of the ecosystem. Societal stress may reflect both participation and, or, non-participation in various economic, social and, or, cultural activities. For Aboriginal people, societal stress has most often meant loss of culture, and poor physical and mental health.

In the last three decades, industrial developments in the Canadian north have encouraged efforts to identify and understand activities that stress human populations and their environment. Indicators, also known as valued social components (VSCs), and expressions of stress in local populations have varied both in number and nature. In 1986, 16 indicators were identified to monitor effects from oil and gas developments in Mackenzie Delta and Beaufort Sea communities (DEMRS., 1986); 14 indicators were listed in the 1996 BHP-GNWT Socio-economic Agreement (BHP & GNWT., 1996); and a recent community-based study in Lutselk'e has identified about 40 indicators, each with a qualitative and quantitative component (Parlee & Lutsel K'e First Nation, 1997). Gerein (1998) developed an instrument to measure community wellness based upon a number of indicators including governance and social participation, population health, economy, housing, justice and safety, education, and culture. Several documents identify other indicators of health and well-being (Bjerregaard & Young, 1998; CPHA., 1997; DHSS., 1999). The literature of the past few decades has traced the changing views of these indicators, particularly as societies have developed and changed in northern Canada. The rate of socio-economic change in the Canadian north has been rapid (Section 3.2), making indicators of stress and change equally dynamic.

The socio-economic agreement (October 1996) between the GNWT and BHP Diamonds Inc. established 14 indicators of community wellness.

1. Teen birth rate
2. Number of social assistance cases
3. Average income
4. Number of communicable diseases
5. Number of family violence complaints
6. Number of property crimes
7. Number of alcohol and drug related crimes
8. High school completion rates
9. Employment and participation rates
10. Potential years of life lost
11. Number of children in care
12. Number of injuries
13. Number of suicides
14. A housing indicator

Indicators of stresses within human populations can be subjective, and may be useful and meaningful only if standards and values are shared. Further, individuals and groups may cope or manage stresses differently, as a result of a number of socio-economic and cultural factors. Communities and individuals in the WKSS area may share commonalities but have differences in standards, values, expectations and, or, coping mechanisms and support. The Dene, Inuit and Métis do not necessarily share the same values any more than individuals of European origin.

The use and meaningfulness of indicators are also influenced by:

- Reliability and, or, consistency (comparability) and quality or validity of data collected over time (*e. g.* lack of longitudinal studies and the difficulties discerning naturally occurring change across populations from change resulting from project or development-influenced activities);

- intervening variables (*e. g.* community attitudes about professionals in the community may influence reporting of crimes, visits to the health centre, or attendance at school);

- cultural and personal bias (*e. g.* the number of children in day care may be viewed as enabling women to participate in wage economy but for others, it may indicate a lack of family responsibility or less value being accorded to children);

- community perspectives (*e. g.* communities with similar economies and populations may have different values and attitudes for example, about people receiving income subsidies);
- small populations or numbers of participants (*e. g.* small numbers may limit the availability and meaningfulness of information or pose threatens to individual privacy); and

- natural occurring change across populations and changes the are isolated from project or development-influenced changes.

For these reasons, efforts to collect, interpret and analyze information on interactions between and among people and their environment, cannot be identified or predicted with precision. Combining traditional, community and scientific knowledge is the current approach to improving both the quality of information about, and the understanding of these stresses.

NWT and Nunavut Aboriginal communities have common interests in land and resources, and a shared desire to control the social, economic, cultural and political conditions that characterize their communities. Some Aboriginal communities are actively asserting control through the implementation of land claims and impact benefit agreements (IBAs), participating in non-renewable resource development; or developing structures for self-government.

Community control and collaboration has been integral to a project in Lutselk'e that monitors socio-economic impacts of mineral resource development. This project, which began in 1996, has used a collaborative or action research methodology to increase the community's capacity to benefit from development while mitigating negative effects. The project has been undertaken in phases. In the first phase of the project, community perceptions of community health, monitoring and indicators were determined. Community health was defined as the ‘Dene way of life’. Three themes or journeys toward community health - self-government, healing and cultural preservation - and a number of sub-themes were identified. The themes express the community’s desire for control or self-determination, concerns regarding social issues, and the desire to protect language and culture (Parlee, 1998). The Lutselk’e monitoring project followed a four-step process: 1) gathering information through home-visits; 2) summarizing information and communication; 3) evaluation of information with a committee; and 4) reporting. Data collection has been the focus of the second phase of the project. To date seven, four-month monitoring cycles have been completed (Table 9a-9e).

Some common themes have emerged from the various efforts to identify stressors, particularly on non-industrial, Aboriginal populations. Economic activity and population growth are two activities producing stress Aboriginal participation in wage employment has been identified as a key indicator of stress or change.

Low participation of Aboriginal people in the wage economy contributes to poorer socio-economic circumstances among this segment of the NWT and Nunavut population. This is not a recent occurrence. Since regional economic studies were conducted in the 1950's and 1960's, subsequent economic studies have consistently found that compared to non-Aboriginal northerners, Dene, Métis and Inuit in the NWT and Nunavut have less participation in, and derive fewer benefits from the wage economy (DEDT., 1990; DIAND., 1970). In WKSS area communities:

- Most non-Aboriginal people of working age (15 or more years of age) are active in the wage earning labour force (89%) compared to only 65% of Aboriginal people of similar age.

- About two-thirds of all employed persons in the NWT were born and raised outside of the territories.

- The average income of individuals living in the predominantly non-Aboriginal community of Yellowknife was $39,086 while average incomes of adults in other WKSS area communities ranged from $12,126 (Rae Lakes) to $28,915 (Cambridge Bay) (SC., 1996).

- The majority of people not working and wanting a job have Aboriginal ancestry (Table 7).

Literacy and numeracy skills lead to self-sufficiency and individual participation in family, school, work and community life. In the NWT and Nunavut, persons who have not achieved grade 12 are considered to have low literacy levels. Adults with low levels of formal education and training are less likely to participate in the wage economy; more likely to be receiving income support; and are more often involved in high risk behaviours or to live in high risk circumstances than those with higher levels of education (Lutra, 2000a). In 1999, 19% of adults in Yellowknife and 65% of adults in other WKSS communities have not achieved grade 12 (BS.,1999). In WKSS communities (excluding Yellowknife) 78% of adults who are not working and want a job, had not achieved grade 12. A minimum of 12 years of education is required for most entry level jobs in the 21st century.

Since formal education has been available in the NWT and Nunavut, high school graduation rates have continued to be low. In the NWT graduation rates are about 30% overall and 5% among Aboriginal students. Nationally, graduation rates are about 70% (DECE., unpublished). The reasons for early school leaving are complex and inter-related, and based on circumstances in the home, school and, or, community, as well as in the personal lives of students (Lutra, 1992). Some students are particularly challenged in the school environment. An estimated 46% of students in the NWT require but are not receiving additional supports (*e. g.* beyond the regular school program) (DECE., 2000). Other students lack motivation and interest in school due to poor relationships in and outside of the educational environment. Others lack encouragement to pursue education (Lutra, 1994).

The interactions of non-Aboriginal and Aboriginal values and expectations in the school environment also influence educational and economic successes. These interactions have been examined in terms of school relationships (D. Wall Res. Group, 1996), the history of educational experience in the north (Barnaby *et al*., 1991; Carney, 1971), teaching techniques (*e. g.* which separate skills for earning a living from learning about, for example, moral values, scientific or religious ideas, human relations, and the relations of human beings to the rest of the natural world) (Abele, 1989), and the influence of culture or teaching and learning styles (Bright, 1999). In some manner, these and other factors have been identified as stressors in the human environment, particularly as society places greater emphasis on achieving higher levels of formal education. Education and training institutions are criticized for trying “to make native people fit into economic and political institutions transplanted from the south” rather than responding to economic needs and the well-being of people within their particular context (Abele, 1989). To minimize stresses associated with lack of success in formal education and training programs, holistic programs, culturally appropriate curricula, community-based training, individual training programs, and the training and hiring of teachers of Aboriginal descent have been advocated and, or, implemented (Bright, 1999; DECE., 1994).

While communities have replaced seasonal camps as the centre of activity and of emotional, social and political life for Aboriginal people in the WKSS area, the lifestyle and expectations associated with harvesting and camp life have not necessarily been abandoned. Like the camps of long ago, there are strong ties among community members that are strengthened by family alliances, and traditionally valued ethics such as cooperation and voluntary, non partnership-based sharing (Collings *et al*., 1998). Today, youth seek good paying wage employment but fear alienation from their community if they pursue it. Adults fear for the continuity of culture, family and community if young people leave communities in search of higher education and wage employment (Condon, 1990; Condon *et al*., 1996). For these reasons (and others), employment opportunities in hydrocarbon and mining industries have created stresses for individuals in the WKSS area and elsewhere in northern Canada (IWGMI various dates; Lutra, 1995; Pierce & Hornal, 1994).

Recruitment and, or, training initiatives have been introduced to develop familiarity and comfort in a distant workplace. Long distance rotational commuting has been implemented to enable Aboriginal employees to return home, hunt for food and otherwise participate in family and community life before returning to work (Pierce & Hornal, 1994). Still, communities worry that employment demands will result in a loss of traditional skills or "brain drain", creating stresses that impact on the social health and well-being of both families and communities (Dogrib Treaty 11 Council, 1995).

In the absence of ongoing and viable community-based wage earning opportunities, traditional activities have sustained populations in the WKSS area. "*The north may well be the only place where a poor man's table is laden with meat*" (Usher, 1976). This may not be the case in the future. Recent studies show that few youth (15 to 24 years of age) in the NWT and Nunavut participate in, or wish to pursue traditional economic activities (Condon *et al*., 1995). Inuit youth view hunting, fishing and other subsistence activities as leisure (Stern, 2000). Less than 2% of NWT individuals of this age trap and earn less than $2,500 each year from these activities. About 7% of NWT youth earn income from arts and crafts activities, and most earn less than $1,000 per year from sales (Lutra, 1996). Individuals who trap and earn less than $2,000 annually, when offered wage employment, see paid work as a superior method of gaining an income (Stabler *et al.*, 1990). Recognizing the desire among youth for wage employment, some Aboriginal elders in the WKSS area have given conditional support for mining activities on their traditional lands (BHP & Dia Met, 1995). These same elders recognize that many young people will not be able to sustain themselves in the future from traditional activities.

The ability to meet basic living needs continues to be a source of stress among populations in WKSS area communities. For decades, social assistance and income subsidies have been available to offset the lack of paid work and adequate input from traditional activities (Section 3.2). Today, the majority of persons seeking assistance, do so for economic reasons, particularly where wage income is insufficient relative to the high cost of living and, or, there are inadequate jobs for local residents. Many of these low income families participate in the service sector or in traditional activities such as arts and crafts production. A smaller number have social needs (*e. g.* disability or illness) which prevent them from participating in the wage and, or, traditional economy. In 1996 and 1997, 36% of the NWT and, or, Nunavut population received or were a member of a household receiving income support (Lutra, 1998).

For the Aboriginal populations of the NWT and Nunavut, housing conditions continue to improve. Bigger houses along with smaller household size have decreased the risk of infectious disease (*e. g.* tuberculosis) while improved sanitation has decreased exposure to several micro-organisms. Still, the growing populations of the NWT and Nunavut have created demands for more housing and for income to construct and maintain shelter. In 1992, almost 3,600 or 24.1% of NWT and Nunavut households were in need of affordable, suitable (*e. g.* number of bedrooms) and, or, adequate housing (*e. g.* running water, indoor toilet, shower and, or, bath). In 1996, 4,346 or 23.2% of NWT and Nunavut households were in need of major repair (NWTHC., 1996) and in 2000, 20% of households in the NWT were in this category (NWTHC., 2000). Securing affordable, suitable and adequate housing in Aboriginal communities may be more challenging in the WKSS area due to larger than average-size households. In Dogrib Treaty 11 communities, the average household size ranges from 3.9 people (Wekwetì) to 4.7 people (Wha Ti) (SC., 1996). The lack of adequate and suitable housing has been identified in numerous studies as contributing to the incidence of family violence, increasing the rate of crime, affecting performance in school, and influencing the physical and mental health of household members. Globally applied land-use planning and housing practices may also contribute to societal stress. These practices place more importance on functional services than the social, cultural and environmental needs of the people (*e. g.*, traditional kinship groupings, open space for gathering and access to the land and water) (Pin Mathews Architects, 1997).

Although food security has improved, the 1991 Aboriginal Peoples Survey found that its availability was a problem for an average of 15% of Aboriginal adults in Nunavut regions (20% in Baffin and 12% in Kitikmeot and Keewatin). The availability of food was a problem in particular communities rather than in whole regions. In the WKSS area, the availability of food was a problem for about 20% of Aboriginal adults in Wekwti and 5% to 6% of Aboriginal adults in Rae Lakes and Wha Ti. Studies show that dietary practices and food security (*e. g.* reasonable access to a nutritionally adequate and culturally acceptable diet) are affected by the high cost of food (which is 85% higher than in the nearest, large southern Canadian city), fear about the ability to feed the family, fear about the safety and supply of country food, lack of money to buy food, and inadequate food to eat. These problems are most serious among families on income support (Lawn & Langer, 1994).

A recent study into the health of NWT students found that students, particularly Aboriginal students at all grade levels, are missing essential nutrients in their diets and tend to eat more "junk foods" than young people in the rest of Canada. Students most frequently lack foods from milk and, or, milk products (although many may have an intolerance for dairy products) and fruit and, or, vegetable groups as well as calcium, and vitamins A, C and D. Students' sugar consumption is also much above the national average. The lack of vitamin A and calcium, and the high use of sugar in the diet of Aboriginal families has been corroborated in other studies. It is a particular concern for women of child-bearing age and those who are pregnant or lactating, as well as for the health of young children (Peart & King, 1995)**.**

A recent study in the community of Lutselk'e on traditional knowledge and health (Lutsel K'e Dene First Nation, 1998) examined the relationship between knowledge of the land, knowledge of traditional food sources and preparation, and the health of community members. This relationship was not surprising but elders in the community also saw a link between hard work, especially that of a traditional lifestyle, and a long life. For them the solution to health problems in the community rested, in part, on teaching work skills to the younger generation so they too could work hard and be healthy.

Socio-cultural stressors have had both positive and negative impacts on the health and well being of Aboriginal people. Life expectancy for Canadian Inuit more than doubled between the 1940's and the 1990's (Bjerregaard & Young, 1998). Still, people in the NWT and Nunavut live four to five years less than the average Canadian and are twice as likely to die of injuries than other Canadians. Alcohol is a contributing factor to most accidents and injuries (DHSS *et al*., 2000)

The rapidly growing, young population in WKSS area communities has generated many social, cultural and economic stresses. Like the rest of Canada, birth rates in the NWT and Nunavut have been declining over the past ten years. Still, in 1998 NWT birth rates were 18.6 per 1,000 population, almost twice the national average of 11.8 per 1,000 population (DHSS *et al*., 2000) and the average birth rate in Nunavut was 29.8 per 1,000 population for the five years between 1992 and 1996. During this period, average birth rates in Cambridge Bay and Kugluktuk were 26.8 and 26.1 respectively per 1,000 population. (BS., 1998). In the Dogrib community of Rae-Edzo, the average birth rate rose from 25.8 per 1,000 in 1986 to 30.8 in 1996, but it fell in Wekweti̇̀ from 23.5 per 1,000 population in 1986 to 14.8 in 1996. Teen births create additional socio-economic stresses. Children born to teenage mothers are more likely to live in households with lower levels of education, literacy and income (DHSS *et al*., 2000). In the NWT, average teen birth rates between 1992 and 1996, were 2.75 times more likely to give birth than women of the same age in the rest of Canada (DHSS *et al*., 2000). Compared to in-migration (estimated at about 2% per year since the 1976 Canada Census), birth rates have the greatest influence on population growth.

Children and youth under the age of 20 years make up 40% of the NWT population. In Treaty 8 and 11 communities, children 14 years of age or younger make up 32% and 36% of the population, respectively. Children make up about 38% of the population in the West Kitikmeot subregion. Youth (between 15 and 24 years of age) in the various WKSS area communities make up 15% to 20% of the population. The youthfulness of the population is creating economic pressures, as well as inordinately high demands on housing, education and social services and infrastructure. Recent studies are showing evidence of despair, hopelessness and powerlessness among youth (Lutra, 1996). About 22% of the individuals receiving social assistance in the NWT and Nunavut in January 1995 were between the ages of 18 and 25 (Lutra, 1996). It has been estimated that between 20% and 30% of NWT and, or, Nunavut children live in poverty (DECE., 1994) although a definition of child poverty in the NWT does not exist. Child poverty has economic, psychological and social costs. About 3% of NWT preschool-aged children are in care mainly due to neglect and parental alcohol abuse. Between 1994/95 and 1998/99, an average of 275 children in WKSS area communities (in the NWT) were taken into care (DHSS *et al*., 2000) Children may be taken into care because of poor parenting, neglect, abuse and, or, developmental delays (Lutra, 1996; The Child Welfare League, 2000).

Inter-generational conflict also creates stresses within WKSS area communities. English is the language used in most Aboriginal households in the NWT but elders are most likely to use their Aboriginal language. *"...over the next 15 to 20 years, English may well become the language of choice for almost all NWT' residents"* (DHSS., 1999). Loss of Aboriginal language means that children may have difficulty understanding and learning from their grandparents, and have different values and ways of thinking and acting (Bright, 1999). Lack of continuity creates stresses for and among individuals, families and communities.

4. STRESS EFFECTS

4.1. Introduction

Previous sections of this report have described the present environment of the WKSS area, its ecosystems and parts of their food webs (Section 2.3). Many different types of stress affect the WKSS area and these have been summarized together with likely causes of stress in Sections 3.1 and 3.2. The types and extent of many human activities in the WKSS area have been described in Sections 3.3 and 3.4. This section now considers the effects of stress on ecosystems and the environment in more detail. Where information is sufficient, emphasis is also given to the most important cause and effect relationships.

In reality, most situations are a reflection of multiple effects that have occurred in response to a combination of causes; although there is often a common underlying "trigger". For example, when international mineral or metal market conditions are thought to be suitable, management of a company may make an economic decision to open a mine. By association, this decision may also initiate road, air or marine construction, increase local and regional wage employment and the growth of settlements, increase vehicular traffic, and open wilderness areas otherwise isolated from human contact to greater use. Further, all development occurs against a background of societal change that includes the impacts of western culture and values on many Aboriginal people. It also occurs against a background of continuing environmental change that is largely driven by both climatic and geological processes over which people have little control (Andrews & Pelletier, 1989; Maxwell, 1987; 1992). Without control, historical context may be particularly useful in adaptation to changing situations, such as those that may arise as a result of probable climate change (Robinson & Cohen, 2000). Generally, ecosystems evolve and adapt to most natural forms of stress but because of the scale, rapidity and variety of change, human activities may overwhelm the short term adaptive capacity of natural ecosystems. Already, there are concerns for number of species present in the WKSS area (COSEWIC., 1995 (and updated to 2000)). Short term adaptive capacity may also become a concern in parts of human society, itself.

In Canada, quantitative assessments are now used to determine if a species may be at risk, in some way (Species of Concern). COSEWIC uses criteria similar to the IUCN system (Gardenfors *et al.*, 1999; IUCN., 1999). Species of Concern in ecozones of the WKSS area presently include (Carrière, 2001):

Threatened Species - Peary Caribou (Low Arctic population), Peregrine Falcon (subspecies *anatum*), Shortjaw Cisco (Great Slave Lake) and Woodland Caribou (Boreal population - from provisional assessment);

Species of Special Concern (Vulnerable) include - Bering Wolffish (Bathurst Inlet), Grizzly Bear, Peregrine Falcon (subspecies *tundrius*), Polar Bear, Short-eared Owl and Wolverine;

Endangered Species include - Bowhead Whale (Western Arctic population) and Eskimo Curlew.

It is not possible to predict the future but it is known that many forms of development have potential to cause significant environmental impact, and many species of fish, birds and mammals (including people) may be affected. Several species are particularly adapted to the northern environment and in the extreme, if they are lost, they could not be replaced (Section 2.3.4.). Lesser effects, such as those that might influence behavioural characteristics (*e. g.* prey behaviours and breaks in the continuity of inter-generational learning) could also have major impacts on species survival. Such losses could pose great stress on many northern communities that continue to depend on them as a source of food, and in other ways as entities deeply embedded in Aboriginal culture and belief. Also, though not fully understood, there are significant interdependencies among and between plants and animals, and between them and the surrounding environment, such as between biota and fire. Each needs the other to maintain a balanced ecosystem, and this includes the roles of natural parasites and predators in the terrestrial, freshwater and marine ecosystems (Section 2.3.4).

While such concerns do not imply that there should be no development, they do imply that it is more than just prudent to proceed with caution. With developments there are varying degrees of environmental risk and uncertainty, and it is essential that effects monitoring should be reliable and sufficiently sensitive to make timely change in human activity. Effects monitoring needs to be based on concepts of "biological integrity" (Cairns, 1986) rather than the "most sensitive species" (Karr, 1991), and the early response to stress by aquatic ecosystems make them a valuable indicator of change. For example, changes in species composition of the phytoplankton community may occur in response to several types of stress and the incidence of morphological abnormalities in benthic invertebrates is strongly influenced by pollutants (Schindler, 1987). However, in many northern ecosystems where species diversity is low, changes in abundance may be a more useful indicator of stress response (Section 2.3.3.2). Further, effects monitoring means not only the local effects of development but, also, the cumulative effects of development (both direct and indirect effects) over a region (such as the WKSS area). Many stress effects in the environment are also related to stress effects in people though, often, such effects and their extent are different in human communities. Thus, it is important that the impact of development on the environment should not be considered in isolation from its impact on people (Sections 3.2 and 4.3).

Stress has the potential to cause change in the environment. Whether or not the resultant changes are considered as "positive" or "negative" depends on how they are viewed as an influence on human activities. Some of the effects of past development in the WKSS area have been severe, particularly where activities were not sufficiently controlled (noted later in this Section). For the future, however, sustainable development seeks to reduce stress and to keep human activities and environmental change within limits that do not radically alter or impair future use of renewable resources (Section 5).

In keeping with this approach to sustainable development, a number of conservation measures have also been undertaken or are under consideration in the NWT and Nunavut. In the WKSS area (Fig. 1), Parks Canada has identified the North Water polynya at the east end of Dolphin and Union Strait as an area of special biological interest, and the East Arm of Great Slave Lake as a possible National Park Reserve (Beckmann, 1994; CWS., 1993; Hamre & Cozzetto, 1999a; 1999b; Seale & Cozzetto, 1997; 1998). The Wollaston Peninsula (Arctic Island Caribou calving), and the Melville Sound and Kugluktuk areas (Gyrfalcons and Peregrine Falcons) have been proposed for consideration as wildlife conservation areas (DRR., 1995; Ferguson, 1987). In addition, there are other federal sanctuaries and conservation areas that may be an external influence on wildlife within the WKSS area. These include the Thelon Wildlife Sanctuary, Wood Buffalo National Park (also designated as a RAMSAR site under the 1978/1981 Ramsar Convention on the Conservation of Wetlands of International Importance), Queen Maud Bird Sanctuary, and Tuktut Nogait National Park (CWS., 1993; Hamre & Cozzetto 1999a; 1999b; Seale & Cozzetto, 1997; 1998). Parks Canada also has interest in Bathurst Inlet (as a natural area of Canadian significance). The Ellice River uplands just east of Bathurst Inlet (Bathurst Caribou herd calving) and the Horton Plain west of Kugluktuk (Bluenose Caribou herd and year-round Muskox range) have been proposed for consideration as wildlife conservation areas (DECE., 1994; DRR., 1995).

These initiatives address only site-specific concerns. Although they are both collectively and individually extremely important. At a more general level of concern, Tables 12 and 13 provide summaries of the different forms of stress that are likely to increase in the WKSS area over the next 20 to 50 years, and their associated effects.

4.2. Stress Effects Due to Human Activities

4.2.1. Global Climatic Change

4.2.1.1. Natural Processes and Human Influence on Climate

A number of factors influence the temperature of the Earth's atmosphere and climate, the most predictable of which relates to astronomical cycles. Well defined irregularities in the Earth's orbit around the sun and a slight wobble in the planet's axis result in small but significant changes in received radiation, especially toward the poles. These cycles (Milankovitch cycles) have periodicities which extend over extremely long periods of time, from about 20,000 to more than 100,000 years (Chin & Yevjevich, 1974). Many cycles closely correlate with major climatic changes evident throughout the Pleistocene glacial period. At present, the most significant astronomical influence on climate is the movement of the Earth's axis. The axial tilt reached its maximum about 11,000 BP and will reach its minimum about 10,000 years in the future when differences in seasonal contrast will be least. Because of this and if it were the only influence or even if it were to be the most significant influence, the Earth would be expected soon to enter a cooling phase or to have already entered it (Chin & Yevjevich, 1974).

Mean summer and autumn temperatures have generally declined over much of the northern hemisphere since 1940 even though mean annual temperatures have increased (Cohen, 1997; Cohen *et al*., 1994). A seasonal decline of this sort is probably consistent with the effects of climate change expected to occur as a result of reduced axial tilt. However, there is no evidence to support this particular association as a cause and effect relationship, and there is no certainty that this hemispheric temperature trend will continue. Indeed, from geological data and based on variations in average annual global temperature between glacial and post glacial periods, it would be almost impossible to determine the signature of this form of astronomically driven climate change over time intervals of much less than several centuries (perhaps a tenth of a degree in 2 or 3 centuries). Therefore any temperature change brought about by axial tilt would be most likely to occur as a slow and underlying long term geological fluctuation. Based on the known astronomical associations between the Earth's planetary motion and glacial events, existing interglacial warm climatic conditions are expected to last several thousand more years (Broecker, 1998).

There are other factors that may alter both received solar radiation and atmospheric response to it (Lockwood, 1979). The causes of many unusual warm and cold periods which have occurred throughout historic time appear to reflect a combination of astronomical cycles, solar fluctuations (particularly sunspots (Bartusiak, 1989)), volcanic activity, ocean-atmosphere interactions and the carbon dioxide content of the atmosphere (Anon., 2000c; 2000f; Gribbin, 1983; Shindell *et al.*, 1999; Skinner, 1985).

Sunspot cycles correspond to the formation of large dark patches on the surface of the sun. They are caused by variations in solar magnetism and the number of patches increase to a maximum during the peak of a cycle. The cycles occur over intervals of 8 to 15 years and average about 11 years (Mitton, 1977). But recorded sunspot intensity (number of sunspots occurring during the peak of a cycle) also varies over longer periods of 80 to 90 years (Immen, 1995; Mitton, 1997). It has been suggested that variations in the output of solar energy associated with sunspot cycles would be too small to affect the Earth's climate (Broecker, 1999). However, it also seems that the release of solar energy is neither as constant as once thought, nor is it only related to solar brightness. Variations in brightness are likely to affect the Earth's near surface atmospheric temperature, but variations also occur in the release of UV radiation. This likely affects high altitude wind and ozone concentrations in the atmosphere. The discharge of subatomic particles in association with strong variations in the Sun's magnetic field may influence the Earth's cloud cover and rainfall (Broad, 1997). For example, there is some correspondence between sunspot cycles and water levels in the Great Lakes region of North America. Certainly, some of the variations in the record of dust and chemical content of glacier snow, the width of tree rings, and some plant and animal cycles in both terrestrial and aquatic environments seem to reflect solar cycles (MacLuich, 1974; Reckahn, 1986).

Recent evidence suggests that bright patches (faculae) that occur together with the more obvious dark patches during sunspot cycles, override the dark effect and actually increase rather than decrease solar output during the sunspot peak (Broad, 1997). This might explain why northern Europe (and North America) cooled considerably during a period of extended low sunspot activity between 1640 and 1720. From the early 1900's to about 1940, the length of sunspot cycles was short and the Earth's near surface temperatures increased. Between 1940 and 1980, the length of cycles became longer and atmospheric temperatures declined. However, sunspot cycles became shorter again after 1980 and this has coincided with further increases in the Earth's near surface temperature. On this basis, it is quite possible that variations in solar output account for much of the rise in the Earth's near surface temperature between about 1860 and 1980 (Anon., 2000d). Based on more specific measurements of variation in the solar magnetic field and its effects on the Earth, solar output could account for almost all of the warming experienced between 1860 and 1930. Since 1970 solar influence can account for only about one third of the global warming that has occurred (Anon., 1999a).

In addition to the effects of direct solar heating at and near the Earth's surface, measurements show that 10 to 20% of the change in energy output of solar cycles occurs in the form of UV radiation (Shindell *et al*., 1999). Under natural conditions, much of this radiation is absorbed by ozone in the upper atmosphere and this process warms the ozone and raises the temperature of the stratosphere. However, and due to the release of certain types of man made chemicals (Section 4.2.2.1), ozone depletion has been particularly noticeable since the early 1970's (UNEP., 1989). This has resulted in stratospheric cooling. Model studies suggest that changes in stratospheric temperature affect planetary waves in the atmosphere and, in turn, modify tropospheric circulation over the Earth's surface. Another effect is also linked to ozone depletion and reduced stratospheric heating. In polar regions and at very high altitudes (about 21 km above the Earth's surface), ice crystals can form polar stratospheric clouds at extremely low moisture contents when temperatures fall to about -78º C or lower. These clouds may further contribute to changes in the stratospheric heat balance (Shindell *et al*., 1999). Ozone depletion and its effects on stratospheric heating in response to UV radiation, are likely to persist over many decades to come (EC., 1991; UNEP., 1989).

At the Earth's surface, heating and cooling are more rapid in areas without cloud cover (Anon., 2000c) but, in the atmosphere, water vapour is the dominant carrier of heat transferred from the equator to the poles. Models suggest that with higher temperatures in the troposphere, evaporation from the ocean increases and leads to more wet days a year at high latitudes and heavier rains at mid and lower latitudes. There is some evidence to suggest that El Niño and La Nina events may be becoming stronger (Anon., 2000f). Increased quantities of water vapour in the atmosphere also act as a feedback mechanism and add further to the greenhouse effect (Ramanathan, 1998). Under the influence of warming and increased water vapour in the tropical troposphere, more moisture may also transfer into the stratosphere and, additionally, contribute to stratospheric cloud formation (Kirk-Davidoff *et al*., 1999). The extent to which ozone depletion has actually reduced stratospheric heating is poorly quantified. The influence of variations in the solar discharge of subatomic particles and variations in solar magnetism on climate are less certain.

Volcanic activity may also contribute to climatic variation and, when eruptions are powerful enough to inject dust and SO_2 into the upper atmosphere, stratospheric dispersals can result in hemispheric cooling that lasts for periods of several years (Gribbin, 1983). Conditions such as this are thought to have occurred following the massive volcanic explosions of Tambora (1815) and Kratakau (1883). Other effects may be possible, such as the release of heat or nutrients to the marine environment from underwater volcanic activity, corresponding changes in oceanic conditions including thermal structure and productivity, and subsequent exchanges between the ocean and atmosphere. Volcanic activity that releases large quantities of CO_2 and little dust to the atmosphere would cause atmospheric warming, if sustained over long periods of time. The geological record from marine sediment cores indicates that natural increases in phytoplankton would also act to remove the CO_2 by photosynthesis. However, there is a considerable lag (measured in tens of thousands of years) between these mechanisms of release and increased sequestering of CO_2 (Anon., 2000b). Although statistical relationships do exist between climate features such as the El Niño Southern Oscillation (ENSO) and high atmospheric concentrations of volcanic aerosols, they appear to be no greater than would be expected from random associations (Self *et al*., 1997). Under some circumstances, volcanic activity can be an important influence on climate. But, usually, large scale vulcanism is an infrequent event and its effects on climate are not long lasting. Man made aerosols (*e. g.* from combustion) also produce climatic cooling but the effect is considerably less than the warming of greenhouse gas emissions (Charlson, 1997).

Based on evidence by association, it seems most probable that variations in total solar output (particularly brightness) have been a major influence on climate over the period for which records are available. It is also possible that global warming could have been greater without the influence of recent ozone depletion. Climate, however, is not simply the response of the atmosphere to received solar radiation. The composition and behaviour of the atmosphere is closely coupled to the oceans that cover about 85% of the Earth's surface and to plant material present on land and in the sea. Thus there are many other feed-back mechanisms which have potential to further alter atmospheric response to solar variations.

Warming at the Earth's surface will tend to tend to decrease the density of all surface waters. It will intensify the hydrological cycle by which water is evaporated and transferred to the atmosphere as water vapour. This process will also result in the transport of more freshwater (as precipitation) to higher latitudes (Broecker, 1998). Global oceanic circulations are linked and deep Atlantic waters that move southward into the "polar raceway" of the Antarctic Ocean become redistributed to the Indian and Pacific oceans, and from the Pacific to the Arctic Ocean. Differences in the density of the water masses have a major influence on these movements. It is thought that circulation in the North Atlantic may be particularly sensitive to changes of the inflow and mixing with Arctic Ocean water (Broecker, 1997; 1998).

Although deep waters of the North Atlantic are much warmer than those of the Arctic Ocean, their higher salt content makes the density of the two water masses more nearly the same. Atmospheric warming that increased freshwater discharge from the Arctic Ocean would alter the salinity and density of mixed Atlantic and Arctic waters that form the deep return flow of the Atlantic "conveyor belt". There is concern that salinity of these mixed ocean waters could be sufficiently reduced to modify density and effectively shut down major components of circulation in the North Atlantic (Broecker, 1997; 1998). Under this condition, the transport of warm surface waters in the North

Atlantic drift would also decline and regional cooling would affect large areas of western and northern Europe. Models of ocean circulation based on a 50% increase of precipitation and runoff over evaporation (Broecker 1997), or an atmospheric warming of about 4 to 5º C, support this (Broecker, 1998). Reduced warmth in the North Atlantic would affect evaporation and air temperature. It could also affect the position and behaviour of large scale atmospheric phenomena such as the North Atlantic Oscillation (NAO), and the El Niño Southern Oscillation (ENSO) of the Pacific Ocean.

There is evidence to suggest that changes in the characteristics of the Atlantic deepwater return flow may be occurring, already. Salinity measurements of deep water between the Shetland and Faroe islands in the Northeast Atlantic have been made since 1893. Until recently, the salinity of this mixed Arctic and Atlantic water has been highly constant, and sufficient to provide a calibration standard (Anon., 1999b). But over the past two decades, salinity has declined by 0.01 $g{\cdot}kg^{-1}$ of seawater and the temperature of deep water has increased (the -0.5º C temperature depth dropped by 60 m between 1988 and 1997 (Anon., 1999b)). Flow reversals have also occurred. For example, in 1982 and 1983, deepwater flowed south from Greenland into the Norwegian Sea but ten years later the flow was reversed (Anon., 1999b). Feedback mechanisms may be occurring in the North Atlantic and related processes could have far reaching but as yet little understood impacts on climate in the western Arctic, including the WKSS area. On the other hand and although it is not known to what extent similarities may be drawn beween present climate and the mid-Holocene high (see later comments in this Section), available evidence does not indicate that this warm period was suddenly terminated by rapid and detrimental climate change. Since present Arctic and sub-Arctic climate is not yet as warm as it was during the mid-Holocene, it would seem that threshold conditions (if they occur) would be at a level, at least, above the mid-Holocene high.

Human activities release large quantities of “greenhouse gases” into the atmosphere where their influence may partially override other tendencies towards global cooling (such as reduced solar output). Greenhouse gases include water vapour, CO_2, CH_4, NO_x, CFCs, and O_3, (CCPB., 1991). These gases allow passage of short wave radiation from the sun but block long wave radiation, much of which is re-emitted from the Earth’s surface. This traps heat near the ground, but it may also contribute to further reductions of temperature in the upper atmosphere and increases in the frequency of stratospheric cloud formation (a process that is also poorly quantified (Kirk-Davidoff *et al.*, 1999; Shindell *et al.*, 1999)). As previously noted, changes in stratospheric heating are thought to influence atmospheric circulation (and perhaps to intensify polar vortices).

The gases differ greatly in effect (EC., 1991; UNEP., 1989) and although water vapour is the most important greenhouse gas (Broecker, 1996), its concentration in the atmosphere is highly variable. Of the other major constituents and given that present trends in atmospheric composition do not change during the rest of this century, CO_2 will likely contribute to more than 70% of the greenhouse effect. Methane, which is about 20 times more effective than CO_2 as a greenhouse gas, could contribute to about 17% of potential warming. Nitrous oxides are more than 300 times as effective as CO_2 as a greenhouse gas and could contribute nearly 8% of potential warming. Chlorofluorocarbons (CFCs) and related aerosols range from about 4,000 to about 24,000 times more effective than CO_2 as greenhouse gases, and will likely contribute to about 3% of the warming effect (Mitchell, 2000)

The release of CH_4 from peatlands and wetlands is expected to increase as a result of temperature induced microbial activity (Section 2.3.4.1, (Nadelhoffer *et al*., 1992)), and rising temperatures could also affect gas hydrates that are buried in sediments. However, there is no evidence that hydrates became a significant source of greenhouse gas at the end of the Younger Dryas (11,800 BP) when global temperatures increased rapidly (Broecker, 1996). Present conditions appear to be no more favourable for their release. Estimates suggest that global levels of CH_4 have increased considerably over the past three centuries and that much of the increase has been due to industrial and agricultural activities (Ovenden, 1989). During past interglacial periods (Section 2.2.2.7), this gas contributed about one-quarter of the greenhouse effect of CO_2. Methane breaks down in the atmosphere to produce water vapour and, for each 1^{o} C increase in temperature, water vapour will increase by about 6 %. The effect of water vapour on climate is complex. In very general terms, the effect depends on two things: how much water vapour is carried into the stratosphere where high level cloud formation may cause cooling at lower levels in the atmosphere; and how much enters lower levels in the atmosphere where cloud formation can trap heat near the Earth’s surface. Model studies suggest that water vapour has a major influence on global climate. In part, this is because of feedback. During glacial maxima, the effects of water vapour could have been considerably greater than those of CO_2 (Berger & Loutre, 1997).

Changing patterns in land use, deforestation, intensive agriculture and the spread of desert lands may all contribute to increased greenhouse gas concentrations in the atmosphere, both by greater gas release or by reducing the ability of ecosystems to sequester such gases (Anon., 1998; 1999c). Over the past 150 years or so the net production of terrestrial ecosystems is thought to have increased significantly in response to greater availability of C. But the response by vegetation to further increases of CO_2 could decline, as the fertilization effect becomes saturated (Kuicao & Woodward, 1998). Difference in regional effects may become very significant (Betts *et al.*, 1997).

Present understanding of feedback mechanisms in the C cycle are not yet sufficient to adequately quantify terrestrial biospheric processes (Rodhe *et al.*, 1997).

Human activity has very likely contributed to recent warming trends in global climate and signatures of climate change are present in a wide array of climate data. It is difficult to separate and quantify the extent of human related effects (Allen *et al*., 2000; Corti *et al.*, 1999), but natural conditions remain dominant. For example, Hulme *et al.* (1999) suggest, based on simulations of precipitation runoff, that natural conditions predominate. Corti *et al.* (1999) suggest that recent warming of the northern hemisphere is mostly related to the thermal structure of circulatory regimes in the atmosphere.

Despite uncertainties, some things are known with a very high degree of probability. They are that the combustion of fossil fuels is a major source of greenhouse gas emissions from human activities. Based on the modelling of a great number of possible scenarios there is almost no likelihood that the release of CO_2 from this source to the atmosphere will cease to increase for at least the next 50 years, despite the best likely applications of conservation and control technologies (Anon., 2000e). Therefore if human activities have contributed to some part of recent global warming (particularly over the past 20 to 30 years) it is almost certain that the effects of this contribution to warming, whatever they are, will also continue and increase. What may happen in the latter part of the 21st century is much less clear, most likely greenhouse gas emissions will begin to decline but it is uncertain by how much (Anon., 2000e). As a reflection of greenhouse gas emissions, the forecast of global warming to the middle of the 21st century appears to be robust but the extent of warming after atmospheric equilibrium composition is reached is uncertain. It is even less certain that, when achieved, equilibrium will be maintained (Allen *et al*., 2000). Estimates, that are heavily weighted by projections of fossil fuel combustion, predict concentrations of atmospheric CO_2 will double by 2050. The mean annual global temperature will rise between 1.5 and 4.5^{o} C (CCPB., 1991). However, the rise in temperature is expected to be uneven and the greatest increase is expected to occur at high latitudes.

The geological record provides a means of extending the record of observed climate change and perhaps gaining some further insight into cause and effect relations. After some time lag, cooling in the North Atlantic during the Younger Dryas period, between 17,700 and 11,500 BP, seems to have resulted in cooling of the northern Pacific Ocean and western North America (Benson *et al.*, 1997). In part, this lag may reflect processes associated with the circulation of water between the Atlantic and Pacific oceans (Broecker, 1997; 1998). Geological evidence, based on comparisons of core data from ocean sediments and glacial ice cores suggests that other links between climate and ocean response in the North Atlantic are possible. Over the past 110,000 years, conditions have switched between moderate and intense cold in Greenland. These changes occurred over periods of a few years to decades, every thousand years or so (Broecker 1997). During 6 of these very cold events (Heinrich events), icebergs dropped debris from Greenland off the coast of France, and it is thought that Canadian ice sheets also, alternatively, stored and released freshwater to interrupt Atlantic Ocean circulation (Broecker 1996). Asian winds (producing dustfall from the Golbi Desert in Greenland) and surface salinities of the Pacific Ocean have also undergone large synchronous changes over periods of a few decades (Broecker, 1997).

Near the end of the Younger Dryas (at the end of the last glacial period), and based on N isotope data from ice cores, temperatures were about 15º C colder than now on the Greenland ice cap (Severinghauss *et al*., 1998). Warming at the end of the Younger Dryas was abrupt and could have occurred in as little as 3 years, or less, during which snowfall also doubled (Beaulieu, 1997). This warming may have been as much as 7º C and coincided, to within a decade or so, with a rapid rise of CH_4. The cause of this warming is not known but it demonstrates that extremely rapid hemispheric change can occur in global climate.

Average annual global temperatures are probably as warm now as at any time in the past 4,000 to 5,000 years (Maxwell, 1987; 1992). Temperatures in the northern hemisphere are likely their warmest in 400 years (Serreze *et al*., 2000), but similarities between present climate and the mid-Holocene high are limited. Global coastlines, then and now, were similar and so were surface sea temperatures, but the axial tilt of the Earth was different during the period of the mid-Holocene high (Pelletier, 2000). At that time, increased solar radiation was received during summer in the northern hemisphere, the temperature contrast between land and sea was greatest in summer, and monsoon circulation was enhanced relative to the present. Comparisons have also been suggested between present climatic conditions and the Medieval warm period, between 1,000 and 1,300 AD. However, there appear to be significant differences, as well, between this past and the present climate. Data suggest that the Medieval warm period was characterized by 2 or 3 warm periods that lasted only 20 or 30 years each, and that this warming was somewhat patchy (Crowley & Lowery, 2000). Composites of the Medieval warm period may not be closely comparable to the more constant and widespread warming of the present.

Over the past century, the global mean surface air temperature has warmed by 0.3 to 0.6º C (EC., 1991; Serreze *et al*., 2000), and 0.2 to 0.3º C of this warming has occurred during the past 40 years (Serreze *et al*., 2000). Precipitation has also increased in Canada, north of 55º N, since the 1960's.

Much of this has been associated with position of the Atlantic cyclone track. The greatest increase in air temperature over northwest North America has been during winter and spring, but over the Arctic Ocean the increase has been greatest during spring and summer. There has been a pronounced warming over much of North America since the 1970's but, at the same time there has been a cooling over the North Atlantic (Serreze *et al.*, 2000). Based on records since about 1960, annual average temperatures have increased by 0.25º C per decade in the western Canadian Arctic. They have also decreased by a similar amount in the eastern Canadian Arctic (northern Quebec, Labrador and Baffin Island). The NAO is a component of the Arctic Oscillation. The strong northerly flow across eastern Canada is characteristic of the positive phase of the NAO when both the Icelandic Low and Azores High pressure atmospheric systems intensify. This condition has existed over the past 2 decades. There is evidence that the Arctic Ocean has been warming and the length of the seasonal melt has increased (Serreze *et al.*, 2000). During the mid 1990's, the surface area of Arctic sea ice decreased at a rate of about 2.9% per decade. Outflow of Arctic surface water through the Fram Strait has increased, and underlying warmer but more saline Atlantic water has extended further into the Arctic Ocean (Serreze *et al.*, 2000).

In the middle Mackenzie River basin, average annual surface air temperatures have increased by about 2º C between the Alberta-BC border and Rae Lakes, and by about 1.5º C at Norman Wells and the East Arm of Great Slave Lake, over the period 1900-1990 (Skinner & Majorowicz, 1999). Ground surface temperatures show an even greater rise over this same period. On a regional basis, temperature records of groundwater in wells at depths greater than 50 m indicate that significant warming has occurred over the past half century. Ground surface temperatures have increased by about 5º C or more in prairie grassland areas and by 3º C or more in boreal areas (UNEP., 1989). Locally, warming has been greatest where there has been land disturbance, such as pipeline construction and timber cutting (Skinner & Majorowicz, 1999). Warming has not been constant. Widespread warming is thought to have occurred across much of the Arctic during the period between 1820 and 1920. This may coincide with globally low atmospheric concentrations of volcanic aerosols (Serreze *et al.*, 2000). In the middle and lower Mackenzie Valley, there was general warming between 1890 and 1940, cooling between the 1940's and 1970's, and a further warming has occurred since then (Skinner & Majorowicz, 1999). The WKSS area has experienced modest warming but less than in the Mackenzie River valley and Yukon regions (Cohen *et al.*, 1994; Cohen, 1997; Hardy & Bradley, 1996).

Precipitation records from the WKSS area span a short period of time (Section 2.2.1) and evidence from proxy data is very limited. Based on analysis of tree rings from stands of White Spruce near Inuvik, growth (ring width) appears to be more influenced by availability of moisture than an increase in temperature (Szeicz & MacDonald, 1996). Growth has been greatest during periods of increased precipitation (and, or, least evaportation during the previous season). Over the past 900 years or so, growing conditions appear to have been best between: 1185-1205, 1215-1260, 1510-1560, 1725-1740, 1770-1780, and 1925-1940 AD. Poor growth occurred between 1125-1170, 1260-1300, 1395-1405, 1585-1610, 1700-1710, and 1820-1855 AD. During dry and cold conditions, Arctic outflows may have followed a more meridional atmospheric circulation, although generally drier periods seem to have existed in both northern Quebec and northwest Canada between 1260-1300 and 1600-1850 AD. Moisture levels were probably high between 1170 and 1250 AD (Szeicz & MacDonald, 1996).

Geological evidence from sediments indicates that lakes of the Great Basin area of central North America have responded to climatic events of global scale. Broecker (1996) has suggested that, under the influence of increased heating, massive cumulus clouds would have formed in the tropics and fed vast quantities of moisture high into the atmosphere towards the end of the last glaciation. The high level lake stages which developed about 14,000 BP would have been, therefore, an expression of greatly increased precipitation, associated with that moisture. The geological record suggests there is broad coherence of climate among many sites in western North America and that this may be related to sea surface temperature in the tropical Pacific (Laird *et al.*, 1998). Well developed regions of low atmospheric pressure off both the east and west coasts of North America are associated with drought in the northern Great Plains (Laird *et al.*, 1998). Extreme droughts were common at Moon Lake in North Dakota prior to 1,200 AD, and at both this region and in the upper Mackenzie valley, moisture levels increased after about 1,200 AD. Apart from this association, there is little evidence for a relationship between climatic conditions in northwest Canada (WKSS area) and those of the northern Great Plains. While proxy precipitation data from North Dakota can be extended northwards into Saskatchewan (and possibly into the extreme southeastern part of Alberta), the 2,300 year record from the Moon Lake region (Laird *et al.*, 1996) shares little in common with events in the middle and lower Mackenzie Valley. The Moon Lake data appear to be strongly influenced by seasonal incursions of air masses from the Gulf of Mexico whereas the northern Mackenzie Valley region has remained under the influence of Arctic and north Pacific air masses. This is consistent with present air mass time-frequencies at Inuvik (Rouse *et al.*, 1997), in which Arctic air is present 100% in winter, 85% in spring, 55% in summer and 88% in the fall, and Pacific air makes up the balance.

Natural variability in climate is known to be considerable throughout the WKSS area and predates any effect that may be occurring from the release of greenhouse gases. Rapid warming (15,000 to 10,000 BP) brought an end to the last glacial period and the WKSS area became ice-free about 8,500 BP (Section 2.2.2.7). Locally, the cooling effects of large lakes may have persisted for an additional time. The warming was followed by cooling and then warming again about 5,000 BP (mid-Holocene high). Shortly before 3,000 BP there was another period of cooling (Bryson & Wendland, 1967; Maxwell, 1987; 1992). Diatom assemblages from lake sediments in the Lac de Gras area (Pienitz *et al*., 1999) show clear evidence of warming and more humid conditions between about 5,000 and 3,000 BP. This mid-Holocence warm event is widespread across northern North America but unrelated to Milankovitch cycles. It has been suggested that retreat of the Arctic front allowed greater influence of Pacific air masses at that time (Pienitz *et al*., 1999).

Within recorded history, large variations in winter and summer temperature are already known to exist across much of northern Canada. There are considerable variations in precipitation, and year-to-year differences in ice cover and thickness may vary by as much as 30% (Ball, 1983; Catchpole, 1985; Dunbar, 1985; Fisher & Koerner, 1983; Koerner & Fisher, 1981; Wilson, 1985). In addition to year-to-year variations about some mean value (*e. g.* annual temperature or total precipitation), there may be changes in the frequency of extreme events such as storms, coastal surges, drought, and fire. There are few certain relationships between possible climate change and specific weather events.

