The Use of Traditional Environmental Knowledge to Assess the Impact of Climate Change on Subsistence Fishing in the James Bay Region, Ontario, Canada

by

Yukari Hori

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

This thesis used traditional environmental knowledge (TEK) to assess the impacts of climate change on food security for First Nations communities located in the western James Bay region of northern Ontario. In addition, climate scenarios were derived from General Circulation Models (GCMs) and Regional Climate Models (RCMs).

The TEK data revealed there were no observable climatic-related effects on fish species (i.e., distributional change) except the fish die-offs of July 2005. Climate data specific for the period of the fish die-offs in the Albany River (the western James Bay region) indicated not only a temporal relationship between a heat wave and the fish die-offs, but also a concurrent period of reduced precipitation. Climate scenarios showed increases in mean air temperature for all seasons, all time periods (2011– 2040, 2041– 2070, and 2071– 2100), and all emission scenarios (A2, A1B, and B1); however, the results for seasonal total precipitation were variable, dependent emission scenarios.

TEK suggest that increasing temperatures may not be the only climate change phenomena of importance; climate variability and extreme events were reported as precipitating fish die-offs and changes in the timing of harvesting of fish. Further research should concentrate on the investigation of climate change and food security issues in sub-arctic regions.

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Overview

Climate change is one aspect of environmental change. A numbers of explanations for the possible causes and effects of climatic change have been reported in the literature (ACIA, 2004). Human societies, particularly those throughout the arctic and sub-arctic regions are greatly connected to this changing environment because their traditional activities and lifestyles have been shaped by the local environment (ACIA, 2004; Huntington, 2002).

The International Panel on Climate Change (IPCC) has been conducting comprehensive assessments of global climate change since 1988 (Githeko and Woodward, 2003; Weaver, 2004). IPCC reports have been released four times since the first report was published in 1990 (MacLellan, 2008). However, studies on the impacts of climate change on the natural and human environments in the north were not available until the IPCC Fourth Assessment Report (AR4) was released in 2007 (Githeko and Woodward, 2003).

Climate model projections have indicated that the most rapid rates of surface temperature increase will be experienced at high northern latitudes (ACIA, 2004; Cohen, 1997). As the climate in the north continues to change, there will be negative consequences for biodiversity, distribution, and population of many local species (ACIA, 2004). Alteration in human systems will be a consequence of this climate change (MacLellan, 2008).

Aboriginal communities in northern Canada have already observed and reported profound environmental changes in recent decades (ACIA, 2004; Cohen, 1997; Furgal and Seguin, 2006). In Canada, Aboriginal refers to three groups: Inuit, Métis, and First Nations (Department of Justice Canada, 2009). Historically, First Nations groups have resided in the Hudson and James Bay regions, which are situated in the arctic and sub-arctic regions of Canada. First Nations communities in these regions harvest and consume traditional foods, such as game meats, fish, berries, and plant species, for subsistence purposes (Berkes et al., 1994, 1995; Tsuji et al., 2006). There has been growing concern that regional climate change may have a profound effect on traditional food systems, human health, and well-being in these northern communities. Understanding and addressing the complex issue of regional climate change and its impacts on First Nations communities requires the use of both scientific analysis, as well as traditional environmental knowledge (Huntington, 2002; Tsuji and Ho, 2002). Traditional Environmental Knowledge (TEK) is a body of knowledge and beliefs transmitted over generations, orally, by indigenous people with respect to their environment (Berkes, 2008).

The main objectives of this thesis is to generate and present plausible climate scenarios for the western James Bay region of northern Ontario, and to address the implications of regional climate change impacts on food security for First Nations communities in the region. Specifically, this thesis will address the implications of regional climate change impacts on food security for First Nations communities using two knowledge systems: western science (e.g., climate data, climate scenarios) and TEK. Chapter 1 will provide a brief literature review of climate change in the north, climate scenarios, and food security in the context of the main objectives of this thesis. Chapter 2 is written in manuscript format; it is expected that results presented in this manuscript will provide valuable information to public policy and decision-makers with respect to regional implications of climate change and food security for northern First Nations communities. Chapter 3 concludes the thesis with some recommendations of the author.

Chapter 1

Introduction

Climate Variability and Extremes

Climate is naturally variable; it has been changing continuously over the years. Although extreme weather and climate events have been observed in the past few decades, there has been increasing concern about the possible increase in the frequency and degree of climate variability and extremes because of anthropogenic-induced climate change (Colombo et al. 1999; Easterling et al., 2000).

In recent years, a number of climate change impacts and adaptation studies have put more emphasis on the variability of climate, as well as on the frequency and magnitude of climate extremes (Barrow et al., 2004). Using statistical theory of climate extremes, the frequency of extremes is more dependent and sensitive to changes in the variability, rather than in the mean climatic values (Brown and Katz, 1995; Colombo et al., 2000; Katz and Brown, 1992; IPCC, 2001b). Moreover, as the climate events are more extreme, the influence of extremes becomes greater (Colombo et al., 2000; Katz and Brown, 1992).

Although society is greatly concerned with weather variability – as the extremes in weather have caused profound impacts on both human society and the natural environment – assessments of the socio-economic impacts of climate change have focused on average climate conditions rather than on variability or extremes of climate (Katz and Brown, 1992). Despite the effort that has been expended on constructing climate models, most of the present models are generally based on changes in the mean climatic values (Barrow et al., 2004; CCCSN, 2007). Therefore, the construction of climate models that provide useful information about climate variability and extremes is a major challenge for climate modeling researchers (Barrow et al., 2004; CCCSN, 2007).

It is important to note that Aboriginal elders in Cree and Inuit communities are already noticing that some environmental indicators that have been used for interpreting and forecasting weather patterns, no longer coincide with the current weather conditions (Nickels et al., 2006; McDonald et al., 1997). The local elders have used such weather prediction knowledge for understanding wildlife, as well as for interpreting animal distributions, migration patterns, and local vegetation growth because the knowledge is needed to obtain food (Laidler and Gough, 2003).

Vegetation and Wildlife

Changes in the regional climate are expected to affect northern vegetation and a varied range of wildlife that have been significant to the Cree and Inuit communities of the north (ACIA, 2004; Furgal and Prowse, 2008; Laidler and Gough, 2003; McDonald et al., 1997). As for many northern Aboriginals, vegetation and wildlife play a vital role in local diet, traditions and cultures, economics, and spirituality (Furgal et