Separation of natural and human-induced effects within recent climatic data is not distinct (Allen *et al*., 2000; Corti *et al*., 1999) and although there is a present warming trend the extent to which it will continue is uncertain. The likelihood that future conditions might become similar to those of the late Tertiary Period of geological history (Matthews, 1989) is conjectural. Changes that may be associated with precipitation (quantity and form) are uncertain (Cohen *et al*., 1994). Based on analogy with palaeoclimatic information, some increase in precipitation is probable at high latitudes and this would most likely occur during the open water season (as at present).

Palaeobotanical evidence such as tree ring data and pollen distributions, relict stands of trees that became established under previous and more benign climatic conditions north of the present tree line, and relict peatlands, suggests that there have been significant vegetational changes both before and throughout the period of human occupation. Geological evidence also indicates that brief but rapid changes in climate have occurred even during glaciation. It has been suggested that these may have been related to the global evaporation-precipitation balance (including continental run-off). In particular, it seems possible that changes in the rate of production of cold and deep North Atlantic Ocean water might move climate from one quasi-stable state to another (Broecker *et al*., 1985).

In summary, two factors are most likely to influence climate in WKSS area over the 21st century. If the recent trend of solar activity remains the same it will contribute to global warming. However, solar activity might increase, or it could decrease (and cause less heat to be received at the Earth's surface). The effects of warming from greenhouse gases is almost certain to continue. The influence of many other factors on climate in the WKSS area are not predictable but could cause either significant warming or cooling. On balance, it seems most likely that climate will continue to become warmer, at least to the middle of the 21st century, and that this warming will be accompanied by a modest increase in precipitation (mostly during summer). There is nothing to suggest that climate will become less variable. Rather, collective evidence suggests that it may become more variable as greater quantities of water vapour transport more heat poleward.

A wide range of effects from climate warming could occur in the WKSS area. Potential environmental effects that represent a relatively quick response to climate warming include: more freezing rain and changes in snow cover and runoff, delayed ice formation, less stable ice cover and earlier break-up, increased wave activity due to extended open water conditions, and increased evaporation (Section 2.2.4). Soil moisture is likely to decrease but fire frequency is likely to increase and to occur earlier in the season (Kane *et al.*, 1992; Kadonaga, 1997). Environmental effects showing a slower response include: thinning of permafrost and changes in its distribution (Section 2.2.5), changes in types and distributions of vegetation (Section 2.3.4.2, (Billings, 1992; Jefferies *et al*., 1992)), rising sea level (globally, the expansion of warmer water could rise sea level by about 0.4 m within a few decades (Schneider, 1998). Over a long period, melting of polar ice caps could cause much more severe coastal flooding. Examples of specific effects are discussed in more detail.

4.2.1.2. Effects of Climate Change - Permafrost

With climate warming (as higher maximum summer and fall temperatures, and an extension of the period of above-freezing temperatures or both), changes could be expected over large areas of permafrost which are presently within 1 to 3^{o} C of melting (Section 2.2.5) or where mean annual air temperatures are greater than -6^{o} C (Rouse *et al.*, 1997). General predictions suggest that much of the permafrost in the discontinuous permafrost zone will gradually disappear over periods of decades to centuries. Instabilities associated with thawing soils, such as ground settlement and slope failure, will likely increase (Burgess, 1998). The southern limit of the discontinuous permafrost zone will likely shift northward. In the continuous permafrost zone, the thickness of the active layer will probably increase and permafrost thickness will gradually decrease.

Specific responses of permafrost and the active layer (rate and magnitude) are difficult to predict (Williams, 1979). They are strongly influenced by water balance and will respond to changes in both temperature and precipitation, and feedback mechanisms. Permafrost conditions are also influenced locally by vegetation, soil moisture, snow cover, and fire (Harris, 1987; Maxwell, 1992: Rouse *et al.*, 1997). Surface organic layers can buffer the ground (Tenhunen *et al.*, 1992) from increasing air temperature and increased snow cover can insulate the ground from geothermal heat loss. Models of the effects of climate warming on peatlands in the Mackenzie River basin suggest that permafrost will persist under protective peatlands north of about Latitude 65 ^{o}N. Moisture levels in these northern peatlands are likely to decrease (Nicholson *et al.*, 1997).

Permafrost underlying moss bogs may be less well insulated from effects of warming than under fens where vascular plant structures provide mechanisms for greater evaporative loss. Soils with low moisture contents warm more quickly than those with high moisture contents but the drier the surface of peatlands, the greater their ability to insulate underlying permafrost (Rouse *et al.*, 1997). Fire may decrease the thickness of insulation over permafrost and melting may result in collapse of the peatland cover. In areas subject to periodic fire, lowering and recovery of peatlands after fire may be an event that is recurrent over periods of 600 to 2,000 years (Rouse *et al.*, 1997).

Table 3 provides a summary of ground sensitivity to permafrost degradation. Although not a widespread sedimentary material, marine silts and clays are likely most sensitive to permafrost degradation. More commonly occurring till veneers and blankets, hummocky till, and esker and outwash materials are also potentially quite sensitive (Rouse *et al.*, 1997). Changes to the landscape that occur in response to the degradation of permafrost (Harris, 1987; Harry & Dallimore, 1989) could take place over very large areas. They include increased rates of erosion, ponding, solifluction, creep, slumping, and slope failure. Lower frost tables may result in the drainage of some peatlands but they may also increase soil water storage capacity. Any and all such changes could have a negative effect on many forms of infrastructure (including: housing, roads and runways, fuel storage, power plants and water treatment facilities, waste storage, and communication networks).

4.2.1.3. Effects of Climate Change - Vegetation

The response to climate warming by Arctic and boreal vegetation is difficult to predict (Section 2.3.4.2), and Fig. 20 shows a range of possible vegetation responses to different forms of changing climate (Rouse *et al.*, 1997; Starfield & Chapin, 1997). If warming occurs, both as an earlier spring and later fall, present plant community structures may shift northward. However, if warming extends only in the fall, other changes could occur and these might include a shift to species better adapted to the new conditions (Sveinbjornsson, 1992). Present evidence suggests that warming will be greater in winter than summer but that winter temperatures will not rise above freezing (Cohen *et al.*, 1994). Fall extension of the open-water season seems likely, and this could cause more freezing rain and early winter snow. Under such conditions, soil moisture might increase favouring expansion of moss over lichen. If the summer growing period does not significantly increase, vascular plants will not colonize northward. If summer temperatures rise by only a small amount, evaporation is likely to rise by only a small amount, and with a longer period of open-water annual precipitation could increase. With more soil moisture and less frequent fire, spruce canopy closure (and loss of lichen) might also increase near the tree line. Tussock vegetation is also very sensitive to changes in soil moisture (*e. g.* in response changes in precipitation, or wind and evaporation). With increasing temperature, rates of peat accumulation would likely increase in tundra areas where it would act as a carbon sink (Oechel & Billings, 1992). In more southerly areas, however, peatlands could become warmer and drier, and increasing microbial activity would likely cause them to become a carbon source (for greenhouse gases, Section 4.2.1.1). The presence of deciduous species within the boreal forest areas (between Great Slave Lake and Great Bear Lake, and along the East Arm of Great Slave Lake (Hartley & Marshall, 1997)) may increase. Some vegetation anomalies north of the present tree line (Johnson, 1979; Kershaw & Rouse, 1976; Timoney, 1995) may also reflect areas of favourable soil (which partly compensate for net radiation effects) and previous vegetational advances under more favourable climatic conditions. Vegetation anomalies south of the tree line (Johnson, 1979; Kershaw & Rouse, 1976; Timoney, 1995) reflect areas of unfavourable soil and the effects of fire.

Based on accumulating evidence and models of warming due to a doubling of CO_2 in the atmosphere (4.2.1.1), it seems likely that normal successional change will be influenced by warm but not very humid conditions. Over the next 50 to 500 years, model studies suggest that grasslands could replace parts of both presently forested areas and tundra uplands in the WKSS area (Starfield & Chapin, 1997). However, if the Pacific airmass becomes a more significant component of the climatic regime (Section 2.2.1), rising humidity would enhance tree growth both near the tree line and possibly at some coastal and near coastal sites. Vegetation response will be very sensitive to water balance in the environment. This is implied from the right-hand panel of Fig. 20, in which the effects of rising or falling water tables reflect overall water balance. Vegetation response will lag climate warming and based on an increase of 3^{o} C per century, it would take at least 150 years for forest cover to begin extension into the tundra (Starfield & Chapin, 1997). Conifer species would be early colonizers and only later would deciduous species begin to replace them.

Other factors may be important, too. For example, It is probable that timber harvest, Moose and predator control practices and fire would have greater effect on vegetation than climate change (Starfield & Chapin, 1997). Also and under the present scenario of climate warming in response to a doubling of atmospheric CO_2, it is possible that the Spruce Weevil will expand its range northwards. It could occupy most areas in the Mackenzie River basin that are presently forested with White Spruce. Weevil infestations in pine forests require a minimum of 720 degree days above 7.2 ^oC (Sieben *et al.*, 1997)).

Although White Spruce and Black Spruce did not die-off during cold summers during the mid 1800's, both suffered from poor growth and recruitment at the tree line. After 1880, both species did well under the influence of warming. During the 1960 and 1970's, cooling again limited growth and recruitment. Most recently, White Spruce and Black Spruce have shown good growth and recruitment in response to warming since the 1980's (MacDonald *et al.*, 1998). However, there is little evidence of a significant northern advancement of the tree line (since 1880).

Satellite data from 1981 to 1991 indicate that plant growth has increased with a longer growing season (mean annual hemispheric warming). This has been most significant between 45^o and 70^o N where spring warming has also occurred together with an early decrease in snow cover (Myneni *et al.*, 1997). Experimental studies indicate that it may be easier for trees to colonize shrub tundra than either heath or tussock tundra and that White Spruce is likely to be one of the most successful colonizing species (Hobbie & Chapin, 1998a). The location of the present tree line probably results, in part, from unsuccessful recruitment (temperatures are too cold to permit germination). Once established the survival of seedlings is further influenced by both availablity of nutrients and competition. Many stands of Green Alder and Balsam Poplar on the tundra are likely relict populations from mid-Holocene warming (Hobbie & Chapin, 1998a).

Carbon and peat accumulation rates over the past 1,200 years have been less in northwest Canada than in northeast Canada, particularly because of low and variable summer precipitation. Recent accumulation rates are similar for areas of rich fen and peat plateau (about 14g $C \cdot m^{-2} \cdot a^{-1}$), and rates for poor fen and ombrotrophic bogs are higher (20 to 22g $C \cdot m^{-2} \cdot a^{-1}$). The annual average rates of peat accumulation range from 0.28 to 0.56 mm over discontinuous permafrost in northwest Canada (Robinson & Moore, 1999). The tree line is a surrogate for the long term average position of the Arctic Front in July (Fig. 8), and over the past hundred years, or so, the front has moved north in many areas. Although forest cover lags this change, areas of tundra have changed from a net sink for atmospheric CO_2 (30 to 100g $C \cdot m^{-2}.a^{-1}$) to a source of CO_2 (by a similar amount). About 20% of the CO_2 released from peatlands passes first through the aquatic environment before being finally released back into the atmosphere (Serreze *et al.*, 2000).

Plant species mediate microbial activity in soil and may influence N cycling in response to rising atmospheric CO_2 (Hungate *et al.*, 1996). All ecosystems with a fixed N-pool will show small increases in C storage in response to rising levels of atmospheric CO_2. Additions of inorganic N cause rapid increases in productivity and N supply. However and as implied in Fig. 20 (bottom panel), the effect is short-lived if N additions are not maintained (Tateno & Chapin, 1997).

Growth experiments indicate that a 4º C atmospheric temperature rise will increase C turnover but little effect is expected on the tundra C balance (Hobbie & Chapin, 1998b). A temperature rise in the growing season will have little effect on total biomass, N content or N uptake in the main plant and soil pools. Rather, tundra productivity seems to be controlled by nutrient availability and length of growing season. Warming stimulates early photosynthesis and above ground biomass (*e. g.* Dwarf Birch) and redistributes N from understory shrubs (*e. g.* Cranberry) thus mediating N availability within the plant community (Hobbie & Chapin, 1998b). Warming also stimulates respiration during the growing season and this is likely associated with root-N uptake for above ground biomass (*e. g.* Dwarf Birch). Experiments with different species of grass indicated that the effects of increasing CO_2 on litter decomposition and N release may be strongly influenced by the root:shoot ratio. In addition, this depends on species traits and nutrient availability. The effects of rising CO_2 on litter decomposition and N-release are species specific (Frank *et al.*, 1997).

General models indicate that uptake of CO_2 in tundra systems can be related to annual precipitation and the mean July temperature ((Christensen *et al.*, 1999), but actual conditions may be more complex. It is uncertain if tundra ecosystems will act, overall, as a sink or source under climatic warming, and it is likely that fluxes of CO_2 and CH_4 are more strongly influenced by soil and vegetation type than by direct temperature change (Hobbie & Chapin, 1996). For example, sedges may assist release of CH_4 by conducting it from anaerobic soil to the atmosphere. Greenhouse gas experiments with elevated temperature and humidity had little influence on release of CH_4 (Verville *et al.,* 1998). Models based on North Slope (Alaska) tussock tundra, predict that rising air temperature and CO_2 content will increase ecosystem C storage. Because N is redistributed from soil to plants, photosynthesis exceeds respiration but consequent increases in C storage are constrained by the C:N ration in vegetation. It is possible that drier soil will decrease C storage because of greater soil respiration. With drier soil, N redistribution from soil to plants is limited by competing processes (*e. g.* N mineralization) Consequent loss of N from the system would contribute to declining C storage. On a percentage basis, modelling suggests that between 1829 to 1990 (from a cool to a warm period) the flux of CO_2 went from -5.4% to +2.3%. There is a high probability of transient events for ecosystem C loss (McKane *et al.*, 1997). Long term sequestering of C in Alaskan tundra was reversed by warm and dry conditions in the early 1980's but the effect diminished. There is now a summer CO_2 sink in some areas. This reflects metabolic readjustment to decadal or longer climate change (nutrient cycling/physiological acclimation, population/ community reorganization). On an annual basis, however, the tundra has been a net source of CO_2 (40g $C \cdot m^{-2} \cdot a^{-1}$ due to "winter" release). Further warming that follows the existing season trend would likely enhance this (Oechel *et al.*, 2000).

Across the WKSS area, *Typhea* marshes and *Salix* swamps give way to sedge and bryophyte fens and bogs to the north. Globally, wetlands are thought to contribute more than 20% of the flux of CH_4 to the atmosphere, and high latitude peatlands contribute about one third of this. Variations in water content and peat temperature regulate aerobic and anaerobic conditions, and the resultant microbial production or consumption of CH_4. Storage of CH_4, in pore water, in the top half-metre of many peatlands is considerable. For example, at Fort Simpson, the summer flux of CH_4 is about 18 mg $CH_4 \cdot m^{-2} \cdot d^{-1}$ (Liblik *et al.*, 1997). In some fens, O_2-rich groundwater may facilitate CH_4 oxidation in water which reduces its flux to the air. With permafrost melting, the flux of CH_4 would initially increase particularly as a result of collapse structures in plateau bogs and palsas. It would later decline as sites dry out and stabilize to lower water tables (Liblik *et al.*, 1997). Permafrost in peatlands confines water flow to the thin active layer. With a doubling of CO_2, the water table might drop 10-20 cm in summer (Fig. 20, see righthand panel for effects). The southern boundary of peatlands could move 200-300 km northwards so that peat plateau and thermokarst pools develop as far north as Inuvik. Low boreal bogs could evolve as far north as the south shore of Great Slave Lake. Warming would not likely influence subsurface peats (greater than 30-40 cm depth). Raised water levels would increase rates of peat accumulation and reduce the thickness of the aerobic zone. Warming the peatland, therefore, may have little effect on decomposition. Fluxes of soil CO_2 are linearly related to water table depth but fluxes of CH_4 are more nearly exponentially related. Warm moist conditions increase photosynthesis and results in N redistribution from soil. Warm dry conditions make photosynthesis only partly compensate for greater respiration, and N is lost to the system. Many peatlands may show little response to increasing levels of CO_2 without both nutrients and moisture (Rouse *et al.*, 1997)

4.2.1.4. Effects of Climate Change - Fire

The frequency of fire is closely related to a weather index (Johnson, 1979; Kershaw & Rouse, 1976) and when fires significantly exceed this relationship, often the cause is human activity. Fire is the dominant form of disturbance in lichen woodlands (Johnson, 1983). The fire season usually extends from late May to the end of August, and the largest burns occur in years with warm, dry summers. Therefore, any climatic shift towards such conditions is likely to increase the occurrence of fire and to advance the start of the fire season (Kadonaga, 1997). In northern Quebec (Payette *et al*., 1989), the average size of burns in the northern boreal forest is about 80 km^{-2}, about 0.8 km^{-2} in tundra areas, and 80 % of all fires are less than 1 km^{-2}. In the same region, the fire rotation period is about 100 years in northern boreal forests and more than 9, 000 years in shrub tundra. Near the tree line (+/- 20 km), it is about 7, 800 years. Within forested areas of the Great Slave Lake region, the reoccurrence of fire decreases northwards towards the tree line (*e. g.* 40 years at 400 km, 50 years at 250 km, and 100 years at 100 km) and fire rarely extends more than 75 km beyond the tree line (Timoney, 1995).

Studies of fire on the Beverly Caribou range (Ferguson, 1983) indicate that surface soil temperatures and net radiation are greatest shortly after burns. Then, conditions may be near optimum for germination of dormant Black Spruce seeds (requiring temperatures between 17 and 28^{o} C). Very early in recovery, grasses and germinating seeds exist under conditions of low moisture content (Kershaw & Rouse, 1976). Soil moisture generally increases over time and by about 12 years after fire, moss becomes the dominant form of vegetation. This gives way to lichen, 25 to 30 years after a fire, with *Cladonia* slowly being replaced by other species of lichens (50 or more years after a burn (Case *et al*., 1996)). In the final phase of recovery, the plant community consists of vascular plants and moss but when fire occurs more frequently than about once in 100 years, a closed canopy does not develop and spruce-lichen cover is maintained. Winter grazing caribou avoid areas where burns are too recent for lichen cover to have become reestablished, or where a lack of fire has allowed extensive canopy development.

In areas of frequent fire, seed banks in the soil are quickly exhausted. Most pine and spruce seedlings appear 3-10 years after a fire and little further recruitment occurs in this even-aged population, until it becomes capable of seed-bearing after another 50 to 75 years. Forest layering begins close to the new parent trees and few seeds are carried more than 100 m (Luc & Luc, 1998). Tree density at recovery sites is much lower than before a fire, and the resulting open forest or lichen heath is more typical of tundra than boreal conditions. A short fire interval and unfavourable climate can rapidly change boreal forest to taiga and species shifts may occur. For example, at Chisasibi in northern Quebec, the average fire cycle is about 109 years but in areas with a 40 year frequency density is greatly reduced and Jack Pine dominates Black Spruce (Luc & Luc, 1998). The longer lived spruce only becomes dominant in areas with greater than average fire interval.

Ground fires reduce C storage and peat accumulation, and increase the likelihood of permafrost melt (Robinson and Moore, 2000). At some fire sites, there may be a lag between fire and the effects of permafrost degradation. For example, germination may be successful and seedlings begin to recolonize a burned area. Initially, seedlings grow well and are protected by surrounding trees, but surrounding mature trees may not survive the delayed effects of soil disturbance associated with melting permafrost. If protection is lost, the young trees loose winter insulation as the snow depth decreases and they become more exposed to wind damage. Deformaties, such as die-back and cushion-form development in young trees, may indicate multiple stress effects associated with fire near the tree line (Arsenault & Payette, 1997).

Because boreal forests are comprised of a few but widespread species, biodiversity is a poor indicator of richness during recovery from fire. Rather, patchiness and canopy development are more useful indices of recolonization. During the pioneer stage of recovery, vegetation patchiness and species abundance tend to be linearly related. With expansion and stabilization the relationship is lost by many species as they cover more of fewer patches (Fortin *et al.*, 1999).

Areas downwind from a burn are also stressed because of low moisture content in the atmosphere (Kershaw & Rouse, 1976). Regrowth is more rapid after an early summer burn than one in late summer. Fire and animal herbivory tend to select for short lived and quick growing deciduous trees. Long periods between fire allow replacement by slower growing but more competitive species. Light seeds favour wind dispersal of willow and Balsam Poplar as early colonizers, though Black Spruce is most tolerant of nutrient-poor soil, and water transport favours heavier seeds (*e. g.* birch). Frequent fires select for grasses and could eliminate evergreens as a seed source at the tree line if they do not reach seed-bearing age before a return of fire. Burns over permafrost may destabilize soil structure and increase summer melt, and require vegetative regrowth to begin at the earliest phase of colonization. On ice-rich permafrost slopes, active layer detachment slides frequently increase after fires.

Based on palaeo-environmental data, fire frequencies in the Porter Lake area (east of Great Slave Lake) have varied considerably over time (Johnson, 1983). The present fire frequency (return period) is about 100 years, at 400 BP it was about 250 years, and at 2,500 BP it was about 400 years. However, under warmer and drier conditions about 1,000 BP, fire frequency was about 50 years. These variations indicate that a changing fire regime, could dramatically effect the environment of the WKSS area.

At sites not affected by fire, vegetation may persist with little response to climate change. Where fires occur, however, recovery may result in major changes in species composition and structure of plant communities. Climate warming models based on a doubling of atmospheric CO_2 result in increased burn severity (by 40 to 50 %) and an increase in burned areas (by about 40%). Recent warming trends are thought to have nearly doubled the size of burned areas in Canadian boreal forests (Starfield & Chapin, 1996). Model studies of boreal forest areas in northern Alberta (Hartley & Marshall. 1997) also suggest that there will be a significant increase in burns, even under low fire scenarios. Under continued warming, productivity is likely to increase for several decades but both coniferous and deciduous species will decline below peak values by the mid 2000's.

It is likely that increases in the frequency of fire will affect distributions of wildlife (Kadonaga, 1997). Species that prefer areas of mature forest (*e. g.* Marten) may significantly decline but species that prefer areas of early regrowth may increase (*e. g.* Moose). Because of their ability as opportunistic feeders, Red Fox may also increase in areas where the effects of fire prevent plant succession to the stage of mature community structure (Latour & Maclean, 1997).

4.2.1.5. Effects of Climate Change - Grazers and Browsers

Grazers and browsers typically remove about 10% of the net above ground annual primary production, and there is little evidence that normal summer grazing has any long term effect on the availability of suitable vegetation (Jefferies *et al.*, 1992). Even intensive grazing by caribou occurs only for short periods (2.3.4.4). Temporary densities of up to 50 caribou$\cdot$km^{-2} over areas of several hundred to a few thousand square kilometres are common on calving grounds, but only for a week or so. During the June calving period, selection of plant material seems to be influenced by weather conditions. With an early spring, the Bathurst herd favoured wet graminoid plant communities but under late spring conditions they shifted to lichen-heath communities. Lichen (mostly *Cladonia*) remained the dominant forage with lesser quantities of early-greening graminoids in early spring or moses in late spring (Griffith *et al.*, 2000). Highly nutritive cottongrass becomes available to caribou cows shortly after, rather than before, calving (Gunn & Dragon 1999).

Caribou do not appear to be closely associated with a specific forage base because fecal deposition is not closely coupled to plants (Jeffries *et al.*, 1992), although this may reflect a short term rather than long term relationship (Gunn *et al.*, 2000). By frequently moving as they graze, animals allow vegetation to recover within a few seasons, and vascular plants usually recover well within one growing season. Animals that feed more intensively and in small patches (*e. g.* geese), may migrate annually to new forage areas (Jefferies *et al.*, 1992). Groups of Barren-ground Caribou are also known to migrate to "fresh" summer grounds (unused for several decades or longer), but the reasons for such change are not well understood (Gunn *et al.*, 2000). They are presumed to be in response to limitations in quality food supply (Jefferies *et al.*, 1992; Miller, 1991).

It is not known how climatic change will affect present range use by different herds of caribou or Muskoxen but it has been suggested that snow cover on the range of the Bathurst Caribou may increase by 10 to 20 % (Brotton *et al.*, 1997). With rising temperatures, there will be a tendency for some areas, particularly in southern parts of the Barren-ground Caribou range to shift from forest to grassland conditions (Fig. 20). This will be most noticeable where revegetation occurs at sites of increased fire frequency. Rising temperatures and possible changes in the water balance may also modify tundra vegetation. The effect is most likely to occur as a redistribution of patchiness as some areas of wetland dry out and other areas become wetter as a result of permafrost melting. A shift of range could occur but most herds will probably also make different use of their existing ranges. It is not clear how an earlier loss of snow cover and earlier availability of cottongrass that is so important to post-calving cows, will influence caribou migration and the time of calving.

Similarly, the northward movement of Muskox from the Rae and Richardson rivers area that appears to be associated with early availability of willow leaves (Gunn & Fournier, 2000), could continue to follow the same pattern but over slightly different time frames. Or, there might be a range shift to benefit from newly developing communities of tundra vegetation. A range shift in this herd of Muskoxen will, however, give rise to a specific concern. At present, the herd appears to be isolated from other Muskoxen in the WKSS area.

This herd is known to suffer from a severe infestation of the parasitic lungworm *Umingmakstrongylus pallikuukensis* (Hoberg *et al.*, 1995). This particular parasite has not been reported from other herds of Muskoxen in the WKSS area. The molluscan slug *Deroceras reticulatum* acts as an intermediate host and the parasite is thought to be ingested with forage and cycled back into the environment from fecal material. Hoberg *et al.* (1995) have suggested that this parasite may be a Pleistocene relict that has persisted only in the area now ranged by the Kugluktuk herd, or which was carried as a residual by Muskoxen from the Bluenose Lake area as they recolonized their previous range. Any further shift in the range of this herd, that increases the likelihood of overlap or mixing with other mainland herds, could have a devastating effect on Muskox recovery throughout the WKSS area and beyond. However, if this particular parasite is a Pleistocene relict and it only occurs in the herd near Kugluktuk, there is hope to believe that the herd would not naturally spread it further as a result of climatic warming. The mid-Holocene warming that lasted more than 1500 years provided conditions which were warmer than present, and at least as warm as may be expected from the effects of greenhouse gas warming over the next 50 years. If the herd remained isolated during the mid-Holocene warming, natural isolation may persist.

Population cycles in many species of animals (*e. g.* lemmings and Snowshoe Hare) appear to be linked, at least to some extent, to the availability of food and in particular to plant availability (Section 2.3.4.3). Population dispersals (*e. g.* Lynx) may also be linked to areas that do not share the same cycle. For both caribou and Muskoxen, winter grazing (thus general condition or survival) has the potential to be of even greater influence on population size than predator control. Winter grazing by caribou may also have a greater impact on vegetation than summer grazing, and lichen "pastures" can take 20 to 40 years or more to recover from intensive use (Henry & Gunn, 1991). Lichen woodlands may reflect the effects of both winter browsing and summer fire (Henry & Gunn, 1991; Johnson, 1983). Increased fire frequency near the tree line (Section 4.2.1.4) is probable in response to climate warming and this may influence sites of the annual rut along the tree line (Gunn & Dragon, 2000). No significant shift of the tree line or rutting activity is anticipated.

Browsing removes woody shoots on deciduous plants and this causes compensatory growth (Section 2.3.4.4). In the process, carbohydrates are used to create more tissue but leaves remain largely unprotected by plant toxins (secondary metabolites formed from carbohydrates (Bryant & Reichardt, 1992)). Vegetation switching in the summer diet allows browsed plants (mostly deciduous) to recover and to create more carbohydrates, due to their high rates of photosynthesis. Severe defoliation by insects does not reduce shoot numbers and thus carbohydrates can be converted into plant toxins (as a deterrent and to decrease food value of the leaves (Bryant & Reichardt, 1992)). Many plants have developed an evolutionary response to browsing. For example, taiga willow and birch have greater plant chemical defence against browsing hare than tundra willow and birch (Bryant & Reichardt, 1992). There are, therefore, close relationships between plants and animals which are particular to different climatic conditions within the WKSS area. If climate change occurs slowly, these plant and animal systems should adjust easily to the change. If changes are rapid, major problems could occur. For example, taiga browsers (with greater tolerance of plant toxins) could replace tundra browsers, leaving less plant material to support some tundra species (Bryant & Reichardt, 1992).

In addition to the quantity and quality of winter food, its access and availability for both caribou and Muskoxen appears to be particularly sensitive to climatic conditions (Section 2.3.4.4.). Myneni *et al.* (1997) have noted vegetation response to warming in areas west of Bathurst Inlet (1981-1991 satellite data), and this is corroborated by local observations of residents from both Kugluktuk and Bathurst Inlet (Thorpe & Kadlun, 2000; Section 4.2.3.4). Caribou travel on hard surfaces with minimal snow cover but the energetic cost of walking on crusted snow increases dramatically (DRR., 1996). Lower water levels would be less energy-demanding for caribou at river and lake crossing but changing ice conditions could have considerable influence on safe crossing of lake ice and sea ice, particularly at Bathurst inlet and between Victoria Island and the Kent peninsula (NPCTT., 1996; NPC., 1997, Thorpe & Kadlun, 2000). Freezing rain or heavy snow can present a major problem for Muskoxen that have a limited ability to dig through such cover (Barr, 1991). When coastal waters were ice-free, catastrophic losses were recorded in the east Greenland Muskox herd (during 1938 and 1939, 1953 and 1954) and also on Melville and Bathurst islands (1973-74). High Arctic die-offs also occurred in the mid-1990's (Gunn, 1998). The ability of caribou, Muskox and Snowshoe Hare to outrun predators is also very dependent on surface conditions (Section 2.3.4.5).

In northern ecosystems, there are many points in the scales of both time and space where animal populations are particularly vulnerable to stress. Populations with high rates of reproduction and rapid growth are most capable of sustaining high rates of predation but have large nutritional needs. Where vegetation provides lower levels of nutrition, animals have lower rates of reproduction and growth, and survive by minimizing exposure to predation. Although general models of population response to stress are simplistic and ignore many of the complexities of natural systems, they can reflect a range of naturally occurring survival strategies. For example and with regard to grazing (Ferguson, 1996), if some form of stress is widespread but largely unaffected by population density (*i. e.* a density-independent stress such as increased snowfall or summer drought), chances of survival increase if a large population is widely dispersed. Somewhere, under the least unfavourable conditions, there will be survival. On the other hand, under density-dependent control (*e. g.* a limited food supply) populations may be able to survive best as very small groups where the effects of grazing are within the reduced but sustainable yield of habitat. Somewhat comparable strategies for survival may have been used by Aboriginal people, as well (Section 2.4). It is not known to what extent either "strategy" may have been significant but it is certain that herds of caribou and Muskoxen have survived past climatic extremes and isolation. They successfully recolonized large areas of northern Canada after glacial retreat (Section 2.2.2.7, (Barr, 1989; 1991; Hall, 1989; Urquart, 1981)).

4.2.1.6. Effects of Climate Change - Freshwater Species

Based on studies in boreal lakes, longer ice-free periods, higher evaporation rates and increased water residence times, and increasing nutrient concentrations and productivity appear to be most evident in relatively small and shallow lakes (Schindler, 1997; Schindler *et al*., 1990). Reduced runoff and lower water levels (Section 2.2.1, Spence, 2000; Spence *et al*., 2000) could be extremely detrimental to biological communities in deltas and associated perched lakes (Schindler, 1997). Lake alkalinities are likely to rise with climate warming (Schindler, 1997) and permafrost melt may contribute to nutrient additions (Evans, 2001). During the growing season, concentrations of nutrients such as DOC, P and Si are likely to decline as a result of increased biological activity and demand (including primary productivity). The combined effects of a longer ice-free season, an increase in thermocline depth and an increase in epilimnion temperature will act together to greatly increase degree-day values and the length of the growing season in the aquatic environment (Schindler, 1997). In turn, this will influence rates of hatching and development, reduce lifespans and change species distributions. Distributions of fish, amphibians, aquatic insects, and plants may respond to climate warming by northward range extension (where barriers do not limit species migration and colonization). Species displacement by more competitive forms may also occur (Regier & Meisner, 1991).

Major community species shifts are possible at all trophic levels (Schindler, 1997). Several forms of microscopic plants are sensitive to changes in both water quality and temperature. The remains of diatoms (composed of silica) which accumulate in the bottom sediments of lakes and ponds can provide particularly detailed records of environmental change. Evidence of past changes in both boreal (Pienitz & Smol, 1993; Pienitz *et al.*, 1995) and high Arctic environments is well established (Douglas *et al*., 1994). However, at higher levels in the food web, the extent of change is more difficult to assess (and to attempt prediction) because of the significance of site-specific conditions, and the extent to which connectedness is maintained among and between areas of critical habitat. For example and because of reduced precipitation or increased evaporation, spawning sites could be lost without tributary access for migratory species such as Arctic Char (Section 2.3.3, (Sly, 1995)).

The extent to which cold-water species in large lakes would be affected by anticipated climate warming is uncertain (Melville, 1997). Recent studies at Toolik Lake (Alaskan Arctic) indicate that, over a 16 year period, there has been a 3º C rise in the July epilimnion temperature (McDonald *et al.*, 1996). Because of this warming and based on bioenergetic models, y-o-y Lake Trout need 8 to 10 times more food to sustain their development. But because the lake is nutrient limited, like almost all high latitude lakes, there is little evidence of increased primary production. Typically, y-o-y Lake Trout remain in littoral habitat where protection from predation is least, but where temperatures are highest and the need for food greatest. It is likely that many of the y-o-y Lake Trout from this habitat no longer survive their first winter and, therefore, warming without increased nutrient supply could greatly reduce Lake Trout populations (McDonald *et al.*, 1996).

4.2.2. Long Range Transport of Atmospheric Pollutants (LRTAP)

4.2.2.1. Processes Affecting Received UV-B Radiation

Ozone in the atmosphere is present both at great height (high level) and close to the ground (low level). It is produced naturally as a result of photo-oxidation, particularly in the stratosphere (15 to 50 km above the Earth's surface). Emissions from combustion sources increase the amount of low level ozone. Near the ground, ozone acts as a pollutant and can negatively affect both plant and animal health. At high levels in the atmosphere, however, ozone forms a filter, shielding the Earth's surface from harmful components of solar radiation (Section 3.3.3.2, (EC., 1991)).

Atmospheric circulation redistributes pollutant gaseous and fine particulate emissions, globally. By means of both vertical and horizontal movements, air-masses are progressively move poleward on both sides of the equator and then back towards the equator. Several ozone-depleting gases (mostly man-made and from regions of mid and low latitude) are carried to higher latitudes, and a number of persistent chlorinated and other halogenated compounds are of particular concern. These include CFCs 11, 12, and 113 (lifetimes about 75 to 110 years), carbon tetrachloride (lifetime about 67 years), methyl chloroform (lifetime about 8 years), and halon 1301 (lifetime 110 years). Nitrous oxides (from combustion and fertilizer sources) can also destroy ozone but usually break down within the troposphere and before being carried up into the stratosphere (EC., 1991).

In the stratosphere and in the presence of sunlight, chlorine (from CFCs and other man-made chemicals) undergoes a catalytic reaction with ozone, to form oxygen and chlorine monoxide. The chlorine monoxide repeatedly disassociates and chlorine continues to split many more molecules of ozone. The natural formation of high level ozone and its depletion (particularly by pollutants) occur simultaneously but, because of the quantity of ozone-depleting gases and their long lifetimes, rates of depletion can exceed formation. Ozone depletion in the stratosphere is seasonal and it is most severe at high latitudes (EC., 1991).

During each northern or southern winter, cold and relatively dense polar air masses tend to separate from the rest of the global circulation, forming what is known as a polar vortex (Alt, 1983; EC., 1991). The Arctic vortex is less coherent than the Antarctic vortex. This is largely because of the greater influence of land mass relief on atmospheric circulation in the northern hemisphere. Received solar radiation declines greatly in polar regions with the advance of each winter period and ice crystals form in the stratosphere as temperatures drop to very low levels (Section 4.2.1.1). With the loss of sunlight during winter, photo-chemical processes cease and ozone-depletion declines to a minimum. At the same time, chlorine and other halogens become attached to the ice particles in the stratosphere. This process results in a seasonal concentration of ozone-depleting substances over each pole. It is exacerbated by any condition that increases the formation of polar stratospheric clouds. With increasing sunlight during the spring, photochemical reactions increase in the stratosphere and the cycle of ozone depletion begins again. Rates of depletion are most rapid in spring. Because the Arctic vortex has been less stable than the Antarctic vortex, ozone depletion over the south pole has been 4 to 5 times more severe than over the north pole. Over regions north of latitude 50^{o} N and between 1978 and 1987, concentrations of high level ozone decreased by about 2.5%. Between the late 1970's and early 1990's ozone-depletion over the Arctic increased to about 10% (IASC., 1995). Depletion increased to about 40% during the 1996-1997 period (Hansen & Chipperfield, 1998).

Recent studies have raised additional concern, particularly about feedback mechanisms in the atmosphere (Shindell *et al.*, 1999; Walker, 2000). Tropospheric warming appears to cause the position of the Arctic vortex to move north and to form a more stable feature, less influenced by planetary relief (Shindell *et al*., 1999). Warming at the Earth's surface also intensifies tropical heating and may raise additional water vapour into the stratosphere (Broecker, 1996). Together, increased moisture and a more stable vortex would tend to increase the development of polar stratospheric clouds. Nitric acid is a natural constituent of stratospheric chemistry. It reacts with chlorine to form chlorine nitrate that, in turn, reduces the amount of chlorine available for ozone-depletion. With more moisture, stratospheric ice particles could increase in size and if sufficiently large they would fall under their own weight (stratospheric precipitation). Ice particles removed from the stratosphere would also remove nitric acid, and this might make more chlorine available and further increase ozone depletion (Walker, 2000). Northward movement and greater stabilization of the Arctic vortex might therefore intensify stratospheric ozone-depletion, creating similar conditions in both polar regions.

Ozone depletion is not permanent and natural regeneration will eventually replace lost ozone. However, there will be a lag time of several decades between reduction of pollutant emissions and exceedence of their atmospheric lifetimes, and increasing quantities of newly formed stratospheric ozone (UNEP., 1989).

Solar UV is received as short (C), medium (B) and long wave (A) radiation. The UV-C is potentially lethal but high level ozone absorbs almost all of it. UV-B (280 to 320 nm) is less severe in its effects but more of it penetrates the ozone layer. UV-B represents about 1% of the total received radiation (Vincent & Pienitz, 1996). Much of the UV-A passes through the ozone layer but this radiation is relatively harmless. Depletion of stratospheric ozone is therefore likely to increase the quantity of UV-B received at the Earth's surface. The extent of further increase is uncertain (Walker, 2000). However, recent models simulating changes in stratospheric ozone depletion and the effects of greenhouse gas emissions provide an estimate of increases in the amount of UV-B radiation that may be received during springtime, between 60º and 90º N (Taalas *et al.*, 2000). Based on these simulations, UV-B dosage will increase by about 90% from the period 1979-1992 to 2010-2020. The corresponding (northern) hemispheric dose will increase by about 14% over the same period but by only 2% from 1979-1992 to 2040-2050, indicating the longer term effect of emission control (Taalas *et al.*, 2000).

4.2.2.2. Effects of Increasing Amounts of Received UV-B Radiation

Increased dosage of UV-B radiation (as a result of ozone depletion) may give rise to a wide range of health related problems in both plants and animals. These include: sunburn, cataracts, skin cancer, dysfunction of the immune system, growth impairment, and loss of fecundity (EC., 1991). Humans produce melanin, and many species of invertebrates, algae and fish taken from high latitude and polar waters have mycosporine-like amino acids that absorb UV-B (Karentz *et al*., 1991; Leavitt *et al.*, 1997). The extent to which photosynthesis in plant communities may be affected by increased UV-B radiation in the WKSS area is not known, nor is the extent to which some plant species may be more susceptible to damaging effects than others. However, there is considerable potential for harm in terrestrial (Oechel & Vourlitis, 1994) and aquatic ecosystems (Rampino & Etkins, 1990; Smith, 1989; 1990; Smith & Baker, 1979; Smith *et al*., 1992).

In some recent years, more than 50 % of the high level ozone layer has been lost in the Antarctic during the spring, and this has been associated with a significant increase in UV-B penetration of the atmosphere. In clear water (fresh and marine), UV-B can penetrate deeply into the photic zone and studies on marine algae show that photosynthesis may decrease by 6 to 12% (Ryan, 1992). About 10% of received UV-B can penetrate 2 m of ice and studies indicate that the photosynthesis of ice algae may decrease by 5%. Pigmentation in plants and animals absorbs UV-B but the extent of this protection is not known.

Dissolved organic carbon (DOC) is a surrogate for the brownish water colour associated with dissolved organic matter that provides an important protective screen for UV-B radiation (Leavitt *et al*., 1997; Pienitz & Vincent, 2000; Pienitz *et al.*, 1999; Schindler *et al*., 1996). In lakes, the protective effect is greatest below the tree line. It decreases above the tree line where concentrations of DOC in water are usually less than about 5 $mg \cdot l^{-1}$ (Section 2.2.4). The depth to which photosynthesis can occur is limited by the penetration of sunlight in water. Because of increasing water clarity above the tree line, photosynthetic depth increases from about 1.5 m in the boreal forest (500 km below the tree line), to about 5 m at the tree line. It is more than 10 m, 500 km above the tree line (based on data from northern lakes, mostly in Quebec (Vincent & Pienitz, 1996)). Likewise and with declining concentrations of DOC, water is increasingly transparent to UV-B radiation. UV-B penetration depths increase from less than 10 cm (500 km below tree line) to nearly 150 cm (500 km above the tree line). In northern lakes, small phytoplankton and benthic algae are important sources of primary productivity and studies on cyanobacteria have shown them to be very sensitive to changes in UV-B, particularly at low temperature (Vincent & Pienitz, 1996).

Changes in lake and river DOC may respond to variations in the UV dose received by vegetation but during the past 10,000 years or so, climate (temperature) has been by far the most important influence on DOC (Pienitz & Vincent, 2000). This effect is most dramatic in the sediment record from lakes at the tree line (near Lac de Gras), where interpretations show that DOC increased from average values of about 1.8 $mg \cdot l^{-1}$ before the mid-Holocene warming, to about 5.8 $mg \cdot l^{-1}$ during this warming, and have averaged about 1.4 $mg\ l^{-1}$ from about 3,000 BP to the present. The advance of Black Spruce forest during the mid-Holocene warming contributed much to the DOC increase. Maximum values dropped from about 7 $mg\ DOC \cdot l^{-1}$ to about 1 $mg\ DOC \cdot l^{-1}$ at the tree line from slightly before 3,000 BP to the present, and reflect a return to dwarf and shrub vegetation (Pienitz & Vincent, 2000). The variations in DOC are equivalent to changes in UV exposure over two orders of magnitude. They are much greater than expected from the actual variation in received UV radiation that is occurring as a result of ozone depletion (Pienitz & Vincent, 2000). Leavitt *et al.*, (1997) studied lakes in the Canadian Rockies between 51º N and 53º 30’ N. From sediment data, they were able to demonstrate that the depth of UV-B penetration increased dramatically between 1850 and 1900. This increase was associated with changes in DOC rather than received radiation. The DOC variations (1850-1900) coincide with drought at lower elevations and cooling near the tree line. Because DOC is at low concentrations, many lakes from the tree line northward are extremely sensitive to the effects of changing DOC on penetration of UV-B (Leavitt *et al.*, 1997)

Solar radiation is not constant. Emitted UV radiation varies (Mitton, 1977) and it may be several decades before regulation and control of emissions of ozone depleting gases allow recovery of the stratospheric ozone layer to be well established. For the next several decades, potential exists for decreased production at the base of the freshwater food web above the tree line. This would be due to further increases in UV-B, and reduced DOC if increased evaporation exceeds precipitation (Section 2.2.4). Likewise and although the extent of effect is uncertain, increasing cataract and skin cancer (in humans and other animals) and reduced photosynthetic efficiency (in terrestrial and aquatic plants) may be anticipated (EC., 1991; Oechel & Vourlitis, 1994; Vincent & Pienitz, 1996).

4.2.3. LRTAP, Organic, Metal and Radionuclide Contaminants

4.2.3.1. LRTAP - Persistent Organic Contaminants and Effects

Organic contaminants in the WKSS area include pesticides and other persistent substances (Section 3.3.3.2), and Table 12 provides a list of those that are of most concern in the Canadian Arctic. The most common pesticides include DDT and its degradation products (DDD and DDE), dieldrin, heptachlor epoxide, chlordane, toxaphene (a mixture of PCCs), and HCH (Gregor, 1990; Gregor & Gummer, 1989). Other persistent substances include chlorobenzenes, PAHs, PCBs, PCDDs and PCDFs (EC., 1991).

DDT is now used primarily for malarial control (outside North America). Chlordane is used in termite control and as a broad spectrum insecticide. HCB is used as a fungicide to treat seeds and as an industrial chemical. Toxaphene has been used as an insecticide on cotton, cereal grains and some fruits and vegetables (Tesar, 2000). Total HCH includes γ-HCH (Lindane) and is still used as a pesticide in North America and Europe, and HCH isomers (especially α-HCH) are prominent in seawater (Muir & Norstrom, 2000). PCBs are still widely used as heat exchange fluids in heavy electrical equipment (including in North America) and there are residuals from earlier usage as additives in print, paint and plastics. PCBs continue to be released into the environment as a result of poor waste management, recycling and reclaiming practices (Muir & Norstrom, 2000; Tesar, 2000).

Some of the lowest loadings of persistent organic contaminants in North America occur in the western Canadian Arctic (Swyripa *et al*., 1994). Concentrations of persistent organic contaminants are low throughout most of the WKSS area but their spatial distributions and temporal trends are are not well defined. Based on sediment data from Great Slave Lake and Lake Ontario, northern contaminant levels are about two hundred times less than in the Great Lakes region of southern Canada (Mudroch *et al*., 1992).

There are many sites where small quantities of waste materials may contain contaminants (particularly along the shores of the Coronation Gulf), and there are few larger point sources of persistent contaminants such as municipal and industrial wastes, military wastes from DEW-line sites (on Victoria Island), and disposal in the Coronation Gulf (NPCTT., 1996; NPC., 1997). Releases and loadings from tributary sources are thought to be small. For most contaminants found in biota from this region, there are no major sources within several thousands of kilometres (EC., 1991). A large part of the contaminant burden in fish and wildlife found in the WKSS area has been, and continues to be, contributed by the long range transport of atmospheric pollutants

(LRTAP). These pollutants disperse into aquatic and terrestrial ecosystems by various transfer mechanisms (Fig,. 21).

Most persistent organic contaminants carried in the air are transferred to the Earth's surface attached to dust particles, and attached or dissolved in rain, snow and ice particles (and as cold condensates). Direct transfer by absorption also occurs (Jensen *et al.*, 1997; Macdonald *et al.*, 2000; Muir *et al.*, 1999b). Some portion of these contaminants is retained in the terrestrial environment and enters the terrestrial food chain, but relatively high concentrations of contaminants are associated with melt and runoff (Freitas *et al.*, 1997). These are carried into rivers and lakes where a further portion enters the aquatic food web, but only a small amount becomes associated with bottom sediments (Paterson *et al.*, 1998). Although many physical processes in lakes affect contaminant transfer and availability, studies on northern lakes indicate that lake size has little effect on concentrations of ΣPCBs in water or fish (Paterson *et al.*, 1998). For the most part, Arctic and sub-Arctic lakes act as a conduit rather than a sink for persistent organic contaminants (Freitas *et al.*, 1997).

Airborne contaminants may reach the sea surface directly or by runoff and erosion from the land. Numerous transfers continue to move persistent organic pollutants through different parts of the Arctic and sub-Arctic ecosystem (Freitas *et al.*, 1997; Jensen *et al.*, 1997). In this multistep process, seasonal revolatilization is indicated by elevated levels of organic contaminants in summer air (Barrie *et al.*, 1997). Burial of contaminants in Arctic ocean sediment is limited by the very low concentration of suspended particulate material. Many chemicals remain in suspension (in dissolved phase). Because of the effectiveness of global atmospheric and oceanic circulatory systems there is no absolute resting place for persistent contaminants. Rather, they become ever more dispersed. However, in practical terms and apart from volatilization, there are few mechanisms available to remove contaminants once they do become buried in deep lakes or Arctic ocean sediments. Concentrations of HCH in Canadian Arctic waters seems to be related to the combined effects of outgasing of HCH isomers (particularly α-HCH) and the extent of polar ice cover (Muir & Norstrom, 2000).

Most persistent organic contaminants that continue to transfer between different living and non-living components of the environment slowly degrade, as a result of physiochemical and biochemical processes (usually to less toxic forms). These changes may require considerable time. In the WKSS area, many of these organic contaminants are also likely to be persistent for 50 years or more (Tesar, 2000).

Persistent organic contaminants have a wide range of physicochemical characteristics. These greatly affect how contaminants are transported in the environment, and the effects of various transfer mechanisms on them (Jensen *et al.*, 1997; Macdonald *et al.*, 2000; Muir *et al.*, 1996, 1999b). Figure 22 illustrates some of the characteristics. For example, in a warm atmosphere (at 20º C), napthene, HCB and HCH are mostly present in gaseous form whereas DDT and benzo *a* pyrene remain in particulate form (left-hand panel). At much lower temperatures (and relative to γ−HCH), several contaminants including α-HCH, pyrene, toxaphene, dieldrin and endosulphan partition more strongly than others to the liquid phase (centre panel). Physicochemical properties also influence how effectively contaminants can be scavenged from the atmosphere by precipitation of rain and snow (right-hand panel). Snow scavenging is thought to be one of the most important mechanisms for transferring organic contaminants to the Arctic terrestrial ecosystem (Hoff *et al.*, 1999). Snow is generally a much more effective scavenger than rain (Gregor, 1990; Gregor *et al.*, 1996) and the transfer of DDT, c-chlordane, dieldrin and toxaphene by this means, can be many tens to hundreds of times greater than for γ HCH. Snow sampling provides a good indication of potential contaminant loading to the Arctic but few contaminants exhibit a simple pattern of seasonal deposition (Strachan *et al.*, 1997).

Air mass and wind direction records indicate that the WKSS area lies under the influence of Arctic air for most of the year. But there are significant incursions of Pacific air over the northern half of the area, particularly during summer (Section 2.2.1). In addition, incursions of warm continental air may also cover the southern part of the area during summer. Further, distributions of persistent organic contaminants within parts of the Mackenzie River system may not reflect conditions that otherwise appear to influence the rest of the WKSS area. This is because much of the headwater drainage of the Mackenzie River system lies in the Rocky Mountains. These mountains lie under an air mass trajectory regime very different from that which directly affects the WKSS area. The Athabasca River, for example, rises from the Columbia icefield where Pacific and Asian air masses have an annual frequency of about 68% and North American continental air about 32% (Donald *et al.*, 1999). However, during the May-July period (when precipitation is highest and atmospheric pesticide concentrations are greatest), the North American air mass (which may draw from as far south as Mexico) is dominant for 54% of the time (Donald *et al.*, 1999).

Weather event back-casting and models of atmospheric circulation (Pudykiewicz & Dastoor, 1996), and identity of dry-fall and "finger-printing" of contaminants, strongly imply atmospheric transport from distant sources in North America, Europe and Asia. Because of atmospheric processes, some contaminant loadings tend to be event-related, particularly with snowfall. Some loading are also specifically related to the occurrence of Arctic haze (Anon., 1990; Pfirman *et al.*, 1994; Wadleigh, 1996). This haze is concentrated in the lowest 5 km of the atmosphere and reaches maximum development during February and March (Muir *et al*., 1992) but it was not reported prior to the 1950's (Lockhart *et al*., 1992). Brown snow in the Keewatin district, for example, is thought to comprise loess from western China and soot from coal combustion in China and Russia (Gregor & Gummer, 1989; Welch, *et al*., 1991). Atmospheric transport of ΣDDT and PCBs may include sources as far away as Mexico and Central America. Loadings of PCBs are greatest from dry fall (Barrie *et al*., 1992). Long range atmospheric transport is also a source of PCDDs and PCDFs.

The composition of PAHs in snow is typical of emissions from combustion in mid-latitudes of the northern hemisphere. Increasing concentrations of PAHs in the upper layers of soil, snow and lake sediment from northern Canada follow global trends (Gregor *et al*., 1994). In rivers, it is very noticeable that concentrations of PAHs are closely associated with the availability of particulate organic matter. Where the quantity of this material is small, concentrations of PAH tend to be highest (Jefferies *et al*., 1994). For example, concentrations of suspended organic matter in the Burnside, Thelon, Ellice and Coppermine rivers (Fig. 7) were 0.93, 1.3, 8.4 and 26.4 $mg \cdot L^{-1}$, respectively; and concentrations of PAHs in this material were about 750, 350, 100, and 50 $ng \cdot g^{-1}$ dry weight in these same rivers (August 1993 data (Jefferies *et al*., 1994)). In the Mackenzie River, seasonal concentrations of PAHs also increase in association with suspended sediments between May and September (Jeffries *et al.*, 1997).

Sediment samples from Great Slave Lake suggest that there are multiple sources of PAHs to this lake and that loadings have increased significantly since the 1960's (Evans *et al.*, 1996). Sources include long range atmospheric transport, local inputs (*e. g.* Hay River) and inputs from the Peace-Athabasca drainage basin (Mudroch *et al*., 1992). In the Slave River, PAHs are associated with both natural oil seeps and manmade sources (tar sands and other industrial activities). Of 16 PAHs generally present in industrial wastewaters and known or suspected to be carcinogenic most were present in the Slave River at at very low concentrations at or near detection limit (McCarthy *et al.*, 1997a). Pyrene, benzo *a* pyrene, fluorene, fluoranthene and benzo *ghi* perylene were associated with suspended sediments and did exceed LEL but not SEL (Ontario). Based on *Daphnia magna* (zooplankton) and *Hyalella azteca* (amphipod) tests, PAHs in the Slave River are not thought to adversely affect biota (McCarthy *et al*., 1997a). A wide range of persistent organic contaminants are present in the lower Slave River (including chlorinated phenolics, dioxins and furans that are likely from distant upstream pulp and paper mills) but with very low concentrations, at or near analytical detection limits (Evans *et al*., 1996; McCarthy *et al.*, 1997a). PAHs are the dominant form of contaminant in Great Slave Lake and probably over much of the WKSS area, and the greatest concentrations of chlorinated organic compounds are present as PCBs (Evans & Headley, 1993; Evans *et al.*, 1996).

Ocean water quality between Victoria Island and the mainland (Section 2.2.4) may be influenced by low concentrations of contaminants from the Mackenzie River system. River loadings from northern Russia are another potential source of contaminants (Jensen *et al.*, 1997). This is because of eastward circulation in the stable polar mixed layer of the Arctic Ocean, that has low density and residence times of up to 20 years (Barrie *et al.*, 1992). In Arctic marine waters, particulate concentrations are very low and contaminant scavenging and settlement to the sea floor is minimal. Both seasonal volatilization that causes contaminants to pass from the sea to the atmosphere and ice-rejection (cryoconcentration) may act as "contaminant pumps". Together, these processes contribute to a systematic build up of contaminants in the Arctic environment. Concentrations of HCH are associated with latitude. Elevated concentrations have been found in many northern freshwaters (Bidleman *et al.*, 1994a; 1994b; Freitas *et al.*, 1997; Mackay *et al.*, 1994).

Contaminant loadings and their levels in non-living components of the environment are only "part of the picture". The other part relates to what happens to them in Arctic and sub-Arctic food chains that are characterized by slow-growing and long-lived species and by a human population that exists as the top predator, and is still dependent on local fish and wildlife for a significant part of its food requirement.

Animals, throughout the food web, have excretory processes that can remove many types of contaminants. However, persistent organic contaminants occur at increasing concentrations at higher levels in the food web as a result of bioaccumulation (EC., 1991; Hargrave *et al.*, 1996). Most tend to accumulate to higher concentrations in fat and some body organs (particularly the liver). Persistent organic contaminants in muscle tissue are generally at lower concentrations. Recent contaminant concentrations generally associated with fish and wildlife in the WKSS area are summarized in Fig. 23. This figure illustrates the effects of accumulation in Arctic marine biota (Section 2.3.2) and freshwater biota (Section 2.3.3), and biomagnification through successive trophic levels of the food web. Persistent organic contaminants that concentrate strongly in fatty tissues, such as ΣDDT and ΣPCBs, show the highest degree of bioaccumulation in food chains (Kidd *et al.*, 1998).

In Fig. 23, panel A records relationships between concentrations of PCB-135 and trophic level and panel B records relationships between toxaphene and trophic level. The upper and lower panels are generally comparable but based on significantly different data sets and means of interpretation.

Trophic levels in the upper panel, have been derived from observation. Although information is not sufficient to allow direct comparison among trends in freshwater and terrestrial ecosystems (Sections 2.3.2, 2.3.3 and 2.3.4), general similarities exist (EC., 1991; Jensen *et al.*, 1997; Wong, 1985). Equivalent PCB concentrations in phytoplankton at the base of aquatic food webs are generally less than 1 $ng \cdot g^{-1}$, as are those in terrestrial lichens (WKSS area). Caribou graze on vegetation, much as zooplankton graze on phytoplankton, and tend to have PCB concentrations similar to those at the second trophic level. Wolves (which prey on caribou) and Lake Trout (which feed on amphipods and may also feed on other fish) have PCB concentrations which place them at or slightly above the third trophic level.

In the lower panel, $\delta^{15}N$ represents parts per thousand difference from atmospheric standard, and tissue $^{15}N/^{14}N$ is an effective means of characterizing trophic levels, that increase at each trophic transfer (Atwell *et al.*, 1998). Values of $\delta^{15}N$ are more effective as a means of characterizing the trophic level of a group than an individual (Atwell *et al.*, 1998). Concentrations increase with each trophic level in the food web. Variations about the trend line are most likely related to differences in the lengths of individual food chains (including differences in diet) which can be both site and species specific (Anon., 1994; Evans *et al.*, 1996; Kidd *et al.*, 1998). It may possible for concentrations of suspended sediment to influence the availability of some organic contaminants (including PAHs). For example, toxaphene is higher in fish from the East Arm of Great Slave Lake, where the concentrations of suspended sediment are lowest. The East Arm is also likely to be least influenced by input from the Slave River, although it is thought to be one of the larger sources of contaminant input to the lake (Evans *et al.*, 1999).

In the WKSS area, terrestrial species (Table 13) carry lower body burdens of ΣDDT and ΣPCBs than most aquatic and avian species (Table 14), and this reflects shorter food chains and lower trophic levels and a general lack of contaminant contribution from distant wintering grounds. However, Table 13 also demonstrates that many contaminants become increasingly concentrated in fatty tissue in both grazers (caribou) and predators (wolves).

Some migratory birds (*e. g.* Oldsquaw, Pintail, Semipalmated Plover and Water Pipit) carry elevated body burdens of contaminants (*e. g.* ΣDDT and PCBs) from their wintering grounds (Table 14). A similar relationship has been reported in Herring and Mew gulls, and Caspian and Black terns from Great Slave Lake (Weyland, *et al.*, 2000). However, concentrations of persistent organic contaminants in the eggs of Willow Ptarmigan from coastal areas of the western Arctic were mostly below analytical detection limits (Wakelyn *et al.*, 1999). Data presented in Table 15 show that contaminant levels in browsing and grazing birds are minimal. Levels increase dramatically in most water birds and the highest contaminant levels occur in fish-eaters that are also at a higher trophic level. When birds fall prey to other species, their contaminant concentrations are added to those of existing regional sources (Table 14). This additive effect is particularly noticeable in top raptor species (*e. g.* Peregrine Falcons, an endangered species (EC., 1991; Shank & Poole, 1994)) that migrate and carry elevated body burdens from their wintering grounds (Johnstone *et al*., 1994; 1996).

In general, contaminant levels in avian omnivores are greater than terrestrial omnivores (Tables 14 and 15). In some Mink, however, concentrations of PCBs, dioxins and furans may be relatively high. The reasons for this are not entirely clear (Deh Cho First Nations, 1999). The diet of Mink includes fish and small mammals (*e. g.* Snowshoe Hares and Northern Red-backed Voles) that are mostly at a lower trophic level than the fish (Poole *et al*., 1997; 1998). A wide range of persistent organic contaminants were detected in wild Mink from the lower Slave River, the East Arm and outlet of Great Slave Lake, and the lower Liard and lower Mackenzie rivers. In Mink liver samples, the highest group means were 9.5 ng ΣDDT$\cdot g^{-1}$ and 73.1 ng ΣPCB$\cdot g^{-1}$. Concentrations of ΣDDT, ΣPCB, ΣChlordane and Dieldrin declined on northerly and westerly gradients. Mink are known to be very sensitive to contaminants. Generally, the contaminant levels were one to two orders of magnitude lower than observed to cause reproductive impairment, reduced kit survival or lethality in adults (Poole *et al*., 1997; 1998). In Beaver and Muskrat that have a largely vegetarian diet, concentrations of most contaminants (both organic contaminants and heavy metals) are very low (Kennedy *et al*., 1999).

Concentrations of contaminants in fish (Table 14) reflect trophic position and differences in diet and, to some extent, condition, especially fat content (Muir *et al*., 1997). Contaminant concentrations are strongly influenced by trophic position and generally decline: Burbot > Lake Trout > Inconnu > Walleye > Whitefish. Data in Table 16, emphasize the significance of DDT, PCB and toxaphene contaminants, and to a lesser extent HCB, in both Walleye and Burbot. Because tissue materials are different (Walleye muscle and Burbot liver) the left- and right-hand panels are not directly comparable. But each panel shows that similar contaminant trends exist in both species in the Slave River. The levels of DDT, PCB, toxaphene, and HCB were higher in the fish from the Slave River than in fish from the two lakes but otherwise trends were similar, whether or not the fish came from a common drainage. These data indicate, strongly, the role of long range atmospheric transport as a major contributor of many contaminants to the WKSS area. Fish do not bioconcentrate PAHs and concentrations of total PAH in several species from different location in the WKSS area show relatively little variation (Table 17).

With the exception of toxaphene, most western Arctic marine and freshwater fishes contain levels of organochlorine contaminants that are lower, often by more than ten times, than levels in marine and freshwater fishes from southern Canada (EC., 1991; Norstrom & Muir, 1988). Elevated concentrations of HCH and toxaphene have been reported in Pacific Herring and Arctic Cod. In much of the Arctic, levels of toxaphene are higher than PCBs in fish (EC., 1991; Norstrom & Muir, 1988). The effects of toxaphene (and many other persistent organic contaminants) on fish and wildlife are not well understood. Toxaphene concentrates in fatty tissues and is not released back into the body unless an animal is nutritionally stressed and fat reserves are remobilized as an energy source. Experimental studies in fish suggest that this process could lead to lethal effects under starvation and changes in fertility and egg viability (Delorme *et al.*, 1999).

Chlordane and PCBs account for about 80% of the organochlorine present in the fatty tissue of marine mammals (Norstrom *et al*., 1988). Concentrations of PCBs in Beluga Whales are nearly ten times greater than in Ringed Seals, and Beluga Whales from the western Arctic tend to have higher levels than those from the eastern Arctic. However, concentrations are still two to three times less than those of Beluga Whales from the Gulf of St. Lawrence (Muir *et al.*, 1990). Concentrations of about 5,000 $ng{\cdot}g^{-1}$ for PCBs, 3,500 $ng{\cdot}g^{-1}$ DDT and 6,000 $ng{\cdot}g^{-1}$ have been reported in Beluga Whale blubber in the western Canadian Arctic (Muir *et al*., 1996; 1999a; 1999b).

There are geographic and temporal differences in the trends of concentrations of persistent organic contaminants in the Arctic. Concentrations of both chlordane and PCBs increased by about 50% in Beaufort Sea Beluga Whales between 1983 and 1994. Concentrations of ΣDDT were similar in 1972 and 1994 (but declined from 1972 to 1983, and then increased). Concentrations of toxaphene decreased by about 25% between 1983 and 1984 (Muir *et al.*, 1999a; 1999b). These variations probably reflect the combination of direct loadings of contaminants to the Beaufort Sea area and indirect loadings from more distant sources in the Mackenzie River drainage.

Concentrations of ΣHCH are highest in Polar Bears and seals in the Canadian Arctic, and are coincident with levels in ocean water (Muir & Norstrom, 2000). There has been no change in ΣHCH concentrations in seals from the mid 1980's to mid 1990's. In Polar Bears from the Amundsen Gulf -Beaufort Sea, west Viscount Melville Sound, and Queen Maud Gulf-Larsen Strait areas, recent concentrations of ΣPCB ranged between about 4,600 and 8,600 $ng{\cdot}g^{-1}$, Σchlordane between about 1,500 and 2,100 $ng{\cdot}g^{-1}$, DDE between 52 and 112 $ng{\cdot}g^{-1}$ and dieldrin between 85 and 147 $ng{\cdot}g^{-1}$ (Muir *et al.*, 1999a; 1999b). Concentrations of ΣPCBs are lower in seals from the

Canadian Arctic than in the Greenland, Scandinavian and Russian Arctic, and this may reflect differences in diet (Muir *et al.*, 2000). Small pelagic fish (*e. g.* Arctic Cod) form much of the diet of seals in the Canadian Arctic but piscivorous fish, at a higher trophic level (*e. g. Gadus* spp.), likely comprise more of the diet of seals elsewhere in the Arctic (Muir *et al.*, 2000). Concentrations of ΣPCBs increased in Polar Bears from the Eastern Canadian Arctic between the 1970's and 1980's but are now in decline (Muir & Norstrom, 2000).

Because Ringed Seals are near the top of the marine food web and accumulate contaminants over several years, they can be useful indicators of ecosystem health. Concentrations of many contaminants are lower in female than male seals because lactation has the effect of lowering contaminant residues (Stern *et al.*, 1999). Long term records of DDT and PCBs in Canadian Arctic wildlife (including Ringed Seals) began in the late 1960's (EC., 1991), and periodic sampling of biota indicates that levels of ΣPCB have generally declined by half since the early 1970's. Concentrations of ΣPCBs in seals from Holman declined by more than two-thirds between 1972 and 1991. Most declines occurred before 1981. Since then, a further but slight reduction has occurred in the less chlorinated congeners (Stern *et al.*, 1999). The decline in concentrations of ΣDDT has been more continuous (Muir *et al.*, 1999a; 1999b). Across the Canadian Arctic, concentrations of ΣDDT in seals are generally less now than two decades ago. Concentrations of many other persistent organic contaminants are slowly falling and levels of α-HCH have declined since the 1980's (possibly related to the phase out of technical-HCH in India (Bidleman *et al.*, 1996). Extremely low concentrations of PCDDs and PCDFs have been reported from fish and wildlife in the western Arctic (Anon., 1994; Herbert *et al.*, 1996). Concentrations of PCBs and some other persistent organic contaminants may, however, continue to increase in lake sediments, at least for a few more years. Concentrations of similar contaminants in lakes from more southerly regions of Canada have begun to decline as the contaminants are released through the process of volatilization (Gregor *et al.*, 1994). Because of the colder climate, this process is slower in northern regions. Thus, there is a lag between declines noted in more temperate areas and those expected to occur in the WKSS area.

Other factors also influence the residual period of contaminants in both terrestrial and freshwater environments (Donald *et al.*, 1999). Persistent organic contaminants are retained in deposits of glacial snow and ice that form headwaters tributary to the Mackenzie River system, at high elevations in the Rocky Mountains, where transfer from the atmosphere may have been ”enriched” by cold condensation (Donald *et al.*, 1999). In mid latitudes and near sites of use, many pesticides peaked in the 1960's and almost all have declined since the 1970's. In headwater glaciers, ΣDDT, dieldrin, ΣChlordane all reached maximum concentrations and flux values during the 1980's, a decade after they were banned in North America. Both Lindane and ΣChlordane had peaks in 1960 and 1980, and the flux of HCB reached a maximum in the 1990's. The concentrations of this contaminant may still be rising (Donald *et al.*, 1999). Continued use outside North America could delay declines in contaminant concentrations of glacial ice in headwater areas. Regional climatic changes, perhaps external to the WKSS area, will also regulate storage (in glacial ice) and release (as glacial melt water). Pulses of contaminant release into the downstream environment will particularly affect the aquatic ecosystem and could persist for many decades yet to come (Donald *et al.*, 1999).

Outside North America, major production of HCH ceased in China in 1985, in the USSR in 1992, and it has remained in "low-level" use in India (for public health protection). During the past decade, levels of α-HCH have declined rapidly in the atmosphere, particularly as a result of degradation under tropical and temperate climatic conditions. As a result of this loss, α-HCH, at higher latitudes, now represents more of the total global inventory. Contributions from atmospheric transport to higher latitude is thought to be of less importance (Wania, *et al.*, 1999a). However, the net direction of air-sea flux in Arctic waters has reversed. Ocean waters and lakes are now a diffuse source of HCH resulting in further redistribution at low concentrations. This process is controlled by temperature and the relative concentrations of HCH in air and water, in response to Henrys Law constant (Li *et al.*, 1999). The effects of climate can also be seen to have a selective effect on PCBs. As with HCH, only a small amount of the global PCB inventory is thought to be transported to high latitudes but, during this movement, there is a shift towards lighter and more volatile congeners (Wania *et al.*, 1999b)

Based on present knowledge and risk assessments that address a wide range of toxic responses, concentrations of most contaminants are thought to be at levels well below thresholds which affect the health of fish and wildlife. Uncertainties remain with respect to the effects of some classes of contaminants, including those known as endocrine disrupters. These contaminants are thought to have potential for causing a wide range of defects, particularly during the early stages of embryo development. Concentrations of ΣDDT and ΣPCBs in some bird eggs may be high enough to lower reproductive survival, particularly as a result of eggshell thinning (*e. g.* Peregrine Falcons (Johnstone *et al.*, 1994; 1996)). The concentration of ΣPCBs in some Polar Bears may be high enough to interfere with vitamin A and thyroid hormone transport (Norstrom *et al.*, 1999). The effects of toxaphene, at high concentrations, remains uncertain (Delorme *et al.*, 1999). In many top Arctic predators including humans, β-HCH is a major contaminant and both α− and β-HCH are significant endocrine disruptors (For human health see Section 4.3.2; and TDI, Section 8.0).

For the foreseeable future, concentrations of most persistent organic contaminants are not expected to increase much above present values. This depends to a large extent on their control and regulation in many developing countries including Mexico and other countries in South America (Section 5).

4.2.3.2. LRTAP- Mercury and Effects

Mercury occurs in rocks and soils. Both inorganic and organic forms are naturally present, and very small quantities of metallic Hg can occur in both liquid and gaseous phase under most environmental conditions. It is highly mobile in the environment, and is rapidly dispersed in both gaseous and vapour forms. Mercury usually enters the food web in minute quantities. Bioconcentration of Hg is selective and related to food web structures. Microbial processes act to methylate and demethylate Hg. Monomethyl mercury is the most toxic form of the metal. Photochemical processes affect Hg in the troposphere. At high latitudes, Hg concentrations seem to follow trends that are similar to those of ozone. With the onset of polar sunrise and advancement of polar spring, photo-oxidation is thought to convert Hg from gaseous to particulate form. Particulate Hg has a shorter residence time in the atmosphere and concentrations of Hg decline in the air during the April to June period (Schroeder *et al.*, 1997; 1999a; 1999b). High levels of Hg have been reported in snow on the frozen Beaufort Sea, between mid February and early May (Welch *et al.*, 1999a; 1999b). Concentrations of Hg in snow melt also increase with latitude. They are high in the western Arctic between April and June.

Mercury and several other trace metals are naturally present in fossil fuels. Combustion provides an important mechanism for their release, as contaminants, into the environment. In North America, combustion from fossil fuels contributes more than one-third of Hg emissions to the environment (Natan *et al.*, 2000). Even with improved fuel technology, increasing energy demand is unlikely to result in significantly reduced global Hg emissions from this source. On the other hand, regulations and controls are reducing the emissions of Hg from other sources, particularly waste incineration. Most of the electrical power generated in the mid-west United States and in Alberta, is derived from combustion of fossil fuels, particularly coal (Keating *et al.*, 2000). It is likely that emissions from these power plants can be carried directly into the WKSS area during the summer. These emissions also add to the global inventory of atmospheric pollutants. On a percentage basis, global Hg loadings comprise Asia 46%, Western Europe 16%, North America 15%, Eastern Europe and former USSR 13%, and Africa 5% and central and South America nearly 3% (Pirrone *et al.*, 1996). Significant quantities of Hg are also released into the environment as a result of microbial processes and the degradation of organic matter in flooded soils. Newly formed reservoirs and diversions can be a major source of methyl mercury (MeHg) to the aquatic environment and the atmosphere, as in many parts of the Hudson Bay drainage basin (Anon., 1987;

Brouard *et al*., 1990; Jackson, 1987; 1989). Mercury is widespread as a global contaminant.

Global loadings of Hg have generally increased over the past two centuries and during the early 1990's, concentrations in the atmosphere of the northern hemisphere were increasing by about 1.5% annually (Slemr & Langer, 1992). These observations are supported by dated soil, peat, and lake sediment core profiles. The profiles indicate there has been a doubling in such concentrations since the start of the 19th Century (Slemr & Langer, 1992; Lockhart *et al*., 1994). Lockhart *et al.* (1999b) analyzed metal profiles in sediment cores from several northern lakes and determined that Hg (and possibly Pb) increased in relation to the effects of long range transport. Lead, however, often reflects regional rather than global patterns of loading, as seen in Scandinavian data (Renberg *et al.*, 2000). Lockhart *et al.* (1999b) estimated that the flux of Hg increased by about x 0.3 at Lake Belot, x1.5 at Great Bear Lake and by x 3.9 at Ste Therese Lake, since the 1950's. Lockhart *et al*. (2000) confirmed the reliability of the sediment core data. Concentrations of other metals have also increased as a result of human activities in the environment but Hg is most widespread and of greatest concern (Jackson, 1987).

Historically, Hg emissions and deposition in North America are thought to have been greatest when it was widely used for metal extraction in the early mining industry. Pirrone *et al.* (1998) estimated that anthropogenic emissions peaked at about 1,708 $t^{-1} \cdot a^{-1}$ in 1879, that following a decline they peaked again at about 940 $t^{-1} \cdot a^{-1}$ (1920), and that between 1970 and 1989 emissions have been about 325 to 330 $t^{-1} \cdot a^{-1}$. More recent estimates (quoted by Schroeder, 1999a) suggest that most North American emissions might be less than this and that total Global emissions are higher. Due of the mobility of Hg in the environment, lower North American emissions may not, of themselves, significantly benefit the northern environment. Also, because of its high volatility, Hg is easily remobilized from temporary sinks in the environment and re-emissions from old mine sites, waste dumps and other sources are likely to add to current and future emissions for some time Pirrone *et al.* (1998). Total anthropogenic emissions of Hg from developed countries have remained more or less stable over the past decade but emissions from other parts of the world have increased by 2.7 to 4.5% annually. On a global basis, anthropogenic emissions are thought to have peaked in 1989 and may be declining, again, by about 1% per annum (Pirrone *et al.*,1998). Although emissions from some types of sources may decline, emissions from others may increase. It seems probable that global Hg emissions will tend to rise, at least to some extent, over the next several decades. It is unclear, however, whether they will closely follow the projected rise of carbon dioxide from combustion of fossil fuels. If so, that could amount to a near-doubling of the Hg loading from global emissions over the next 50 years.

In general, slow growing animals that are high in the food web, accumulate most Hg. However, there are many exceptions to this and they are mostly related to food selection. Age may or may not be a factor related to body burdens of Hg. Polar Bears, for example, are higher in the food chain than the seals that they feed on but they may have lower body burdens of ΣHg (Atwell *et al.*, 1998). This is thought to be because the bears select for skin and blubber, rather than seal meat. Muscle and organ tissues generally have a higher Hg content than skin and blubber. Selective feeding, however, may also result in increased concentrations of persistent organic contaminants in the Polar Bears, relative to seals.

Measurements indicate that there is an increase of 3 to 5% in $\delta^{15}N$ at each trophic step in the food chain, and many Arctic sea birds at a similar trophic level and with similar $\delta^{15}N$ values have different concentrations of Hg (Atwell *et al.*, 1998). These differences, likely, reflect availability of Hg in their wintering grounds (Section 4.2.3.1). For example, King Eider and Common Eider from Holman have less Hg but more Se in their livers than eiders from the central and eastern Canadian Arctic, and levels of Cd are also lower (Wayland *et al.*, 1999). Since much of the body burden of Hg in birds is also keratin-bound, contaminant levels can be significantly reduced during the process of moulting (Atwell *et al.*, 1998). In the WKSS area, as in other areas of the Canadian Arctic, long range atmospheric transport contributes small but significant quantities of Hg and other metals such as Zn, Cd and Pb to both aquatic and terrestrial ecosystems (Section 3.3.3.2 (EC., 1991; Jackson, 1987)).

Mercury levels can be high in top-predator fish under natural conditions (*e. g.* Lake Trout). No consistent relationship exists between concentrations of Hg in fish and concentrations of Hg in ambient waters or bottom sediments (Johnson, 1987; Lockhart *et al.*, 1999a). In some freshwater systems, where concentrations of Hg in fish are relatively high, there may be a weak relationship between geology or lake characteristics such as water colour (a surrogate for DOC), and Hg in biota. Selenium in the environment may have some influence concentrations of Hg in fish (*e. g.* in fish from the Mackenzie River (Lockhart *et al.*, 1999a; 1999b)). But, Se in fish seems to have little effect on the concentration of Hg in fish.

There is a close relationship between concentrations of Hg in fish tissue and its rate of loading to the environment (Andersson *et al.*, 1991; Anon., 1991; Muir *et al.*, 1986; Slemr & Langer, 1992; Wagemann *et al.*, 1990). This is most evident in top-predator fish (*e. g.* Lake Trout). For example, in the Hudson Bay region, many fish important to the diet of Cree and Inuit (*e. g.* Lake Trout, Walleye, and Northern Pike) had high concentrations of Hg before the impact of hydroelectric development (Perusse, 1990). Mercury concentrations were close to Health and Welfare Canada guidelines for sport fish consumption (0.5μg·g^{-1}) and exceeded those for unlimited consumption (0.2 μg·g^{-1}). Reservoir flooding caused levels of MeHg to increase and, as a result, more fish had Hg levels in excess of the consumption guidelines. However, because of differences in the structure of the food web, concentrations in Lake Whitefish remained, generally, within the guidelines.

A somewhat similar situation may exist in the WKSS area but supporting data are limited. Concentrations of Hg in Northern Pike from both the Hay River and Slave River have been reported to be about 0.3 μg·g^{-1}, and concentrations in both Northern Pike and Walleye from Resolution Bay exceed 0.2 μg.g^{-1}. In this area, to the west of the Slave Delta, the "finger print" of both metal and organic contaminants also appears to be distinct from other parts of the lake (Boucher *et al.*, 1997). Concentrations of Hg in Lake Trout were about 0.3 μg·g^{-1} from Colville Lake and 0.1 μg·g^{-1} from lake Belot. However, concentrations of mercury in Lake Whitefish from Colville Lake were much lower, about 0.02 μg·g^{-1} (Table 18). These data indicate that existing levels of Hg in some country foods are already close to critical levels for unlimited consumption (Muir *et al*., 1994). Concentrations of Hg from the breast muscle of birds indicate that although browsing and grazing birds have only low levels of contamination (generally less than 150 ng·g^{-1} or 0.15 μg·g^{-1}), other types of feeders and especially fish-eating ducks may have much higher levels of Hg contamination (some reaching 1.9 μg·g^{-1}, (Table 15)).

Concentrations of Hg in muscle tissue from Beluga Whales from the western Canadian Arctic (about 1.5 μg·g^{-1}) are a little higher than those from the eastern Canadian Arctic, and seem to reflect natural conditions (Jensen *et al*., 1997). Organic Hg in muscle tissue of both Beluga and seals is mostly in the form of MeHg and this represents about half of the ΣHg in an individual. The toxic effect is therefore less than if all Hg was present as MeHg (Wagemann *et al*., 1999a; 1999b). Concentrations of Hg in surface marine waters tend to be lower in the eastern than the western Canadian Arctic, and may reflect both the influence of regional geology on runoff and differences in atmospheric loadings. At a lower level in the food web, the mean concentration of Hg in Ringed Seals is about 0.4 ug·g^{-1} in both the eastern and western Canadian Arctic (Wagemann *et al*., 1996).

Changes over time strongly imply an increase in global emission, and between 1984 and 1993 to 1994 concentrations of Hg in livers from Beluga Whales increased by about 2-fold (Wagemann *et* *al*., 1996). Elevated levels of mercury in marine mammals are often associated with naturally elevated levels of Se (Kari & Kauranen, 1978; Wagemann *et al*., 1990). In these animals, Se seems to act as a protective mechanism and to reduce potential toxicity to the animals (Anon., 1983; Lockhart *et al*., 1999a; 1999c; Pelletier 1985; 1986; Speyer, 1980; Srikumar & Akessen, 1992; Turner & Swick, 1983; Wren *et al*., 1986). It is thought that demethylation of mercury occurs in the liver. Mercury and Se combine in 1:1 ratio to form insoluble amorphous particles of mercuric selenide and these accumulate as individuals age (Wagemann *et al*., 1999). Mercury present in the brain and spinal chord of Beluga appears to be only in the inert form of mercuric selenide, and not in the toxic form of MeHg (Lockhart *et al*., 1999d). However, the extent to which Se may also protect human consumers, such as Aboriginal hunters, is poorly understood (EC., 1991; Valentine *et al*., 1992).

Mercury is potentially less of a contaminant problem in the terrestrial environment, where food chains are often shorter than in the aquatic environment (*e. g.* lichens - caribou - wolf, Section 2.3). Concentrations of Hg in the livers of Barren-ground Caribou from Inuvik, the Beverly herd, and Cambridge Bay were about 0.5, 0.4 and 0.2 $\mu g \cdot g^{-1}$, respectively (Elkin *et al*., 1996a; 1994), but concentrations in muscle tissue would be expected to be considerably less.

Although present concentrations of Hg in fish and wildlife from the WKSS area are generally within consumption guidelines, concentrations will probably increase and Hg contamination is likely to remain a concern for the foreseeable future, particularly in some freshwater and marine species.

4.2.3.3. LRTAP - Radionuclides and Effects

Geological conditions control most of the naturally occurring radionuclides. In the WKSS area, they are generally present at low concentrations (Section 2.2.2.5). Small quantities of radon gas (^{222}Rn) are released naturally from rocks and soils and, in permafrost areas, local concentrations may increase where melting degrades normally present ice barriers. Radon tends to be of concern in buildings where basements floors are not sealed or where ventilation is poor. Radon is generally of more concern in southern areas of the Canadian Shield than in the Arctic (Van Oostdam *et al*., 1999). Some mining activities have produced local "hot spots" and, locally, elevated levels of ^{226}Ra have been associated with uranium mining and processing (Port Radium and Rayrock (Veska & Eaton, 1991)). Recent studies at Lutselk’e showed evidence of impacts from past uranium mining at nearby Stark Lake, and the presence of low concentrations of Rn in some buildings (Lutsel K’e Environmental Committee *et al*., 1999; Papik *et al*., 1999). Follow-up studies indicated that the background gamma radiation at Lutselk'e averaged about 0.8 m $Sv \cdot a^{-1}$, about twice the global average but well within the range of normal conditions. Radiation hotspots (10 to 100 times greater than community background) were present at the old mine site and required remedial action (because local residents do not enter the mine area, this is considered more an environmental than a health concern). Concentrations of gamma radionuclides (^{137}Cs, ^{226}Ra, ^{232}Th and ^{235}U) were similar at the community water intake, Stark Lake, and Great Slave Lake and well below health concern (Papik *et al.*, 1999). Radiation levels were somewhat above health guidelines in the community hall, indicating a need for remedial action, and the source of this radiation is thought, most likely, to be natural. Concentrations of some metals (Al, Cu, Fe, Sr and U) in a stream near the Stark Lake mine were above environmental guidelines but this, also, may be a natural condition (Lutsel K'e Environmental Committee *et al.*, 1999).

Where there is little evidence of local "radiation hot spots", dispersal by atmospheric transport may be considered the most important anthropogenic influence. Lichens are an effective trap for many atmospheric contaminants, including radionuclides, and provide a major source of these materials at the base of the terrestrial food web. Concentrations of naturally occurring ^{40}K (with a relatively long half-life) are similar in Barren-ground Caribou from Inuvik, Cambridge Bay and Pond Inlet (Baffin Island), and in Moose from southern Manitoba. However, concentrations of ^{134}Cs and ^{137}Cs, that have been derived from atmospheric tests of nuclear devices, increase from west to east across the Arctic. The presence of these isotopes in Canada is largely due to atmospheric transport (Elkin *et al.*, 1994; 1996b; Jensen *et al.*, 1997). During the 1950's and 1960's, Barren-ground Caribou had concentrations of ^{137}Cs at levels 10 to 100 times greater than those in southern beef cattle. Since the moratorium on atmospheric tests in 1963, however, accumulations of radionuclides from long range atmospheric transport have greatly declined in the caribou (Smith *et al.*, 1996). Recent concentrations of ^{137}Cs (half-life about 30 years) in Barren-ground Caribou from Inuvik (2.8 $Bq \cdot kg^{-1}$), Cambridge Bay (20.3 $Bq \cdot kg^{-1}$) and Pond Inlet (36.5 $Bq \cdot kg^{-1}$) are considered low and of no health concern (Elkin *et al.*, 1994; 1996b). The aquatic food chain also provides a significant pathway for human intake of ^{137}Cs (Van Oostdam *et al.*, 1999) and values of up to up to 20 $Bq \cdot kg^{-1}$ have been reported in Arctic fish. Small quantities of ^{134}Cs (less than 0.7 $Bq \cdot kg^{-1}$), with a half-life of about 2 years, may reflect the residual effect of the Chernobyl accident in 1986 (EC., 1991; Elkin *et al.*, 1996b).

4.2.3.4. Climate Change, Atmospheric Pollutants and Environmental Indicators Noted by Aboriginal People

Recent studies have begun to document traditional knowledge in Dene and Nunavut communities. Parlee *et al.* (2000) have reported that elders have extensive knowledge of the Kache Kue, a traditional area of the Dene around the East Arm of Great Slave Lake. The area extends, approximately, from Gordon Lake to Lac de Gras, to Artillery Lake, and to the south of Lutselk'e. Elders have stated that there have been significant shifts in the distributions of some animal species, that some behavioural patterns (including seasonal migrations) have changed, that the populations of some species have changed significantly (not as a result of Dene hunting or trapping), and there have been changes in the quality or condition of some species. In particular, the numbers of White-fronted Geese have declined significantly (and are no longer hunted), and patterns of Barren-ground Caribou migration have changed and there may be fewer caribou using this part of their winter range.

The *Tuktu and Nogak Project* (Thorpe, 1997; 1998; Thorpe & Kadlun, 2000) included the Nunavut communities of Cambridge Bay, Umingmaktok, Bathurst Inlet and Kugluktuk. It has documented evidence of extensive recent environmental change. Snow and ice melt earlier and freeze later in this region, and melting occurs first within the communities. Freeze-up used to be complete by early September but now this may not occur until late October or even early November. Weather is not consistent and conditions are difficult to predict, and it has become more stormy and windy. Ice is thinner and the development of early leads in sea ice may affect caribou crossings. Caribou do not like to climb out of the water onto ice, which is dangerous and difficult for them. Currents make openings unpredictable in parts of Elu and Bathurst inlets. More caribou are thought to be drowning but this may also reflect increased observations by hunters who now travel further with snowmobiles. Sporadic freeze-thaw conditions are increasing and this may affect the availability of vegetation for a variety of browsing and grazing animals. More water is present on the ground surface in spring and the number of Ground Squirrels seems to have declined, coincident with this. The number of plant varieties on Victoria Island has increased, and shrubs are growing larger all over the region, especially willows and alders. Caribou are showing a preference for richer vegetation. They are also seeking shade and some are moving to the coast to keep cool in summer, and to be in areas where insect populations are lower. Caribou are thought to eat mushrooms to maintain body moisture.

Traditional knowledge has also documented major climatic change at Holman, on the west coast of Victoria Island. There, it was normally safe to travel on sea ice by mid October, but now this travel is not safe until the end of October (Thorpe & Kadlun, 2000). There is less snow pack, and the condition of seal pups and Polar Bears has declined (pups have less time to bask and fatten-up on the sea Ice and are less available to the bears).

Further north, elders at Sachs Harbour on Banks Island, have also reported that weather has become much less predictable. The autumn freeze-up may now be up to a month later than usual, and the spring thaw is earlier. The community depends heavily on seals for food, and the multi-year sea ice is smaller and drifts further from the community in summer, taking the seals with it. The winter sea ice is thinner and broken, and more dangerous to travel on. Fall storms have become more frequent and severe (and thunder and lightning have been observed for the first time). Permafrost has been melting during summer, causing large scale shoreline slumping, lake drainage, and damage to buildings. For the first time, Barn Swallows and (American) Robins have been seen on the island, salmon have been caught in nearshore waters, and large numbers of flies and mosquitoes have also appeared (IISD., 2000).

Many of these observations also complement reports of environmental change based on traditional knowledge from the central and eastern Arctic (Sections 2.2.1 and 4.2.1 of this report, and also Section 4.2.3.4 of the first *State of Knowledge Report* (Sly *et al.*, 1999); Arragutainaq *et al*., 1995; McDonald *et al*., 1995; 1997). For example, traditional knowledge from across the Canadian Arctic is consistent with climate records that document warming in the western Canadian Arctic and cooling in the eastern Canadian Arctic. The boundary between these warming and cooling areas passes within Hudson Bay. Across the Arctic, there is greater variability in the weather, sudden changes are more frequent and difficult to predict, and there are indications of change that may relate to the influence of atmospheric pollutants and increases in received UV radiation.

4.2.4. Effects of Mining

This section considers only stress effects that are specific to mining (Section 3.3.3.3). Associated effects (Keith *et al*., 1981) are discussed in relation to exploitation, settlements, transportation. Mining-specific activities are mostly related to exploration, extraction and processing, and closure. The exploratory phase (including staking, survey, and test evaluation) may require clearance of vegetation, use of explosives, test drilling and temporary camps (Clarke, 1973). Just under 3.65 million hectares of the Slave geological province were staked as of March 31, 2001.

All activities create noise and explosives can be particularly disruptive to wildlife. For example, caribou are particularly sensitive to disturbance during calving or summer feeding (Cameron, 1994; Cameron *et al*., 1992; Gunn, 1983), as are waterfowl during their moult or nesting (Bromley, 1998). Effects on animal feeding and behaviour may be less during winter, when they are dispersed

(Section 2.3.4.4). Percussion effects may injure fish and aquatic wildlife at some distance from the source of explosions. On a seasonal basis, percussions may also startle and deflect migrating and staging birds, and exclude the use of habitat for tens of kilometres around (possibly, thousands of square kilometres) (Bromley, 1998). Explosives have been used to crater the ground surface for disposal of wastes and this may cause both short and long term instability in the permafrost surface (also allowing scavenger access (Clarke, 1973)). In addition, blasting is particular cause of concern for the Dogrib who believe that the spirit of the rocks is destroyed by it (Dogrib Renewable Resource Committee & Treaty 11 Council, 1997).

Recent studies of the effects of exploratory diamond drilling through lake ice indicate that most impacts are localized and of short term duration (Wilson, 1999; 2000). The potential effects of contaminant release associated with effluent from this drilling are relatively low but somewhat site-dependent, and may be influenced by both the type of rock that is being drilled and the extent to which under-ice water motion causes dilution and dispersal. Common salt is frequently used when drilling in permafrost to avoid freezing-in. On land, waste saline solutions may locally kill vegetation, degrade water quality, or destabilize the permafrost (van Diepen, 1975). Surface rutting by vehicles may also degrade underlying permafrost, and soil scars can expand and persist for many decades or centuries (Bliss & Peterson, 1992; van Diepen, 1975). Where soils have been bulldozed, vegetative recovery is dependent on the extent to which any part of the original seed bank remains available. Unlike the effects of fire, and even rutting by vehicles, bulldozing also removes most propagules resident in the soil. Without some form of reclamation, plant regrowth can take a very long time (Vavrek *et al.*, 1999).

Dogrib elders suggest that the flagging tape used by prospectors on claim stakes and tied to trees frightens caribou, and has caused the animals to change the trails that they use. The Dogrib are aware of these effects because of their hunting experience. In the past, caribou have been hunted by directing them along a fence constructed of trees, in part by scaring them with flags and ribbons that move in the wind (Zoe *et al*., 1995). In avoiding the flags and ribbons, the caribou were directed towards a place where they could be intercepted and killed. Recent experiments with flutter strips suggest that they could be used as a means of keeping caribou away from selected areas (such as mine tailings) without causing severe startle or other unintended avoidance reactions (Gunn *et al.*, 1998a). In 1995, it was also noted that caribou avoided the ice road to the Lac de Gras mine site in spring. The movements of vehicles, especially semi-trailer traffic, appeared to scare them. The fear of movement is thought to be enhanced in spring when caribou may not see clearly because of snow blindness (Legat & Zoe, 1995). Stress effects vary with location and season but after exploratory activities cease, most residual effects would be expected to be localized.

Mining activities, particularly movements and noise (Gunn, 1983), seem to create more avoidance reactions in animals than the presence of buildings and other structures. Extraction and processing activities include plant construction, operation of heavy equipment, rock removal (underground mining and open pit), disposal of waste rock, and disposal of sludges and tailings. Each mine site is different. Depending on the type of ore and technology used to process it, gas and particulate emissions may affect air quality and and liquid wastes may affect water quality (McNeely *et al*., 1979; Puznicki, 1996). Lichens are particularly sensitive to emissions of sulphur dioxide, SO_2 (van Diepen, 1975). During winter months, ice fogs can occur in low lying areas, such as open pits or natural hollows or valleys, and may retain combustion emissions from power plants and other equipment (van Diepen, 1975). This form of stress is very localized and is of most concern as an employee health issue rather than an environmental impact. Dust from roads, excavations and material piles may be blown around mine sites where it can be another cause of local stress. Coatings of dust on plant leaves reduce photosynthetic ability and may reduce gas exchange through stomata, causing die-back or selective survival in vegetation (such as dwarf shrubs and fewer plant species (Gunn *et al.*, 1998b). Wind blown dust from tailings ponds can also be acidic, and this may be an additional factor influencing plant survival in and around mine sites. At the Lupin Mine site, sand has been used to cap tailings and to inhibit wind erosion and blowing dust, and to encourage the formation of permafrost (Gunn *et al*., 1998b).

Often, a flexible approach is necessary to address changes in mine development, either as a result of unexpected site problems or market requirements. Recently, a number of unexpected issues have been addressed at the Ekati diamond mine site. These have included: sewage disposal into Kodiak Lake and downstream eutrophication, N-enrichment of lakes (thought to be from wind-blown explosives dust and gas), landfill improvements, acid mine waste (generated from biotite schist waste rock), changes to containment of tailings to accommodate revised operations at the mine site, and review of proposed wetland reclamation (ABR Inc., 2000; IEMA., 1999). Originally, the Ekati mine was approved to develop 5 kimberlite pipes (Fox, Koala, Leslie, Misery and Panda). Further assessment of the Leslie pipe has shown it will be uneconomic to develop but BHP has applied for approval to develop 3 additional pipes (Beartooth, Pigeon and Sable (BHP Dia Met., 2000)). This will significantly increase the “footprint” of the mine site and the MVEIRB has recommended the proposal be approved with conditions.

Gas and particulate emissions from stacks are usually controlled by scrubbers, precipitators and filters but, for a few very large mining and processing operations, there may be a significant release. This is because the quantities of emission are so large that, even though control technologies may be highly efficient and retain all but a few percent or less of contaminants, the final release can still be environmentally significant. Recent past operations of gold mines at Yellowknife provide an example of contaminant releases from large mines.

At Yellowknife, both SO_2 and As were released during the process of ore roasting. Large quantities of SO_2 were released from the Con Mine prior to 1970, when the S content of the ore dropped dramatically and roasting was no longer required. However, emissions from the Giant mine continued to 1999. Prior to closure and on a comparative basis, daily emissions of SO_2 from the Giant mine were about the same as the total annual emissions of this gas from the Jackfish Lake power plant (serving most of the Yellowknife area (Anon., 1993)). The long term release of SO_2 contributes to acidification (Anon., 1986; Klohn Leonoff, 1992) of soil and water and it may cause declines in many forms of biota (Campbell & Stokes, 1985; EC., 1991). It may also increase difficulties in breathing, particularly for people suffering from respiratory problems such as asthma (Anon., 1995a; 1995b). Although they were not regulated, emissions of SO_2 at the Giant mine declined somewhat, over the past decade. Prior to mine closure, SO_2 emissions were thought to fluctuate between about 50,000 and 65,000 $kg \cdot d^{-1}$ (Anon., 1993). Emissions varied on a daily or shorter basis. During most of the past decade, long term atmospheric concentrations of SO_2 at Yellowknife met Canadian desirable air quality objectives (annual arithmetic mean maximum concentration 30 $\mu g\ SO_2 \cdot m^{-3} \cdot a^{-1}$) although short term variations did exceed the maximum desirable level (450 $\mu g\ SO_2 \cdot m^{-3} \cdot h^{-1}$). Between 1994 and 1997, exceedence of hourly air quality guidelines decreased by two-thirds (DRWED., 1998). Sulphur dioxide converts rapidly to sulphate in the atmosphere and the highest annual rates of sulphate deposition occur downwind (southeast) and within 0.4 to 1 km of the stack. Depending on wind speed and duration, the effects of SO_2 emissions were found to effect vegetation 3 to 5 km from the Giant mine (Anon., 1993). Southerly winds are frequent during the summer months and, because of this, concentrations of SO_2 tended to be lowest at the downtown monitoring site in Yellowknife, between May and October (DRWED., 1998).

The Giant mine also used a combination of electrostatic precipitation and baghouse filter technologies to remove most of the arsenic (as As_2O_3) produced during the roasting process. Arsenic is toxic and a known carcinogen (Anon., 1995a; 1995b) and, at the Giant mine, the release of As peaked at about 880 $kg \cdot d^{-1}$ in 1958. Since then, improved emission controls reduced this release to about 20 to 30 $kg \cdot d^{-1}$. Except on two occasions (both in 1988, when pollution controls malfunctioned at the Giant mine), concentrations of ΣAs in the air were below the Ontario 24 h air quality limit of 0.3 $\mu g \cdot m^{-3}$ since 1985. There are no national air quality standards for As

(DRWED, 1998; Wilson, 1998). Typically, concentrations of As were a hundred times or more than background levels expected in remote areas (Anon., 1995a; 1995b). The Giant mine closed in 1999 and was sold to Miramar. Ore from both mines is now processed at the Con mine which is also owned by Miramar. The roaster at the Giant mine remains closed and atmospheric emissions of As are no longer a concern (ore treatment at the Con mine uses a different technology).

The geochemistry of mine wastes greatly influences the acidity of mine drainage and leaching of heavy metals. Acidity is strongly related to the amount of S in the rock, and the natural formation of sulphates and sulphuric acid when material is exposed to air and precipitation. Rocks rich in Ca and Mg, however, may act to reduce acidification. Acid potential (AP) is expressed as the quantity of calcium carbonate ($CaCO_3$) required to neutralize 1,000 kg of waste. The net neutralizing potential (NNP) is the balance between AP and the neutralizing potential (NP) of other materials available to neutralize acidification. Mines with wastes having a high negative NNP are likely to produce acid drainage if untreated (Klohn Leonoff, 1992).

For example, waste rock at the Tom mine (Fig. 5) contains about 0.28% S, the AP value (kg $CaCO_3 \cdot t^{-1}$) is -7.0 , the NP is +22.3, giving an NNP of +15.3. At the Lupin mine (Fig. 5), tailings have 3.1 to 3.5% S, AP varies between -99 and -110, NP varies between +7 and +27, and values of NNP range between -72 and -91 (Klohn Leonoff, 1992). Thus, there is much greater probability that acid drainage would develop at Lupin than at Tom if material remained untreated. Exposed tailings at the Lupin Mine have been generating acid drainage for several years. Most tailings associated with diamond mining activities are not expected to have a high S content and are unlikely to be strongly acidic. The neutralizing capacity of exposed bedrock material generally decreases in the following order: limestones and marble > siltstones and dolomites > shales and basic igneous rock > and granitic rocks (which have very little neutralizing capacity (Anon., 1986)). Glaciomarine and glaciolacustrine sediments generally have more neutralizing capacity than glaciofluvial deposits (including eskers and kames), or thin soils over non-calcareous bedrock (Sections 2.2.2.2 to 2.2.2.7, and 2.2.4 to 2.2.6).

The solubility of several metals (*e. g.* As, Cd, Cu, Fe, Ni, Pb and Zn) is influenced by acidity, and hence the rate at which they may be dissolved or leached from solid phase materials (Klohn Leonoff, 1992). Concentrations of some heavy metals from mine effluents may reduce growth of aquatic plants, or bioaccumulate in fish and wildlife (affecting their health or that of predators at higher levels in the food web). To avoid detrimental environmental effects, Canadian regulations require that mine effluents have a pH of 6 or more (*i. e.* may be only slightly acidic), that total suspended solids should be no more than 25 $mg \cdot l^{-1}$, and that concentrations of As, Cu, Ni, Pb and

Zn should not exceed 0.5, 0.3, 0.5, 0.2 and 0.5 $mg \cdot l^{-1}$, respectively. To limit the effects of alkalinity, there is generally a requirement that effluent values should not exceed pH 9.5 in the NWT and Nunavut (Wilson, 1998).

There are many different technologies for extracting metals from rocks and, depending on site-specific conditions, different mines extracting the same metal may use different processes. Over time, also, new techniques may replace old techniques (*e. g.* changes in the use of Hg in gold extraction). Many mines use ponds to provide temporary or permanent storage of tailings and milling wastes. They also discharge process chemicals into the ponds, and complex chemical "soups" are often present in tailings ponds. For example, cyanide is used extensively in gold extraction (Anon., 1987). Chemical additions are made to precipitate specific compounds and to stabilize the discharge so that it complies with effluent standards. A three stage process has been used at the Giant mine where effluent quality was significantly improved after 1981 (Acres Internat., 1993). In this process, cyanide and most metals were removed by addition of lime and chlorine, ferric sulphate was then added to react with As, and in the third stage precipitates were treated with flocculants to produced settled material. Treated water was held in polishing ponds for about two weeks before release (Mudroch *et al*., 1989). Natural degradation of many chemical compounds also takes place in tailings ponds and is particularly influenced by temperature, mixing of the water, bacteria, and UV radiation. High concentrations of several metals, including As, Cd, Cr, Cu, Hg, Ni, Pb and Zn can be associated with sediments below the discharge or overflow of some tailings ponds, such as those in the Kam Lake and Back Bay areas of Yellowknife (Jackson, 1996; 1998; Jackson *et al*., 1996). Although the quality of outlet waters may periodically exceed water quality guidelines, the good quality of most receiving waters usually has been maintained by dilution and dispersal. In the Back Bay area, benthic biota have been used to trace the influence of contamination more than 1 km from source (Baker Creek) but contaminant levels in fish (unless locally territorial) reflect regional rather than local conditions. The fish rarely exceed guidelines for occasional consumption (Jackson, 1996; 1998; Jackson *et al*., 1996).

Mining in northern Canada has often relied heavily on natural degradation for the treatment of effluents. However, in many areas, ice formation limits the effect of wind on water mixing. Low temperatures slow reaction rates, including bacterially induced biochemical reactions, and they also limit the degradation by UV radiation. To have the same effectiveness as tailings ponds in southern Canada, tailings ponds in the WKSS area often need to be larger (van Diepen, 1975). In addition, there are now concerns that estimates of evaporation, previously used in the design of tailings ponds, have significantly underestimated rates of actual evaporation. This problem could be exacerbated with climate warming (Gibson *et al.*, 1998; Spence 1995; Spence *et al.*, 2000). Where they are not large enough, tailings ponds may not meet the intended quality of outlet water. For example, in Yellowknife Bay during the 1970's and before major improvements in process technology at the Giant mine, cyanide was reported in water (van Diepen, 1975) and high levels of several heavy metals were reported in sediments and fish (Jackson, 1996; 1998; Jackson *et al.*, 1996)). Presumably, much of this contamination was derived from the effluents of tailings ponds in which treatment processes and retainment were not consistently effective.

Mining in the WKSS area is usually a short term activity, and many operations frequently last for only a few years or at most a few decades (DEMPR., 1995). Today, there are strict requirements governing mining activities and the closure of mines, and they are intended to minimize the long term impacts on the environment and to avoid potential future negative effects on the health of people, plants and animals. For most mines, minimum remediation means that buildings and equipment must be removed, hazardous wastes must be removed or treated, shafts and vents must be filled and sealed, and slopes should be stabilized by regrading. Where necessary, tailings, waste rock and mill wastes are also required to be neutralized or sealed to avoid acidification and leaching. Frequently this is achieved by capping with clay to reduce exposure to the air (and oxidation), or by placement of tailings under water where rates of oxidation are extremely slow (Kalin, 1987).

Long term surface tailings storage in the north is made more complicated by the presence of permafrost. While freezing of tailings can enhance the long term stability of material and greatly reduce metal leaching, there are many uncertainties (Kalin, 1987). These include potential future effects of climate warming, heat-generation as a result of chemical oxidation and bacterial processes within the tailings, and stability of the cap and vegetative cover over the tailings and its ability to withstand site-specific erosional effects. Disposal of tailings into natural ponds or lakes (Acres Internat., 1993) offers long term security and stability (after biological recovery from the placement of tailings). However, the security of dams and dykes used to maintain water levels in artificial impoundments may be of concern, particularly if they depend on the use of frozen structures (Kalin, 1987).

The Discovery mine (Fig. 5) in the Yellowknife River drainage provides an example of Hg contamination from an old mine site (Lafontaine, 1994). The Discovery mine operated between 1945 and 1969 and used cyanidization, Zn-dust precipitation and Hg-amalgamation, to extract gold. Most of the Hg was recovered and recycled in the treatment process. Surface mine wastes were subject to acid leaching and drained into Giauque Lake. Concentrations of As, Cd, Cu, Ni, Se and Zn in muscle and liver tissue samples from fish in Giauque Lake and downstream Thistlethwaite Lake are not significantly different from regional values. Levels of ΣHg in many fish samples from Giauque Lake, however, remain well above consumption guidelines. They may have been high enough to affect body condition of some fish. Fish in downstream Thistlethwaite Lake are less contaminated but the decline in concentrations between 1977 and 1992 is less evident than in Giauque Lake. Tissue concentrations (1977) of ΣHg are some of the highest known in freshwater fish (Lake Trout 12.3 $\mu g \cdot g^{-1}$, Northern Pike 4.8 $\mu g \cdot g^{-1}$, Longnose Sucker 3.15 $\mu g \cdot g^{-1}$, Lake Whitefish 1.6 $\mu g \cdot g^{-1}$ and Round Whitefish 2.64 $\mu g \cdot g^{-1}$). Concentrations of ΣHg dropped by about 23% between 1997 and 1992 in Thistlethwaite Lake and remain well above consumption guidelines for each of these species (Lafontaine, 1994). Contamination by both As and Hg is also of concern, because both metals may occur in biologically-mediated methyl-forms that are highly mobile. Much of the As present in lake sediments may be present in dissolved form, in pore water, and available for methylation by sulphate-reducing bacteria (Bright *et al.*, 1996).

There are also a small number of uranium mines whose past operations would not have met current requirements and that were never properly closed down. There are many concerns for the health of people previously employed in these mines (Mathias & Morrison, 1985; Veska & Eaton, 1991). The Rayrock Mine, which was worked for only two years and abandoned in 1959, is such an example. Fill and and sealing should have been applied on closure to shafts and vents to reduce leakage of naturally produced radioactive radon gas (^{222}Rn). Tailings wastes should have been neutralized to avoid leaching of U and other heavy metals from old tailings (EBA Engineering, 1992). Although site restoration was recently completed, contamination occurred in surrounding soils, surface water and groundwater. After the mine opened, radiation levels between 20 and 100 times greater than nearby “background” controls were recorded (Mathias & Morrison, 1985; Veska & Eaton, 1991). Radiation and toxic heavy metals releases continued after the site was abandoned.

A recent study of the abandoned Rayrock Mine (Fig. 5), undertaken by Dogrib Treaty 11, serves as an example of concerns about uranium mining. It demonstrates a general need for long term environmental monitoring of mine sites (Dogrib Renewable Resource Committee & Treaty 11 Council, 1997). Prior to opening of the mine which was close to an important traditional trail, people used to gather in the area for trapping, collecting plants and berries, fishing, and hunting waterfowl and Moose. After the mine was established, the people began to notice a number of changes. Trees died off around the mine and, where effluents were discharged into lakes and rivers, fish became unhealthy. Where chemicals spilled directly onto the land, they killed much of the vegetation. Moose and Snowshoe Hare could not be eaten because they had sores and the meat was discoloured. The fur from fur bearing animals developed a bad odour and fell out.

Early effects on human health became obvious when people working in uranium mines developed lesions on their hands and elsewhere on their bodies, and chemicals burned personal clothing worn on the job. However, known hazards associated with the operation of a uranium mine were not explained to the Dogrib (Dogrib Renewable Resource Committee & Treaty 11 Council, 1997). Further, if mine personnel noticed Dene people collecting berries in areas where contamination had just occurred or using dead contaminated trees for firewood to cook food, the Dene should have told that it was bad to continue these practices (even if they were not working in the mine). Items taken from dumps around the mine may also have been contaminated by radiation or chemicals. The full significance of radiation sickness only became known when one Dogrib worker was sent south for skin tests and was told that other workers were dying. Some people developed tremors. Today the area is considered dangerous and people are afraid to go there. Because lung tissue is exposed directly to radiation when radon gas is inhaled, particular concerns exist with regard to other abandoned uranium mines (such as Eldorado and Echo Bay mines).

Largely as a result of bad practices in the past (both a lack of concern for the environment and for local people), there are many old abandoned mines in the WKSS area. Most of these were gold mines and many pose a number of local but long lasting environmental problems such as metal contamination (Acres Internat., 1993; van Diepen, 1975). Most recently, serious environmental problems have occurred following closure of the Colomac and Giant mines. Low commodity prices were a significant factor in closure, and subsequent problems reflect the importance of fulfilling abandonment commitments made during the licensing process. At the Colomac site, DIAND has been pumping the tailings pond to avoid overflow, during the spring melt. At the Giant site, a plume is leaching downward from some 260,000 tons of As that are stored within the mine. The plume is being controlled by pumping the leachate back into the mine. It is not known if the plume is increasing in size, but given the proximity to Great Slave Lake the plume is of major concern. Remedial work is also required at the Giant mine to deal with elevated levels of As in surface materials throughout the site.

It may reasonable to expect that problems with the 50 year old Giant mine would not happen under current management regimes. However, the Colomac mine was approved in the late 1980’s. Both problems are due to bankruptcy of Royal Oak Mines prior to proper abandonment. Governments have been left to clean up the mess at a cost of hundreds of millions of dollars to taxpayers. Looking to the future, it will be important to minimize the accrual of any more such liabilities.

4.2.5. Effects of Harvest and Exploitation

Northern populations of Aboriginal Dene and Inuit are continuing to grow and they probably now exceed their historical maximum (in the WKSS area). In total, the number of people now on the range of the Bathurst caribou is more than 23,500 (Lloyd, 1996). Country foods remain an extremely important part of Aboriginal diet and economy (Sections 2.4.2, 3.2 and 3.3.3.4), and although Inuit make some use of marine species, Dene, Inuit and Métis make most use of freshwater fish and caribou. All Aboriginal groups have been living in settlements for several years, but hunting activities continue to follow migrating groups of caribou, and traditional hunting and trapping areas are still in extensive use (Section 3.2 (Hall, 1989)). Non-Aboriginal people also make use of Barren-ground Caribou. Mine development has required some changes in hunting and trapping but, fortunately, there has been no large scale shift away from traditional areas.

In the past, heavy hunting of Muskoxen for hides and meat, particularly between about 1860 and 1915, resulted in the near extirpation of mainland herds (Barr, 1989; 1991; 1995). By 1917, when protective legislation was finally introduced, it is likely that fewer than 500 animals remained on the mainland (Section 2.3.4.4). Recovery of Muskoxen has been very slow. Killing was prohibited in 1924, and the Thelon Game Sanctuary (Fig. 1) was established in 1927, in part to reduce poaching (Barr, 1989; 1991). However, it was not until after the 1960's that mainland populations began to show significant recovery. More than one factor may have delayed recovery. Small numbers were probably taken for Aboriginal food and wolves may have kept calf survival to a minimum, but poor weather (particularly freezing rain) may also have been a significant factor (Barr, 1989; 1991). Also, it is not known to what extent any part of the original herd may have remained a discrete component or if herd dispersal (as numerous small groups of animals) may have slowed recovery (Barr, 1989; 1991). For example, should the Kugluktuk Muskox population be considered a separate herd (Gunn & Fournier, 2000; Hoberg *et al.*, 1995) and managed as such? It is clear, however, that this species is very sensitive to hunting pressure, particularly, if coincident with poor weather and strong predation. Some populations may also suffer from debilitating parasitic infections. Infection by parasitic lungworm appears to be a particular problem in the Kugluktuk Muskoxen (Sections 2.3.4.6, 4.2.1.5, 4.3.1 (Gunn & Fournier 2000; Hoberg *et al.*, 1995)). A limited hunt for Muskoxen in the WKSS area has been recently approved (estimated to be about 3% of the WKSS area herd (D'Hont, 1998)). Population data are limited, and it is not clear to what extent hunting and other environmental influences will affect the future stability and recovery of these animals (Graf & Shank, 1989).

Barren-ground Caribou (Section 2.3.4.4) are a major source of food for both Dene and Inuit people. Traditionally, most hunting was done with dog-teams (Hall, 1989) and, as a result, caribou were taken as food both for the Aboriginal communities and for the dogs that provided transport. With the influx of traders into the region, demand for caribou meat greatly increased and hunting pressure rose dramatically. It seems probable that the use of firearms almost exterminated the Dolphin and Union Caribou herd which was thought to have migrated annually across Coronation Gulf (Hall, 1989; Urquart, 1981). Snowmobiles and off-road vehicles have replaced dogs over the past two to three decades and large quantities of dog food are no longer required (Johnson & Ruttan, 1993). Aboriginal populations have been increasing but greater use of non-traditional foods has helped to keep country food requirements within manageable levels (Section 3.2). Changing lifestyles are now being associated with a decline in subsistence hunting but recreational hunting is increasing. In the future, therefore, the net effect of these changes together with a rising appreciation of the nutritional value of traditional foods (Section 4.3.1), may well result in a greater demand for caribou meat.

Caribou management (their use as source of food) is applied to specific herds, that are each defined by use of distinct calving grounds (Gunn & Fournier, 2000). However, range shifts and mixing of herds make them difficult to manage without good population and distribution information, and only recently, has the Queen Maud Gulf herd (most recently named the Ahiak herd (Case, 2001)) been recognized as a distinct mainland herd (Gunn & Fournier, 2000). The winter ranges of caribou from the Queen Maud Gulf, Beverly and Bathurst herds are known to overlap east of Clinton-Colden Lake (where taiga and tundra merge) and into northern Saskatchewan. Relations between the Queen Maud Gulf herd and other herds to the east are not well defined (Gunn & Dragon, 1998; Gunn & Fournier, 2000). During the 1980's and 1990's, caribou from the Dolphin and Union herd (Victoria Island) began returning to their traditional winter grounds on the Kent peninsula where they may be replacing animals from the Queen Maud Gulf herd (Gunn & Fournier, 2000). Shifting patterns of range use have required readjustment of herd management, such as the quota for commercial harvest by Cambridge Bay and Bathurst Inlet hunters (NPCTT., 1996: NPC., 1997). This demonstrates the need for both flexibility and cooperation among community interests, on a continuing basis.

At present, the Bathurst Caribou herd appears to be stable, with a population of about 350,000 (Lloyd, 1996) and there are about 1,400 to 3,000 wolves on the same range (Bromley & Buckland, 1995; Case *et al*., 1996). Based on these estimates and if each wolf consumes 15 or more caribou a year (Case *et al*., 1996), the total wolf kill could range between about 21,000 and 45,000 per year. Year-to-year variations are probably considerable but, in general, it is estimated that wolves cause about 25% of annual calf mortality and about 10% of annual adult mortality in the herd. Hunting is approved for an additional 16,000 caribou. The combined annual predator take and harvest is therefore at least 11%, and it could be more than 17% with a large wolf population. At present, there is no indication that the herd can not sustain this level of harvest (Case *et al*., 1996). However, as with Muskoxen, it is known that caribou populations are sensitive to range conditions (Barr, 1989; 1991; Case *et al*., 1996). It is possible that dramatic declines could occur as a result of a combination of reduced availability of food supplies due to poor weather conditions, and continued predator and hunting pressures. Weather could also affect survival as a result of conditions particularly favourable for insect harassment (including nostril and warble flies, blackflies and mosquitoes), or parasitic infection.

Wolf populations also fluctuate in response to the availability of caribou and the survival of wolf pups may be very low, especially at dens near the tree line where the travel distance to sites of summer kill can exceed a female's ability to return with food (Section 2.3.4.5, (Bromley & Buckland, 1995)). Over the long term and although wolf predation may fluctuate considerably, both wolves and caribou persist and this relationship has existed for a very long time (Johnson & Ruttan, 1993), at least since the last glaciation (9,000 to 10,000 years ago). In poor years, many wolves die of starvation (especially pups) and in good years their numbers increase. Historical records indicate that population of the Bathurst Caribou herd has varied considerably (from about 220,000 in 1982 to more than 400,000 in 1984). Some of the variation could be due to migration into and out of adjacent herds (Case *et al*., 1996; Hall, 1989) although there is no clear evidence of this (Gunn, 1998). If range conditions were to decline or significant out-migration was to occur, difficulties might arise, both for the caribou and wolf, and for people dependent on them. To be effective, natural predation needs to be quantified and resource use management requires reliable and timely information about herd size and condition.

Wolf management is an important issue. During the early and mid-1990's, about 700 wolf pelts were taken, annually, throughout all of the NWT and Nunavut, at what was probably a sustainable level. More recently, Saskatchewan hunters (from Fond du Lac and Black Lake) are reported to have used snowmobiles to take 460 wolf pelts in one winter from the Rennie Lake region, south east of Lutselk'e (Mitchell, 1999). Some of the wolves travel considerable distances (Walton *et al.*, 1999) and probably came from dens in the north of the WKSS area. The wolves would have followed the Barren-ground Caribou south to their winter range, thus making them more accessible to Saskatchewan hunters. A hunt of this size might have considerable impact on wolf packs over a very large area, particularly if it severely damaged family structures (Meech, 1995) by selecting for the leaders and most virile members of the wolf population. A take of 460 wolves would represent 15 to 30 % of the total estimated wolf population on the range of the Barren-ground Caribou (Bromley & Buckland, 1995; Case *et al*., 1996). This hunt raises numerous concerns about the need for cooperative management, links between wolf and caribou management, and hunting practices (hunting from snowmobiles, for example, is not allowed in the Yukon).

Information about the populations of other species hunted or trapped (in the WKSS area) is very limited but relative to the Bathurst Caribou herd, only small numbers of Woodland Caribou and Moose, and few bears are taken by hunters (Chalmers, 1990; D'Hont, 1998). These harvests are thought to be within sustainable levels but, again, the impacts of harvesting remain uncertain

(Bromley, 1998). A more consolidated approach to Grizzly Bear management may be required because recent studies have shown that high rates of exchange exist between members of what were previously thought to be distinct groups (defined as the North Slave, Bathurst Inlet and Kugluktuk populations). Both males and females exchange between groups (McLoughlin *et al.*, 1999). During years of plenty, trapping appears to be generally below levels that may stress target populations but, near the bottom of some population cycles (when prey are scarce), several species may be additionally stressed by this activity. The extent of this problem is not clear but Lynx are thought to be one of the more severely affected species (Poole, 1989; 1992). Juvenile Lynx are thought to be particularly exposed to capture during periodic dispersals. The use of refugia has been suggested as a means of providing improved survival at times of prey scarcity (Poole, 1997). The extent to which hunting and trapping of Wolverines, foxes and other fur-bearers affects population dynamics in the WKSS area also remains uncertain (D'Hont, 1998; Gunn, 1998). In the Kitikmeot sub-region, the take of Wolverines (shot and trapped) is heavily weighted towards young males that comprise about 35% of the total take (Mulders, 2000). This compares with 18 to 28% of the total in Alaska, BC and the Yukon, and adds concern to the effects of potential future loss of wilderness refugia as a result of increasing development in the WKSS area.

Because most species of ducks, geese and swans in the WKSS area migrate seasonally and over great distances (Section 2.3.3.3), their harvesting is continental rather than regional. For example, Aboriginal harvests in the western Canadian Arctic take a significant portion of the regional populations of geese and swans (1987 to 1990 data), ranging from 13.3% for Canada Geese, 4.7% for White-fronted Geese, 2.4% for Lesser Snow Geese, to 1.3% for Tundra Swans (Bromley, 1996). Respectively, these harvests represent about 30%, 16%, 19% and 25% of the total continental harvest of the regional populations of these species (Bromley, 1996).

In recognition of the effects of unregulated continent-wide harvest pressures on many species of migratory birds, the *North American Migratory Birds Convention* (1917) established a closed season for hunting from March 10 to September 1, as a conservation measure. As a further step and to protect nesting and breeding birds, large areas of the NWT were set aside as sanctuaries during the 1950's and 1960's (Wagner & Thompson, 1993).

Little thought was given to how the convention would affect northern Aboriginal people who depended on ducks, geese and swans for food (and cultural renewal), particularly since most of these migrants arrived in northern areas after the hunting period closed. Sanctuaries further limited access to the resource. For many years, law-enforcement tolerated subsistence hunting and, in general, Aboriginal treaty rights were upheld. The conflicts between Aboriginal needs and the intent of the convention have been recognized for some time (Wagner & Thompson, 1993), but formal amendment occurred only in 1998. Several complex issues are involved, including social, economic and biological issues, and many biological issues are not yet resolved. For example, northern harvests are selective of both long-lived species (*e. g.* geese, swans and sea-ducks) and short-lived species (*e. g.* ducks of terrestrial and freshwater areas). Non-breeders comprise a significant portion of the spring harvest of many geese, swans and sea-ducks, so the effects of this harvest may be somewhat comparable to that of fall harvest (after breeding). However, the effects of spring hunting on pair associations and breeding success are uncertain. The spring harvest of short-lived ducks, prior to breeding, may have a much greater effect on population dynamics than the fall harvest (Bromley, 1996).

Attempts to open commercial fisheries have been made in many areas of the WKSS area but, in most lakes, neither abundance nor growth rates are capable of sustaining intensive fisheries (Section 2.3.3.2, (McCart & Den Beste, 1979)). Commercial fishing for Lake Whitefish and Lake Trout began in Great Slave Lake in 1945 but, very quickly, it was found that Lake Trout could not support this fishery (Hubert, 1989; Davies *et al*., 1987). By 1956, Lake Trout were virtually extirpated from the main (western) basin and their stocks have not recovered in this part of the lake (Davies *et al*., 1987; Hubert, 1989; McCart & Den Beste, 1979; Yaremchuk, 1986). A similar collapse occurred in the East Arm in 1974 (Davies *et al*., 1987; Hubert, 1989). This resulted in closure of that commercial fishery, as well. The remaining commercial fishery in the main basin depends heavily on Lake Whitefish (with a small by-catch of other species). Small stocks of Lake Trout remained in the East Arm and have slowly rebuilt but there has been a marked decline in the number of large old fish (trophy fish). Lake Trout in the East Arm now support a highly valued recreational fishery and domestic fisheries at Lutselk'e and Reliance (Hubert, 1989; McCart & Den Beste, 1979). Fishing lodges on the East Arm opened in 1938 and 4 lodges cater to more than 1,000 guests, annually. In addition there are 5 outfitters (Davies *et al*., 1987; Hubert, 1989; McCart & Den Beste, 1979). Over the long term, commercial fishing (opened for Lake Whitefish and Lake Trout in 1969) was not found to be viable in Lac la Martre but an important domestic fishery continues there and at other lakes on the Camsell and Lockhart river systems. Commercial fisheries for Arctic Char have been tried at Kugluktuk and Cambridge Bay (Sections 2.3.2.2, 3.3.3.4 (McCart & Den Beste, 1979)). The Arctic Char fishery at Cambridge Bay (1960) was moved to Wellington Bay (also on Victoria Island) in 1961 because of rapid depletion by overfishing. Since 1986, it has been sustained at about 6,000 $kg \cdot a^{-1}$. A more varied domestic fishery continues at Kugluktuk, and in Bathurst Inlet (Ellis, 1962; McCart & Den Beste, 1979; Zoltai *et al*., 1980).

Adult Lake Trout have low natural mortalities, but they are very sensitive to fishing pressures and may not mature until 7 to 14 years or older in Great Slave Lake, and older still in more northern lakes (*e. g.* 10 to 16 years old in Great Bear Lake). In many Arctic and sub-Arctic lakes, Lake

Trout do not spawn annually, egg counts may be low (until several years into adulthood), and larval and juvenile survivorship is also low. With slow replacement, stocks of Lake Trout can collapse rapidly and may take several decades to recover from overfishing. For example, in Great Bear Lake, the catch of Lake Trout declined rapidly from 0.49 $kg \cdot ha^{-1}$ to 0.23 $kg \cdot ha^{-1}$ in the 1970's (as mortality exceeded spawning escapement) (McCart & Den Beste, 1979; Yaremchuk, 1986). Arctic Char grow more quickly and mature earlier, especially stocks that migrate to ocean waters for summer feeding (Baker, 1987; Johnson, 1976; McCart & Best, 1979). They are more capable of sustaining moderate levels of harvest. Landlocked stocks of Arctic Char are more sensitive to overfishing and can support only occasional harvest (McCart & Den Beste, 1979).

Lakes characterized by populations of large old fish have “climax” populations and, just as young trees are suppressed by low light under a closed canopy, young fish are forced to feed around the edge of lakes where predation is heaviest. Where harvest effects are minimal, there is little change in the age structure of Lake Whitefish populations. However, with a greater rate of replacement, this species can be more responsive to fishing pressure than either Lake Trout or Arctic Char (Healey, 1975; 1980; Johnson, 1976). In the Great Slave Lake area and with an average annual mortality of 0.2, the peak biomass of a Lake Whitefish population would be about 7 years old. At an annual mortality of 0.4, the age of peak biomass would be about 3 years, and for a mortality of 0.8 the age would be about 1 to 2 years. Lake Whitefish are thought to be able to support a more intensive fishery than either Arctic Char or Lake Trout (Healey, 1975; 1980).

Based on nutrient levels and the amount of phytoplankton, estimates of long term sustainable fish yield in lakes within the WKSS area are typically less than 0.5 $kg \cdot ha^{-1} \cdot a^{-1}$. However, many northern lakes have been managed primarily for Lake Whitefish and, as a result, the by-catch of Arctic Char and Lake Trout has severely depleted their stocks (McCart & Den Beste, 1979). At various times, fly-in fishing has also depleted stocks in several inland lakes and streams (McCart & Den Beste, 1979). Commercial fishing reached a peak in 1971, with fishing in 25 lakes for a total commercial catch of about 375,000 kg (McCart & Den Beste, 1979). Both economically and environmentally this could not be sustained, despite various attempts to establish periodic fisheries (*e. g.* fishing intensively for one or two years and then leaving the lakes unfished for an additional 4 years). Many of the commercial fisheries have continued as domestic fisheries. In addition to the lodges on the East Arm of Great Slave Lake, there are 43 recreational lodge fisheries in the WKSS area (many around Great Bear Lake and other parts of Great Slave Lake). Management of fisheries requires sensitivity to species composition and awareness of the rapidity with which overfishing can result in collapse of stocks (Hubert, 1989; McCart & Den Beste, 1979).

Fish and wildlife are important resources for resident populations but people who move into an area for temporary employment (*e. g.* mining and mineral exploration) may place large additional demands on Arctic Char, Grayling, Lake Trout, Northern Pike and Walleye. Non-resident hunting could also place heavy demands on Barren-ground Caribou, and populations of ducks and geese. Further, air transportation now provides a ready means of export for fresh and frozen specialty foods to other parts of North America, Europe and Asia. There is potential, if not carefully managed, for some sources of country foods to be rapidly depleted. Aquiculture in the freshwater environment appears to be of limited economic viability (Baker, 1987) but mariculture (*e. g.* blue mussels) might be practical in some coastal areas where there is sufficient planktonic material and a high quality environment.

As with all predator-prey relations, human use of selected species will result in a compensatory response by the species affected, as long as the balance between human demand and resource production is maintained. Over-harvesting occurs when compensatory mechanisms are exceeded, and under-utilisation may occur when regulations are not responsive to changing local conditions or are based on inappropriate information (Johnson & Ruttan, 1993). Unfortunately, in most of the WKSS area, neither the extent of carrying capacities nor the importance of natural predators (*e. g.* wolves) in maintaining ecological stability are adequately understood or known (Barr, 1989; 1991; Bromley, 1998; Bromley & Buckland, 1995; Hall, 1989). Evidence suggests that most problems that have been associated with past exploitation in the region owe their origins to management and commercial practices of non-Aboriginal and non-resident groups (Davies *et al.*, 1987; Hall, 1989). Adherence to good hunting practices is also of particular concern, both in terms of minimizing waste and causing a minimum of disturbance to wildlife (Gunn *et al.*, 1988; Johnson & Ruttan, 1993).

4.2.6. Effects of Settlements

The extent to which settlements in the WKSS area may influence existing ecosystems and the environment is poorly documented and difficult to assess (Section 3.3.3.5). Generally, large communities have greater influence than small communities but population size is not an adequate guide to the extent of effect. Large populations usually require more houses but, also, the more prosperous a community, the larger the houses and the larger the size of each lot. Similarly, the larger each house, generally the more water is consumed on a per capita basis, and the more fuel is used for heating, power, and for vehicles. Thus the use of all kinds of resources (*e. g.* land, water, fuel) often increases at a greater rate than just the increase in human population (reflecting, in addition, a process of changing expectations). The activities of people living in a community are also related to to the age structure of a population, and younger populations tend to exert greater impact on surrounding areas than older populations. Most northern communities are characterized by young populations (Section 3.4 (SC., 1994; Sly, 1995)).

In general terms (Bernard *et al*., 1995; EC., 1991; SC., 1994), the growth of settlement may be expected to result in the following:

- Increasing and permanent conversion of natural landscapes into urban and other developed forms (including: buildings, roads, airstrips, fuel storage facilities, parks and public access areas). In total, urban and developed areas probably cover considerably less than 0.1% of the West Kitikmeot and Slave geological province.

- Increasing demand on water resources for many uses (*e. g.* drinking and cooking, household washing and cleaning, waste disposal, dust control, and fire fighting). At most sites, water supply (both quantity and quality (Acres Consult., 1982; HBT-Agra, 1993; Puznicki, 1996)) is not a limiting factor either on population growth or the support of local aquatic environments.

- Increasing quantities of solid wastes for disposal (mostly by burial or incineration) and discarded containers and non-functioning equipment (NPCTT, 1996: NPC,1997), because recycling is not required nor is it economically viable in many locations. On a site-specific basis, acidification, leaching nutrients (*e. g.* phosphorus, nitrogen, and organic carbon), toxic materials (*e. g.* salts, heavy metals, phenols), increased bacterial counts (*e. g.* total and fecal coliforms) and dust, may degrade ground and surface water supplies, and air quality (as in Yellowknife (Anon., 1993; Jackson, 1996; 1998; Jackson *et al*., 1996). On a per capita basis, solid wastes may often exceed 600 $kg \cdot a^{-1}$ (M. M. Dillon, 1991).

- Increasing quantities of sewage wastes. Depending on both site-specific conditions and the suitability of treatment technologies applied, sewage wastes may degrade the quality of the receiving environment (both treatment systems and their operation may be inadequate, and bacterial degradation of water supplies occurs at many locations (Jackson, 1996; 1998; Jackson *et al*., 1996)). On a per capita basis, gray water and sewage may often exceed 20 $m^{-3} \cdot a^{-1}$ (M. M. Dillon, 1991).

- Increasing quantities of hazardous wastes at sites away from major road links. Significant quantities of hazardous wastes are shipped out of the Yellowknife and Hay River areas (for treatment and or disposal) but little hazardous wastes are removed from remote communities

(Vista Engineering, 1994). Hazardous wastes are made up mostly of antifreeze (ethelyne glycol), solvents, paints, filters and oil wastes, and batteries (mostly lead-acid). About 70% of all hazardous wastes in the area are comprised of some form of petroleum product (Vista Engineering, 994). Seepage into groundwater can be a particular concern where disposal occurs too close to community water supply (Sly, 1995).

- Increasing use of fuel oil (*e. g.* for heating, power production, and vehicles) will increase emissions of sulphur dioxide, nitrous oxides, carbon monoxide, PAHs, soot. On a site-specific basis, emissions may impair local air quality (particularly under still air conditions and where hollows or valleys allow ice fog to persist (van Diepen, 1975)).

- Increasing use of fuel oil (in all forms), also, will likely be associated with increasing spillage affecting groundwater, fresh and marine surface waters, and ground surface conditions on a site-specific basis).

- Expanding "halos" of noise and light pollution (which create a negative response in some wildlife) are associated with larger settlements (including mining camps, (Clarke, 1973; van Diepen, 1975)). Large communities also create greater feeding opportunities for scavengers and generalist feeders (creating a positive response in some wildlife). Non-native plants and animals brought into a community by people may compete with and negatively influence local species (and this could include the spread of disease and parasites).

- Other forms of “disturbance halos” can be associated with increasing damage to surrounding environments as a result of discontinuous human presence, including road and off-road traffic, temporary construction and maintenance, recreation and cabin and, or, camping site use.

- “Resource use halos” associated with domestic hunting, trapping and fishing also vary with the size and type of community (*e. g.* Aboriginal or non-Aboriginal community, its age structure, and main economic activities) and characterize a greater or lesser dependence on country foods.

The most important external effects of settlement on the natural environment (Bernard, *et al.*, 1995) can be characterized by various forms of halos. As settlements grow, however, waste disposal and the quality of potable water supply may also become critical factors; these are largely internal and affect areas within the communities.

Comparative data are not available but approximations suggest, for a small community of a few hundred people who depend on local resources for a significant part of the food supply, halo areas for different forms of effect might be:

Housing, urban infrastructure, water supply, and landing strip	2 to 5 km^{-2}
Air and water quality degradation (emissions and waste disposal and, or, treatment)	5 to 10 km^{-2}
Noise and light disturbance	5 to 10 km^{-2}
Disturbance halo (particularly road off-road access)	100 to 500 km^{-2}
Resource use halo	< 5000 km^{-2}

For a large mature market community that is considerably less dependent on local resources for food supply (*e. g.* Yellowknife), and based on relative population, the resource use halo may be less but areas of effect from other forms of activity may be significantly greater than the example given.

Unfortunately, significant haloes of persistent organic contaminants may also exist around some communities as a result of special circumstances, such as improper storage or disposal of contaminated wastes. At Cambridge Bay, for example, both the hamlet dump and a nearby DEW-line site provide a significant source of PCBs that have been traced into the sediments and biota in the surrounding bay (Bright *et al.*, 1995). Total PCB concentrations are about 45 $ng \cdot g^{-1}$ (dw) in sediments near source but decline rapidly, and remain at background levels in sediments of Wellington Bay and Queen Maud Gulf. Total PCBs in clams (*Mya truncata*) from near source were between 1.1 and 1.7 $ng \cdot g^{-1}$ (ww) and values were higher in filter-feeding mussels (*Mytilus edulis*), but were below detection in clams from the Queen Maud Gulf. Contaminant levels of ΣPCB were also higher in detrital-feeding sea urchins (maximum concentrations about 55 $ng \cdot g^{-1}$) and followed trends in sediments. Contaminant levels in Four-horned Sculpins (whole fish, excluding liver tissue) near the top of the marine food chain in this area, reached 220 $ng \cdot g^{-1}$. This value approaches concentrations in Ringed Seal blubber (Bright *et al.*, 1995). However, patterns of PCB congeners in sculpins from Cambridge Bay, Wellington Bay and Queen Maud Gulf were different. Congener patterns in sculpins from Wellington Bay and Queen Maud Gulf reflected the influence of long range transport and contribution from precipitation and runoff from the land surface rather than the dump site. At Cambridge Bay, this evidence shows that local contamination by PCBs is overlaid over regional contamination by a similar pollutant.

4.2.7. Effects of Transportation Corridors

Only the general effects of increasing numbers and length of transportation corridors for roads, shipping, air, and electrical transmission on the northern environment are known. Limited information specific to the WKSS area is available (Section 3.3.3.6, (Clarke, 1973; DT., 1999; 2000; GNWT., 2000b; Sly, 1995; Williams, 1979; van Diepen, 1975)). Future development of oil reserves from the North Slope (Alaska) and Beaufort Sea may occur in the relatively near future and the Mackenzie Valley is one of the possible corridor routes under consideration for pipeline construction. A pipeline corridor for southward transport of polar gas is possible but existing proposals also place it outside the WKSS area. A road corridor linking an Arctic coastal port (Bathurst Inlet) to highway 3 (Yellowknife or a more westerly point) seems to be the most probably form of corridor development in the WKSS area (DT., 1999; 2000). The construction of transportation corridors significantly modifies habitat by reducing vegetation cover. Often it also alters surface drainage and the stability of permafrost. Winter roads require the use of borrow-pits for gravel, but all-weather roads are more disruptive and could have a critical impact on rare habitat. All weather roads require large quantities of sand and, or, gravel for road construction (often taken from esker sources) and the roadbed may need to in-fill areas of wetland. Roads also need bridges and culverts for crossings, and they require seasonal dust control. Unfortunately, spills and traffic accidents are also associated with road corridors.

At some times of year, animals may avoid activity and noise associated with roads (*e. g.* caribou cows and calves) but at other times the same species may be attracted to roads and open areas because of reduced insect densities or the presence of salt (Gunn, 1983; Mueller & Gun, 1996). Likewise, isolated structures may provide shading and sites of reduced harassment from warble and bot flies (Barren-ground Caribou bulls may actively select road and building locations during the fly season (Gunn, 1983; Gunn & Dragon 1998; Mueller & Gunn, 1996)). The response of caribou to linear structures is not well understood (GNWT., 2000b). Increasing road traffic is expected to lead to increasing road kill of both large and small mammals (numbers not available) and, so far, methods (*e. g.* fencing) have not been applied to consistently redirect caribou.

Roads and transportation corridors with cleared ground provide many species with easier travel (including migrating caribou) and may accelerate processes for dispersal and “colonizing” new areas. Unfortunately, the same corridors also provide easier access for vehicles and off-road transport and therefore increase the size of areas under pressure from recreation, hunting, fishing and trapping. Both temporary and permanent barriers to fish migration could affect species survival in isolated parts of a watershed. Avoidance and range extension and, or, shift may occur in species requiring isolation (Bromley, 1998; Mulders, 2000). Transportation corridors may also increase the spread of non-native (exotic) species, increase the frequency and distribution of accidental fires, and the frequency of contaminant spills (both from vessels and road traffic). Viscera-dumping from roadside hunting may also be a problem, especially as an attractant to scavenger species and the spread of disease and parasites. Increasing connectivity between human settlements also contributes to their increasing rate of growth.

Increasing use of marine shipping corridors in Coronation Gulf is projected for both settlement resupply and transportation of mineral concentrates (DT., 1993; 1995; 1999; 2000). If movements require extension of the brief open-water season, vessels will need ice-breaker support. Ice-breaking and vessel movements would certainly cause startle reactions in wildlife. Weak ice and open water would be potentially hazardous to hunters and people crossing the ice, and to migrating Barren-ground Caribou between Victoria Island and the mainland (Gunn, 1983; Gunn *et al.*, 2000; Klohn-Crippen, 1993). With increasing traffic, the potential for hazardous spills (including oil spills) also increases.

Startle reactions to overflights of aircraft and helicopters have been observed in many species of wildlife (Harrington & Veitch, 1991; 1992; Jacobson, 1979), and flight altitude is significant. During winter months some species may be particularly sensitive to aircraft but at other times they appear to be almost insensitive to them. Many animals in deep snow show a panic response to low flying aircraft (*e. g.* Moose, Muskoxen, and wolves (Jacobson, 1979)), and females with calves tend to be more sensitive to disturbance than bulls (DRR., 1996; Mueller & Gunn, 1996). Barren-ground Caribou cows and calves are particularly sensitive to disturbance during calving and summer feeding (Cameron, 1994; Cameron *et al.*, 1992; 1995; Dau & Cameron, 1986). During winter, Barren-ground Caribou feeding in wooded areas showed only slightly more response than those resting, generally a third or less responded in some way to low flying aircraft (Jacobson, 1979).

Both increasing access to fish and wildlife (hunting, trapping and fishing) and the potential for increased accidental fire are particularly significant with respect to road development, and to a lesser extent with electric transmission and gas transmission corridors (Clarke, 1973; van Diepen, 1975).

4.2.8. Effects of Hydroelectric Development

Relative to other northern projects (Pearse *et al.*, 1985) like La Grande (Quebec), Churchill Falls (Newfoundland), and Ogoki (Ontario), existing and potential hydroelectric development in the WKSS area is extremely small (Fig. 7, Section 3.3.3.7). However, because annual precipitation is low throughout the WKSS area and natural seasonal flow is extremely peaked (Section 2.2.4), any forms of flow modification for power generation have the potential for significant impact (Acres Consult., 1982; HBT-Agra, 1993). Most impacts from hydroelectric development within the WKSS area will be local. Depending on the extent of flow modification, potential also exists for additional down stream changes (Bernard *et al*., 1995). All of the following effects have occurred with hydroelectric development elsewhere in northern Canada (Sly, 1995) and some could happen in the WKSS area, but mostly at a local scale. The extent to which any of these effects might be significant in the WKSS area is not established.

In general, reduced tributary discharge during spring and early summer may weaken circulation and decrease vertical stratification in receiving waters (lake and marine). Changes in stratification may also influence upwelling of deep water but, locally, wind conditions may be more important. Locally, surface air and water temperatures may decline, and break-up of nearshore and some offshore ice may be delayed.

Greater discharge during winter may increase the size and movement of under-ice freshwater plumes. Locally, sea-ice could thicken and form earlier. With increased river flow, rapids, falls, narrows may be larger and remain open longer. With decreased flow, winter ice may form to the channel bed and alter the composition of surviving plant and animal communities.

Often, nutrient concentrations and biological productivity increase in impoundments, and downstream, immediately after construction. Over the long term, however, these temporary increases are not usually sustained. Elders from the community of Lutselk'e have noted that fish condition declined significantly after completion of hydroelectric development on the Taltson River in the 1960’s (Bielawski, 1993; Parlee *et al*., 2000). Although freshwaters are usually nutrient poor relative to marine waters, changes in discharge can influence additions of nutrients to lake and marine surface waters from upwelling.

Impoundments trap much of the sediment normally carried instream and because of this downstream flow has an increased capacity to carry sediment. Greater capacity can result in increased downstream erosion, even though peak flow may be reduced. Changes in flow regime will also affect channel and bank conditions. With reduced river flow, saltwater may penetrate further into estuaries.

Levels of MeHg in biota are known to increase in impoundments and downstream (EC., 1991). This is largely as a result of increased microbial activity associated with the breakdown of organic matter in flooded terrestrial soils and vegetation. Concentrations of Hg also appear to increase in lakes surrounded by areas of clear cut vegetation, in part because of changes in soil microbial conditions and in part because of increased runoff. The increases are in addition to those naturally occurring, and from long range transport of atmospheric pollutants (EC., 1991). They are greatest in wide shallow impoundments and least in deep narrow flooded river valleys. They may persist for a long time. There is no evidence to suggest that impoundments significantly effect downstream concentrations of contaminants other than Hg. Methyl mercury can move downstream in dissolved form, on sediment and organic matter, and in biota, and it is possible for levels of this contaminant to be higher in fish downstream than in fish from the impoundment.

Changes in flow, siltation, and barriers and diversions may limit movements of resident and non-resident fish species (including anadromous fish) and other biota in river-lake systems (and between rivers and the sea). Water level and flow manipulation within and downstream of impoundments may also kill fish eggs and vegetation, and displace other dependent biota including fur bearers. Flooding and drawdown can increase shore and permafrost instability, and greatly increase erosion and turbidity. High levels of turbidity restrict water for drinking supplies and may reduce fish habitat. Sedimentation and standing debris also degrade habitat. Collectively, effects can result in displacement of fish (and other animals) and may also affect seasonal metabolic and reproductive capabilities.

If salinity and temperature regimes are modified as a result of changing freshwater discharge in estuaries, distributions and survival of many different types of biota may be altered. Some estuarine populations may be dependent on critical habitat (*e. g.* they would collapse if spawning habitat were to be lost). In areas affected by modification of the freshwater plume, the balance between ice algae and planktonic primary production might be altered. The timing of ice break-up could be critical to the effectiveness of grazing invertebrates upon which larval fish depend.

Changes in ice conditions may influence use of affected areas by aquatic species (Bromley & Buckland, 1995; Jacobson, 1979) and, consequently, modify harvesting opportunities. For example, more open water at rapids and falls could increase opportunities for trapping aquatic fur-bearers. On the other hand, increasing ice cover in bays or estuaries could reduce waterfowl harvest.

In addition to the effects of water level control and manipulation within the WKSS area, parts of this region are also influenced by control and manipulation of waters flowing from areas outside the WKSS area. In particular, water levels in Great Slave Lake and Great Bear Lake and flows in the lower Mackenzie River are influenced by manipulation of water stored in the headwaters of the Peace River. Reduced spring run off and flow could greatly affect habitat in the Slave delta. The amount of water available for release from storage basins would also decrease as a result of increased evaporation from reservoirs and lakes. Under the influence of climate warming and in response to a doubling of CO_2, it is anticipated that changes will occur in the existing evaporation and precipitation balance of the Mackenzie River basin. Future November to March water levels in Great Slave and Great Bear lakes are likely to be lower by a few tens of centimetres (enough to affect river crossing and navigation on the Mackenzie River (Cohen, 1997)). But to this must be added the effects of unknown and uncertain changes in the present regimes of headwater manipulation. These could occur as a result of changes in the external demand for hydroelectric power derived from existing and potential new sites in the headwaters of the Mackenzie River basin.

4.2.8.1. Effects of Hydroelectric Development on Denesoline

The impacts of hydroelectric development have been keenly felt by some Aboriginal people in the NWT. Impacts resulting from the Taltson hydroelectric development were reported by Dene of Lutselk'e and are viewed by them as a desecration of the land (Beilawski, 1993; Parlee *et al.*, 2000). The land flooded, called Nanúla Kúé has changed considerably, as has the Denesolines' ability to live on it. Examples of impacts noted to the environment are loss of fur bearer habitat due to the flooding of small lakes and channels, caribou and moose moving to new areas, destruction of shorebird nesting habitat, decrease in waterfowl and grouse, and diseased and inedible fish. Water quality has diminished and people cannot drink the water from the area because of the impacts of decomposing trees and changes in sedimentation. The hydrology has changed and water levels and their impact on ice formation are no longer predictable. This makes travel dangerous and the death of two people has been blamed on the presence of thin ice in an area where it was formerly safe. Travel is also made dangerous by sunken trees and drowned islands. Cabins were destroyed as were traditional camping places and established traplines. Graves were either flooded or destroyed by ice-push or driftwood scouring the shoreline. Inherent within this list of impacts is the loss of knowledge that the Denesoline have of this part of their land (Beilawski, 1993; Parlee *et al.*, 2000).

4.2.9. Effects of Tourism and Recreation

The environmental effects of recreation and tourism are not well defined (Section 3.3.3.8). Recreational activities usually occur near settlements where access is by road and, or, water (*e. g.* Ingraham Trail, east of Yellowknife). Tourism also may be local but often it extends (by air and, or, water) to more distant locations such as remote lodges (*e. g.* Bathurst Inlet (Hancock, 1979; PC., 1978)) or for wilderness excursions (*e. g.* Coppermine River (Raffan, 1979)). At sites away from accommodation (*e. g.* cabins, camp grounds), recreational activities (*e. g.* boating, camp-party, sports and swimming) tend to cause most noise and to have greatest light and scent halo effects. These effects may act both to displace some animals (*e. g.* Moose, Woodland Caribou, and a variety of waterfowl) and to attract scavengers (including Ravens, Wolverines, and Black Bears). Tourism to lodges usually has less effect on wildlife than recreation and, because of the very small numbers of events and people involved, wilderness excursions have least effect (at present). However, with growing interest in eco-tourism, significantly greater impacts could occur from visitors if wilderness travel increases (Bernard *et al*., 1995). Many species of wildlife would probably avoid more traveled areas. The effects of transport used in recreation and tourism are similar to those already described (Section 4.2.7), and accommodation at cabins, lodges and camp sites is similar in effect to those associated with small settlements (Section 4.2.6). Both solid waste disposal and reduced water quality (bacterial degradation) are important existing and additional concerns (Bernard *et al*., 1995; McNeely *et al*., 1979; Puznicki, 1996). Most tourism and recreation takes place during the summer months and these activities have little effect on winter conditions at the same locations. Northern Lights tours are usually close to existing settlements (mostly Yellowknife) and have little effect on the environment or winter distributions of wildlife.

Assuming that tourist and recreational activities are distinct from hunting, fishing and trapping, their most significant forms of impact include: both selective avoidance and attraction of wildlife, environmental degradation due to improper waste disposal, and accidental fire. Vehicle-rutting, garbage and other forms of site degradation are also known to be a problem at some small and over-used territorial parks (Hamre & Cozzetto, 1999a; 1999b; Seale & Cozzetto, 1998).

4.3. Stress Effects on People

Section 4.2 has described many of the environmental effects that may be associated with different forms of stress. It is clear that most of these effects could have an impact on people in the WKSS area. For example, late freeze up and early melt due to climate change, will likely increase the hazards of over-ice travel, and increase the need for all weather roads. Climate change might also cause major shifts in the migration and seasonal range of key species (*e. g.* Barren-ground Caribou), and these could increase the distance that hunters must travel from settlements. In addition, limits on fish consumption might become necessary if the levels of some pollutants rise further (*e. g.* mercury).

Social, economic and cultural forms of stress also affect people. Social legacies broadly affect many aspects of life in communities of the WKSS area. The number of young people who need employment and recognition in a mixed society, but who lack culture-based skills, is increasing. Consumerism is rising, but so too is the gap between expectation and the means of achievement. The loss of traditional knowledge, less appreciation of its value to sustainable development, challenge to traditional values and lifestyles, addictions and reduced health and wellness also reflect a variety of economic, cultural and social stresses.

Determining the extent to which people in the WKSS area are effected by stresses in their environment is as complex as identifying the stressors themselves (Section 3.4). Stress effects are dynamic and variable. They are both perceptual and real, and they are expected and unexpected. Depending on individual and community circumstances, some effects may occur only after multiple changes in the environment while others may occur as a result of a single event. Stress effects on people are discussed in this section in terms of effect on exposures to contaminants and infection, economic and social security, culture and traditions, power and control.

4.3.1. Human Exposures to Contaminants and Infection

In the central and eastern Canadian Arctic, differences in contaminant concentrations in Cree and Inuit populations can reflect differences in diet (Sly, 1995). For example, elevated levels of Hg have been associated with consumption of freshwater fish, whereas elevated levels of persistent organic contaminants tend to be associated more with consumption of marine mammals. Some concentrations of organic contaminants (*e. g.* PCBs) are also known to be higher in communities of the eastern Arctic than in more southerly parts of Canada (Dewailly *et al*., 1989). However, differences in contaminant concentrations are likely to be less significant in most people living in the WKSS area. This is because contaminant concentrations in many country foods tend to be lower and because diets of Dene, Métis and Inuit peoples are more similar.

It is thought that the nutritional value of many country foods is a more important factor than concern about contaminant effects (Kinloch *et al*., 1992). But, while assessments of the relative benefits and risks of depending on country foods for a major portion of dietary requirements are ongoing (Dewailly *et al*., 1996), it is prudent to be aware of potential implications for both positive and negative effects. Traditional foods provide a significant source of vitamins A, E and C, Fe and Zn, and are generally superior to store-purchased foods for the intake of proteins, vitamins E and C, Fe, Mg, K, P and Zn (Kuhnlein *et al*., 2000). Store purchases include milk, eggs, chicken and hamburger meats but carbohydrates form a major part of most Kitikmeot diets. Relative to other northern communities in the Inuvialuit and Nunavut, Kitikmeot communities may make somewhat less use of traditional foods. The average intake of both traditional and store foods falls short of standard nutrient levels for vitamins A and E, Ca, folic acid, fibre and some nutrients (Kuhnlein *et al*., 2000). Recent studies have not indicated how nutrient deficits might best be corrected but it is clear that further reductions in the use of traditional foods would likely increase them.

The principal pathway by which persistent organic contaminants enter human populations is through the food supply. Concentrations of persistent organic contaminants have been measured in human tissues (including samples from northern Canada) and, in general, contaminant levels are highest in tissues with a high lipid (fat) content. Fatty tissue is used by the body as a convertible energy store and for insulation. The presence of organochlorines in fatty tissue reflects accumulation in response to exposure over an extended period of time. Concentrations of organochlorines in blood samples are indicative of their equilibrium between fatty tissue and blood. Concentrations of MeHg in blood suggest response to more immediate exposure. Children may be more affected by these contaminants than adults. Recent health studies in Nunavik (Dewailly *et al.*, 2000) suggest that some Inuit children may be particularly susceptible to middle ear infection (*Otitis media*). This is thought to be a result of pre-natal exposure to DDE, HCB and dieldrin. Susceptibility may be reduced by breast-feeding during the first trimester. Any potential problem would be further reduced in women of reproductive age by maintaining a diet of traditional food high in nutrients but low in organochlorine contaminants (Dewailly *et al.*, 2000).

Concentrations of contaminants in humans have the potential to reach high levels as a result of accumulation and biomagnification at lower levels in the food web. At very low concentrations, the effect of contaminants on human health become close to natural background conditions. A lack of effect can be expressed as a health guideline for unlimited or occasional consumption, or (more precisely) as an acceptable or tolerable daily and annual intake value. In Table 19, intake values for Pb, Hg and several organic contaminants are expressed on a daily basis, and for radionuclides on an annual basis. Contaminant levels in most sources of country food in the western Canadian Arctic and sub-Arctic are one hundred to a thousand times less than levels considered critical for human health.

Figure 24 characterizes much of the country food available to Dene, Métis and Inuit communities on a seasonal basis. Harvest times and availability vary across the WKSS area and some species, such as Moose, are not usually available to Inuit and, likewise, seals are not available to Dene and Métis. Table 20 indicates some of the differences in the fall and late winter country food diets among WKSS area communities, and the importance of caribou, fish and seal to Inuit communities. In Deline, Rae and Lutselk'e, the leading country foods provide 25 to 30% of dietary energy requirments at this time. Comparable values for the Kitikmeot sub-region are from 11 to 29%. In the Kitikmeot sub-region, caribou, Arctic Char, Muskox and Lake Trout are the most important traditional foods in both summer and winter (Table 21). These are consumed by at least half the population. In summer, considerably more traditional foods are available, and Eider Duck, Ringed Seal, Blueberries and geese also figure prominently in community diets. However, only caribou and Arctic Char represent more than 10% of food use.

Traditional foods are generally considered to be an important source of nutrients for most Aboriginal communities in the WKSS area (Gilman *et al*., 1997, Kuhnlein *et al*., 2000; Van Oostdam *et al*., 1999). The potential of some traditional foods as a source of nutrients is summarized in Table 22. However, the extent to which each source may yield its maximum value depends both on the freshness and preparation of the food, and what part is consumed (*e. g.* the vitamin contents of muscle tissue, organs and blood differ significantly). Diets that include caribou, seal, Arctic Char and berries are an excellent source of the nutrients listed in this table, and also provide many other nutrients and minerals (Gilman *et al*., 1997, Kuhnlein *et al*., 2000; Van Oostdam *et al*., 1999).

Tables 23 and 24 provide a summary of contaminant concentrations in several country foods used by Aboriginal communities and, as noted in Table 23 the concentrations of many organic contaminants are significantly lower in the western Arctic than the eastern Arctic. In most WKSS area communities, the intake of organic contaminants remains well below Health Canada guidelines. Chlordane and toxaphene, however, somewhat exceed provisional TDI values for average and high dietary intake at Cambridge Bay, and are mostly associated with consumption of marine mammal fat (Kuhnlein *et a*l., 2000). Tolerable daily Intake (TDI) values are based on risk analyses rather than the background levels of a contaminant (see TDI, Section 8.0)

Concentrations of Cd and Pb also tend to be less in country foods from western Arctic but concentrations of Hg may be higher in country foods from the western Arctic. Table 24 indicates that, because of residual effects, concentrations of As in berries may be high at some existing and abandoned mine sites, where they can exceed health guidelines. Recently released studies from the Kitikmeot area (Kuhnlein *et al*., 2000) indicate that the average intakes of As, Cd, Hg and Pb remain below the TDI levels. However, for a few individuals who have a high consumption of caribou and Arctic Char, As and Pb may somewhat exceed provisional TDI values (Kuhnlein *et al*., 2000).

Table 25 shows the extent to which the average daily intake of country foods exceeds health guidelines at Dene and Métis communities in the WKSS area. Out of 1,012 dietary reportings from 16 communities, there was no exceedence for CBZ, DDT, dieldrin, HCH, or PCBs. Chlordane, toxaphene, Cd and Pb accounted for less than 1%, each, of exceedences. Although high concentrations of Cd have been found in human blood samples, these appear to be directly related to smoking and not to the effects of diet. Levels of Cd in smokers can be 5 to 6 times higher than in non-smokers and represent a serious health concern (Rey *et al*., 1997). About 1% of exceedence was attributed to As and about 4% to Hg. Chlordane and toxaphene were mostly associated with consumption of Beluga muktuk and blubber, and with Arctic Char and Burbot. Arsenic was mostly associated with consumption of cisco, and Hg was associated with a broad spectrum of country foods. Overall, the information presented in this table substantiates the general safety of country foods consumed by these communities. It is further supported by the recent caribou and Moose sampling program completed in the Sahtu Region (Berti *et al.*, 1998; Sahtu Dene Council *et al.*, 1999). However, Table 25 also highlights the potential for possible future problems associated with Hg, should concentrations of this metal continue to rise in the environment.

Table 26 provides a summary of the total radiation dose received by some northern communities. Natural radiation is, by far, the most significant source at each community and, on an annual basis, all of these doses are far below accepted health standards (Table 19). These data, however, do not characterize the effects of exposure to radiation "hotspots" such as occur at some abandoned mine sites (*e. g.* Rayrock (Veska & Eaton, 1991)).

There are additional concerns that involve the possible spread of infectious diseases and parasites, both of which may be related, in some way, to climate warming. Some diseases may be "imported" by people and animals moving into the WKSS area. For example, in Canada as a whole, the reported incidence of malaria has risen by about 3 fold since 1984 (Kelleher, 2000). While most of this increase is related to travel rather than to invasive infection that too has increased. Malaria was present in the Great Lakes region of southern Canada at the time of European settlement but it is not presently a significant health problem in that region. Reasons for this remain unclear. Certainly the drainage of large areas of marsh and wetland have contributed to the decline of malaria but significant areas of marsh and wetland remain. Possibly, agricultural run-off and, or, effluent discharge (Evans, 2001) may be additional factors. Malaria is not expected to become a serious threat in the WKSS area but other diseases, especially those carried by insects, birds and rodents could become invasive under climate warming. Also, there is concern that warming might increase the incidence of existing parasitic infections. Little is known of the potential for increased disease and infection in fish and wildlife of the WKSS area.

The DRWED (NWT) has a systematic disease survey of wildlife. In 1997, a three year project of community-based monitoring of wildlife was begun with the communities of Fort Good Hope, Kugluktuk and Fort Resolution (Elkin *et al.*, 2000). This monitoring targets the fall and spring harvests of caribou. Although most of the animals inspected were considered to be in good health, several abnormalities were reported (Elkin *et al.*, 2000). These included: *Brucellosis* (most evident in the Bluenose herd, in the fall), warbles (present in all inspected Bluenose and Bathurst caribou in the spring), *Sarcocystosis* (present in most Bluenose and Bathurst caribou, as a mild infection), liver tapeworms (most evident in Bathurst caribou where nearly half of the animals inspected were infected), muscle tapeworms (present in about 20% of Bathurst caribou), gastrointestinal parasites (most evident in Bluenose caribou, in the spring), and lungworms (present in about one third of the animals inspected). Concern has also been raised about a possible spread of lungworm parasites from the Kugluktuk Muskox herd to other herds of Muskox (Section 4.2.1.5). Related concerns about the spread and incidence of parasites in many other species of fish and wildlife exist where the effects of warming are likely to be greatest in the WKSS area.

4.3.2. Economic Security

Economic security is one of the pillars of human existence. Economic security is created through access to and adequacy of food, clothing and shelter. Human effort or work, both paid and unpaid, is the single most important human activity affecting economic security. In hunting and gathering economies, access to land and harvestable resources is basic to security. In wage-based economies, paid work or access to the currency of exchange is fundamental to security. In the blended, mixed economy of the WKSS area, access to land and harvested resources as well as paid employment or cash inputs are necessary to economic security (Section 3.2). However, development that undermines cultural identity, compromises values or fails to preserve or enhance environmental quality is neither sustainable nor healthy (Wismer, 1996). It provides little long term economic security. Economic security in a more holistic sense, is influenced by a broad range of conditions and circumstances. These range from very local and personal factors such as individual interests, skills and self confidence, to regional and national factors such as access and use of resources, to equally complex factors such as government policy and funding, global market conditions and technologies.

Some studies have argued that the harvesting component continues to be the cornerstone of the northern economy and of a healthy Aboriginal society (Fast & Berkes 1994). If economic security is predicated on this assumption, a healthy land, water and resource base and access to these resources are required to sustain economic security. Various studies have found that the economic security of Aboriginal people in the NWT has been threatened in the last century by competition for land and resources for industrial or other uses (Abel, 1993; Watkins, 1977). The literature has argued that the reduction in harvesting activities can threaten cultural expression and individual identity. Resulting high risk social behaviours (Berger, 1977; Condon, 1990; Condon *et al.,* 1996; Hall, 1986) can trigger undesirable changes in diet and health status (Receveur *et al*., 1996). In addition, a lack of understanding of subsistence economies such as those based on hunting and trapping, by consumer groups, can deny the very underpinning of sustainable communities (Freeman, 1997). Strong subsistence sectors also reduce the need for other social support programs and enhance the transfer of traditional knowledge (Wismer, 1996). In effect, the use of traditional knowledge acts to conserve traditional knowledge, to conserve biodiversity of the environment (Michael, 1997), and to sustain economic security. A lack of current documentation about the relationship of harvesting activities to the economic security of WKSS communities, at the beginning of the 21st century, limits further statements about this component of the economy.

While harvesting activities may be the cornerstone of the economy of Aboriginal people, cash inputs are also necessary to meet basic needs and aspirations within modern-day WKSS area communities. Historically, access to paid work on a full or part-time basis throughout the NWT has favoured skilled and, or, educated workers from southern Canada and elsewhere in the world. Imported workers have been attracted and maintained with lucrative wages and benefits (housing, travel and living subsidies) that have not been available to indigenous workers (Legislative Assembly NWT, 1996). These circumstances created disparities and inequities in human relationships and the socio-economic circumstances of and among, indigenous and new northern residents. There is evidence that these trends are changing and greater paid work opportunities may be available to, and taken up by Aboriginal people and other indigenous northerners (BHP & Dia Met, 2000; Diavik, 1997).

Access to paid employment throughout the NWT and WKSS area communities, is being facilitated by the higher levels of formal education now being achieved by northerners of working age. Achievement of higher level education is most noticeable among Aboriginal people particularly Aboriginal females. The reasons for this may be a greater understanding of the relationships between education and, or, training, and lifestyle and work choices; more education and training opportunities at the community-level; an increasing desire to compete for wage employment; and greater demand for skilled employees by, for example, Aboriginal land claim organizations and corporations **(**BHP & Dia Met, 1995; BS., 1984, 1989, 1994; DE., 1989a). Presumably, greater access to wage employment, training and long distance commuting arrangements will increase economic security and reduce some stress effects which have been experienced in the past. For example, long distance commuting or rotational industrial wage employment at distant work sites has been identified as diminishing stress effects. But these activities may also create new or additional stresses. These stresses have been documented as advantages and disadvantages (NOGAP., 1986):

ADVANTAGES

Home communities are buffered from direct contact with industry induced influences.
Workers in a controlled situation have fewer options for tardiness and absenteeism.
Workers have blocks of time for hunting or resource harvesting.
Cultural interaction is facilitated and community support systems remain intact.

Income is provided to pursue traditional harvesting activities.
Dependence on government transfer payments is lessened.
Training is provided and job skills are developed.
Workers are better able to provide food, housing and clothing for families.

DISADVANTAGES

Emotional stress and worry resulting from worker-family separation.
Worker loneliness and family stress may result from unfamiliarity with the workplace.
Workers are suspicious of the fidelity of spouses.
Less time, overall, may be available for hunting, trapping and fishing.
Increased income may be spent on alcohol and drugs, causing related social problems.
Diet may change when away from home.
Prejudice and discrimination may occur at the worksite.
Increase wage income breaks down traditional modes of sharing and support.
Wage income changes distribution of income and may create poverty.
Periodic "boom and bust" events create unstable sources of employment and income.
Child neglect and discipline problems may increase in the absence of one parent.
Conflicts may increase between parents, about child rearing, management or household issues.
Attraction to apparently lucrative jobs may increase rates of school drop out.
Traditional skills may be lost.
Benefits from wage labour may not be realized due to lack of money management skills.
Mental and physical health problems may be associated with wage culture.
The cost of living may increase in response to an increase in community income.

Stress effects from rotational employment documented in the 1980's seem to hold true today. Industrial wage employment particularly in a rotational work situation, is viewed as contributing to alcohol abuse and drug abuse. The reasons for this relate to increased income together with greater stresses in personal relationships inherent in long distance commuting circumstances. These stresses are reflected in jealousies and fears for the fidelity of spouses; concerns for the safety of women and children; effects of sexually transmitted diseases; and increases in violent crime. The successes of industrial rotation employment and perhaps to a lesser degree other wage earning activities such as job training, can be undermined with substance abuse. Financial stress can increase in families when income is spent on alcohol and drugs instead of basic family needs. On the other hand, individuals, most often men, who are unsuccessful in securing wage employment in industrial developments, tend to experience despair, anger, loss of self-esteem and the likelihood of more alcohol abuse. One reason for this is the prestige that wage employment has come to have in some communities, compared to making a living off the land (SWC-NWT., 1995).

Preliminary findings from research conducted in Lutselk'e offer another view of rotational work. Almost 90% of respondents (n=21) said that their employment had not affected their relationship; 51% had bought outdoor or on-the-land equipment and, or, tools; and 37% said that they spend an extra two to three days on the land each month. Turnover in full-time positions staffed by workers from the community, however has been high - 100% over one year (Marlowe et al., 2000).

An attitudinal survey now being completed by BHP's Ekati mine and scheduled to be published in April 2001, may shed additional light on this issue.

A shift toward wage employment, particularly industrial employment, among all northerners may produce other stress effects. Employment activities that depend on external market forces tend to fluctuate widely and this is reflected by the success and stability of businesses costing less than $30k relative to those costing more (Meyers, 1996). Downturns in industrial activities can result in job losses which devastate the economic security of communities. The withdrawal of the oil industry from the Beaufort-Mackenzie Delta Region in the 1970's provides an example of extreme "boom and bust" effects.

A restrained fiscal environment in all levels of government and changing social policies continue to diminish income supports and threaten the economic security of segments of northern populations (Lutra, 1998). A lack of economic independence among over one-third of the NWT population is a source of stress on communities, as well as government and local organizations. The degree to which dependency on social assistance or income subsidies impacts on northern communities is also influenced by attitudes about income supports. In general, there is understanding and acceptance of social assistance income subsidies for social reasons (*e.g.* disability, illness). There is less tolerance for those who receive it for economic reasons (*e.g.* lack of suitable jobs). Young people are making up a greater percentage of the total people receiving assistance (Lutra, 1998). The lack of involvement of young people in the wage and, or, traditional economy is a growing concern in the north. Stress effects associated with a reliance on income subsidies and the increasing difficulty associated with garnering these supports, results in a wide range of high risk behaviours which impact on individual health, safety and security.

A variety of studies have identified the availability of increased wage employment and cash income earning opportunities as ready deterrents to the need for income support. While evidence has been provided in the northern environment, that this is indeed the case, other experiences have shown that the reverse is true. Over the four-year period of the Fort Good Hope-Chevron Canada Resources joint venture for oil and gas exploration, the small Dene and Métis community in the NWT experienced a dramatic increase in social assistance payments. The reasons for this may have included a lack of skills or confidence to take up guaranteed jobs, increased costs in the community, unrealistic job expectations, a lack of sharing of wage earnings, and, or, poor money management or budgeting skills (Little *et al*., 1994).

4.3.3. Social Security

Social security is freedom from poverty and exposure, and an absence of fear or anxiety for personal safety within the context of other human relationships and the natural environment. Social security and economic security are inter-dependent. For example, a loss of work or economic security can trigger changes in diet or in shelter, creating a loss of social security.

The nature of the work done contributes to the structure, organization, and well-being of society and to social security. For example, during the fur trade, Dene societies shifted from relatively egalitarian gender-based societies to become male oriented. With the introduction of government programs, services and communities after WW II, northern Aboriginal people experienced policies that dictated the issuance of support payments to females, thereby changing the economic role of women (Sections 2.4.4 and 3.2 (Abel, 1993; Ryan, 1995)). In recent decades, the vast majority of wage earning opportunities in northern communities have been in government human services. These jobs have tended to be taken up by women who aspire to follow traditional care giving and family oriented work (BS., 1984, 1989, 1994; DE., 1989a; DE., 1989b, Lutra, 2000). Community-based wage earning has, to a large extent, displaced males as the chief provider. This has undermined their security, self-esteem and identity. The prevalence of suicide, alcohol and drug abuse (including Fetal Alcohol Syndrome/Effects) has increased. Crime and family violence have also increased as a result of acculturative stress, the breakdown of the traditional family units, and the changing roles of men and women. (Bayly *et al*., 1985; Bjerregaard & Young, 1998; Chambers *et al*., 1993; GC., 1993).

Family violence is a serious and pervasive problem throughout the NWT and Nunavut (Chambers *et. al*., 1993; DHSS., 1999; GC., 1993; Zellerer, 1996). Stresses associated with depression in women have been linked to persistent family violence (Bjerregaard & Young, 1998). Children who experience violence in the home are more likely to become abusers themselves (DHSS *et. al*., 2000). A wide range of issues are associated with family violence including patriarchy and power, traditions, spirituality or lack thereof, changing family relationships and lifestyles, roles of leadership, influence of religious institutions, alcohol and other additions, cultural values of non-interference, a lack of community sanctions, and conditioning to family violence (Chambers *et al*., 1993; Zellerer, 1996). Women of all ages, backgrounds and occupations are victims of abuse. Abusers are from all walks of life. Most cases of family violence are not reported to the police. Child abuse including child sexual abuse is probably the most pervasive and under-reported of violent and abusive acts in the family. Many people do not want to recognize, talk about, or report the problems of family violence (Chambers *et al.*, 1993; GC., 1993; Zellerer, 1996). In the three years between 1996 and 1999, the number of spousal assault complaints rose from 77 to 123 in Yellowknife. They decreased from 54 to 44 in smaller WKSS area communities (excluding Kugluktuk and Cambridge Bay) (DHSS *et al*.,, 2000).

Overall, crime rates in the NWT are nearly three times the national average. The NWT's young population may be one factor contributing to higher rates of crime (property crimes are disproportionately perpetrated by male youth 12 to 17 years of age). The use of alcohol or other drugs is associated with most crimes in the NWT and, or, Nunavut (DHSS *et al*., 2000) including violent crime which is about six times the national average. In the last two decades, the NWT and, or, Nunavut had the highest percentage increase (about 67%) in Criminal Code offences in Canada. While similar research has not been conducted in WKSS communities, violent crime in the Baffin Region of Nunavut is more strongly related to whether a community was settled by forced relocation than to measures or levels of socio-economic deprivation (Wood, 1997).

Throughout this century, both Dene and Inuit have experienced famine, epidemics and death at rates that have undermined the security, continuity and health of family and culture. Northern people no longer disappear into southern Canadian institutions (*e.g.* with mental illness or tuberculosis) or far-off residential schools for months or years at a time as was the case in earlier decades. Still, these practices have undermined trust within families, fragmented family relationships, and contributed to feelings of isolation and apathy towards the family unit. Broken or fragile family relationships have strengthened individual dependencies on external systems for security and support. A dependency on economic and social relationships which extend beyond and,or supersede those of the family unit, have weakened individual and collective capacity to manage stress and accommodate change. For example, many parents rely on schools to discipline and socialize their children or social workers to resolve family problems. Individuals may have fewer cooperative relationships with family members, be less consistent in their care and protection of weaker members, and less responsible for contributing to the socio-economic security of others. Statistics showing high levels of child abuse, elder abuse, youth crime and suicide are cited as evidence of the weakened state of family units in the NWT and, or, Nunavut (Chambers *et al.*, 1993; GC, 1993). Literature respecting hydrocarbon activities in the Beaufort-Mackenzie Delta a decade and one half ago, suggest that industrial work activities may further weaken family units as workers become alienated from their home community, and less inclined to care for and protect family members (NOGAP., 1985).

In recent decades, people have expressed deep concern about the state of mental health within northern communities. However, efforts to understand the changing nature of mental health and the subsequent threats to socio-economic security, have been overshadowed by issues of alcohol abuse, crime and family violence. One of the key indicators of poor mental health is suicide and suicide attempts. Communities in the WKSS area, like those throughout the north, have inordinately high rates of suicide. Suicide among Inuit youth, 16 to 30 years of age, is ten times higher than among any other group in Canada (GC., 1993). Typically, suicide is viewed as a result of depression and hopelessness that is exacerbated by a lack of economic and social security. Suicide among Inuit youth has been described as a cry for help from individuals suffering from the effects of *'inter-generational tension, intra-family violence, altered and destructive relationships between husbands and wives, family break-up and generally an increase in disruptive domestic life in Inuit communities'* (GC., 1993). Individuals caught between the values and expectations of traditional and modern day culture and lifestyles are considered most vulnerable (Lutra, 1996). The concern exists that industrial development may widen gaps between traditional and modern day lifestyles and increase vulnerability. Little current evidence exists to validate these concerns.

Possibly the most pervasive factor affecting the social security of northern people is alcohol and drug abuse. Substance abuses contribute to poor mental and physical health. They also account for high rates of crime including violence and injury, high conviction rates, and the high number of Aboriginal people incarcerated. Uses of alcohol, drugs and tobacco in the NWT and WKSS area communities, are well above national averages. Alcohol and, or, drugs account for as much as 88% of unlawful offences in some WKSS area communities (Diavik, 1997). Alcohol and, or, drugs are involved in accidents and, or, injuries and a significant number of violent deaths (BHP & Dia Met, 1995; Diavik, 1997; DHSS., 1999; Lutra, 1996). The main medical conditions in the WKSS area communities, cancer, respiratory and nervous system, injury and poisoning, may also be linked to the high use of alcohol, drugs and, or, tobacco (BHP & Dia Met, 1995; Diavik, 1997; DHSS., 1999; Lutra, 1996).

A history of alcohol abuse has led to perceived high rates of fetal alcohol syndrome (FAS) and fetal alcohol effects (FAE) among children and youth (Kowalsky & Verhoef, 1999). The history of, and reasons for substance abuses are complex but the effects are overwhelming. There is little agreement or evidence to confirm that increases or decreases in alcohol and drug consumption and resultant social problems are related with either more or less employment, or economic benefits. There is however a growing body of research citing the lengthy history of abuses, guilt, shame and loss of self-esteem as lying at the very root of such problems (Chambers *et al*., 1993; SWC-NWT., 1995). Collectively, the effects of acculturation that result in loss of identity, self sufficiency, self-worth and well being may underlie many of the problems associated with substance abuse, violence and injuries (Stieb & Davies, 1995). Reversal of these effects may greatly reduce many of these problems (Chambers *et al*., 1993; SWC-NWT., 1995).

Numerous studies have linked the social and physical well-being of NWT Aboriginal people to the health of the traditional economy. The rationale for these linkages is that harvesting activities not only provide basic economic security but also shape societal relationships, cultural expression and individual identity and security. Country foods offset the cost of imported foods, provide important nutritional value, and promote and sustain family and community social structures and values (Section 2.1 (Collings, 1997; Pierce & Hornal, 1994)). For example, caribou hunting helps people maintain their cultural identity as the hunt often is a group activity. Sharing country food harvested helps to structure and maintain social alliances (Condon *et al*., 1995; Hall, 1986). Country food such as caribou, is also a relatively less costly source of nutrition. Caribou has a high nutrient density and, when used in its entirety, provides most required nutrients (Christensen, 1989). The only essential nutrient which caribou is deficient in is vitamin D. In earlier times, people used other food sources such as fish liver oil to balance this need in their diet. Recent studies in Dene and Métis communities of the NWT indicate that country foods provide 10 to 27% of the intake of total food energy, 35 to 61% of protein intake, 4 to 17% of fat, 34 to 64% of iron, 34 to 65% of zinc, 5 to 82% of vitamin A, and 3 to 9% of calcium. Changes in food harvesting and, or, consumption patterns may account for findings in several WKSS area communities in 1996, that the intake of both vitamin A and calcium was below levels recommended for adult health (CIPNE *et al*., 1996).

While Aboriginal households continue to consume country foods, the dietary circumstances of many are poor (CIPNE *et al*., 1996). Poor dietary circumstances may be due to a number of factors, including: loss of traditional knowledge about nutritional values; lack of familiarity about the nutritional values of presently used foods; improper use and preparation of foods; inadequate supply and, or, low consumption of country foods among household members most vulnerable to dietary deficiencies (*e. g.* young children and women of child bearing age (Christensen, 1989). However, no substantive data have been published to indicate how or if industrial activities such as mining are impacting on the economic or social security of Aboriginal northerners (Davidson, 1994). It is known, however that dietary changes resulting from a reliance on food purchased from stores along with an increasingly sedentary lifestyle have compounded problems of health and wellness in many Aboriginal communities. These changes have increased the likelihood of obesity, diabetes, high blood pressure and dental caries (Bjerregaard & Young, 1998; Stieb & Davies, 1995).

4.3.4. Culture and Traditions

The culture of a people is their way of life reflected in social, economic, political, intellectual and spiritual activities, and expressions of values and beliefs are unique to each culture. Berkes *et al.*, (1998) have stated that although the “language” of traditional knowledge may differ significantly among Aboriginal peoples (metaphorical imagery and spiritual expression may indicate differences in contest, motive and conceptual underpinning), the concepts of traditional (ecological) knowledge are comparable. Thus, some ecosystem-like concepts incorporate spirits of animals and other natural objects, and enhance feedback in traditional knowledge in ways comparable to adaptive management. Historically, the cultures and traditions of both Dene and Inuit were founded on an inter-dependence with the animal, plant, spiritual and human worlds. Language, individual and collective beliefs and practices together with socio-economic and political organization focused on the maintenance of harmony and balance among these elements. A sense of place and role, and fulfillment of individual responsibilities ensured collective security. The shared goal of survival shaped the moral code of ethics of sharing, respect, non-interference and the use of persuasion rather than authoritarianism (Ross, 1992). Northern cultures have endured a series of disruptive events and influences whether through church, school, state, industry or natural circumstances, which have systematically or haphazardly undermined age-old beliefs and traditions (Abel, 1993; Bjerregaard & Young, 1998; Chambers *et al.*, 1993; GC., 1993; Ryan, 1995)

Today, individual and collective activities within contemporary WKSS area communities do not always encourage or enable the expression of culture or traditions. Institutions, structures and systems rooted in European traditions, whether municipal models of governance or institutionalized care of the elderly or preschoolers, have stymied, frustrated, contradicted and, or, diluted many traditional practices. As a result, a good number of northern people lack connection not only to their own feelings, history and experiences but also to any collective set of values and beliefs (Chambers *et al.*, 1993). This is a source of stress among people of all ages and the effects of these stresses may be manifested in the circumstances described in section 4.3.3.

A body of research suggests that a healthy traditional economy can and does restore a cultural connection among Aboriginal peoples. As the “store” or “bank” for Aboriginal people, the land provides for economic security as well as social and cultural strength. It is the land, its resources and the cultural, heritage, historic, and burial sites on it, that offer a sense of identity, belonging and place in the world that is missing in many contemporary northern communities. (Condon *et al.*, 1995; Parlee, 1998b). As relationships to the land are threatened by industrialization and development, the effects of these stresses on Aboriginal culture and traditions of the WKSS area increase (Parlee & Lutsel K’e First Nation, 1997).

4.3.5. Power and Control

The extent to which individuals and groups are able to make and influence decisions that affect their lives, lies at the heart of power and control. The power base of the Dene and Inuit, has and continues to be derived mostly from the land and its resources. Aboriginal people in northern Canada including the WKSS area, have experienced more than a century of efforts to alienate and remove their people from the land. For example, through game legislation and harvesting regulation, treaties, community and settlement efforts, and expropriation of land and resources for industrial development (Abel, 1993; Fumoleau, 1973). The overall effects have been to marginalize Aboriginal people, who have had little control over decisions respecting the use of lands and resources. Most have derived little or no benefits from the use of lands and resources (Berger, 1977) and an inability to prevent damage to the environment may have as much impact on the community as the impact of the damage itself (Beilawski, 1993).

Aboriginal people became organized politically during the 1970's (Sections 2.4.4 and 3.2) and have fought for recognition of their rights to land, resources and governance. They have significantly influenced development, through, for example, the Mackenzie Valley Pipeline Inquiry. They have also entered into agreements, such as impact benefit agreements, to assert power and control over the use and benefits of lands and resources. These efforts seek to address long held concerns of Aboriginal peoples in the WKSS area that are generally shared by other Aboriginal Canadians, that:

> - *"resources and habitat have been exploited for the profit of southerners, with little socio economic advantages to themselves;*
>
> - *they have experienced little if any participation in decision-making processes.*
>
> - *They have seen few plans to protect the lands which they have inhabited for countless generations.*
>
> - *They have seen few plans for long term benefits through employment in spin-off industries which could be created by the projects in question"* (Malcolm, 1995).

Future industrial resource development in the WKSS area has the potential to increase stress effects on people in the region. Efforts to ensure Aboriginal participation and access to benefits, may reduce these stresses. The literature currently does not document the extent to which stresses are being created, managed or reduced as a result of new approaches to Aboriginal involvement in power and control of land and resource uses.

4.3.5.1. Respect for Land Ownership and Treaties

Some Dogrib elders stated that treaties signed in good faith have not been lived up to. Outsiders do not appear to respect the Dogrib's ownership of the land, nor the animals that live on it. Given these experiences they are concerned about mining development . They are frustrated that they cannot trust what they are told by outsiders. Elder, Pierre Wedzin states: "*They [Whites] look up to money as if it were their god. They are impossible. ... If we think there is no hope, there will be no hope as the white man is very ambitious. They work, and we cannot see them with our own eyes. They work with hard rocks, but to them it's as if it were pliable wood. ... We as a people depend on words [which are sacred and carefully chosen], yet those who have come [representing Whites] aren't the boss*" (Legat & Zoe, 1995).

Aboriginal people have expressed their frustration in having to deal with so many departments and individuals on issues related to government or business. It makes it difficult for them to determine who has real authority and what rules and agreements are actually in place. Elder, Andrew Gon states:

"Why do they have so many people for k'ade [in positions of authority] ... Why do they have k'ade for different things and they all think different.... They don't talk the same way. They all work different ways...." (Legat & Zoe, 1995).

4.3.5.2. Demonstrating Respect for the Land

Tensions may arise when developers or others using the traditional lands of Aboriginal people act in ways that are not considered respectful. Many Aboriginal people believe that the land and animals are aware of human actions. Among the Dogrib, animals must be treated according to *ekw'i naàw* - the rules of people. The outcome of breaking these rules is serious and can result in ill fortune or the guardian spirit of the animals causing them to move to another area. It is understandable that people who depend on many animals would be concerned about the impacts of people who do not know the rules (Legat *et al.*, 1994).

Offences to the land have been observed through past mining operations (Section 4.2.4). The physical damage resulting from mining operations, the lack of reclamation or clean up when mines close, and the continued harm to people and animals through contaminants is an ongoing concern. Elder Andrew Gon states: "*They have been working at Wati?a (a deserted mine site).... They have been working there with the nàedili [poison] and they never clean it and they just leave it like that. They never bother to clean it and they have been spilling nàedili on the land. It is just like there is* *a big hole in the land. All those people have been working on the land; all the people who were working there are no longer living. It is just like they have been killing people, it is the same. To this day they have never bother to ndè segaleà-lè [clean it up]; what about if the animals goes on that land and eats it and drinks the water. Maybe the animals have been traveling around in this area, and we eat them. Maybe if we kill the animal and eat it we might get sick because of that"* (Legat et al., 1994).

4.4. The Future

With the large number of youth entering the work force each year, residents of the WKSS face every new venture inside their community and on the land, with a mixture of hope and apprehension (Section 3.2). They hope for real and lasting benefits that will create much needed jobs for young people, increase income, and provide new training and education and business opportunities. At the same time, northerners worry about the adverse effects of development on the land, the wildlife, the water and, on the beliefs, values and identity of the people. These conflicts create tremendous stress. The stress effects on northern populations may be both positive and negative but the rapidly changing circumstances in the north severely limit any certain prediction of how these stresses will play out in the WKSS area.

Tables 25 and 26 provide a summary of the potential for environmental change and its importance to northern communities. Table 27 indicates the probability that various forms of environmental stress will increase locally or regionally over the next 25 to 50 years; and Table 28 indicates the significance of effects that are likely to be associated with these various forms of stress. Tables 27 and 28 provide a somewhat similar summary of the probability that various forms of socio-economic stress will increase, and the significance of their associated effects. For the foreseeable future it seems highly probable that stress will continue to be associated with wage employment, cash income, higher education and training and mental and physical health (Table 29). It is also very probable that these forms of stress will continue to exert a significant effect on both individuals and communities (Table 30).

5. SUSTAINABLE DEVELOPMENT IN THE WKSS AREA

The stated vision of the West Kitikmeot/Slave Study Partners is to achieve sustainable development in the WKSS area *"which respects aboriginal cultural values, so that the land is protected, culture is preserved and community self sufficiency and, or, reliance is enhanced."* The Partners firmly believe that providing useful information to decision-makers is an essential ingredient for achieving sustainable development. This chapter will discuss some other tools available to assist in achieving sustainable development in the WKSS area.

5.1. Sustainable Development and Stewardship

The World Commission on Environment and Development coined the term *Sustainable Development* in 1987 (WCED., 1987), and defined it this way: *"Sustainable development means development which meets the needs of the present without compromising the ability of future generations to meet their own needs."*

This concept provides a foundation on which it is possible to integrate social, economic and cultural development with environmental considerations. Sustainable development depends on the ability of the ecosystem (including people) to remain stable and in balance. It implies careful use of resources, both renewable and non-renewable, and that the ecosystem should not be degraded.

Long before the term *sustainable development* was used, the idea of stewardship, or wise use, has been a guiding philosophy for many peoples. Stewardship is a recognition that, in terms of the natural environment, people don't own anything. Rather, an opportunity exists to use the environment in ways that support and please people, and this opportunity transfers from one generation to the next. Since people now have the ability to greatly change the environment and ecology of the planet (including the WKSS area), a high degree of stewardship exists. In the long term, stewardship rather than ownership may be of greatest importance in the wise use of renewable resources; as stated by Leopold (1949) *"We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect"*.

5.1.1. Stewardship and Aboriginal Culture

Many aspects of the traditional economy are present in the modern concept of sustainable development (INAC., 2000b). To Aboriginal people in North America, the notion of land extends beyond the physical landscape and it includes the living environment and people. As stated by

Rosalie Tailbones: *"It's the land that keeps things for us. Being our home it's important for us to take good care of the dwelling, the land, for wherever you go is home";* or, as noted by Madeline Drybones *"The land we live on is our home"*(Legat *et al.*, 2000). Here occupancy is seen as inextricably linked with the responsibility for stewardship. Aboriginal concepts may not preclude resource use but rather support wise use (Berkes *et al.*, 1998; Sly, 1995)

Prior to the contact period between Europeans and Aboriginal peoples (Section 2.4.2), Aboriginal "rules" for stewardship of land, animals and people kept people in balance with natural resources (Legat, 1998a; Johnson & Ruttan, 1993; Zamparo, 1996). This was essential, since people's survival depended on such reciprocal relationships. Traditional knowledge provided the basis of such rules, and beliefs and myths gave reinforcement to the approach. Values and beliefs leading to moral code or environmental ethic are an important part of traditional knowledge.

One of the most important aspects of this form of stewardship was respect, and this included not only respect for other people but, of equal and sometimes of greater importance, respect for the land and the animals and their spirits. Such respect ensured that nothing was wasted, animals were killed only for necessities, and that as far as possible the kill was quick and clean. Also, disturbance of other animals was kept to a minimum. The role of traditional knowledge reinforced by belief made the practice of Aboriginal stewardship very effective. Contemporary relationships (between people and their use of resources, Section 3.2) are generally weaker.

Many Aboriginal communities pursue a mixed economy to gain cash to support traditional activities (*e. g.* hunting, trapping, fishing, crafts, carving and other domestic activities), aiming for sufficiency rather than accumulation. Subsistence activities are an important part of "the reason for being" and they are the hub around which other economic activities move. Subsistence activities are of vital importance in maintaining cultural identity and self-worth, and sustainable use of resources is not just a biological issue but one that involves social, economic, legal and many other issues (Freeman, 1997). Constant levels of take are rare, because Arctic and sub-Arctic ecosystems are naturally highly variable and many activities are sustainable only when they respond to the rhythm of the environment (which also includes people (Freeman, 1997). A renewable harvest that meets some distant consumer demand, rather than being consistent with local productivity, is not sustainable.

Generations of people have made their living in the WKSS area by harvesting country foods (such as ducks, geese, fish, caribou, Moose and Muskoxen), and if future generations are to continue this practice, carrying capacities should not decline and neither should abundance of the wildlife resource.

To be viable, wildlife populations must be large enough and sufficiently dispersed to withstand losses due to weather, starvation, fire and disease (Sections 2.3.4.4, 4.2.1.5 and 4.3.1). For some wildlife, isolation is important, even though a particular habitat may be required for only a very short period of time (*e. g.* calving grounds of Barren-ground Caribou). Further, all species of a community should continue to interact with one another to maintain system integrity. This includes predator-prey relationships such as those among caribou, wolves and carrion-eaters (Sections 2.3.4.5 and 4.2.5).

Some species are naturally more abundant or have higher rates of replacement than others and resource use can reflect this. There are special concerns, however, for species of low abundance. Once extinct, species can not be brought back (*e. g.* Woolly Rhinoceros, Mammoth, and Sabre-tooth Cat that were present in the glacial refugium of the northern Mackenzie Valley only 10,000 to 14,000 years ago (Harrington, 1978; Kurten, 1988)). Also, even if similar replacement groups of wildlife could be introduced, they might not carry appropriate adaptations or behavioural characteristics. Adaptations like the winter changes that occur in the burrowing feet of Collared Lemmings or the hooves of Barren-ground Caribou, behavioural responses learned as juveniles in wolves and Muskoxen, or the migratory instincts of Arctic Char are not likely to evolve over short periods of time.

To maintain a balance within the ecosystem, development should occur in ways that meet the needs of both people and the ecosystem. For example, mining is a short term activity, perhaps a few decades in duration at most locations, but technologies exist to return many areas to a productive form (though perhaps different from an original state). This type of activity should represent only a temporary loss of natural renewable resources if its development, including reclamation and closure, is well managed. In most areas, including the WKSS area, development occurs not as a single activity but in the cumulative form of many activities. Knowing the potential effects of various activities and having a greater understanding of the environment and the effects of these activities will certainly help to reduce the negative effects of development.

5.1.2. Cumulative Impacts

As general terms, both environmental impact and cumulative impact have been used many times already in this report but further clarification is useful to more fully appreciate their significance in relation to sustainable development. Figure 25 illustrates the fact that temporal and spatial scales of effect increase as the level of impact rises from an individual of a species, to a population of that species, to the community in which that population is a member, to an entire ecosystem. The implication to be drawn from this is that any attempt to characterize or monitor change must be appropriate to the scale of effect as well as the level within the ecosystem at which the effect is occurring. Indicators of stress effects at the level of an individual are not likely to be well suited to characterize stress effects in a community and the adage that *"you can't see the forest for the trees"* exemplifies the need for appropriately integrated forms of indicators suited to different levels in the ecosystem.

The upper panel of Fig. 26 illustrates how components are often related in an environmental impact matrix (*e. g.* an environmental component such as a tailings pond, and project actions such as operation or reclamation). It also shows how several environmental impact matrices combine to produce a cumulative impact in which the total effect may be greater than the sum of individual parts. The lower panel of Fig. 26 illustrates some of the human perceptions of changes in state that can result from various forms of stress effect, and which can apply to any level within the ecosystem. In very simple terms: increasing stress results in degradation; relaxing stress allows for remediation or enhancement; preserving means, essentially, no change; and conserving means limiting further degradation. Figure 27 indicates that interactions associated with cumulative impact become increasingly complex, and the effect of rising stress from cumulative impact would be to steepen the trend of degradation (Fig. 26).

The state of human communities can be degraded, conserved and enhanced just as the state of animal communities, or the environment in which both exist. Many forms of response to stress, whether environmental or human, are non-linear and effects may not be easily discerned until some type of threshold has been crossed, resulting in a new state of being. All such changes relate to both singular and multiple impacts. Once an environmental threshold has been crossed, change is not exactly reversible although something similar to a pre-existing condition may be re-established. This applies just as much to the human condition as to other living components of the environment. It is important to be able to recognize early warning signs appropriate to various thresholds.

As a further complication, and because the process of reversing degradation across a threshold is moving against natural tendencies toward disorder, more energy and effort are required to correct an undesirable condition than to create it, hence the precautionary principle.

The adoption of "themes" could provide an effective means of cumulative effect monitoring because, by their nature, they are an integrated form of indicator. Themes include trends in the natural environment, economy, community characteristics and human health (NPC., 1997). The health of the environment could be indicated by selected measures of water and air quality, and population and habitat characteristics of selected fish and wildlife (including birds). The economy could be reflected by selected measures of natural resource harvesting, wage employment, commercial and industrial activity and consumption. The community might be characterized by some measures of demographics, services, health care, education, community activities and culture. Health, social equity, safety and security could provide additional indicators of the quality of life.

5.1.2.1. The Global Context: UNEP - GLOBIO Study

The GLOBIO study (Global methodology for mapping human impacts on the Biosphere) forms part of the UN Environmental Program. It provides an example of a recent and very large scale assessment of cumulative impacts of human activities on the environment. GLOBIO is intended for application at a global scale and a recent pilot study has been applied to the Arctic as a whole. Much of the information for the pilot study has been drawn from northern Scandinavia and Russia (west of the Ural mountains). Many aspects of the methodology used by the pilot GLOBIO study are generally applicable to the needs of cumulative impact assessment in the WKSS area. However, regional characteristics of the WKSS area would require significant change to existing components of the GLOBIO study. For example, because most taiga and tundra environments are characterized by only a few species of highly specialized plants and animals, density (abundance) is a more useful indicator of ecological health than diversity. The development of roads and various forms of infrastructure, and increasing zones of influence along road and pipeline corridors provide a powerful image of increasing cumulative impact over time. This form of output would be just as appropriate for the WKSS area as it has been for the GLOBIO plot study.

The GLOBIO study has a strong environmental focus and links different groups of information. The lower group includes:

off-site reduced abundance or survival of wildlife;
fragmentation and, or, loss of habitat;
physical destruction of habitat;
pollution, waste material, and noise;
and growth of non-indigenous settlements and, or, immigration.

The middle group (at a conceptually higher level of integration) includes:

increased pest species, overgrazing, more predation, and disruption of natural buffer mechanisms;
health risks, deforestation, decertification, land and water degradation;
social conflicts, increased competition for grazing land, hunting and fishing.

The upper group includes:

land and water degradation, loss of biodiversity, increased poverty and social conflicts.

The pilot study includes model projections of three growth scenarios: a stable infrastructure growth rate based on conditions between 1940 and 1990 extrapolated to 2050; a reduced growth rate of 50 per cent and an accelerated growth rate of 200 per cent. The methodology and conclusions have been subject to scientific peer review (UNEP, 2001). Citing from a recent UN press release (UNEP, 2001):

"........................ Findings have come from a pilot of study of UNEP's Global methodology for mapping human impacts on the Biosphere (GLOBIO) which for the first time looks at the cumulative impacts of human activities on the environment. Previous work in this area has detailed the impact on habitats, ecosystems and wildlife close to a development. But this new study draws on the conclusions of some 200 scientific studies from around the globe. These are shedding new light on how human activities not only affect the environment close by but trigger significant changes and disturbances considerable distances away from a road, settlement, mine or other infrastructure development. Some of the impacts are immediate whereas others are cumulative, gradually undermining the ecosystems upon which humans and wildlife depend for food, water and shelter. The pilot study has focused on the Arctic ....

Wildlife Studies of more than 100 species show that some Arctic animals will suffer more than others as the region becomes more industrialized. Animals avoid areas near infrastructure, breeding success decreases in developed areas and habitats become fragmented. The ecological impacts of losses of habitats and redistribution of animals away from development may also substantially affect foraging success or survival in areas beyond these initial zones of disturbance and hence result in overgrazing, erosion and reduced breeding success ....

Arctic roads quickly reduce the abundance of Reindeer and caribou five kilometres from the highway; the populations of large predators such as wolves and bears are affected two kilometres from the development and birds one kilometres from the infrastructure.

Sensitivity is particularly high in the Arctic. Reindeer and caribou are among the most sensitive species in the Arctic to human activity, often reducing the use of grazing grounds by 50 per cent to 90 per cent within four to 10 km of roads, power lines or resorts. Large Arctic carnivores abandon areas when road densities reach typically around 0.5 to 0.6 km/km squared ....

Arctic birds suffer when development leads to drainage of wetlands. They also suffer from traffic noise as a result of the building of new roads. Studies indicate that a variety of bird populations can fall by as much as 44 per cent up to 1.5 km from a new road.

The cumulative impacts of the kind of piecemeal development now taking place in the Arctic is having even wider impacts on the region's ecosystems as result of longer term changes in features such as hydrology, pollution levels and the condition of the permafrost and tundra ....

A new road may affect the abundance of wildlife up to five kilometres away, but the cumulative impacts on their ecosystems can be detected up to 20 km away ....

The cumulative impacts of power lines and pipelines can spread up to 16 km away from where they are physically located. The ecological footprint of human settlements ("haloes"), *including cities, towns and mining or oil exploration camps, can disturb ecosystems up to 40 km away.*

.... there are *likely to be winners as well as losers among the Arctic's wildlife with animals adapted to scavenge benefiting at the expense of those with more specialized life styles.*

By 2050 there are *likely to be less migratory birds and mammals like Arctic Foxes and Reindeer but more gulls, Red Foxes, and crows. Basically human kind's interference in the delicate, ecological, balance of the Arctic will allow the scavengers and marauders to take over the scene at the expense of more specialized birds and mammals, which will decline and even, in some cases, disappear. With new infrastructure such as a road there is a whole chain reaction ....*

Powerlines and pipelines have relatively little short term impact on Arctic vegetation. Changes in snow cover and minor disturbances in soils normally only occur up to 500 metros from such structures.

Cumulative, longer term, impacts are likely to be felt further afield. Disturbance to vegetation from power line and pipelines may affect ecosystems up to two kilometers from such infrastructures as a result of changes in the permafrost and damage from off-road vehicles used to service and maintain such structures.

The cumulative impacts on vegetation of a road can be detected up to 10 km away by changes to the sensitive permafrost and water discharge, by bringing in hunters or logging companies in forested areas. Human settlements can impact the vegetation of local ecosystems up to 30 km *away ....*

Many different groups of indigenous people, including the Saami, Nenets, Komi and Chukchi of Eurasia and the Dogrib, Cree, Innu and Yupiit of North America, rely on hunting and herding of reindeer and caribou.

Such peoples have, over thousands of years, developed social networks, traditions and cultural life-styles based on the movements of these animals.

But the GLOBIO report warns that the industrialization of the Arctic threatens the traditional existence of many indigenous peoples.

Northern Scandinavia and parts of Russia are examples of areas where the current growth of infrastructure related to transportation, oil, gas and mineral extraction is increasingly incompatible with land requirements for reindeer husbandry. In these areas infrastructure growth is associated with the loss of traditional lands and conditions forcing indigenous people to abandon nomadic herding patterns for more sedentary life styles Future industrialization is likely to affect the lives and cultures of indigenous peoples in Alaska, Canada and Greenland as many of their traditional foods and activities gradually disappear.

This first report is on the Arctic but work is proceeding to map and assess human impacts on a global level. All the environmental problems we are grappling with today - health, pollution, resource conflicts and land and water degradation - is the result of heavy impacts on less than 20 per cent of the Earth's land area. Imagine the scale of environmental problems globally when we reach a 50 to 80 per cent level of impact in less than 100 years ....

GLOBIO is not science fiction or doomsday predictions. It allows us to chronicle with far greater accuracy land and water degradation processes that have resulted from the human expansions of the last 50 years ...."

Other highlights from the GLOBIO report indicate *"that up to 80 per cent of the Arctic will be affected by mining, oil and gas exploration, ports, roads and other developments by 2050 if the industrialization of one of the world's last wilderness areas continues at current rates.*

Scientists with the United Nations Environment Programme (UNEP) are warning that the Arctic's rich and abundant wildlife will suffer with birds and larger mammals such as Reindeer, caribou, Polar Bears, wolves and Brown Bears (Grizzly Bears) *at greatest risk.*

At the turn of this new millennium less than 15 per cent of the Arctic's land was heavily impacted by human activity and infrastructure. However, if exploration for oil, gas and minerals, developments such as hydro-electric schemes and timber extraction continue at current rates, more than half of the Arctic will be seriously threatened in less than 50 years.

This will lead to increasing pressure on the life-styles of indigenous peoples as well as on precious habitats and ecosystems in an area of the world vital for wildlife and for regulating the Earth's climate ....

In the last part of the 20th century, the Arctic has been increasingly exposed to industrial exploration and exploitation as well as to a growth in tourism. The growth in oil, gas and mineral extraction, transportation networks and non-indigenous settlements are increasingly affecting wildlife and the welfare of indigenous people. Various plans are under way to extend the infrastructure and development into new regions such as the Yamal Peninsula of Russia, the Arctic National Wildlife Refuge in Alaska and the Barents Sea region.

Plans are also well advanced to open up a vast new seaway around the roof of the world. The Northern Sea Route, a 5,600 km stretch of water running from the Barents Sea in the west to the Bering Strait in the east, could significantly reduce the sailing time from Europe, Scandinavia and Russia to the Far East.

However, experts are concerned that the development of the route is primarily intended to exploit the rich oil, gas and mineral resources of Siberia. The start of just part of the route will result in a previously unknown level of industrialization of Siberia. This will add to pressures on the Arctic generally as a result of a sharp rise in the number of ships operating in the region, port and road developments and improved access to new oil, gas and mineral fields.

Infrastructure brings primary industrial development but also secondary, more uncontrolled development, in terms of increased human immigration and settlements. These in turn increase the risks of deforestation, overgrazing, social conflicts, pollution of water, land degradation and fragmentation of habitats .... Findings show that even with stable rates of industrial growth, mirroring those that have occurred in the latter part of the last century, an estimated 50 per cent to 80 per cent of the Arctic will reach critical levels of human-induced disturbance by 2050.

The report estimates significant human disturbance even at lower growth rates of infrastructure.

It concludes that 40 per cent of the region's wildlife and ecosystems will be critically disturbed by 2050 if growth occurs at half or 50 per cent of levels seen since the period 1940 to 1990.

If infrastructure growth accelerates, doubling or increasing by 200 per cent over the same period, 90 per cent of the Arctic will suffer significant human-induced disturbance by 2050.

.... *Vast tracts of the Arctic are designated as protected areas. However, many key ecosystems are poorly protected, particularly in the southern part of the Arctic, where most of the development is happening."*

5.1.3. Planning for Sustainable Development

Limiting the extent of environmental impacts is clearly a very important part of the process of sustainable development, but more is also required. Sustainable development seeks to meet broad community objectives by creating positive conditions that are beneficial to people. Using an earlier example, mining has the potential to be disruptive of the local environment, while also having the potential to provide for present and future betterment of both Aboriginal and non-Aboriginal societies in the WKSS area. The potential for betterment, however, depends just as much on how economic gains affect and are used within communities as it does on the ways in which development takes place. To achieve sustainable development it is necessary not only to respond to activities as they occur, but to direct development towards an objective. In its most basic form, development should meet three essential and equal objectives. Ideally, none should be pursued to the detriment of another:

an economic objective .... production of goods and services;
a social objective .... maintenance and enhancement of quality of life (including culture);
an ecological objective .... maintenance, and, or, enhancement of environmental conditions.

Objectives have to be realistic and in the WKSS area it is important to know, for example:

- what short term products and services are possible and desirable;
- what long term products and services are possible and desirable;
- what are the infrastructure needs for communities;
- what are the educational needs for the future of communities;
- what forms of decision-making would improve community involvement;
- what can be done to improve community wellness; and
- what level of dependence on country foods is desirable.

Although these and similar sets of information would be an invaluable guide, sustainable development requires something more, again. Process is another component of sustainable development and has a major influence on the extent to which people are willing to support the concept. Information and expert support have to be readily available to all parties, there has to be sufficient time for discussion, and above all, decision-making should be transparent. Objectives should be formulated around some form of overall vision of what people want, and the clearer the vision and the more people that share it, the stronger it becomes. The use of visioning and forward-looking objectives as part of the overall approach is possibly one of the most challenging issues to be faced in adopting the concept of sustainable development.

Though seemingly simple, the concept of sustainable development poses extremely complex questions that must be set against a framework of continuing change in both time and space. Further, what does sustainable mean in terms of the WKSS area? Does it mean sustainable only in terms of the resources of the WKSS area, as in “self-sufficient”, or the sustained present use of WKSS area renewable resources, as in “self-sustaining”, or something else such as self-reliance? Indeed how far can the WKSS area think of itself as an “island”, isolated from what goes on around it?

In several ways, already, there have been significant advances within the WKSS area toward sustainable development. Many steps have been taken, particularly over the past decade, such as devolution of legislative and administrative authority, land claim agreements, co-management agreements and impact-benefit agreements.

Sustainable development is a vision which must be constantly striven for. If sustainable development will be achieved through human decisions and actions, then good tools will be needed to make good decisions.

5.2. Tools for Achieving Sustainable Development in the WKSS Area

5.2.1. External Stresses: Actions by Northern and Aboriginal People

Global climate change is likely the greatest environmental threat facing the WKSS area. It is also one of the greatest threats facing the world as a whole. The potential for ecological disruption is at a scale entirely greater than the sum of all current and proposed development in the WKSS area. It is beyond the direct control of the residents of the region, or even of Canada itself, and can be dealt with only in international meetings at the highest levels (Sections, 4.2.1, 4.2.3.1, 4.2.3.2). There is global concern because a prompt and significant response by the international community appears to have stalled. The 1997 *Kyoto Agreement*, to reduce global greenhouse gas emissions required developed countries to cut emissions by 2012, while allowing developing countries to make individual commitments. It would have allowed for emission trading. The United States has not ratified the Treaty and recent indications suggest that US legislation to reduce CO_2 emissions from power plants will not receive key support. In Canada, many provincial governments (that are responsible for energy policy) remain uncertain of future policy directions. In Alberta, for example, increased power production from coal-fired plants is expected to raise emissions over the next decade to about 40% above the 1990 level. Yet under the *Kyoto Agreement*, Canada agreed to cut 2012 emission levels to 6% below those of 1990; emissions are presently about 13.5% above 1990 values (McIlroy, 2001).

A study of traditional ecological knowledge (Thorpe & Kadlun, 2000) known as *Tuktu and Nogak* (caribou and calf) has begun to document Inuit knowledge of the caribou. In this study, elders have also described the effects of climate change on caribou and other species, their distributions, land use and feeding patterns, population changes, the influence of ice conditions on migration routes, behaviour, vegetation changes and numerous other characteristics of the environment in and around Bathurst Inlet. Again, the study has pointed to the disconnect in information transfer between youth and elders. At Bathurst Inlet, the *School of Tuktu* (Thorpe, 1998) has been used as an aid to record Inuit knowledge of caribou and also to involve youth through participation in an Elder-Youth camp. This and similar activities in other Aboriginal communities provide an important move to avoid the darkness of forgetting and the future exclusion of traditional knowledge from sustainable development.

A recent example of northerners, including people from the WKSS area, taking action on external stresses may be seen in the *Whitehorse Declaration on Northern Climate Change* (Circumpolar Climate Change Summit and Exposition, 2001). In this declaration, experts take responsibility and seek to focus the attention of policy and decision-makers on key northern issues, and the need for effective actions .... locally, regionally and globally. It reflects increasing concern, particularly among northern residents, at the rapidity of climate change and the extent to which it may affect sensitive Arctic and sub-Arctic environments.

"Whereas we recognize that residents of the Circumpolar North are witnessing disturbing and severe climatic and ecological changes; and,

Whereas we recognize that this interdisciplinary issue requires an unprecedented level of collaboration by all nations and all sectors of their societies; and

Whereas we recognize that Northern residents need to take stronger measures to reduce their *own greenhouse gas emissions, and we also recognize that, regardless of the success of these measures, the Circumpolar North will remain highly reliant upon global actions to reduce greenhouse gas emissions;*

Therefore, we the undersigned participants at the Circumpolar Climate Change Summit, held in Whitehorse, Yukon, Canada, on March 19th to 21st, 2001, declare that the following actions need to be taken to address climate change and its impacts in the Circumpolar North:

1. We must develop a strong northern message on the effects of climate change and present this message nationally and internationally;

2. We must use traditional knowledge and improve our scientific capacity to understand climate change impacts on northern ecosystems, economies, cultures, traditions and communities;

3. We must develop tools that will enable communities to better understand climate change, reduce their greenhouse gas emissions, and adapt to changing climatic and environmental conditions;

4. We must ensure that all new and existing policies, standards, regulations, legislation, and management agreements become consistent with the goal of reducing greenhouse gas emissions and our vulnerability to climate change;

5. We must establish effective incentives and remove the many barriers to improved energy efficiency and the widespread use of renewable energy; and,

6. We must ensure that all institutions, businesses, governments, families and individuals take far stronger measures to reduce greenhouse gas emissions."

The threat posed by atmospheric transport of pollutants is another major concern in the WKSS area, and there are two main issues associated with LRTAP. The first relates to mercury. While levels of many persistent organic contaminants are showing signs of decline in the WKSS area (or, at least, they are no longer showing a significant increase), levels of mercury may not be in decline. Mercury contamination is of most particular concern in some species of fish (such as Lake Trout and Walleye) which are an important traditional food for many Aboriginal people in the WKSS area,. High levels of mercury are also present in seals and Beluga. Mercury contamination is spread through the processes of LRTAP and fuel combustion for power generation is one of the most important sources of emission. Mercury from coal and oil is released together with greenhouse gas emissions and, if CO_2 emissions continue to increase, it may be expected that concentrations of mercury will also increase. Control technology is not yet capable of providing sufficiently reduced levels of greenhouse gas and heavy metal emissions from the combustion of fossil fuels.

While persistent organic contaminants are not generally thought to be a health concern in the WKSS area (Papik, 1998), they provide a good example of the effectiveness of northern aboriginal interventions and lobbying. Studies undertaken as part of the first phase of the *Northern Contaminants Program* made a significant contribution to the *UN protocol on Long Range Transport of Pollutants* that was signed in Denmark in 1998. The protocol comes into effect after the signature of 16 countries and will apply bans, limits to use and loss, and manufacture of 16 persistent organic contaminants; it is similar to the UN protocol for cadmium, lead and mercury (Stone & NCP Management Committee, 1999). These protocols address, mostly, the more industrialized countries of Europe, Scandinavia and North America. The second phase of the *Northern Contaminants Program* is contributing to discussions on a much more inclusive UN *Protocol for Persistent Organic Pollutants* that began in Kenya (1999) and are likely to continue through 2001 (Stone & NCP Management Committee, 1999). One of the most important aspects of this protocol will be to influence international manufacture and use of selected persistent organic contaminants (Banks, 1998). Early criticism of the Federal Government's approach to protocols on persistent organic pollutants suggested that it gave too much emphasis to aspects of economics and trade and not enough to concern for public health (Keith, 1998). However, over the period of ongoing negotiations, Aboriginal concerns and involvement have received significantly greater recognition (Fenge 1998; 2000). As noted by Fenge (2000):

"Although few in number, Inuit and other indigenous peoples in the Arctic have influenced international negotiations towards a global convention on persistent organic pollutants (POPs) out of all proportion to their numbers through research, public education, and co-ordinated advocacy and lobbying. This fact is important internationally, for what they have done in the global POPs process - to the benefit of all Canadians - can be repeated in other global environmental negotiations that address Arctic concerns such as climate change, ozone depletion, and perhaps even biodiversity conservation. In particular, the Canadian Federal government should learn an important lesson: northern indigenous peoples lobbying from their unassailable high moral ground can, in partnership with the federal agencies, achieve foreign policy objectives that Canada alone may not".

At of the end of 2000, it is unclear whether a global convention on POPs will be concluded and whether its provisions will be strong enough to address health concerns across the Arctic, but there is no doubt that Canadian Aboriginal peoples have contributed greatly to any success that may be achieved.

It is gratifying to note that, as preparation of this report draws to a close, delegates from more than 100 countries adopted a UN convention on dangerous chemicals on May 22nd., 2001, in Stockholm. A total of 50 countries must ratify the treaty to make it legally binding and Canada will be one of the first UN members to do so. The treaty (evolved from the *Protocol for Persistent*

Organic Pollutants) will ban or severely restrict the use of 12 persistent organic pollutants (aldrin, chlordane, DDT, dieldrin, dioxins and furans, endrin, heptachlor, HCB, mirex, PCBs and toxaphene). Contributions by Canadian Aboriginal people have, been, indeed, significant!

5.2.2. Environmental Management

There are stresses associated with exploration and mining, transportation and waste management, and concerns are routinely raised at public hearings regarding effects of such activities on the environment. There are also legacies from past activities which remain to be addressed and conditions raised to current standards.

Environmental management and approaches to improving community well-being in the WKSS area are evolving as a result of a number of processes, notably negotiation and settlement of aboriginal claims. The processes include establishment of co-management bodies for land use planning; permitting, assessing, reviewing and monitoring development proposals, and managing wildlife, water and protected areas. Legislation envisions cumulative impact monitoring programs in the WKSS area and regular audits to evaluate cumulative effects of development and the effectiveness of institutions are included in the *Mackenzie Valley Resource Management Act* (MVRMA) passed in 1997 (MVRMA, 1997).

Many of the approaches used in past environmental management have been inadequate and would not meet current standards. As reported by the NCP (1997), there are numerous dumps of waste material throughout the WKSS area. Many of these contain contaminants and one of the most important actions required continues to be removal and clean up many of these sites (Keith, 1998). It has been estimated that as much as 0.2% of the surface of the Yukon and NWT has been contaminated by PCBs from DEW-line sites (Furgal & Keith, 1998). There is also need for remedial work at a number of mine sites, municipal waste dumps and abandoned camps, and to stop further dispersal of contaminants.

In the WKSS area, there are different patterns of land and resource ownership, and associated legislative, regulatory, policy and management regimes. These, combined with the various states of settled and unsettled land claim agreements, have created new opportunities for achieving sustainable development. At the same time, many of the organizations within these new regimes are young and their operations are not yet standardized, nor are the relationships among them fully established. Their track records are too short to allow for detailed evaluation of their effectiveness in moving toward sustainable development, or in implementing the aboriginal values and world-view that have strongly influenced the negotiations which led to their development. This condition has created a legal framework for non-renewable resource development that is both complex and in transition (Alex Kerr Compass Consult. & Michael Doggett and Assocs, 2000b).

5.2.2.1. Settlement Agreements

Although there are many points of similarity among the settlement agreements that have been and are being negotiated between Aboriginal groups and the Federal Government, there are many significant differences that reflect both a degree of autonomy and a degree of protection sought by individual groups (Fig. 16, INAC., 2000d). All settlements result in a transfer of title over significant amounts of land in a claim area to claimant groups, with the balance of land and resources in a settlement area remaining under the ownership of the Crown and managed through co-management mechanisms.

Only one settlement agreement has been completed in the WKSS area. *The Nunavut Final Agreement* (NFA) was completed in 1993 (INAC., 1993). The NFA establishes several co-management institutions including the Nunavut Planning Commission, Nunavut Impact Review Board, Nunavut Water Board and Nunavut Wildlife Management Board as Institutions of public governance. The NFA also led to division of the then Northwest Territories into Nunavut and the Northwest Territories on April 1, 1999.

The creation of Nunavut Territory under the NFA has changed the face and nature of government in Nunavut. The vast majority of the population is of Inuit descent and the legislature and government directly reflect this. The negotiators of the NFA envisioned public government and NFA beneficiaries working together for the benefit of Inuit and all residents of Nunavut in a way that reflected the values of the residents.

The Dogrib Treaty 11 Council signed an Agreement-in-Principle (INAC., 1999b; 2000e) in 2000 and it is expected that a final agreement will be signed in 2001 or 2002. Co-management is a significant element of this claim as well. Co-management bodies charged with resource management under the Dogrib claim will be established through the MVRMA. This is the same legislation which has established co-management bodies under the Gwich'in and Sahtu settlements.

The Akaitcho Treaty 8 claim is far from the agreement-in-principle stage, and there are questions as to how far the claimants input will be sought at present, and included in resource management decision making.

The negotiation and implementation of Aboriginal land claims and self government agreements have created an environment and to some extent, mechanisms to address long standing socio-economic issues (Sections 3.4 and 4.3). Self-government agreements empower Aboriginal communities and enable members to play a prominent role in health, social, education, housing and governance decision-making boards and agencies. These and other agreements also encourage active Aboriginal participation in finding and implementing sustainable social and economic solutions for building healthier communities. Compared to directives or expertise from outside the community, home-grown solutions have local ownership and therefore, tend to be more successful. Land claims and self government agreements are contributing to more Aboriginal decision makers, managers and service providers and these people are a source of pride among elders and a powerful motivating force for future generations. While there is little doubt that land claims and self government agreements are strengthening Aboriginal communities, limited human capacity and past legacies continue to thwart best efforts to engage individuals in activities that will improve their own or their community's circumstances.

In unsettled claim areas, the legal and policy framework applicable to the minerals sector provides few opportunities for Aboriginal participation in the rights issuance process (*e. g.* mineral claims or land leases). On settlement lands where sub-surface title remains with the Crown, commercial interests can acquire mineral rights, but are required to have to have consent to enter on to Aboriginal lands, with disputes resolved by a surface rights tribunal (INAC., 1993). The concerns and interests of Aboriginal groups are generally considered in relation to exercise of such rights by co-management institutions during the regulatory process (INAC., 1993; 2000e). New case law (*i. e.* Delgamukw) suggests that in the absence of a land claim agreement, the Government of Canada is obliged to consult with Aboriginal groups before making land and resource management decisions (Alex Kerr Compass Consult. & Michael Doggett and Assocs, 2000b).

In areas without settlement agreements, the legal and policy regime provides limited opportunities for participation in the management of lands and resources (including the protection of lands and resources). While there are some measures for consultation, a more direct role in decision making about where and how resource development activities will take place is lacking (Alex Kerr Compass Consult. & Michael Doggett and Assocs, 2000b).

5.2.2.2. Co-Management Boards

Co-management boards in the WKSS area are generally structured so that half of their membership are nominated by the government (combination of territorial and federal as appropriate) and the remaining half by claimant groups. In all cases the Minister (of DIAND) appoints the members and retains the right to approve, reject or send back the recommendations of a co-management body. However, the Minister must provide reasons where his decision varies from the recommendations of a board.

The appointment of Aboriginal chairmen has raised the stature of co-management in many northern communities. It has certainly helped all parties to appreciate and work towards better ways of communicating and involving northern communities. Over time, a level of trust has begun to develop in many boards and this is seen to be an extremely valuable outcome (Morgan & Henry, 1996). For the most part, decisions reached by the co-management boards have been supported by the organizations represented and to this extent, the boards have achieved something more than an advisory capacity. It is also recognized that trust and respect is something hard to gain and easily lost. Also, several boards have requested that agencies keep the same people as their representatives, in part because of trust but also because of the process of cultural understanding that is evolving at the board level.

The Nunavut Wildlife Management Board was established in 1994 and is responsible for policy and management of wildlife throughout Nunavut, and for some species (*e. g.* caribou) there are specific management boards. Other co-management institutions include: the Nunavut Planning Commission that is responsible for planning and regulation of land use, the Nunavut Impact Review Board that is responsible for environmental assessment and review of projects in Nunavut, the Nunavut Water Board that is responsible for water use, and the Surface Rights Tribunal that deals with entry and compensation to holders of surface rights (NPC., 1997).

The MVRMA is intended to be the vehicle for establishing co-management boards throughout the NWT, with the exception of the Inuvialuit Settlement Area which pre-dates the Act. The MVRMA establishes co-management boards for land use planning, land and water management, and environmental assessment and review within settlement areas. The Act enables co-management boards to be established throughout the entire geographic area under the Act, and to cover activities in as yet unsettled areas and activities which may affect more than one settlement area. To date, all claim areas except Akaitcho Treaty 8 have either nominated members or are in the process of selecting nominees.

The oldest co-management board in the WKSS area which was created through an aboriginal claim is the Nunavut Wildlife Management Board, which is seven years old. Many of the boards currently operating in the WKSS area have lifespans much shorter than this, and the Mackenzie Valley Land and Water Board was created most recently (2000). It will be important to evaluate the effectiveness of these boards and their decisions once they have established a track record.

Responsible management can only take place where information and an understanding of it are sufficient to make good decisions, and it can only be effective when it involves all of the interested parties; in the WKSS area, they include both Aboriginal and non-Aboriginal peoples. Across the North, there are many examples of evolving co-management (Berkes, 1994; Berkes *et al*., 1991; Feit, 1988; Haugh, 1994; MacLachlan,1994). They include resource management boards that issue licenses and set quotas, and many of these have strong representation from local trappers, hunters and outfitters associations (Gunn *et al.*, 1988). However, many of the present and future issues can not be resolved by one agency alone (even though it represents multiple interests). For example, discussions to establish the proposed Tuktut Nogait National Park (northwest of Kugluktuk, Fig. 1 (Seale & Cozzetto, 1997)) involve the Inuvialuit settlement region, the Nunavut settlement region, the Sahtu Dene settlement region, and Parks Canada. The discussions are extremely important, not only because there are differing interests among the parties, but also because the park will span three land claim settlement regions and because it covers much of the calving ground of the Bluenose Caribou herd (Hall, 1989). Managing use of the herd and monitoring its health and population size in this area will require considerable cooperation and sharing of information, and it will be further complicated by the need to understand the extent to which this herd may mix with the adjacent Bathurst Caribou herd and, possible movements across the Dolphin and Union Strait to Victoria Island (NPC., 1997). Inclusion of some of the Arctic-island Caribou may also occur (Hall, 1989). Similar problems exist in managing use of the Bathurst Caribou herd which may also mix, in part, with the Beverly and Queen Maud Gulf Caribou herds (Section 4.2.5).

5.2.2.3. Environmental and Cumulative Impacts; Assessment, Review and Monitoring

Environmental assessment in the WKSS area has experienced a rapid evolution in the past few years. The MVRMA established approaches to land, water and environmental management that consider environmental, social, cultural and economic impacts (including cumulative impacts) of non-renewable resource development. The Act is seen as providing a foundation for ensuring that non-renewable resource development occurs in a way that promotes sustainable development.

Environmental assessment has moved from a regulatory process led by DIAND to a multi-stage process where proposals receive preliminary screening by the Mackenzie Valley Land and Water Board or another agency, depending on the permit applied for. If a proposal meets certain criteria it is sent to the Mackenzie Valley Environmental Impact Review Board (MVEIRB) for environmental assessment. The environmental assessment may recommend a full environmental review panel. Where a project has impacts beyond the Mackenzie Valley, it may also require review under the *Canadian Environmental Assessment Act* (1995) or by the National Energy Board.

The BHP Diamonds Project panel review was undertaken under the Federal Environmental Assessment and Review Process (prior to establishment of the Canadian Environmental Assessment Agency (CEAA)). The Diavik Diamonds Project was reviewed under a Comprehensive Study process managed by DIAND, and this review was still underway when the MVRMA came into force. All future reviews will be done by the MVEIRB under the MVRMA. A number of difficulties associated with the early hearings (Anon., 1996; Can. Inst. Res. Law, 1997) have been addressed as participants have become more familiar with process and requirements. However, the need for sensitivity to social and cultural needs of Aboriginal communities and to provide sufficient time for all parties to contribute effectively to the assessment process remain a concern (MVEIRB., 2000d).

Most environmental assessment processes now include a requirement to include Traditional Knowledge in the assessment. Traditional knowledge carries with it the potential to be a highly valued commodity and one that can contribute greatly to the effective application of sustainable development. It is neither a threat to environmental assessment, nor is it of only marginal value (Stevenson, 1997). Traditional ecological (environmental) knowledge carries with it information about the land and its use by various Aboriginal peoples, and their experiences and understandings of the regional environment as a whole (Legat *et al.*, 2000), and the changes that have occurred within living memory and before (as noted throughout this report and particularly in Section 4).

Aboriginal and non-Aboriginal groups may be limited in terms of their capacity to assess the information that is presented (Alex Kerr Compass Consult. & Michael Doggett and Assocs, 2000b).

The NFA envisions a Nunavut General Monitoring Program (NGMP) to determine the state and health of ecosystems in Nunavut. The NGMP is also under development, with the West Kitikmeot region of Nunavut serving as the initial monitoring area.

In addition to these agencies and programs mandated by legislation, a number of other, non-legislated organizations have been created or are under development. Subsequent to the BHP Panel Review an environmental agreement was negotiated between the Federal Government, the GNWT, BHP and aboriginal organizations from the WKSS area. Among other things, it established an Independent Environmental Monitoring Agency (IEMA) as a watchdog over the environmental activities and reporting by the proponent. The IEMA monitors BHP’s activities and reviews environmental management plans and reporting, but does not collect primary data. A similar agreement has been negotiated with Diavik, establishing an Environmental Monitoring Advisory Board. These two organizations are set up as registered societies funded by the proponents and managed by nominees of the signatories to the agreements. In both cases, monitoring activities do not extend to social or economic conditions although socio-economic monitoring is the subject of an agreement between the GNWT and BHP Diamonds.

The IEMA was tasked to follow "the ecosystem approach", that is to take a holistic approach and it has noted that this may be difficult given the constraints related to its terms of reference and its dependence on BHP for funding (IEMA., 2000). The agency also states that there is a growing need to consider the effects of cumulative impacts at the mine site that already extends over 6.9 km^2, and to recognize that these may further increase as a result of operations at the new site of the nearby Diavik mine (see also, MVEIRB., 1999). The independent monitoring agencies need to be able interact at the two mine sites (IEMA., 2000). There are further issues of substantial importance related to the proposed Snap Lake and Jericho diamond mine which may also contribute to cumulative impacts (*e. g.* they share parts of the same transportation infrastructure that supports the Lac de Gras area and the Lupin mine). In addition, the Jericho mine (Tahera Corp., 2000) will be in the Nunavut Settlement region and subject to a different regulatory body.

In response to questions and concerns regarding the cumulative effects of mining in the WKSS area and the creation of monitoring agencies for each new mine, the Minister of Environment directed that a regional monitoring agency be established by March 31, 2001, as part of his decision to approve the Diavik project. This has evolved into a process to develop a Cumulative Effects Assessment and Management Framework (CEAMF, (Jacques Whitford Environ. Ltd., 2000)), now expected to be completed late in 2001. The CEAMF development is being jointly led by DIAND and DOE.

The MVRMA also requires that a Cumulative Impact Monitoring (CIM) program be established throughout the Mackenzie Valley and a process to develop the CIM has been underway since 1998. In addition, the MVRMA requires a regular audit of cumulative effects of development, effectiveness of land and water management and deposits of waste. The first audit is required to take place by 2003.

Existing monitoring programs in the region are largely limited to project-specific monitoring by companies, or limited scale data gathering, with the exception of the Coppermine River Cumulative Effects Monitoring Program (CRCEMP). This program is a joint initiative of DIAND, DFO, DOE, and BHP and Diavik diamond mines. The program has developed ecosystem goals and objectives and a conceptual set of monitoring components, with the assistance of a working group of stakeholders. Baseline water and sediment quality data have been collected and data collection stations have been installed throughout the Coppermine River basin. The process of developing specific indicators and a detailed research program has been initiated.

5.2.3. Industry-Aboriginal Agreements

A variety of arrangements and agreements can be included within the framework of an Impact and Benefit Agreement (IBA). The term is most commonly applied to project-specific, private agreements between an Aboriginal community(s) and a resource development company. IBAs generally provide opportunities for a community to participate and receive economic benefits from a project, including participation in the management, monitoring and mitigation of social, cultural, economic and environmental impacts (Alex Kerr Compass Consult. & Michael Doggett and Assocs, 2000a).

Economic benefits, capacity building, environmental protection, and maintenance of social and cultural fabric are required for effective participation of Aboriginal people in non-renewable resource development. In their review of IBAs as tools for securing Aboriginal participation in non-renewable resource development, Alex Kerr Compass Consult. & Michael Doggett and Assocs (2000a) concluded that IBAs are one tool for securing effective participation. IBAs provide economic benefits to Aboriginal communities through jobs and employment, business opportunities, and financial benefits (cash payments, profit sharing) and can contribute to local economic diversification. In these regards, the first benefit agreement (Ulu mine project) entered into by Nunavut (represented by the Kitikmeot Inuit Association) was particularly important because it set precedent on four principles (O'Reilly & Eacott, 2000):

"Major developments on Inuit-owned lands would add "value" to affected community/regional economies.

Impact benefit agreements would be considered a strategic and long term economic development tool to help build corporate capacity for Inuit.

Impact benefit agreements should be considered an instrument for fostering good will and should provide the foundation for Inuit and developers to "work together" from project inception, through production, and finally to abandonment.

An Inuit content factor in considering and evaluating tenders for mine services meant there would be strong incentive for all potential contractors to maximize Inuit participation."

However, concerns have been raised about the use of IBAs as a mechanism for support of environmental monitoring and abandonment (IEMA., 1999; 2000). Also, IBAs may not provide the best mechanism for capacity building and environmental, social and cultural impacts monitoring and mitigation. Others tools to secure Aboriginal participation include tenure instruments (*e. g.* surface leases), regional agreements, and cooperative, multi-stakeholder initiatives.

5.2.4. Round Tables

In Canada the concept of the "Round Table" has been used as a vehicle to move toward sustainable development. A Round Table involves all sectors of the economy in developing ways to achieve sustainable development. At present neither territory has a round table in place, although the GNWT's *Sustainable Development Policy* does envision an NWT Round Table.

The National Round Table on Environment and Economy has released a report of its Aboriginal Communities and Non-Renewable Resource Development Task Force which includes recommendations specific to the North and to the Slave geological province.

5.2.5. Partnerships

Partnerships are formal relationships that are formed for mutual benefit. Partnerships are formed for a variety of reasons including sharing responsibility without significantly increasing costs, accessing additional resources and increasing opportunities to address specific needs. Partnerships are the new way of doing business and addressing environmental and socio-economic issues in the WKSS area. Partnerships have been formed to respond to healing, disability, labour force development, and early childhood issues. Partnerships have involved public and Aboriginal governments, non government or voluntary organizations, and individuals. Partners share authority, risk, responsibility, accountability, investment and benefits. While more groups are entering into partnerships to achieve specific purposes, the lack of formal agreements, and different expectations and motivations have terminated many partnerships before any results could be achieved. Healthy, successful partnerships offer great potential for WKSS area communities, particularly with respect to deriving sustainable sociocultural solutions.

The WKSSS, itself, has been a Partnership negotiated entirely separately from the regulatory process to collect and provide information to decision-makers is an essential ingredient for achieving sustainable development on the environmental and socioeconomic cumulative effects of development in the WKSS area (Section 1).

5.2.6. Community Health and Well-Being

Rapid and profound societal changes have occurred in the WKSS area, over the past century. These have stemmed from epidemics, acculturative stress, colonization, breakdown of the traditional family unit, and the changing roles of men and women. Many of the changes have undermined the security, health, well-being and culture of Aboriginal peoples. Institutions, structures and systems rooted in European traditions have stymied, frustrated, contradicted, diluted and, or, weakened Aboriginal cultures and communities. The social, economic, cultural and political characteristics of most WKSS area communities today (Section 4.3) can be linked to this legacy.

The existence of a mixed economy that involves one set of values in a wage-earning society and another set of values tied to individual and, or, group use of natural resources has also contributed to numerous social problems in northern communities (George & Preston, 1987; Scott, 1992; Stephenson, 1991).

Acculturation has given rise to many effects and one of these has been the loss of the intergenerational transfer of traditional ecological knowledge that naturally occurred in the practice of traditional activities. There are concerns that youth seems to have lost much of the respect for the land (Marlowe *et al.*, 2000).

Responses to a legacy of poor socio-economic conditions have most often been project-specific and short-term in nature. Fragmented approaches and, or, resources (*e. g.* initiatives, programs, services, funding) rather than long-term, holistic socio-economic development processes and supports have made few inroads into creating healthy and sustainable communities.

5.2.6.1. Human Health

Human health has been identified as a concern in many parts of northern Canada, and particularly in relation to the value of traditional foods and exposure to persistent organic contaminants (Shearer, 1998). DIAND responded to concerns about widespread contamination of the northern ecosystem and risks to human health with the formation of an inter-governmental technical committee in 1985. The committee expanded to include northern Aboriginal partners in 1989, and developed a five year research and monitoring framework known as the *Northern Contaminants Program's Strategic Action Plan*. The *Northern Contaminants Program* (NCP) became a part of the *Green Plan* of the Federal Government, and a component of the *Canadian Arctic Environmental Strategy* in 1991 (Jensen *et al.*, 1987). Government and Aboriginal partners have continued to manage the program and funding for this work. This program has been the principal source of support for most of the recent health-related northern environmental research.

Studies (under NCP) on benefit and risk associated with diets of traditional foods will be completed, soon, in the West Kitikmeot region (Kuhnlein *et al.*, 1999) and these, and those already completed in many Dene communities, are expected to reinforce existing views that strongly support continued use of traditional foods as a highly valued source of nutrition. Throughout the north, special attention is being given to establishing what, if any, relationships exist between persistent organic contaminants and immune system effects such as child infections, and neural behaviour effects in children (Anon., 2000a). Fortunately, few of these effects are likely to be of major concern to Aboriginal communities in the western Arctic and sub-Arctic, where levels of persistent organic contaminants are generally low (Papik, 1998), although results should provide further insight into contaminant problems due to external influence.

Both government and Aboriginal communities have recognized the importance of communicating information from the *Northern Contaminants Program*, especially as it may create better appreciation of the potential health effects of contaminants. Contributions have been made through establishment of a contaminants curriculum in the high and junior-high school programs (Carpenter *et al.*, 1997), and through opportunities to provide information and feed-back in Dene and Inuit communities (Mills, 1997; *Mills et al.*, 1999; Usher *et al.*, 1999). The need for contaminant and, or, health information and opportunities for questions and comments will continue to exist indefinitely and these initiatives provide an important means of developing understanding and confidence in northern health studies.

5.2.6.2. Community Wellness

Health and well-being are generally understood as the state of being free from ailment or malaise. Good health and well-being denotes satisfaction, happiness, security and comfort. Community well-being is generally accepted as a reflection of physical and mental well-being among people and their communities. The GNWT identifies indicators of wellness as: a strong sense of community, a strong sense of family life, an emphasis on personal dignity, a state of well being; a strong sense of culture and tradition, and zero tolerance for violence. In Aboriginal communities in the WKSS area, a more holistic view links individual and community wellness to the health and well-being of the environment, societal relationships, and cultural and spiritual values (Fig. 28). For example, in Lutselk’e, community health is viewed as a way of life. Regardless of definition, community health and well-being are essential elements of sustainable communities.

Community wellness can be expressed through a variety of actions and behaviours, including:

strong generational bonding (elders and youth) and successful parenting; acceptance of the legitimacy or authority of traditional and cultural ways of being and doing (*e. g.* healing circles, community justice); acceptance of personal responsibility and use of healing processes where needed; participation and, or, contribution to collective good (*e. g.* individual sense of place in a group), gender parity, and family as a basic human unit. In Lutselk'e, wellness is expressed in large part by self-government, healing and cultural preservation activities as they reflect the community's desire for self-determination, addressing social issues and keeping the Chipewyan culture and language strong (Parlee & Lutsel K'e First Nation, 1997).

The wide-ranging indicators or expressions of community wellness suggest that not all solutions fall within the "powers" of an affected community. More often than not, solutions can only evolve as a result of constructive solution-making undertaken jointly by both Aboriginal and non-Aboriginal people. However, communities themselves must agree on those elements or ways of life that are important to them, and work together to achieve sustainable responses to those that are unacceptable or indicate lack of wellness. Support to help communities deal with complex, interrelated and deep-rooted wellness issues must be holistic, coherent, and long term in approach. Decades of top-down directives and funding for health and well-being have had little if any effect on rebuilding individual and community wellness in the WKSS area.

5.2.7. Human Capacity

WKSS area communities lack adequate numbers of people with the skills, knowledge and specialized expertise to respond to the wide range of internal and external opportunities and demands that confront them daily. Lack of capacity severely limits the ability of WKSS area residents to actively and knowledgeably participate in political, economic, social or environmental decision making. For example, limited capacity in WKSS area communities makes it difficult for their people to influence the pace and scale of industrial developments, understand risks, monitor and assess impacts on humans and the environment, and, or, maximize opportunities and benefits.

Building capacity (*e. g.* developing potential) at the community level is seen by northerners as *"..a fundamental prerequisite to deal with issues facing communities today"* (GeoNorth, 2000). Low literacy and education levels and a lack of skills and training (including leadership training) create barriers to building capacity in WKSS area communities (Economic Strategy Panel, 2000; GeoNorth, 2000; Lutra, 2000a). Health and wellness issues (*e. g.* alcohol abuse) affect peoples' ability to benefit from education, training and employment opportunities (Dogrib Community Services Board, 1999; Economic Strategy Panel, 2000).

The fragmentation or lack of resources to build and support capacity (*e. g.* programs, services, funding) creates stress within WKSS area communities (Section 3.4). Building capacity requires a coordinated, holistic, community-based approach. Communities, Aboriginal organizations and all levels of government and industry need to be partners in building processes and mechanisms that build capacity. There is a need to assess progress and document what works, to share information with other communities and to increase understanding (GeoNorth, 2000).

6. INFORMATION NEEDS

6.1. Background

The WKSSS was set up to collect and provide information that would assist sustainable development in the WKSS area. One of the first questions raised was what information would be needed to do this? The following summary outlines much of the work that has preceded preparation of the *Revised State of Knowledge Report*.

Many environmental and socio-economic studies have been undertaken in the WKSS area, and these were collected and reviewed, and information gaps were identified before the study formally began (Cizek *et al*., 1995a; 1995b). Another study prepared development scenarios for activities such as exploration, mining, community development, transportation infrastructure in the WKSS area. It documented ecological effects as a basis for predicting possible impacts of various development activities on the land (Bernard *et al*., 1995).

A comprehensive consultation process took place among the WKSSS Partners regarding priority issues of concern to them. This consultation included two major workshops and ongoing meetings of the key partners during 1995. The discussions on research priorities led to a major workshop in February 1996 to develop a research strategy for the WKSSS (WKSSS.,1996). The workshop produced a list of 70 research priorities ranging from general areas of research such as *the impact of local and regional development on communities* to more specific topics such as *baseline information on Grizzly Bear*.

Information prepared for environmental assessment of the BHP Diamonds project, the first diamond mining proposal in the WKSS area, was particularly important (CEAA., 1996). This was also the first environmental assessment panel review done on a project in the region. Both the assessment panel report and testimonies of presenters and interveners to the panel were examined. From these, a comprehensive list of issues and concerns was prepared.

All of this work was then used by a team of consultants to assist the WKSSS in refining its strategy for selecting research proposals. The methodology of *Valued Ecosystem Components/Valued Socio-economic Components* (VECs/VSCs) was used. The WKSSS Partners reviewed and revised background documents, then appointed representatives to attend a workshop in November 1996. The process of selecting VECs/VSCs and a set of likely development activities in the WKSS area was completed. Using interaction matrices, the workshop assessed how each VEC/VSC might be affected by each development activity. Each of the interactions was ranked, based on the intensity and spatial extent of the possible effects. The highly ranked interactions were then further considered in terms of the research required to assess the effects or impacts. A number of research issues were identified and the the group determined which of them were best addressed by the WKSSS. The group also identified other agencies and organizations who it was felt should address the remaining research issues. The consultants drafted a set of research questions based on the workshop results and listed priority issues identified for research by the WKSSS. These questions were reviewed at a follow-up workshop held in early January 1997 (Geonorth & Axys Environ. Consult., 1997; <www.wkss.nt.ca>).

The WKSSS Board reviewed and refined this work, and prepared a set of 10 Priority Research Questions on which it wished to focus (WKSSS., 1997). In some cases particular issues were agreed to be important, but it was felt that the responsibility for the research already rested with another agency or organization(s). Some issues were of major concern to a minority of the WKSSS Partners, so were not included in the Priority Research Questions. However, it was felt that the list of Priority Research Questions should remain flexible and should take into account new information, and it was agreed that the questions could be reviewed from time to time.

This revised *State of Knowledge Report*, and particularly the following sections, are part of a review which will result in a proposal for a new set of research questions for the WKSS area. The synthesis provided by this report provides further guidance about information gaps and the need for specific types of research (See Sections 7.1 and 7.2).

6.2. Collection and Use of Information

Based on the contents of the first *State of Knowledge Report* and this revised *State of Knowledge Report*, several areas of knowledge can be identified where there is a lack of information required to support decisions at various levels of policy making. Many of these areas are the same as those already recognized (Section 6.1). The following summary is therefore intended to avoid duplication and to complement research needs previously identified by the WKSSS (CEAA., 1996; Geonorth & Axys Environ. Consult., 1997; WKSSS., 1996; 1997). Often a lack of information is termed an “information need” and that can lead to unfortunate oversimplification. A lack of knowledge and a need for information are not the same thing.

The seeking of knowledge for its own sake creates an unending demand for information and one of the first questions that must be asked is what information is essential; thus, drawing attention to the concern that is to be addressed. Stress and effect matrices (or interactive matrices) are a valuable means of site-specific environmental impact assessment. They have also been used to characterize gaps in non-site-specific knowledge that are applicable to more general decision-making (CEAA., 1996; Geonorth & Axys Environ. Consult., 1997; WKSSS., 1996; 1997).

If information is to be collected efficiently, the questions or concerns that are to be addressed must be clearly framed, first. Since it is not intended to frame a range of questions within this report, information gaps can be considered only in relatively broad terms. No attempt is made to suggest who should gather information. For example, traditional knowledge may be able to contribute significantly to an overall understanding of the ecosystem and environment of the WKSS area, but this report can do little more than encourage such input. How information is collected is equally important. Because the WKSS area is such a large and diverse area and costly to access, how is it possible to gather environmental information that is needed, reliable, at an acceptable cost and within useful time frames? The problems of information gathering are similar in many fields of study and, perhaps, some common solutions are possible. Broadly, there are two ways of looking at gathering information and, in general, use is made of whatever information is available.

- Collecting a range of generally standardized information that can be drawn upon in response to several different user needs (*e. g.* monitoring information).

- Collecting information that is specific to some requirement (*e. g.* survey information).

Much information already exists in the form of maps, aerial photographs and satellite imagery that could be used to address some of the gaps in knowledge identified by the WKSSS (CEAA., 1996; Geonorth & Axys Environ. Consult., 1997; WKSSS., 1996; 1997). An increasing quantity of one-time and site-specific information is also being accumulated, especially in relation proposed mineral developments in the WKSS area. In addition, a substantial body of environmental knowledge already exists in many other parts of Canada, much of which is closely applicable to the WKSS area. For example, water quality requirements for several key species of fish (*e. g.* Lake Trout) are known. Contaminant concentrations that are likely to be critical for many forms of wildlife are known. Guidelines have been established for human consumption of many country foods. Also, although understandings about long term exposure to low levels of contamination are less well established, several ongoing programs in wildlife, fisheries and human health are directed at key issues.

Most information needs that apply to the WKSS area fall into one of three general types: base information (covering any topic where little or no information presently exists), bridging information (building links between existing sets of information that are often very different and of only limited use), and trend information (continuing collection of data to show change over time).

The use of meta data systems to record what forms of information are available and the use of geographic information systems to locate such information would make it easier for all users to search for information and to trace where it is stored. If such systems were available in the WKSS area, they would be very useful. However, because of the costs associated with information control (update and access), maintenance and user support it would be best if they were operated as part of an existing institution rather than a stand-alone facility.

The following summary applies to non-site-specific information and has been grouped to follow the structure previously established by the WKSSS (Section 7 (WKSSS., 1997)).

6.3. Socio-Economic Information

The pace and extent of change in the lives of the people of the WKSS area has been and continues to be profound. As discussed (Section 4.3), significant gaps exist in the understanding of certain key drivers of change. Many of these gaps exist as a result of a lack of trend information. In particular, little is known of the extent to which increasing industrialization and industrial employment in the WKSS area is altering community and family and individual lifestyles, structures and organization. To a large extent, perspectives on change resulting from industrialization are dependent on data gathered in the 1980's. Little is known about the influence of industrial employment on renewable resource harvesting practices or participation levels, or on social or economic security, particularly of traditionally isolated Aboriginal populations. Some information is beginning to emerge (*e. g.* from community-based monitoring activities undertaken in Lutselk'e) however, high turnover in full-time positions staffed by workers from the community and small samples (*e. g.* 21 workers) limit the quality of these data. An attitudinal survey now being completed by BHP's Ekati mine and scheduled to be released in April 2001, will provide addition information on this issue. The effects of rotational work need to be re-evaluated, including suggestions that it may be associated with increased substance abuse. Further, it has long been a premise of industry and contemporary governments that increased wage employment and cash income earning opportunities are deterrents to the need for, and use of income subsidies.

This report points to very troubling social circumstances in many parts of the WKSS area. Monitoring and managing these circumstances have challenged governments at all levels. A recent report on community health and well being produced as part of the BHP-GNWT socio-economic agreement (DHSS *et. al.*, 2000) provides baseline and trend analysis to monitor and assess the impact of the Ekati diamond mine. Continued attention is required both in the form of research and discussion but these activities should be concentrated at the level most directly affected by at risk behaviours, that being the community level. Further, new and equally troubling social behaviours are emerging in the WKSS area. These pose major risks to health and well-being, and little is known of these behaviours and their impacts. The most visible of these are gambling, prostitution and organized illicit drug activity. Little, if any formal research has been done into these activities. Community based research, monitoring and response which taps into local understanding of issues and their causes and effects may provide new insights.

Monitoring and understanding of the socio-economic circumstances of some WKSS area communities has been hampered by incomplete baseline data. This problem is particularly acute when endeavoring to understand the circumstances in the small communities of Dettah, Ndilo, Bathurst Inlet and Umingmaktuk. Census Canada currently does not collect data for the latter three communities.

In recent years, as a result of Aboriginal land claim agreements and the assertion of Aboriginal land and resource rights, more and more communities and, or, regions have entered into impact benefit and other formal agreements to ensure that benefits accrue to them from industrial developments. The literature (IWGMI., 1990-1996; Little *et al*., 1994) seems to indicate that a great deal of faith is placed in these agreements. We know so little about the effectiveness of these “tools". For example, government implementation of land claim agreements may be evaluated but Aboriginal implementation is not. Impact benefit agreements are private, so opportunities to understand whether these are effective don't exist. The experience of some partnerships has been documented but lessons learned or experiences are not well known. Best practices documentation is needed. Little is known about the extent to which these agreements are meeting expectations and, or, fulfilling agreed upon requirements. Questions relate to how Aboriginal communities can most appropriately participate in and benefit from development, and how best to ensure that benefits are shared equitably within communities. This knowledge will be important to ensure the health of the WKSS area people and their environment.

One of the objectives of this report was to present the results of traditional knowledge research as well as to integrate it with scientific knowledge where possible. However, compared to scientific research, very little traditional knowledge research has been done within the WKSS area. As stated early in the report (Section 1), this is an emerging field of study. Therefore, it is not surprising that there is little information available that presents the current state of knowledge of the inhabitants of the area. Traditional knowledge has the potential to contribute information and understanding of almost every aspect of life (including the social, cultural, health and well-being of people) and the environment of the WKSS area.

6.3.1. Traditional Economy

As discussed in Section 3.2, the relative importance of traditional economic activities varies among households and communities in the WKSS area. There have been efforts in the last few decades to understand the role of the traditional economy within the context of overall socio-economic change. But, there is a lack of current documentation about the relationship of harvesting activities to the economic security of WKSS area communities at the beginning of the 21st century. Assessment of existing information and needs in relation to harvesting and changes in harvesting patterns (and success) and consumption would provide better appreciation of the role of the traditional economy. The relationships between harvesting, consumption and community health are clearly important. Any changes, such as a shift from subsistence to recreational hunting, need to be monitored and assessed, particularly as they may be affected by employment and development. Some studies initiated under the *Northern Contaminants Program* and some of the studies sponsored by the WKSSS (WKSSS., 1997) are contributing to a better understanding of traditional economies in the WKSS area (Anon., 2000a; Dewailly *et al.*, 1999; Jensen *et al.*, 1997; Kuhnlein *et al*., 1999; Marlowe *et al.*, 2000; Parlee *et al.*, 2000) but they present only a partial "picture". From information presently available, many similarities seem to exist between traditional economies in the western Canadian Arctic and those of Cree and Inuit communities, further to the east (McDonald *et al.*, 1997; Sly, 1995).

6.3.2. Social and Economic Benefits and Dis-benefits

For many decades, the benefits from economic development activities in the WKSS area have flowed mainly to non-Aboriginal people and to non-residents in the form of employment, higher incomes and improved quality of life. It has been the view of many Aboriginal people that only dis-benefits such as alienation from and, or, harm to lands and animals, have flowed from economic development. Since the 1970's, Aboriginal people in the WKSS area and elsewhere in the NWT and Nunavut have worked to ensure dis-benefits are minimized and, or, mitigated and benefits maximized. The extent to which this is or has been achieved is unknown.

The benefits and dis-benefits of mining and other development activities on the Aboriginal inhabitants of the WKSS area are not sufficiently understood. A study of the impacts of uranium mining (Dogrib Renewable Resources Committee and Dogrib Treaty 11 Council, 1997) as experienced by some Dogrib, shows that Aboriginal knowledge can play a vital role in assessing the impacts to health, spirituality, and economy and other aspects of the environment. A study of the impacts of hydroelectric development on Denesoline (Beilawski, 1993) also showed impacts to traditional travel routes, and to the economy through changes to the habitats of game waterfowl and fur bearers. It has also raised safety concerns about the effects of changing ice conditions in flooded areas. Lessons learned from the impacts of previous development activities should improve the process of future development and minimize dis-benefits. Further work on the role of Aboriginal people as environmental monitors for development activities could be assessed.

Tension and distrust can be viewed as impacts on wellness. These states are expressed in the view held by some Aboriginal people that developers and other outsiders sometimes act in ways considered disrespectful to the land and animals. As this is perceived to have negative consequences for Aboriginal people, it may be useful to determine if there are ways in which developers can show respect in a culturally appropriate manner.

Since the 1970's, Aboriginal people have fought for recognition of their rights to land, resources and governance. They have entered into agreements to assert power and control over the use and benefits of land and resources. There is little documentation on the extent to which stresses are being created, managed or reduced as a result of new approaches to exerting power and control of land and resource uses.

6.4. Physical and Environmental Information

There are close relations between many of the knowledge gaps associated with each of the following sections, and a substantial amount of overlap exists. As noted, in the previous section, there is also great potential for traditional knowledge to contribute to virtually every aspect of environmental understanding. Studies conducted in other parts of the NWT such as the *Traditional Dene Environmental Knowledge Project* undertaken by the Dene Cultural Institute (Johnson & Ruttan, 1993) and in eastern Nunavut (McDonald *et al.*, 1995; 1997; Arragutainaq e*t al*., 1995) provide numerous examples of detailed knowledge of the environment that Aboriginal people possess and which will be of benefit to policy making. Other studies, relating to caribou, traditional territory and biogeographic knowledge, and community environment are currently ongoing in the WKSS area (Legat *et al.*, 2000; Marlowe *et al.*, 2000; Parlee *et al.*, 2000; Thorpe, 1998; Thorpe & Kadlun, 2000).

6.4.1. Water Quality

Although site-specific information is extremely limited, sufficient is probably known about water quality in the WKSS area to make most broad-based policy decisions. However, water quality is closely linked to the health of wildlife and humans and, because of this, long term trends of persistent contaminants in sensitive species need to be recorded as an indicator of conditions that are generally typical of the region (or significant parts of it). The coverage provided by present information is not adequate to meet these needs. At a minimum, concerns relate to Hg, ΣDDT, ΣHCH, ΣPCBs and toxaphene. While concentrations of many persistent organic contaminants are in decline, there is no indication that atmospheric loadings of Hg are in decline. Because concentrations of many contaminants tend to be higher in snow than surface waters (because of scavenging in the atmosphere), snow sampling may be a useful additional sampling technique applied to monitor long term changes in pollutant contributions from atmospheric sources. Contaminant monitoring (for metals and organic pollutants) is clearly advisable at some military, municipal and mine waste sites.

Many American and Canadian communities that draw their water supply from the Great Lakes maintain a long term record of intake water quality monitoring. This form of monitoring continues to provide an essential part of quality control for public water supply. It also provides a major source of information for research into the influence of both natural (*e. g.* climatic variation) and manmade changes (*e. g.* effluent controls) on Great Lakes water quality. The establishment of a similar long term monitoring program at a few water supply intakes (such as at Fort Smith or Fort Resolution on the Slave River) would be of considerable value (Evans, 2000). In addition, the Slave River represents a major point source of inflow into Great Slave Lake and monitoring of this inflow could indicate upstream changes that might be associated with industrial effluents (*e. g.* pulp and paper mills) and PAHs (*e. g.* hydrocarbon seeps or spills). Because of the low concentrations of most contaminants in the river, indicator species (*e. g.* fish) might be used as well. The extent to which hydroelectric development, dams, diversions, and flow regulation may have influenced water quality (and fish and wildlife) in the region is poorly documented. Assessments of existing developments may help to mitigate problems with both existing and future developments of these types.

Traditional knowledge of the effects of contaminants on wildlife and the physical and emotional health of people in the WKSS area is not well documented. For example, impacts were noted by Denesoline when flooding from hydroelectric projects caused a decrease in waterfowl, diseased and inedible fish and loss of drinking water in some areas (Beilawski, 1993). Water quality monitoring at selected abandoned mine sites and those that have received remedial treatment would also help to provide a greater sense of security. Changes in water quality have had negative impacts where effluent from a uranium mine was discharged into a lake and killed some vegetation around the lake and made the fish inedible (Dogrib Renewable Resources Committee and Dogrib Treaty 11 Council, 1997), and heavy metals (*e. g.* Discovery mine (Lafontaine, 1994)) have polluted fish in tributaries and downstream lakes.

6.4.2. Surface Hydrology

Information about patterns of surface drainage in the WKSS area is available. However, the number of places reporting climatic information, stream flow, water levels, and well data are very limited. Information is sufficient to support site-specific information requirements at only a few locations in the WKSS area. For some requirements (*e. g.* water levels in Great Slave Lake) information from areas outside may be more important than from within the WKSS area (*e. g.* upper Mackenzie River basin). Even at a general level, knowledge of the water balance in the WKSS area and the influence of groundwater, including changes in permafrost, on surface drainage are poorly known and require substantially better understanding (Spence *et al.*, 2000). In anticipation of the effects of climate warming, better and more widely distributed measurements of precipitation and evaporation are also required (Gibson *et al.*, 1998; Spence, 1995). However, instrumentation for long term recording is expensive and costly to operate and maintain in remote areas under extreme climatic conditions. Because of this, there may be value in the use of proxy data that is much more easily obtained and which can be used to “fill-in” gaps in data from existing survey sites. Most information needs with respect to the use of water resources are likely to be site-specific.

6.4.3. Baseline Habitat and Landuse

Habitat and land use are dynamic components of the environment and permafrost is particularly sensitive to any natural or manmade change that may affect its thermal stability. At a local scale, change may be rapid (*e. g.* slope failure, shifting of a river channel, construction of a highway) but large regional changes (*e. g.* movement of the tree line) are characteristically slow. Baseline information is useful as a means of comparison at both local and regional scales. Apart from site-specific information needs, local scale information is often most appropriate in support of studies aimed at understanding some form of process. Most regional scale studies need to be set in a different context. For example, information about precipitation and snow cover, permafrost, vegetation, water balance, soil moisture, fire, and range use and condition (*e. g.* for caribou, Muskoxen, and other harvest species) might be developed and compared with satellite and (limited) “ground truth” information to develop predictive tools for improved long term resource use and conservation strategies. These could be particularly useful in relation to various scenarios of the effects of climatic change (*e. g.* the northward range shift that appears to be occurring in many species of plants and animals).

Much remains unknown or poorly understood about the terrestrial ecosystem and the structure of its food web. In particular, the inter-connectedness of prey species (e. g. caribou and Muskoxen) and predators (e. g. wolves and bears), and partially dependent scavenger species (e. g. foxes, Wolverines and Ravens). Also, the feed-back mechanisms between predators, grazers and plant growth, and fire and vegetational succession. The extent to which habitat (such as areas used by calving caribou) may limit present or future wildlife populations (particularly economically important species) is not known. In Barren-ground Caribou, herd mixing and range overlap also add considerably to difficulties in studying population dynamics. These and many other gaps in knowledge (including quantitative information about environmental processes) limit the ability to model northern ecosystems and to simulate their responses to various types of development and the effects of global climatic change.

The marine environment and ecosystem of the area between Victoria Island and the mainland is virtually unknown and it is difficult to assess what knowledge is required (with respect to the potential impacts of both development and climate change). At least, biological communities, food web structures, and some estimates of productivity should be established, and little is known of the seasonal changes in physical and chemical oceanographic conditions of this area. Relationships between ice cover (including ice form, thickness and stability), seasonal caribou migrations (particularly between Victoria Island and the mainland), seal and Polar Bear distributions are poorly documented. More is known about the freshwater environment and ecosystem but information is fragmentary and needs to be updated, particularly to track the effects of potential climatic change. Little is known about anadromous fish stocks or those that migrate within the WKSS area, and the ecosystems and environments of taiga and tundra streams and rivers (including estuarine areas) are poorly understood.

In terms of people and their environment and given the size of the WKSS area, little heritage site and or archeological research has been undertaken. Further research is required to identify the locations of traditional trails, landmarks, sacred sites, graves, and other types of Aboriginal cultural sites. Research utilizing traditional knowledge and a place names approach has proven to be of great value in identifying places of cultural, historical, and environmental significance as well as past and present land use within the WKSS area (Andrews & Zoe, 1997; Andrews *et al.*, 1998).

It is important to recognize, also, that few (if any) changes relating to habitat and use will occur as a singular circumstance. The extent to which interconnections exist between and among components of aquatic and terrestrial ecosystems in the WKSS area are only partly known and understood. A more holistic insight is required to avoid seeking piece-meal solutions. This report has provided some examples but many relationships have been discussed as if there were discrete, and in very simple terms. Reality is much more complex. For example, the effects of fire will not be just to burn vegetation, and rarely do parasites and disease affect just the target species (they would also affect human use of this species). Climate change is a very real concern and there is a need to understand how it may affect ecosystems of the WKSS area, both qualitatively and quantitatively.

6.4.4. Habitat Loss, Fragmentation and Alienation

Loss of habitat, loss of connectedness between habitats, and alienation of wildlife may be some of the most difficult knowledge gaps to address. Also, some types of habitat are of limited availability in the WKSS area. For example, wetlands suitable for staging shorebirds and waterfowl are limited in extent and any loss could have a major impact on species distributions. Research is needed to better document habitat resources and their use. It is evident that urban development and many other human activities (*e. g.* mining, transport, recreation, and hunting) can have a significant impact on wildlife. However, broad generalizations can not be applied equally to all wildlife or to each form of activity, or to each location. Some species are more “sensitive” than others and their adaptive behaviours may differ. Some human activities have a greater impact than others, and locations are further specific in whether or not they are unique in terms of time and place.

While it is certainly useful to know more about the response of some species to human activity (*e. g*. caribou), it would seem most practical to accept that development will continue and to determine the best ways to minimize its effects on a site-specific basis. Empirical information based on better documentation of the effects of some existing activities (such as mining, hydroelectric power generation, and road and air transportation) would provide better appreciation of the "footprints" of development and the actions required to mitigate its impact. At a more general level of human behaviour, many precedents for mitigative action already exist. For example, experienced Aboriginal hunters have long applied techniques that minimized disturbance and have killed only what wildlife was essential for food, and experienced travelers seek to avoid confrontation with wildlife.

Further, traditional knowledge research on the response of key species to the impacts of development may help mitigate negative impacts. Dogrib elders, for example, have provided insight into the effects of some seemingly innocuous aspects of exploration and mining such as flagging tape (causing caribou to change their routes of travel (Legat & Zoe, 1995). Loss of habitat has occurred with hydroelectric development and Dene tell of the loss of shorebird, fur bearer, and large game habitat in flooded areas (Beilawski, 1993). Obtaining a greater understanding of the habitats in the path of development through traditional knowledge may help mitigate the extent of future effects.

6.4.5. Wildlife Mortality

To ensure the long term availability of wildlife resources, the amount and composition of annual harvests (*e. g.* from trapping, fishing and hunting) and the size and condition of target stocks (fish, birds and other wildlife) need to be known promptly and with sufficient accuracy for well based and timely decisions to be made about resource use. This requires gathering of common information from different sources. Information is only sufficient to demonstrate broad cause and effect changes in populations due to natural mortality (including starvation, disease, condition and predation), harvesting, and climate change or variability. Although there is probably more known about the Bathurst Caribou herd than any other stock in the WKSS area, information about this herd is barely sufficient to meet these requirements. With climate warming, species shifts and invasive occurrences have potential to spread parasites and infections to new areas; the potential for damage from such effects is high.

Little is known about mortality of wildlife resulting from impacts of development within the WKSS area. A few insights were provided by Aboriginal people who noted an increase in diseased fish and higher incidence of dead animals in contaminated lakes (Beilawski, 1993; Dogrib Renewable Resources Committee and Dogrib Treaty 11 Council, 1997). Research using traditional knowledge may better improve understandings between the causes and effects of such occurrence and help to mitigate the impacts of future development.

Some forms of management and traditional knowledge research, could be used together to benefit mechanisms for improved sharing and exchange of information. They could offer ways to make management of resources more effective and responsive to environmental conditions. This could be of particular benefit where jurisdiction is shared or overlapping, where species are migratory, or where there is significant degree of resource interdependence such as associated with predator-prey relations.

6.4.6. Human Health

Human health research falls largely outside the responsibility of WKSS communities (*e. g. Northern Contaminants Program* and extension) and ongoing work continues to relate the effects of persistent organic pollutants and health in Aboriginal communities. Fortunately, levels of many of these pollutants are no longer increasing in the northern environment and most do not pose a health issue in WKSS area communities. However and in recognition of effects that may be associated with climate change and global emissions, Hg remains a significant concern in the environment. Since many WKSS area communities retain a strong dependence on traditional foods, every opportunity should be taken to seek a better understanding of Hg and the environment, and the interactions between Hg and Se in animal and human metabolism. Other important health issues relate to health and smoking, causes of high rates of diabetes, and nutrient deficiencies in Aboriginal diets. While Federal agencies remain largely responsible for research related to many of these concerns, opportunities exist for some initiatives by territorial and municipal governments and by non-governmental agencies (including contributions that may be made through traditional knowledge research).

Valuable insights have being gained about health and wellness in communities through traditional knowledge research sponsored by the WKSSS. An opportunity to build on this work also exists.

6.4.7. Cumulative Effects

The sum of all human development gives rise to cumulative effects. Over time, some effects eventually decline, such as pollution from old mine sites. But, for the most part, there is an additive effect as one after another, forms of development and human activity modify the natural environment. The distributions and abundance of plants and animals may change, hunting, trapping and fishing pressures increase, access to natural resources becomes easier, communities become larger and connected by more roads, and levels of pollution rise. Social, cultural and economic changes occur and these further affect the health and well being of human populations. Because of complex interactions among different effects, cumulative impacts become greater than the impacts of an individual development. Modelling cumulative effects such as the global warming that results from greenhouse gas emissions is complex. Cumulative effects and their impacts can be assessed and computer models can be used to project future trends, but they require that objectives (what such models are intended to show) are clearly defined. The objectives will determine what information would be most appropriate to show some form of impact, and the level of accuracy and resolution that may be associated with an analysis. Cumulative effects and their impacts can be addressed separately as an environmental issue (*e. g.* the relationship between manmade eutrophication and the discharge of phosphorus as a nutrient pollutant). Cumulative effects and their impacts also can be addressed by linking various socio-economic and environmental indicators (*e. g.* GLOBIO pilot study, Section 5.1.2.1).

6.5. Summary of Information Needs

This report shows, in general terms, that much is already known about both human and environmental conditions in the WKSS area. Detailed knowledge is also available about some specific sites and topics. However, gaps in knowledge often make it difficult, if not impossible, to link things together or to track information over time. Much of the information available suffers from a lack of consistent quality and quantity. Traditional knowledge is severely limited by the small amount that has reported and which is available outside Aboriginal communities. The following summary provides a focus for concerns about information that are specific to this report and which have been described in this section. Concerns are particularly related to the ability to define trends in time or changes in space that are occurring in the WKSS area. The summary provides a complement to information needs previously identified by the WKSSS (listed in Section 7).

6.5.1. Socio-economic Information

A. Concerns about the effects of industrialization and wage employment at the community level: *Development in the WKSS area, and most particularly the influence of mining and associated activities, continues to have wide ranging effects on Aboriginal communities and resource-use practices. Many of the effects occur indirectly, but primarily, as result of mining development. Many occur as a result of political and administrative decisions that are also related, at least to some extent, with resource extraction and development. Since it is unlikely that these underlying causes of socio-economic stress can be significantly altered in the near or foreseeable future, it is probable that many decisions will seek to provide treatment of symptoms rather than causative factors. To do this as effectively as possible, it is essential that immediate cause and effect relationships are clearly defined, understood, and quantified. It will also be necessary for much of the information to be updated on an ongoing basis. Community involvement will be a major factor in determining not only that information is useful and reliable, but also that decisions which are based on it can be made to work in the affected communities. The WKSSS supported socio-economic studies at Lutselk'e and this initial work has given valuable insight into the complexities of evolving human stress (Parlee, 1998b; Parlee & Marlowe, 1999; Marlowe et al., 2000). comparable information is needed from most other Aboriginal communities in the WKSS area, specifically:*

1. Increasing Industrialization: *The extent to which increasing industrialization and industrial employment in the WKSS area is impacting on individual, family and community life.*

2. Resource Harvesting: *The influence of industrial employment on renewable resource harvesting participation levels and practices (e. g. the traditional economy)*

3. Socio-economic Security: *The influence of industrial employment on socio-economic security of traditionally isolated Aboriginal populations including the use and attitude about income subsidies.*

4. Rotational Work: *An update and re-evaluation of the effects of rotational work on individual, family and community life.*

5. Negative Activities: *A more clear understanding of gambling, prostitution and organized illicit drug activities in the WKSS area.*

B. Concerns about the effects of industrialization and wage employment at a regional level: *Management decisions applied for the betterment of Aboriginal communities need to be based on information that may be specific to some communities and on information that reflects a broader and more regional perspective. In particular, decisions should be supported by an appreciation of the extent to which they may affect communities, differently, and the extent to which changes in one community may affect another. In addition to an overview (synthesis) of information needs outlined above (A), information is also needed about:*

1. New Approaches: *The extent to which socio-economic stresses are being created, managed or reduced as a result of new approaches to Aboriginal involvement in or authority for land and resource use (e. g. land claims agreements, impact benefits agreements).*

2. Lessons Learned: *The documentation and communication of the benefits and disbenefits of mining and other developmental activities including lessons learned.*

6.5.2. Traditional Knowledge Information

Throughout this revised State of Knowledge Report we have noted examples of Traditional Knowledge (TK) studies that have broadened our understanding of the land, water, plants and animals of the WKSS area. These studies have given us a unique aboriginal perspective on the environment and their importance cannot be understated. Issues of funding for traditional knowledge research, of community control and ownership of the information gathered, and of access to the information by 'outsiders' still remain as obstacles but are slowly being overcome.

The rapid changes that have been occurring in many WKSS communities are seen as a contributing factor in the loss of traditional land-based knowledge. Dependence on the land and its resources has been replace by a dependence on a wage economy. There is no longer a need, or for many a desire, to learn the Traditional Knowledge of their Elders. Its imperative that more effort be put into studying, recording, preserving and using Traditional Knowledge, especially as a balance to the scientific studies conducted in the WKSS area, before it is lost.

6.5.3. Health and Environmental Information

A. Human health: *Activities under the Northern Contaminants Program have helped to draw attention to a number of health concerns, in particular those related to nutritional needs, contaminants in traditional foods, alcohol, smoking and diabetes. Many traditional foods are recognized as an important source of nutrients for Aboriginal people. Thus, continued monitoring of some species (e. g. Lake Trout, Burbot, Ringed Seals, and some water birds) is necessary to ensure that intake levels of Hg and organic contaminants do not exceed health guidelines. Studies on some marine mammals suggest that much of the Hg taken in through the food chain may be stored in some body organs, in a more or less inert form of HgSe material. This process needs to be better understood, not only in terms of its significance to marine mammals but also in human terms. For example, Se is considered to be a toxic substance but does it also act to detoxify Hg in humans? Concerns about alcohol, smoking and diabetes require more attention and are a particular reflection of social, economic and cultural conditions. In particular, it is important to monitor change resulting from for example, public awareness campaigns launched by the GNWT and Health Canada.*

The state of human health and well-being continues to shift as WKSS residents move from rural and, or, land-based to urban and, or, industrialized lifestyles. The process begun by BHP Diamonds Inc. and the GNWT to monitor the socio-economic effects of the Ekati Mine is a good beginning for helping residents, governments and industry understand changes occurring in the human environment. It is important to expand this effort and engage WKSS communities in monitoring and communication activities.

As noted throughout the report, managing changing human health and other socio-economic circumstances within the WKS area is hampered by lack of good quality baseline data. Statistics Canada and the GNWT conduct a variety of surveys (e. g. Canada Census and the NWT Labour Force Survey) but data may not be available in a timely manner or in an appropriate format. Further, the NWT and Nunavut are often excluded from national surveys (e. g. International Adult Literacy Survey) due to high administrative costs and population size. Investing in regular surveys and making data available in a timely and appropriate manner requires immediate attention.

B. Concerns about contaminant trends mostly associated with local sources: *These concerns are in addition to ongoing requirements to ensure that sources of drinking water meet health standards for community supply, or that country foods are safe for human consumption. Presently available information is too limited to track trends over time and changes in the areas of effect that may be associated with site-specific sources of contamination. It would not be practical to attempt to monitor conditions at numerous sites of concern in the WKSS area. Rather, sites could be chosen to be representative of different types of contaminant sources and periodically monitored for selected characteristics of water quality, and for contamination in biological indicator species. The information could be used as a form of alert at these or similar sites elsewhere in the WKSS area. Also, information could be used to show how long contaminant effects are likely to remain significant. Possible examples might include:*

1. Sewage Discharge: *Nutrient, heavy metal and microbial contamination at sites receiving sewage discharge from permanent settlements, camps and lodges.*

2. Mine effects: *Sites affected by acid drainage, metals toxicity, or radioactivity from mining activities (e.g. waste rock, tailings and treatment ponds).*

3. Dumps and Disposal sites: *Metals and organic contaminants associated with municipal dumps and military disposal sites.*

4. Slave River: *Metals and several organic contaminants including PAHs (water/suspended matter) have been reported from the Slave River which contributes large quantities of water from drainage external to the WKSS area. This river acts as a point source to Great Slave Lake.*

C. Concerns about contaminant trends associated with atmospheric transport from distant sources: *Several species of fish and wildlife are now known to accumulate persistent contaminants. Species high in the food chain generally have the highest contaminant concentrations and those that accumulate contaminants over many years can be selected to provide information about long term contaminant trends. Because the concentrations of most persistent contaminants are extremely low in water and suspended matter, it is more appropriate to use biological indicators in which contaminant levels are higher and easier to measure. Further and because of mobility and, or, feeding patterns, many species also provide a natural spatio-temporal integration of contaminants. Trend data provide background and comparative information. Trend data are needed in addition to any ongoing programs that sample contaminants in fish and other wildlife to ensure the safety of country foods for human consumption.*

1. Trend sampling: *Sampling for trend data should, at a minimum, provide information about Hg, ΣDDT, ΣHCH, ΣPCBs and toxaphene. Annual sampling of selected species such as Lake Trout, Burbot and Ringed Seals (each group of similar age and, or, size, and of the same gender) could occur at sites selected to broadly characterize different environments of the WKSS area (including those that may be in remote locations).*

2. Snow Sampling: *Snow is important as a scavenger of persistent organic contaminants in the atmosphere that are carried into the WKSS area by long range transport. Concentrations are influenced by processes such as atmospheric chemistry, patterns of atmospheric circulation and contaminant emissions to the atmosphere. These processes are of relatively short duration (measured in weeks rather than years). Thus, contaminant concentrations in snow will have greater variability and are likely to be less than those which accumulate in biota near the top of the food chain. "Memory effects" in snow and biota are also different . Snow samples may, however, provide valuable additional information (especially where select biota are not readily available for sampling).*

D. Concerns about physical effects of climate change: *There are few sites of long term weather recording in the WKSS area. More are required to provide a comprehensive understanding of climatic conditions that range from boreal to arctic. As with water quality concerns, it will not be practical to significantly increase the number of recording stations in this area. However, it may* *be possible to use other forms of (naturally integrated) data to characterize long term changes and trends in climate, and its effects.*

1. Proxy Data: *Temperature/depth relationships in lakes respond to summer heating and annual measurements (e. g. in late July) can be used as proxy data to show year-to-year and spatial changes occurring in different parts of the WKSS area. Ground surface temperatures can be used in a similar way. Where deep groundwater wells are available, temperature differential within them can be used to estimate trends in time. Ice thickness is closely related to winter cooling and can be measured in both freshwater and marine environments. Freeze-up and break-up are also related to the respective rates of fall cooling and spring warming. Much of this information could be readily obtained, each year, from many different locations across the WKSS area. Consistent measurements of such proxy data could provide much more detailed information on climatic variability, and trends and change than is presently available.*

2. Permafrost: *Permafrost conditions are affected by temperature, but other factors such as the influence of vegetation may significantly modify permafrost response to warming. There may be a significant lag between increasing air temperature and permafrost response. Throughout the WKSS area, vegetation may respond as much or more to changes in precipitation, as to changes in temperature. Sites could be selected to monitor trends and changes in permafrost conditions and vegetation. However, because site-specific factors such as slope, orientation and soil cover can be very significant, complementary information may be required to provide a regional characterization of change. Remote sensing data (e. g. indicating seepage moisture and plant growth) would provide important additional information about the uniformity and extent of change.*

3. Water Balance: *Climate change could have a major affect on water balance in the WKSS area and the extent of effect may differ, significantly, in different parts of the area. Greater knowledge of relationships between precipitation (snow and rain), seepage, run-off, and evaporation is required. Also, it is necessary to have a better understanding of the potential contribution of permafrost-melt to the water balance. It is likely that extensive field measurements could be applied only in a few major, or typical, watersheds. Thus it would be useful to know to what extent proxy data might be useful as an indicator of water balance in different drainage basins (e. g. discharge duration of headwater lakes, duration of over-bank flow, duration of no-flow* *conditions). If suitable, proxy data could be applied to the management of water use in the WKSS area.*

E. Habitat change and range use: *Climate change will affect vegetation (on land and in water) over wide areas, especially as a result of changes in temperature and precipitation. Habitat may be changed, also, as a result of human activities such as road building, mining development, and the growth of communities. Habitat change (e. g. fragmentation, plant colonization, reduced ice or water cover) may very well alter its use and thus the distribution of many species (including people). Many changes will be readily visible on the ground but financial constraints limit the extent to which site-specific information gathering will be possible. Aerial and satellite remote sensing techniques offer the only practical means of determining and quantifying change over large areas. At present, the WKSS area lacks consistent baseline information about the distribution of habitat types and resource use.*

1. Surveys and Observations: *Aerial survey techniques have been used as a means of monitoring wildlife habitat and range use in the WKSS area, particularly in relation to Barren-ground Caribou, and satellite data have been used to characterize habitat. These studies need to be continued (Section 7) but greater understanding is required of fragmentation effects associated with human activities in the environment, and the extent to which halo effects (including wildlife mortality) occur around different types of development. Empirical observations of the effects of different types of development, settlement, roads and other forms of infrastructure provide essential information for construction of better models of both environmental and cumulative impacts.*

2. Indicators: *Environmental indicators need to be developed to simplify the display of information about habitat change and range use. For example, shorebird habitat is very limited in the WKSS area. Climate change could result in a loss of much of this existing habitat. It could also result in opening of new shoreline habitat in areas that are now under some other environmental condition. If climate change continues at the present (rapid) rate, it may be easier to track habitat change from remotely sensed information than to rely on trying to locate the birds based on the use of sightings, alone. Environmental indicators would help to reduce the complexity of habitat change and range use.*

3. Changes in the freshwater food web: *Very little is known about the likely affects of climate change on the freshwater food web, and especially changes that may occur in fish stocks. Warming could reduce water levels and flow, advance spawning periods and increase nutritional needs. Warming is likely to favour some species but to create habitat that is less favourable to others.*

4. Dams, Diversions and Water Control: *The effects of dams, diversions, and water level manipulations on water quality and aquatic (and semi-aquatic species) is poorly documented in the WKSS area. Information about such effects is available from sites in Northern Manitoba, Ontario and Quebec, and much of it is applicable to the WKSS area. However, there are also significant differences; in particular, the WKSS area receives much less precipitation and the regional water balance is very different. Although the scale of potential hydro development is likely to be very different in the WKSS area, nevertheless the potential for environmental impact is considerable. This is particularly so where Aboriginal communities are dependent on local resources for traditional food, as has been documented or the Talston River (Beilawski, 1993).*

F. Wildlife management: *This applies, mostly to human use of renewable resources by hunting, trapping and fishing. Animal populations vary from year to year as a result of many natural factors and in particular weather, food supply, natural predation and disease; human use of the resource is an additional factor. Good information about each of these factors is essential to ensure long term availability of the resource.*

1. Health of Animal Populations: *Climate change may increase incidence of disease and, or, parasitic infections in birds, fish and other wildlife (including both marine and terrestrial mammals). Sample information is used to provide indications of animal populations and their condition in relation to nutrition and disease. This monitoring is an essential part of resource management. With increasing appreciation of the value of traditional foods in Aboriginal diets, however, more of this monitoring information may be needed.*

2. Predators and Prey: *Natural predator-prey interactions exist between many species (e. g. Lynx and Snowshoe Hare, wolves and caribou, and Grizzly Bear and caribou) but the nature and extent of many of these interactions is poorly defined. Major wolf kills have occurred in some parts of northern Canada as a means of allowing a larger take by hunting for some target* *species, such as caribou. These actions have occurred without clear understanding of the roles played by predators in maintaining the health of prey, or the effects of climatic variability on predator-prey relations. There is little understanding of the effects of large scale killing on behavioural learning and societal structure within wolves. Even less is known about most other predator-prey relations.*

3. ***Resource Use:*** *With the potential for increased human use of bird, fish and other wildlife resources (as traditional food), it becomes increasingly important to have good information about the extent to which hunting, trapping and fishing affect the populations of target species. Also, the extent to which any of these activities may be selective of certain groups of a population (such as breeding females or pre-breeding males). Because fishing can have an overwhelming influence on fish populations, fisheries management is particularly sensitive to the need for good information about both stock size and condition, and catch.*

4. Caribou Populations: *Several herds of Barren-ground Caribou have summer and winter range within the WKS area. The herds are defined on the basis of their separate calving grounds. However, the range of each herd varies and at some times of the year members of different herds may mix together (range-overlap). Caribou populations are difficult to estimate and the range overlap and mixing may confound population estimates. More and better information about the populations and herd fidelity are particularly important for resource management (Section 7).*

G. Interactions Between Terrestrial and Aquatic Ecosystems: *Very little is known about the interactions between terrestrial, freshwater and marine ecosystems of the taiga and tundra environments. Nutrient cycling, the roles of microbial populations, and the limiting effects of temperature and moisture content are poorly understood.*

H. Freshwater and Marine Environments: *Very little is known about taiga and tundra stream ecologies in the WKSS area, and this includes food web structures, and the distributions, behaviours and populations of migratory and anadromous fish species. Very little is known about the marine environment between Victoria Island and the mainland. Information is needed on almost every aspect of this environment. Bathurst Inlet is likely an area of special environmental interest. Also, because there are rapidly growing communities at Kugluktuk and Cambridge Bay, areas around these sites are likely to experience most stress from human activity.*

I. Cumulative Impacts: *Techniques for cumulative impact assessment are not yet generally established but a number of initiatives have been taken to apply this form of assessment within the WKSS area. Assessment techniques will link the impacts of multiple developments. For example, they could provide an understanding of the wider (regional) impact of mine development at multiple sites. It is essential that cumulative impact assessment take a holistic approach and that attempts do not proceed piece-meal. It is also likely that different parts of a cumulative impact assessment may proceed separately first, at least to some degree, but that they be designed to fit together in a larger whole.*

1. Environmental Information: *Cumulative impact assessment may include environmental information such as on water and air quality (e. g. from sewage disposal and contaminant emissions), changes in water quantity (e. g. effects of water withdrawal on water resources), construction of roads and other structures, changes to habitat and range use (e. g. from structures and road construction), wildlife avoidance (e. g. from noise and activity), and increased natural resource use (e. g. increased hunting, trapping and fishing by camp populations and greater access to wilderness areas).*

2. Socio-economic Information: *This may include socio-economic impacts such as on use and, or, understanding of Aboriginal languages and cultural practices (e. g. from more global or mainstream assimilation practices), changes in family relationships and structures (e. g. due different work schedules and income earning roles); and changes in and applicability of skills and knowledge (e. g. more industrial and less harvesting or land-based skills).*

3. Traditional Knowledge Information: *Traditional knowledge may provide an important component in many aspects of cumulative impact assessment. Cumulative Impact assessments, eventually, may also link the effects of global components such as climate change, with those of more local and regional origin. They may also begin to integrate some of the links that exist between environmental change and societal change.*

4. Access to information and Meta Data: *Whatever the undertaking of cumulative impact assessment in the WKSS area, it will need the support of many different government agencies, industry and other organizations. It will need to make use of consistent forms of data, particularly data describing trends over time and changes in space. Examples of such information include:*

water quality monitoring, temperature and precipitation recording, and habitat surveys. Meta data, which define what types of information are available about which areas and when, and where the data is available, could contribute significantly to the selection and use of information. Establishment of a meta data system to catalog existing and future available data would be very helpful but cost and skill requirements may suggest use of existing expertise (external to WKSS area) rather than creation of a separate system. The fact that substantial quantities of information have only recently become available about the WKSS area means that early use of a meta data system could be highly beneficial in terms of both cost and service.

7. RESEARCH NEEDS

The following list of "Priority Research Questions" records research needs in the WKSS area, as defined by the WKSSS (WKSSS., 1997).

7.1. Socio-Economic Research

A. Traditional Economy

1. What is the baseline information about the nature of the traditional economy for the region, specifically:

- *a) What are the existing patterns for each community of:*
  - *i) natural resource use?*
  - *ii) harvesting patterns, particularly for caribou?*
- *b) What is the value of the traditional economy:*
  - *i) in dollars?*
  - *ii) in subsistence value (local consumption, cultural well being)?*

B. Social and Economic Benefits/Dis-benefits

2. What are the social and economic benefits and dis-benefits of development to communities:

- *a) Social Benefits/Dis-benefits:*
  - *i) Which indicators are most appropriate for monitoring changes in social wellness?*
  - *ii) What is the baseline information concerning social wellness for each community, using community based indicators? What is the baseline information concerning family related issues (e. g. violence), substance abuse, services and infrastructure, and economic is parity between and within communities?*
  - *iii) What is the traditional knowledge about social wellness?*
  - *iv) What are the socio-economic and human health trends and effects of development, using community based and environmental indicators?*
- *b) Economic Benefits/Dis-benefits*
  - *i) What is the baseline information on economic conditions for each community, using community based indicators?*
  - *ii) What is the indigenous knowledge about community economic conditions?*

iii) What is the indigenous knowledge about the socio-economic and human health effects of non-traditional economic development?

7.2. Physical and Environmental Research

C. Water Quality

3. What is the baseline water quality for the region, specifically:

a) What are the key parameters for water quality from a perspective of:
i) socio-economic/human health?
ii) ecological health?
b) What are the baseline conditions with respect to these parameters?
c) Where should these parameters be measured?
d) What is the distribution, cause and magnitude of poor water quality with respect to key parameters?
e) Where should poor water quality be measured?
f) What is the traditional knowledge about water quality?
g) What are the effects of contamination on the cultural, spiritual and emotional health of people?

D. Surface Drainage

4. What are the regional patterns and variations in surface water flow?

a) from a scientific perspective?
b) from a traditional knowledge perspective?

E. Baseline Habitat and Land Use

5. What is the baseline information about habitat for the region, specifically:

a) what is the distribution of:
i) soil types?
ii) terrain types, especially eskers?
iii) vegetation communities?
b) how are these habitats used by humans and Grizzly Bear, caribou, wolves and Moose?

i) How does this use vary seasonally?
ii) For these species, what are the:
- *most significant habitats?*
- *critical areas?*
- *migration routes?*

6. What is the land use and distribution of human facilities in the region such as:

- *cultural, heritage and sacred sites*
- *camps*
- *cabins*
- *trails*
- *communities*
- *seasonal roads*
- *mines*
- *other infrastructure?*

F. Habitat Loss/Fragmentation/Alienation

7. What is the state of knowledge about the effects of human activities and facilities on ecosystems and key species:

a) species likely to be affected, particularly Grizzly Bear, caribou, wolves, Moose, and endangered or threatened species, in a way that is detrimental to the ecosystem and, or, human well-being?
b) extent of habitat loss or alienation for Grizzly Bear, caribou, Moose, wolves, and endangered or threatened species?
c) known responses and behaviour of Grizzly Bear, caribou, Moose, wolves and endangered or threatened species to human activities/facilities?

8. What mitigation methods are effective in minimizing the effects of human facilities on the movements and behaviour of wildlife, particularly caribou?

9. What is the indigenous knowledge about mitigation methods which are effective in minimizing the effects of human facilities on the movements and behaviour of wildlife, particularly caribou?

G. Wildlife Mortality

10. What is the magnitude and distribution of mortality to caribou, Grizzly Bear and waterfowl from human causes, including recreational and subsistence hunting, vehicle-wildlife collision and killing of "nuisance" animals?

8. GLOSSARY AND ABBREVIATIONS

Acculturation: Mutual influence of different cultures in close contact. Often applied to the impacts of non-Aboriginal culture on Aboriginal peoples.

Acid/basic (rock). In geological terms and referring to igneous rocks, acidic rocks are silica-rich (having free-quartz) and basic rocks are silica poor. See, also, Igneous rocks.

Acidification: Production of acidic material as a result of rock and mineral weathering (often associated with metal mining activities where sulphides, exposed to the air, become oxidized).

Active layer: Surface soil layer that seasonally thaws and freezes.

ADFG: Alaska Department of Fish and Game.

Adventitious rooting: Lateral rooting from stem tissue (above or below ground). See, also, Candelabrum spruce.

AES: Atmospheric Environment Service.

Aerobic: Life and life-related processes occurring in the presence of free oxygen (gaseous or dissolved).

Algae: Large group of non-vascular marine and freshwater aquatic plants of unicellular and multicellular forms (Sub-division of Thallophyta), including: yellow-green, blue-green, green, red, and brown algae. See, also, Cyanobacter.

ALUR: Arctic Land Use Research Program.

Ambient: Surrounding conditions (*e. g.* background air or water quality).

Amphipods: Small shrimp-like crustaceans (Order Amphipoda) having some appendages specialized for swimming. See, also, Mysids.

Anadromous: Migratory species of fish that spawn (lay eggs) in freshwater.

Anaerobic: Life and life-related processes occurring in the absence of free oxygen.

Andesite: Fine-grained, darkish, igneous rock containing plagioclase feldspar, ferro-magnesian minerals and a very small amount of quartz.

Anoxic: Having an oxygen deficiency.

Annual precipitation (wet): Total annual received moisture as snow, ice, rain, and fog-droplets.

Annual received solar radiation: Solar radiation (part or all of the spectrum) received over a year.

AP: Acid potential; extent to which acidic material is likely to be produced (by weathering). See , also, NNP and NP.

Aquiculture: Artificial culture of biota (mostly fish) in freshwater.

Atmospheric: Referring to the gaseous layer surrounding the planet.

Attached algae: Single-celled or colonial photosynthetic organisms (plants) that remain attached to some form of substrate.

Aurora Borealis: "Northern Lights"; light produced by excitation and ionization in the upper atmosphere in response to solar magnetic radiation.

Banded ironstones: Sedimentary rocks containing alternating thin layers of iron, see, also, sedimentary.

Basalt: Fine-grained dark igneous rock containing olivine, pyroxene and plagioclase feldspar but lacking free silica. See, also, diabase.

Base-metal: Mining term including copper, lead and zinc ores.

Batholith: A very large mass of igneous rock intruded into the Earth's crust (may be hundreds or thousands of square kilometres in area). See, also, pluton.

Benthic: Referring to bottom-dwelling and, or, bottom-feeding biota.

BHC: Benzene hexachloride; see, also, HCH.

BHP: Broken Hill Properties.

Biota: Living organisms (including plants and animals).

Biomass: The mass (usually as weight) of living organisms (or a specific group of organisms).

Bioaccumulate: Uptake and retention of chemical substances by an organism.

Bioconcentration: Concentration of a chemical substance in a whole organism or specific tissue from it (*e. g.* blood serum, muscle, kidney, liver or fat).

Biological communities: Groups of plants or animals living together.

Biomagnification: Increasing concentrations of a substance in a food chain. At each higher level, concentration relative to biomass (of that level) increases. Members of higher trophic levels consume members of lower trophic levels and, in the process, they retain persistent contaminants.

Biomass: Quantity of living matter in a defined space.

Biome: A large region that is defined by the characteristics of biological communities living in it. Climate is frequently a controlling factor (*e. g.* tundra biome). See, also, Ecozone.

Bivalves: Animals of the Phylum Mollusca, having shells composed of two parts (*e. g.* mussels).

Blood serum: Clear fluid containing antibodies but without clotting agents.

Bog: A wet peatland in which the soil is composed of organic matter, and the soil water is acidic (containing organic acids) and generally lacking in plant nutrients. See, also, Peatland.

Boreal: Northern; usually referring to forested areas within the Boreal Climate zone (in which coniferous species are frequently dominant).

BP: Years Before Present.

BS: Bureau of Statistics (GNWT).

Caloric value (nutritional): Food value, especially as a source of energy for body heat, growth, activity.

Canadian Shield: Vast area of ancient igneous and metamorphic rocks that forms much of central and northern Canada.

Candelabrum Spruce: Adventitious rooting of black spruce. This occurs where lichen ground cover develops around a tree, and cuts off supply of nutrients and moisture to the tree's roots in the underlying soil. Extensive development of the candelabrum may occur where a tree has multiple stages of adventitious rooting (seeking to outreach the surrounding cover of lichen). See, also, Adventitious rooting.

Cached food: Uneaten or partly eaten food that is hidden or stored for future use.

Carbonate rocks: Sedimentary rocks, such as limestone and dolomite, containing significant quantities of carbonate minerals (*e. g.* calcium and magnesium carbonates). See, also, Sedimentary.

CARC: Canadian Arctic Resources Committee.

Carrying capacity: The population of a specific group or groups of animals that can be supported by a given area of land (usually applied to grazing and or browsing species dependent on ground vegetation, and expressed as a long term average).

CBC: Canadian Broadcasting Corporation.

CCELC: Canadian Committee on Ecological Land Classification.

CCPB: Canadian Climate Program Board.

CDA: Canadian Department of Agriculture.

CEAA: Canadian Environmental Assessment Agency.

Century: 100 years.

CFCs: Chlorofluorocarbons; volatile but stable and non-toxic fluids used as refrigerants. Highly effective as ozone-depleting gases when released into the atmosphere. Halons (*e. g.* Halon 1301) are similar compounds containing bromine and chlorine. They are an efficient fire extinguisher.

Chironomids: Midges (Family Chironomidae) present as small worm-like larvae in soft sediments of freshwater lakes, streams, and rivers.

Chlordane: An organohalide (chlorinated) insecticide.

Chlorinated dioxins: See PCDDs.

Chlorophyll *a*: Green pigment in living plants, necessary for photosynthesis.

Chromite: A ferrous chromite mineral (oxide of iron and chromium).

Ciliates: Microscopic protozoans (Class Ciliata) characterized by hair-like features that cover all or part of the body at some period of their life. A very small type of zooplankton.

Climax population: Population structure of a mature biological community (*e. g.* a forest).

CIPNE: Centre for Indigenous Peoples' Nutrition and Environment (Montréal). See, also, CINE.

Closed canopy: Forest cover lacking open spaces between the trees.

Condensation point: Temperature at which vapour condenses into droplets (gas to liquid).

Congener: Member of the same family of the chemical periodic system.

Coniferous: Trees and shrubs that usually keep their leaves year-round (evergreen).

Copepods: Small, sometimes parasitic, crustaceans (Sub-class Copepoda) living in either fresh or salt water; a type of zooplankton.

Coregonids: Ciscoes and whitefish (Family Coregonidae). Pelagic and benthic fish of the freshwater environment but with tolerance of low salinity. Stocks may migrate to spawn in rivers and lakes.

COSEWIC: Committee on the Status of Endangered Wildlife in Canada.

Country foods: Uncultivated foods obtained by fishing, hunting or gathering.

CPHA: Canadian Public Health Association.

CINE: Centre for Indigenous (Peoples') Nutrition and Environment, McGill University, Montreal. See, also, CIPNE.

CPS: Canadian Parks Service.

Craton: A core of extremely ancient crustal rock that has been geologically stable for a long time (*i. e.* it has not been subject to selective elevation or subsidence, or to orogenic processes such as mountain-building).

Crust: The Outer hard rock layer of the Earth, composed of rocks that are less dense than those in the underlying mantle.

Crustaceans: Members of the Class Crustacea, including crabs, lobsters, shrimps, and water fleas; most are aquatic.

Cryoturbation: Slow movement of frozen ground caused by various cold effects (including freeze-thaw, ice deformation and plastic flow).

Crysolic (order): Soils in which structures are affected by permafrost that is present at a depth of 1 m or less. Turbic Cryosols are intensely disturbed.

CSHD: Climate System, History and Dynamics (research program).

CSSC: Canadian Soil Survey Committee.

Cultural eutrophication: Intentional or unintentional nutrient enrichment of a body of water by additions of nutrients such as nitrogen and, or, phosphorus (*e. g.* from industrial or community sources).

CWG: Constitutional Working Group.

CWS: Canadian Wildlife Service.

Cyanobacter (Cyanophyta): Very small plant-like (algal) photosynthetic organisms, with blue phycocyanin) and green (chlorophyll) pigmentation. See, also, algae.

DCC: Department of Culture and Communications (GNWT).

DDE: See DDT.

DDT: Dichloro diphenyl trichlorethane; an organic insecticide, often present with toxic breakdown products known as DDD and DDE; no longer in general use in Canada).

DE: Department of Education (GNWT).

DECE: Department of Education, Culture and Employment (GNWT).

Deciduous: Trees and shrubs that drop their leaves after each growing season.

DEDT: Department of Economic Development and Tourism (GNWT).

Degree days: Number of days x temperature above some temperature, such as 0^oC (*e. g.* 45 days having an average temperature of 4^o C is equivalent to 45 x 4 = 180 degree days). See, also, Growing degree days.

DEMPR: Department of Energy Mines and Petroleum Resources (GNWT).

Detritivore: Organism that feeds on detrital material, particularly organic matter in the sediments of freshwater and marine environments.

DEW-line: Distant Early Warning (radar) line; part of the post-WW II North American air defence network.

DHSS: Department of Health and Social Services (GNWT).

Diabase: An intrusive igneous rock with composition similar to basalt, but having a coarser crystalline structure.

Diamond: An extremely hard, crystalline form of pure carbon.

DIAND: Department of Indian Affairs and Northern Development.

Diatom: Microscopic unicellular or colonial algae (Phylum Chrysophyta) whose cell walls contain silica. Diatoms are a rich source of food for many forms of freshwater and marine life.

Diatreme: An explosive vent associated with eruptive geological processes.

DIF: Department of Information (GNWT).

DINA: Department of Indian and Northern Affairs. See, also, DNANR, INAC and IAND.

DJ: Department of Justice.

DMCA: Department of Municipal and Community Affairs (GNWT).

DNANR: Department of Northern Affairs and Natural Resources. See, also, DINA, INAC and IAND.

DOE: Department of Environment. See, also, EC.

Dolomites: See carbonate rocks.

DP: Department of Personnel (GNWT).

DRR: Department of Renewable Resources (GNWT).

Drawdown: Lowering of water levels in artificial impoundments.

DRWED: Department of Resources, Wildlife, and Economic Development (GNWT).

Dry-fall: Precipitation of dry particulate material from the atmosphere (often, low concentrations of fine "dust").

DSS: Department of Social Services (GNWT).

DSS: Department of Supply and Services. See also, MSSC.

DT: Department of Transport (GNWT).

Dyke swarms: Clusters of narrow and steeply inclined intrusions of igneous rock (similarly oriented) into existing crustal rock (near flat-lying intrusions are termed sills).

EC: Environment Canada. See, also, DOE.

Eclogite: A metamorphic rock (originally an igneous rock but partly reformed under high temperature and pressure), containing garnet and pyroxene.

Ecosystem health: Ecosystem health refers to the state of physical, chemical and biological processes that support all living organisms, and to the condition of organisms and their communities as well. A pristine state or condition exists where there is little impact from human activities. Degradation occurs where human activities cause lasting negative effects (*e. g.* as a result of contamination, habitat loss or over-harvesting). Activities that improve degraded conditions may achieve restoration (return to near-natural states or conditions) or rehabilitation (return to a well functioning ecosystem but that may differ somewhat from its original structure). Characteristics of healthy ecosystems include: no loss of species diversity, normal patterns of behaviour, no excessive decline or proliferation of organisms (excluding natural fluctuations), no significant increase in disease or deformaties, generally stable community structures, and robust and self-regulating interactions between and among plants and animals. The health of individual organisms and communities of organisms requires a healthy environment (summarized from EC., 1991).

Ecozone: A large region that may be defined by one or more characteristics of the environment such as landform, geology, soil, vegetation and climate. Zones characterized by terrestrial features may or may not coincide with those defined by climatic or other features (*e. g.* some vegetation and climate zones may be comparable but landform and climate zones may differ significantly). Ecozones based on animal and, or, plant communities (*e. g.* tundra wildlife ecozone) are similar to biomes.

Electrostatic precipitation and baghouse filter: Pollution control technologies used to remove particulates from gaseous emissions. Electrostatic precipitators use charge attraction, and baghouse filters use large volume screens to remove particulates.

El Niño: An event off the coast of Peru (that may last for many months) when warm surface waters move westwards across the Pacific Ocean and dramatically influence global weather conditions. As a result of complex and not well understood interactions between the ocean and atmosphere, warmer than normal weather across much of central and northern North America is thought to be associated with some El Niño events. See, also La Nina.

EMR: Energy, Mines and Resources. See, also, NRC.

Endangered species: Any species of plant or animal whose existence is threatened through all or a significant part of its range, often owing to the actions of human beings.

EPB: Environmental Protection Branch.

EPS: Environmental Protection Service.

Esker: A feature of the postglacial landscape. Deposits of sand and gravel, originally laid down in the bed of streams flowing under glacial ice, appear as long winding ridges on top of the ground, as areas become ice free. See, also, Kame.

Ethnographic/Ethnological: Study of the culture of a society (by means of participant observation).

Eutrophication: The natural aging (geological) of a body of water as it fills with sediment and nutrient loadings increase from the surrounding area. These changes result in long term shifts in species composition and, generally, higher biological productivity. See, also, Cultural eutrophication.

Extinction: Complete loss of some species throughout all of its occurrence (*e. g.* Sabre-Tooth Cat and Mammoth).

Extirpated: The total loss of an animal or plant species in a significant part of its total range (such as a large island or some other large area, *e. g.* WKSS area Muskoxen during the first half of this century).

Feather moss: Thick carpet moss of the boreal forest floor (*Hylocomium* spp. and several other species).

Fecal coliform: Types of bacteria associates with animal feces.

Feed-back: When the output of some process applies a new influence to that process, feedback occurs (*e. g.* when solar radiation warms the ground it may release greenhouse gases trapped within the ground, or increase microbial activity that also releases more greenhouse gases). These gases may trap more heat in the atmosphere and further raise global temperatures. In most situations, natural feed-back is self-limiting and there is some upper limit to effect.

Flux: Movement.

FMS: Financial Management Secretariat (GNWT).

FOC: Fisheries and Oceans Canada

Forage: Plant materials used by grazing animals.

Forbs: Any form of herb, except grasses. See, also, Herb.

Fruticose and other lichens: Fruticose lichens have plant-like growths of low tufts and stalks (sometimes extending as much as 10 to 15 cm above the ground), and cover large areas of the tundra and taiga. Other groups of lichens include crustose lichens that spread as a thin crust over rocks and other bare substrates; foliose lichens that form flat lobes and scales (often on rotting vegetation); and bearded lichens that hang from forest vegetation.

FS: Forestry Service (US).

FWS: Fish and Wildlife Service (US).

Gas hydrates: Gas trapped in permafrost ice.

Gastropods: Molluscs having one-piece (univalve), straight or spiral shells, or having no shells or greatly reduced shells (Class Gastropoda). Most move by means of a broad, muscular, basal foot. Many forms are commonly called snails.

GC: Government of Canada.

GDP: Gross Domestic Product (a measure of economic activity).

Geological time scale: This covers time from the oldest known rocks to the present. Units of time are not divided equally and differentiation becomes more detailed as the rocks become younger (Table 2). The longest intervals of time are termed Eons, the oldest of which are collectively termed the Precambrian. From the Precambrian, on, time is further divided into Era and Periods. Further subdivision into Epochs occurs in the Tertiary and Quaternary Periods. In the WKSS area, there are only a few traces of rocks formed between the end of the Precambrian and the late Quaternary Period.

Glacial refugium: A region where species adapted to more temperate conditions were able to survive during periods of glaciation, and from which they later spread to recolonize the postglacial environment.

Glacial till: An unsorted mixture of clay, sand, gravel and larger particles left as residual material after melt and retreat of glacial ice. A form of sedimentary rock.

GNWT: Government of the North West Territories.

Granite gneiss: A rock with the composition of granite but in which there is mineral orientation and structural banding and swirls. The rock has been largely reformed under intense metamorphic heat and pressure, to the extent that its original form may not be discernible.

Granitoid: A granite-like rock. Granites are coarse grained, light coloured igneous rocks that contain plagioclase feldspar, mica and quartz.

Graphite: A soft, gray-black and flaky mineral form of pure carbon.

Gray water: Household and vessel effluent water that does not include sewage waste, mostly from washing and cleaning activities.

Greenhouse gas: A gas that absorbs solar radiation (directly, or reflected from the Earth's surface) and which causes the temperature of the atmosphere to increase (*e. g.* carbon dioxide). A greenhouse-like effect.

Growing degree days: Number of days x temperature above 5º C (*e. g.* 45 days having an average temperature of 7º C is equivalent to 45(7-5) = 90 degree growing days (most plant growth is minimal below 5º C). See, also, Degree days.

GSC: Geological Survey of Canada.

Halogenated organic compounds Also called organohalides; organic compounds in which halogen elements are bound into the molecular structure. Halogens include bromine, chlorine, fluorine and iodine.

HBC: Hudson Bay Company. See, also, NWC.

HC: Health Canada.

HCH (Alpha-, beta-, gamma-, technical-): HCH is an insecticide. The gamma-isomer of HCH is also known as Lindane (a widely used insecticide). The degradation product of this isomer is Alpha-hexachlorocyclohexane. Most HCH is applied as technical HCH (a mixture of alpha-, beta- and gamma-HCH; the mixture is mostly alpha-HCH). See, also, BHC.

Hematite: An iron oxide mineral (ferric oxide).

Heptachlor epoxide: Organohalide (chlorinated) insecticide.

Herbivore: Organism whose principle diet is plant material.

Herb: A seed-bearing non-woody vascular plant whose above ground parts die-off at the end of the growing season. See, also Forbs.

Herd: A group of animals of the same species that generally stay together or that share a common range for most of their lifetime. Herds usually comprise many smaller groups (*e. g.* family groups). See, also, Population.

HRD: Human Resources Development.

Hummocky moraine: Generally coarse material “dumped” from stagnant melting glacial ice, producing an irregular surface over the till material.

Hyperalkaline (rocks): Igneous rocks containing unusually high concentrations of alkaline elements (*e. g.* Ca, K and Na). High Ca is mostly associated with basic rocks, high K with acidic rocks, and high Na with rocks of intermediate composition.

INAC: Indian and Northern Affairs Canada. See, also, DIAND, DNANR and IAND.

IAND: Indian Affairs and Northern Development. See, also, DIAND, DNANR and INAC.

IASC: International Arctic Science Committee (Norway).

Ice algae: Species of algae specifically adapted to living in close association with ice. Ice algae are present in ice and surrounding surface waters and photosynthesize under relatively low light conditions of Arctic and sub-Arctic fall and spring.

ICI: Inuit Cultural Institute.

IEMA: Independent Environmental Monitoring Agency, Yellowknife.

Igneous rocks: Rocks formed, within the earth's crust, after cooling of molten material. Slow cooling produces coarse crystalline structures; rapid cooling produces fine crystalline structures. See, also, Metamorphism.

IISD: International Institute for Sustainable Development, Winnepeg.

Inliers: A region of older rocks surrounded by younger rocks.

In situ: In place.

Invertebrates: Animals having no backbone.

Isomers: Groups of compounds that have the same molecular composition but different molecular structure.

Isostatic recovery: Upward movement of the Earth's surface in response to the decreasing weight of overlying ice, during periods of glacial melt. There is a lag between melt and uplift.

ISTC: Industry, Science and Technology Canada.

IWD: Inland Waters Directorate.

IWGMI: Intergovernmental Working Group on the Mining Industry.

Kame: A sedimentary deposit, often of sandy gravel, formed in a ponded area on the surface (or the edge) of melting glacial ice. After ice retreat, the kame surface remains higher than the surrounding area. See, also, Esker.

KIA: Kitikmeot Inuit Association.

Kimberlite: Compositionally, kimberlites reflect peridotite and eclogite source materials. Texturally, they are composed of broken rock fragments set in a matrix of much finer material and appear similar to some volcanic rocks. Kimberlites may or may not contain diamonds.

La Nina: Under a La Nina event, colder than normal water spreads west from Peru across the Pacific Ocean and may dramatically influence global weather conditions. As a result of complex and not well understood interactions between the ocean and atmosphere, Arctic air may penetrate more deeply into North America (El Niño and La Nina can be thought of as somewhat opposite conditions, with La Nina tending to be the weaker. The reality is much more complex). See, also, El Niño.

Larval fish: An early stage in development, immediately following the hatch of fish eggs. Larval fish are very small and form part of the zooplankton community.

LD: Lands Directorate.

LEL: Lowest effect level; a guideline value indicating that at least one chemical parameter has potential to adversely affect aquatic biota. LEL does not imply that there will be an adverse effect nor does it require biological assessment which would be necessary to establish an adverse effect. LEL provides a warning. See, also, SEL.

Lipids: Organic compounds that are insoluble in water, consisting of fats, oils, and greases.

Loading: The amount of a substance (*e. g.* a contaminant) introduced into the environment over some period of time (*e. g.* expressed as: $kg.a^{-1}$).

Lode deposits: A formation of highly concentrated minerals or metal within a rock.

Loess: Fine-grained, yellowish-brown, wind-blown deposit (many loess deposits were formed by wind erosion of glacial sediments exposed by retreating ice).

LORAN beacon: Beacon that is part of a long range radio navigation system.

Magmatic arc: An oceanic region of magmatic activity (usually as a long arc) close to a subduction zone (where the edge of one plate moves beneath another).

Magmatism: Formation of molten rock as a result of increased heat and, or, pressure within the Earth's crust.

Magnetite: Iron oxide mineral (chemically, a ferrous and ferric oxide mixture).

Mantle: A thick layer of rock surrounding the Earth's core; at depths greater than 100 - 350 km (and depending on rock composition and temperature), rocks become easily deformed (the Asthenosphere).

Marble: Metamorphosed limestone (rock in which mineral calcite has recrystallised under heat and pressure).

Mariculture: Artificial culture of biota (mostly fish or shellfish) in marine waters.

Marshland: A wetland area without trees, in which there is some movement of water (cattails and rushes are often the dominant vegetation).

MC: Museums Canada.

Melanin: A dark brown or black pigment.

Metabolism (biological): All the physical and chemical processes that convert food into living matter, and reserves and waste matter, and energy for all vital processes.

Metamorphism (rocks): Changes in structure and mineral content that occur in any solid rock, under the influence of high temperature and pressure (rocks which completely melt and recrystallize become igneous rocks). See also, Igneous rocks.

Methylation (mercury): Natural microbial processes by which a methyl ($-CH_3$) group is attached to a metal or metalloid in an inorganic compound. Anaerobic conditions favour production of methyl mercury. In neutral or alkaline waters, volatile dimethyl mercury ($(CH_3)_2Hg$) is formed and most passes quickly into the atmosphere. Under more acidic conditions, monomethyl mercury (CH_3Hg^+) is formed. This soluble form is more readily incorporated into the food web through bioaccumulation. Both methylation and demethylation processes may proceed simultaneously within different microbial communities, in the same sediment.

Microtines: Voles.

Milankovitch cycles: Long term periodicities in inclination and motion of the Earth around the sun that relate to changes in received solar radiation. Average periodicities for precession, tilt, and orbital eccentricity are 23,000, 41,000, and 100,000 years (low eccentricity) and 400,000 years (high eccentricity), respectively; frequencies of these effects, in combination, extend over even longer periods of time.

Mineral horizon: Layer containing a mineral concentration.

Moho or Mohorovic discontinuity: Zone of seismic discontinuity at the base of the Earth's crust.

Monocotyledon: A flowering plant with long and narrow leaves that have a parallel vein structure, and fibrous roots (*e. g.* grasses).

Moulting: Process of shedding and regrowth of hair, fur, feathers, or an exoskeleton.

MRD: Mineral Resources Directorate.

MSSC: Ministry of Supply and Services Canada. See, also, DSS and SSC.

MVEIRB: Mackenzie Valley Environmental Impact Review Board, Yellowknife.

Mysids: Small, shrimp-like crustaceans with a carapace over most of the thorax and that have two-branched appendages (Order Mysidaea). Mysids tend to be larger than amphipods. See, also, Amphipods.

NAO: North Atlantic Oscillation; a long term fluctuation in the distribution of large scale atmospheric pressure systems over the North Atlantic.

NATMAP: National Mapping (Canadian geological research program).

Nauplii: First larval stage in development of some crustaceans; the body is typically unsegmented, with only three pairs of appendages and an unpaired median eye. See, also, Zooplankton.

NCP: Northern Contaminants Program (DIAND and partners).

NED: Northern Environment Directorate.

NFA: Nunavut Final Agreement.

Net annual production: Total production, less material used in respiration.

N-fixation: Process by which atmospheric nitrogen is used by some bacteria and blue-green algae to form amino acids (some of these organisms are free living and some are symbionts living in association with plants, *e. g.* in root nodules).

NNP: Net Neutralizing Potential, the balance between AP and NP (values may be positive or negative). See, also, AP and NP.

NP: Neutralizing Potential, the ability of material to neutralize acids (relating to mine wastes). NP values generally apply to the natural bedrock surface at the site of mine wastes. See, also, AP and NNP.

NPC: Nunavut Planning Commission.

NRC: Natural Resources Canada. See, also, EMR.

NREDB: Natural Resources and Economic Development Branch.

Nutrients: Biological health and growth are largely controlled by availability of major nutrients (*e. g*. phosphorus, nitrogen, organic carbon, and silica) and numerous other minor nutrients.

NWC: North West Company. See, also HBC.

NWT: North West Territories.

NWT-CM: NWT Chamber of Mines.

NWT-HC: NWT Housing Corporation.

Ostracism: To socially ignore someone or, in a more extreme situation, to banish, exile, or cast someone out from a community.

Orogen: Large elongated region of the Earth's crust that has been intensely folded, faulted and thickened as a result of crustal movements.

Ozone: A strongly oxidizing gas (molecular formula O_3).

PAHs: Polycyclic aromatic hydrocarbons; a group of compounds formed as a result of incomplete combustion of fuel (including wood, oil and coal). The compounds have a wide range of toxicities.

Passerines: Perching birds.

Passive migration: Movement of an organism with the natural flow of a river or coastal current, with little or no additional effort to accelerate transportation.

PC: Parks Canada.

PCBs: Polychlorinated biphenyls; stable, heat transfer fluids, lubricants and flame retardants, PCB congeners have a wide range of toxicities and persistence.

PCCs: Polychlorinated camphenes. See, also, Toxaphene.

PCDDs: Polychlorinated dibenzo-*p*-dioxins; group of isomers formed as by-products in manufacture of chlorophenol and phenoxy compounds (including some pesticides and wood preservatives), and possibly from municipal incineration. Also, like some of the chlorinated dibenzo furans, PCDD may be be produced as a by-product of chlorinating in the pulp and paper industry. PCDDs range widely in toxicity (2,3,7,8 tetrachloro dibenzo-*p*-dioxin is the most toxic isomer). See, also, PCDFs.

PCDFs: Polychlorinated dibenzo-*p*-furans (closely related to PCDDs). Present as a by-product or contaminant in PCBs and produced, unintentionally, in some chlorinated processes (*e. g.* pulp and paper manufacture) and in association with some combustion. 2,3,7,8 tetrachlorodibenzo-*p*-furan

(TCDF) is the most toxic of these compounds.

Peatlands: Areas dominated by the formation of organic soil in which much of the material is only partly decomposed (also known as muskeg). See, also, Wetlands.

Pegmatites: Igneous rocks (usually late in an intrusive sequence) in which the crystalline structure is extremely coarse.

Pelagic: Actively moving in open water (not drifting).

Peridotite: Coarse grained igneous rock consisting mostly of olivine (with or without pyroxene).

Permafrost: Permanently frozen ground.

Pesticides: Chemicals that are manufactured to kill different types of pests (including insects, worms, mice, rats and other organisms). Insecticides specifically target insects and are a common type of pesticide.

pH: A log. scale that measures the concentration of hydrogen ions; 1.0 is extremely acidic, 7.0 is neutral, and 14.0 is extremely basic.

Photic zone: Uppermost layer of a water body in which penetration of daylight is sufficient to support photosynthesis.

Photochemical reaction: Chemical reaction produced by light energy.

Photo-oxidation: Chemical oxidation induced by light.

Photosynthesis (plants): Synthesis of chemical compounds by organisms containing chlorophyll (plants) in light. The synthesis of carbohydrates from carbon dioxide and a hydrogen source such as water, with the simultaneous liberation of oxygen.

Phytoplankton: Free-floating or suspended microscopic plants in marine and freshwater environments. See, also, Plankton.

Pillow lavas: Lava extruded under water at the Earth's surface. Rapid cooling causes the lava to develop characteristic pillow shaped forms as it solidifies into rock.

Pitchblende: Mineral of uranium oxide (also called uranite).

Plankton: Depending on particle size, plankton (phytoplankton and, or, zooplankton) can be grouped as pico (0.45 to 1.2 mm), nano (1.2 to 5.0 mm), ultra (5 to 20 mm), and micro or net plankton (greater than 20 mm).

Plume: Tongue-like body of freshwater and, or, suspended sediment that is sometimes present where a river enters a lake or the sea. Plumes occur where there is a difference in density between inflowing and receiving waters. Plumes may be present on the surface, at some mid-depth or at the bottom of the receiving body of water.

Plumes of gas and particulate emissions from industrial sources also enter the atmosphere and may travel hundred of kilometres from source.

Pluton: Any large body of intrusive rock, regardless of shape (a batholith may comprise multiple plutons).

Polar vortex: Circulation of the atmosphere around the polar regions (Arctic and Antarctic).

Polynya: Areas of open water that remain uncovered by seasonal ice (for most or all of the year). These areas are usually kept open by current circulation and vary considerably in size. The features are generally stable and develop in the same place each winter.

Polysaccharide: Large carbohydrate molecule made up of many monosaccharide units. Insoluble and unsweet, and important for energy storage (*e. g.* starch, glycogen) and as reinforcing material in plants (cellulose).

POPs: Persistent Organic Pollutants.

Population: All members of some specifically defined group (*e. g.* males and females, juveniles and adults; or the group might include only adult males). Population can apply to a species, a community or some larger grouping of animals and plants, or both. See, also, Herd.

Primary production: Amount of organic matter produced by photosynthesis.

Pyrrhotite: Mineral of iron sulphide (ferrous sulphide).

Quartzites: Metamorphosed sandstone (rock in which mineral quartz is dominant and has recrystallised under heat and pressure).

Radiometric dating techniques: Age determination based on the extent to which isotopic decay has occurred in some radioactive element. Rates of decay are more or less constant and the half-life of a radioactive element is the time taken for half of this isotopic decay to occur (*e. g.* ^{40}K has a half life of 1.3 Ga but ^{14}C has a half life of only 5.7 ka).

Radionuclides: In this report, radionuclides include those of cesium (^{134}Cs, ^{137}Cs), lead (^{210}Pb), pollonium (^{210}Po), potassium (^{40}K), radon (^{222}Rn), radium (^{226}Ra), strontium ($^{90's}$r), thorium (^{232}Th) and uranium (^{235}U).

Range: Area normally occupied by some group of animals, for part of all of a year. If not specified, the range is assumed to be the total annual range (*e. g.* the range of the Bathurst Caribou herd includes winter grounds, calving areas, summer feeding grounds and rutting areas).

Range extension: An increase in the area occupied by some group of animals (*e. g.* in response to changing and more favourable climatic conditions).

Raptors: Any bird of prey (predatory bird).

Rare earth (elements): Rare lanthanide elements such as cerium and hafnium (having atomic numbers between 58 and 72, inclusive).

RCMP: Royal Canadian Mounted Police

Respiration (microbial): Gas exchange between an organism and its surroundings.

Rhizome: Underground part of a plant stem that provides storage, usually horizontal, and from which new buds and leaves may develop away from the parent plant (vegetative propagation).

Sandstone: Sedimentary rock composed of sand grains that have become fused or cemented together.

SC: Statistics Canada.

SCNE: Special Committee on the Northern Economy.

Secchi depth: Measure of transparency based on the depth at which a white disk can be seen, when lowered into water.

Sedge meadow: Open areas of sedge vegetation. See, also, Tussock sedge.

Sedimentary (rock): A rock formed in response to the processes of erosion (by wind, water and ice) and deposition on the land or under water. "Soft" sediments (*e. g.* mud, sand and gravel) are not cohesive but if consolidated by overlying material or cementation, over a long period of time, they develop into "hard" rocks (including mudstones, limestone, and sandstone).

SEL: Severe effect level; a guideline indicating that at least one chemical parameter exceeds a level at which biological assessment is required to establish the effect of a sediment contaminant on aquatic biota (and remediation implemented). This is a sediment quality guideline that was established by the Ontario Ministry of Environment in 1992. The guideline value does not indicate that the sediment will have an adverse affect on biota; rather it indicates that biological testing must be undertaken to establish to what extent there may or may not be an adverse affect. See, also, LEL.

Senescing tissue: Old tissue (that may often die-off in plants).

Shales: Mud (mixture of silt and clay) that has been metamorphosed and developed fine partings perpendicular to formative pressures.

Shrub: A low woody plant without a well defined (single) stem.

Siltstone: Metamorphosed silt (but without well developed fine partings).

SMB: Surveys and Mapping Branch.

Solifluction: Slow downslope movement in soil.

SSC: Supply and Services Canada. See, also, MSSC.

Staging: Seasonal behaviour, particularly in ducks and geese, in which groups of birds gather to feed and rest before leaving on migration.

Stocks: A subset of the population of a species; often used in reference to fish. See, also, Herd.

Stratiform deposits: Layered deposits (applied to mineral layers in some ore deposits).

Stratosphere: Atmospheric layer between about 10 and 25 km above the Earth's surface, in which the temperature is relatively constant, ranging from about -45º C to -75º C.

Subducted: Downward movement of the edge of a plate on the Earth's crust beneath an adjacent plate, as one plate moves towards the other.

Substrate: Stable base onto which an organism can become attached (*e. g.* shell of another organism, wood, sediment, rock or even ice).

Sugar: Simple carbohydrate formed of monosaccharide units that can be readily metabolized to support plant growth or animal activity.

Sunspots: Regions of high magnetic field on the sun. Groups of sunspots vary in size (lasting hours to weeks). Sunspot (magnetic) activity increases to a maximum about every 11 years.

SWC: Status of Women Council.

Syntheses (biological): Processes by which plants and animals make essential compounds.

Taiga: Transitional vegetation zone between a closed canopy boreal forest and treeless tundra. It is characterized by small groups of scattered trees within tundra vegetation and, occasionally, patches of tundra within open canopy boreal forest. Taiga vegetation more or less coincides with the sub-Arctic Climate zone.

Tailings: Waste materials left after extraction of ore from host rock; a waste product of mining.

TDI (PTDI and PDI): Tolerable Daily Intake (an adopted value) and Provisional Tolerable Daily Intake (a provisional value). Amount of a substance (contaminant) that a person may be exposed to, every day of their lifetime, with minimal or no appreciable health risk. Values of TDI are based on epidemiological and toxicological research that establishes at what level there is no observed adverse effect, and to which a safety factor has been applied. Consumption advisories are issued when PDI values exceed TDI. Probable Daily Intake (PDI) values are calculated from information about contaminant concentrations (*e. g.* in food), quantity of food (containing a contaminant) and the body weight (of a person eating the food). Well defined analyses of risk form the basis of both TDI and PDI values

Terrane: A large piece of the Earth's crust having distinct geological characteristics.

Terrigenous: Referring to the land (*e. g.* terrigenous environment).

TKSC: Traditional Knowledge Committee of the West Kitikmeot/Slave Study.

Toxaphene: Chlorinated camphene; an insecticide (which may consist of a mixture of more than 170 compounds). See, also PCCs.

Tree line: Northern edge of the Boreal Forest that may, in part, lie within the taiga. See, also, Taiga.

Trophic levels: Successive levels in the food web. Primary production of plants (including phytoplankton) occurs at the base of the food web, and predator species characterize the upper levels. Some food chains are longer than others and have more trophic levels.

Tuff: Rock formed from the hardening of volcanic ash and ejecta.

Tundra: Treeless vegetation cover (including sedges, grasses, low shrubs, lichens and mosses) that coincides closely with the Low Arctic Climatic Zone.

Tussock sedge: Distinctive clumps of sedge vegetation that form under poorly drained conditions. See, also, Sedge meadow.

Ultramafic: Extremely basic rocks, very dark in colour, that are mostly comprised of ferromagnesian minerals (*e. g.* olivine and pyroxene) and a small amount of plagioclase feldspar.

UNEP: United Nations Environment Program.

USDA: United States Department of Agriculture.

USDI: United States Department of Interior.

USEPA: United States Environmental Protection Agency.

UV radiation: Ultra violet radiation is a form of short wave electromagnetic radiation with wave lengths between about 0.1 and 0.4 μm. It merges into the spectrum of visible light (that has wave lengths up to about 0.8μm).

Vascular plants: Plants having internal structures (vascular bundles) that allow water to be transported within the plant (*e. g.* from roots to leaves).

Vitamins: Organic compounds that are vital in diet, in small amounts, for normal health and growth. Not all organisms require the same vitamins. Some vitamins are synthesized by the animals that need them but some have to be taken into the body as food. Vitamins A, D, E and K are fat-soluble, and vitamins B and C are water soluble.

Volatilization: Released as vapour; changing rapidly from a liquid to a gas.

Volcanic massive sulphides: Large deposits of sulphide metal ores (*e. g.* iron, copper, zinc, lead and arsenic) associated with the formation of volcanic rocks.

Weather index: In WKSS area, east of Great Slave Lake, almost all natural fires occur as a result of lightning strikes. By comparing fire history with environmental conditions, it is possible to characterize fire potential (*e. g.* risk related to moisture content of soil and vegetation) and weather conditions that are likely to start and support a fire (*e. g.* air temperature and moisture, and wind conditions). Fires that do not match weather index conditions for fire are likely due to some other cause.

WKSS area: The West Kitikmeot and Slave geological province and surrounding region, including the Bear geological province and part of the Mackenzie Valley (generally the area shown in Fig. 1). The main focus of this report is on the West Kitikmeot sub-region of Nunavut (that includes part of the Slave geological province) and the eastern part of the Northwest Territory (which includes the remainder of the Slave geological province).

WKSSS: West Kitikmeot Slave Study Society, Yellowknife, NWT.

WMO: World Meteorolical Organization, Geneva.

WRD: Water Resources Division.

WS: Wildlife Service.

WWI / WWII: World War 1 (1914-1918) / World War 2 (1939-1945).

Zooplankton: Animal plankton (*e. g.* nauplii, ciliates, small crustaceans and fish larvae). See, also, plankton.

9. SYMBOLS, NOTATIONS AND USAGE

Ag	Silver
As	Arsenic
Au	Gold
Be	Beryllium
Bi	Bismuth
C	Carbon
Ca	Calcium
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cs	Caesium
Cu	Copper
F	Fluorine
Fe	Iron
Ga	Gallium
K	Potassium
Mg	Magnesium
N	Nitrogen
Na	Sodium
Ni	Nickel
O	Oxygen
P	Phosphorus
Pb	Lead
Pd	Palladium
Po	Polonium
Pt	Platinum
Ra	Radium
Rn	Radon
S	Sulphur
Si	Silicon
Th	Thorium
U	Uranium
Y	Yttrium
Zn	Zinc

As_2O_3	Arsenious oxide
$CaCO_3$	Calcium carbonate
CO_2	Carbon dioxide
H_2O	Water
SO_2	Sulphur dioxide
MeHg	Methyl mercury

a	Year
Bq	Becquerel, number of disintegrations per second from a radioactive source.
^{o} C	Degree Celsius
d	Day
g	Gram
Ga	Giga years (billion years, or 10^9 years)
ha	Hectare (10,000 square metres)
ka	Kilo years (one thousand years, 10^3 a)
kg	Kilogram (one thousand grams, 10^3 g)
km	Kilometre (one thousand metres, 10^3 m)
l	Litre
m	Metre
mg	Milligram (one thousandth part of a gram, 10^{-3}), *e. g.* weight of contaminant in some form of concentration.
mm	Millimetre (one thousandth part of a metre)
ng	Nanogram (one billionth part of a gram, 10^{-9}), *e. g.* weight of contaminant in some form of concentration.
nm	Nanometre (one billionth part of a metre, 10^{-9}), *e. g.* wavelength in part of the electromagnetic spectrum (1000 nm = 1μm).
t	Metric tonne (1000 kg).
μg	Microgram (one millionth part of a gram, 10^{-6}), *e. g.* weight of contaminant in some form of concentration.
μm	Micrometre (one millionth part of a metre, 10^{-6}), *e. g.* wavelength in part of the electromagnetic spectrum.
%	Per cent (parts per hundred), a useful form of common comparison.
Σ	The sum of; *e. g.* ΣPCB means all PCB congeners (that are present).

$Bq \cdot kg^{-1}$	Becquerels; disintegrations per second, per kilogram of material containing a radioactive substance (*e. g.* a radioactive isotope of caesium in caribou tissue).
$\cdot ha^{-1}$	Quantity of something per hectare (*e. g.* lemmings).
$kg \cdot d^{-1}$	Loading of something expressed in kilograms per day (*e. g.* some form of industrial contaminant).
$kg \cdot ha^{-1} \cdot a^{-1}$	Loading of something expressed in kilograms per hectare per year (*e. g.* sulphate ions, as an indication of atmospheric contributions to acidification).
$\cdot km^{-2}$	Quantity of something per square kilometre (*e. g.* hares).
$\cdot m^{-2}$	Quantity of something, per square metre (*e. g.* annual production of plant matter).
$mg \cdot l^{-1}$	Parts per million of something expressed as weight per volume (*e. g.* suspended organic matter in water).
$ng \cdot g^{-1}$	Parts per billion of something expressed as weight per weight (mass).
$\mu g \cdot g^{-1}$	Parts per million of something expressed as weight per weight (mass).
$mg \cdot m^{-3}$	Parts per billion of something per cubic metre expressed as weight per volume (*e. g.* some pollutant in air).
$Sv.a^{-1}$	Sieverts or dose equivalent (defined as absorbed radiation dose times the Relative Biological Effectiveness factor) per year.

10. COMMON AND SCIENTIFIC NAMES

10.1. Amphibians

Chorus/Boreal Frog	*Pseudoacris triseriata*
Wood Frog	*Rana sylvatica*

10.2. Birds

10.2.1. Ducks, Geese and Swans

American Widgeon	*Anas americana*
Black Scoter	*Melanitta nigra*
Brant Goose	*Branta bernicla*
Bufflehead	*Bucephala albeola*
Canada Goose	*Branta canadensis*
Common Merganser	*Mergus merganser*
Greater White-Fronted Goose	*Anser albifrons*
Greater Scaup	*Aythya marila*
King Eider	*Somateria spectabilis*
Lesser Scaup	*Aythya affinis*
Lesser Snow Goose	*Chen caerulescens caerulescens*
Mallard	*Anas platyrhynchos*
Northern Pintail	*Anas acuta*
Oldsquaw	*Clangula hyemalis*
Common Eider (Pacific race)	*Somateria mollissima v. nigra*
Red-breasted Merganser	*Mergus serrator*
Ross' Goose	*Chen rossi*
White-winged Scoter	*Melanitta deglandi*
Surf Scoter	*Melanitta perspicillata*
Tundra (whistling) Swan	*Cygnus columbianus*

10.2.2. Falcons, Hawks and Osprey

American Kestrel	*Falco sparverius*
Bald Eagle	*Haliaeetus leucocephalus*
Golden Eagle	*Aquila chrysaetos*

Gyrfalcon	*Falco rusticolus*
Merlin	*Falco columbarius*
Northern Goshawk	*Accipiter gentilis*
Northern Harrier	*Circus cyaneus*
Osprey	*Pandion haliaetus*
Peregrine Falcon	*Falco peregrinus (*subspecies *anatum and tundrius)*
Rough-legged Hawk	*Buteo lagopus*
Sharp-shinned Hawk	*Accipiter striatus*
Red-tailed Hawk	*Buteo jamaicensis*

10.2.3. Grouse and Ptarmigan

Spruce Grouse	*Dendragrapus canadensis*
Sharp-tailed Grouse	*Tympanuchus phasianellus*
Ruffed Grouse	*Bonasa umbellus*
Willow Ptarmigan	*Lagopus lagopus*
Rock Ptarmigan	*Lagopus mutus*

10.2.4. Gulls, Jaegers, Pelicans and Terns

Arctic Tern	*Sterna paradisaea*
Black Tern	*Chlidonias niger*
Boneparte's Gull	*Larus philadelphia*
California Gull	*Larus californicus*
Caspian Tern	*Hydroprogne caspia*
Common Tern	*Sterna hirundo*
Franklin's Gull	*Larus pipixcan*
Glaucous Gull	*Larus hyperboreus*
Herring Gull	*Larus argentatus*
Long-tailed Jaeger	*Stercorarius longicaudus*
Mew Gull	*Larus canus*
Parasitic Jaeger	*Stercorarius parasiticus*
Ring-billed Gull	*Larus delawarenis*
White Pelican	*Pelecanus erythrorhynchos*

10.2.5. Loons and Grebes

Arctic Loon	*Gavia arctica*
Common Loon	*Gavia immer*
Pacific Loon	*Gavia pacifica*
Red-necked Grebes	*Podiceps grisegena*
Red-throated Loon	*Gavia stellata*
Yellow-billed Loon	*Gavia adamsii*

10.2.6. Owls

Great Horned Owl	*Bubo viginianus*
Short-eared Owl	*Asio flammeus*
Snowy Owl	*Nyctea scandiaca*

10.2.7. Perching birds

American Robin	*Turdus migratorius*
American/water Pipit	*Anthus spinoletta*
Barn Swallow	*Hirundo rustica*
Blackburnian Warbler	*Dendroica fusca*
Blackpoll Warbler	*Dendroica striata*
Boreal Chickadee	*Parus hudsonicus*
Common Raven	*Corvus corax*
Common Redpoll	*Carduelis flammea*
Flycatchers sp.	F. Tyrannidae
Gray-cheeked Thrush	*Catharus minimus*
Harris' Sparrow	*Zonotrichia querula*
Hoary Redpoll	*Carduelisa hornemanni*
Horned Lark	*Eremophilia alpestris*
Lapland Longspur	*Calcarius lapponicus*
Magnolia Warbler	*Dendroica magnolia*
Olive-sided Flycatcher	*Nuttallornis borealis*
Savannah Sparrow	*Passerculus sandwichensis*
Snow Bunting	*Plectrophenax nivalis*
Tennessee Warbler	*Vermivora peregrina*
American Tree Sparrow	*Spizella arborea*

Warblers	*Dendroica* spp.
White-crowned Sparrow	*Zonotrichia leucophrys*
Wilson's Warbler	*Wilsonia pusilla*
Yellow-bellied Flycatcher	*Empidonax flaviventris*
Ruby-crowned Kinglet	*Regulus calendula*

10.2.8. Shorebirds (Wading Birds)

American Golden-Plover	*Pluvialis dominica*
Eskimo Curlew	*Numenius borealis*
Northern Phalarope	*Lobipes lobatus*
Least Sandpiper	*Calidris minutilla*
Red-necked Phalarope	*Phalaropus lobatus*
Sandhill Cranes	*Grus canadensis*
Sandpipers	*Actitis* spp.,*Calidris* spp., *Tryngites* spp.
Semipalmated Plover	*Charadrius semipalmatus*
Spotted Sandpiper	*Actitis macularia*
Stilt Sandpiper	*Calidris himantopus*

10.2.9. Woodpeckers

Northern three-toed Woodpecker	*Picoides tridactylus*

10.3. Fishes

10.3.1. Freshwater Fish

Arctic Grayling	*Thymallus arcticus*
Broad Whitefish	*Coregonus nasus*
Burbot	*Lota lota*
Emerald Shiner	*Notropis atherinoides*
Goldeye	*Hiodon alosoides*
Inconnu	*Stenodus leucichthys*
Lake Chub	*Couesius plumbeus*
Lake Cisco	*Coregonus artedii*
Lake Trout	*Salvelinus namaycush*
Lake Whitefish	*Coregonus clupeaformis*

Least Cisco	*Coregonus sardinella*
Longnose Sucker	*Catostomus catostomus*
Ninespine Stickleback	*Pungitius pungitius*
Northern Pike	*Esox lucius*
Round Whitefish	*Prosopium cylindraceum*
Shortjaw Cisco	*Coregonus zenithicus*
Slimy Sculpin	*Cottus cognatus*
Troutperch	*Percopsis omiscomaycus*
Walleye	*Stizostedion vitreum*
Yellow Perch	*Perca flavescens*

10.3.2. Freshwater and Marine, and Marine Fish

Arctic Char	*Salvelinus alpinus*
Arctic Cisco	*Coregonus autumalis*
Arctic Cod	*Boreogadus saida*
Arctic Flounder	*Liopsetta glacialis*
Arctic Lamprey	*Lampetra japonica*
Bering Flounder	*Hippoglossides robustus*
Bering Wolffish	*Anarhichas orientalis*
Boreal Smelt	*Osmerus mordax*
Capelin	*Mallotus villosus*
Eelblenny	*Lumpenus* spp.
Eelpout	*Lycodes* spp.
Flounder	*Limanda proboscidae*
Fourhorn Sculpin	*Myoxocephalus quadricornis*
Greenland Cod	*Gadus ogac*
Pacific Herring	*Clupea harengus*
Polar Cod	*Arctogadus glacialis*
Saffron Cod	*Eleginus gracilis*
Sand Lance	*Ammodytes hexapterus*
Starry Flounder	*Platichthys stellatus*
Toothed Cod	*Arctogadus borisovi*

10.4. Invertebrates

Ants, bees and wasps	Order Hymenoptera

Beetles	Order Coleoptra
Bot flies (true flies)	*Cephenemyia trompi*
Blackfies (true flies)	inc. sp of genera *Prosimulum ,Cnephia, & Simulum*
Butterflies/moths	Order Lepidoptera
Spruce budworm	*Choristoneura fumiferana*
Caddis flies	Order Trichoptera
Calanoids	(Very small crustaceans, Order Copepoda)
Cyclopoids	(Very small crustaceans, Order Copepoda)
Dragon flies	Order Odonta
Hoppers (freshwater)	*Gammarus* spp. (Order Amphipoda)
Mayflies	Order Ephemeroptera
Mosquitoes (true flies)	*inc. Aedes,* spp.
Baltic Macoma (marine clam)	*Macoms balthica*
Mysids	*Mysid spp.* (Order Amphipoda)
Blue mussel	*Mytilis edulis*
Freshwater shrimp	*Pontoporeia* spp. (Order Amphipoda)
Snow Fleas	*Achorutes nivicola*
Sphaeriid Freshwater clam)	F. Sphaeriidae
Spruce/White Pine Weevil	*Pissodes strobi*
Stone flies	Order Plecoptera
True Flies	Order Diptera
Warble fly (true flies)	*Hypoderma tarandi*

10.5. Invertebrate Composition of Larval Drift (33)

Diptera	73.9%
Cladocera (Order: small crustaceans)	7.9
Arachnida (Order: mites and spiders)	3.6
Branchiopoda (Order: small crustaceans)	3.6
Ostracoda (Order: small crustaceans)	3.2
Trichoptera	2.9
Plecoptera	1.3
Ephemeroptera	1.1
Nematoda (Order: very small worms)	0.6
Oligochaeta (Order: small worms)	0.3
Gastropoda (Order: water snails)	0.2

10.6. Mammals

10.6.1. Aquatic (Marine) Mammals

Bearded Seal	*Erignathus barbatus* (sometimes north end Bathurst Inlet)
Beluga Whale	*Delphinapterus leucas*
Bowhead Whale	*Balaena mysticetus*
Polar Bear	*Ursus maritimus*
Ringed Seal	*Phoca hispida*
Walrus	*Odobenus rosmarus*

10.6.2. Large Mammals

Arctic Fox	*Alopex lagopus*
Barren-ground Caribou	*Rangifer tarandus groenlandicus*
Beaver	*Castor canadensis*
Black Bear	*Ursus americanus*
Gray Wolf	*Canus lupus*
Grizzly Bear	*Ursus arctos*
Lynx	*Felis lynx*
Moose	*Alces alces*
Muskox	*Ovibos moschatus*
Peary Caribou	*Rangifer tarandus pearyi*
Plains-wood Bison	*Bison bison var.*
Porcupine	*Erethizon dorsatum*
Red Fox	*Vulpes fulva*
River Otter	*Lutra canadensis*
Wood Bison	*Bison bison*
Woodland Caribou	*Rangifer tarandus caribou*
Wolverine	*Gulo gulo*

10.6.3. Small Mammals

Arctic Ground Squirrel	*Citellus parryii*
Arctic Hare	*Lepus arcticus*
Arctic Shrew	*Sorex arcticus*
Brown Lemming	*Lemmus sibiricus*

Chestnut-cheeked Vole	*Microtis xanthognathus*
Victoria Collared Lemming	*Dicrostonyx kilangmiutak*
Common/Masked Shrew	*Sorex cinereus*
Ermine/Short-tailed Weasel	*Mustela erminia*
Least Weasel	*Mustela nivalis*
Marten/Sable	*Martes americana*
Meadow Vole	*Microtis pennsylvanicus*
Mink	*Mustela vison*
Muskrat	*Ondatra zibethicus*
Northern Bog Lemming	*Synaptomys borealis*
Northern Red-backed Vole	*Clethrionomys rutilus*
Red Squirrel	*Tamiasciurus hudsonicus*
Rock Vole	*Microtus chrotorrhinus*
Snowshoe/Varying Hare	*Lepus americanus*
Tundra Vole	*Microtus oeconomus*
White-footed Deer Mouse	*Peromyscus maniculatus*

10.6.4. Species Extinct

Mammoths	*Mammuthus* sp.
Sabre-toothed Cats	*Smilodon* sp.
Woolly Rhinoceros	*Coelodonta* sp.

10.7. Vegetation

10.7.1. Aquatic and Semi-aquatic Plants

Bulrushes	*Scirpus* spp.
Cattails	*Typha latifolia*
Chickweed	*Stellaria longifolia*
Pondweeds	*Potamogeton* spp.
Phytoplankton	Chrysophyta
Rushes	*Juncus* spp.
Yellow Pond-Lily	*Nuphar variegatum*
Water-Milfoil	*Myriophyllum exalbescens*

10.7.2. Grasses, Horsetails, Lichens, Mosses, Plankton, Roots and Sedges (examples of typical species)

Blue Joint	*Calamagrostis canadensis*
Cottongrasses	*Eriophorum vaginatum, E. angustifolium, E. scheuchzeri*
Grasses(Poaceae)	*Arctagrostis latifolia, Artophila fulva, Calamagrostis canadensis, Dupontia fisheri, Scolochloa festucacea , Poa glauca*
Horsetails	*Equisetum variegatum , E. fluviatile*
Lichens (Bearded)	*Usnea* spp.
(Crustose)	
(Foliose)	
(Fruticose)	*Cladinia* spp., *Cladonia* spp., *Cetraria* spp.
Mosses (Carpet)	*Sphagnum* spp., *Drepanocladus* spp., *Aulacomnium* spp.
(Feather)	*Pleurozium* spp., *Hylocomium* spp.
Sedges	*Carex aquatilis, C. chordorrhiza, C. rarifolia, C. rotundata, C. membranacea, C. atherodes*
Roots (Bear/Licorice root)	*Hedysarum alpinum*

10.7.3. Herbs and Low Shrubs

Bearberry	*Arctostaphylos uva-ursi*
Bladderwort	*Utricularia vulgaris*
Bog Blueberry/Bilberry	*Vaccinium myrtilloides*
Bog Rosemary	*Andromeda polifolia*
Cinquefoil	*Potentilla* spp.
Cloudberry	*Rubus chamaemorus*
Crowberry/Curlewberry	*Empetrum nigrum*
Fireweed	*Epilobium angustifolium*
Gooseberry	*Ribes oxyacanthoides*
Highbush (Cranberry)	*Viburnum edule*
Labrador Lousewort	*Pedicularis labradorica*
Labrador Tea	*Ledum groenlandicum, L. decumbens*
Liquorice-root	*Hedysarum alpinum*
Lingonberry/ Cranberry/Cowberry	*Vaccinium vitis-idaea*
Moss Campion	*Silene acaulis*
Mountain Avens	*Dryas octopetala*

Mountain/Wood Sorrel	*Oxalis acetosella*
Prickly/	
Three-toothed Saxifrage	*Saxifraga tricuspidata*
Raspberry	*Rubus ideaus*
River Beauty	*Epilobium latifolia*
Saxifrage	*Saxitrage tricuspicale*
Sweet Gale	*Myrica gale*
Tundra Wormwood	*Artemisia* spp.

10.7.4. Shrubs (Woody and Largely Deciduous)

Green Alder	*Alnus crispa*
Tundra Birch	*Betula glandulosa*
Dwarf Birch	*Betula nana*
Dwarf Willows	*Salix* spp.

10.7.5. Trees

Balsam Fir	*Abies balsamea*
Balsam Poplar	*Populus balsamifera*
Black Spruce	*Picea mariana*
Jack Pine	*Picea banksiana*
Specked Alder	*Alnus rugosa*
Tamarack	*Larix laricina*
Trembling Aspen	*Populus tremuloides*
White/Paper Birch	*Betula papyrifera*
White Spruce	*Picea glauca*

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Traditional Knowledge & Lifestyles: V1 *(1.2, 5)*; V2 *(1.2, 4.1-4.3);* V3 *(1.2)*; V4 *(4.1, 4.2, 4.8)*.
Wildlife: V1 *(4.7, 5.1)*; V2 *(3, 4.2, 4.3)*; V3 *(6,7, 9.2)*; V4 *(4.1, 4.2, 4.8, 10.6)*.
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Table 27

n/a

Table 28

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Table 29

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Table 30

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Traditional Knowledge & Lifestyles: V1 *(1.2, 5)*; V2 *(1.2, 4.1-4.3);* V3 *(1.2)*; V4 *(4.1, 4.2, 4.8)*.
Wildlife: V1 *(4.7, 5.1)*; V2 *(3, 4.2, 4.3)*; V3 *(6,7, 9.2)*; V4 *(4.1, 4.2, 4.8, 10.6)*.
Water Quality and Environmental Issues: V1 *(1.5, 2.2, 2.5-2.7, 3.7, 4, 5.1, 5.4),* V2 *(1-4),* V3 *(1, 3-10)*; V4 *(1-3, 4.1, 4.2, 4.8, 4.9)*.
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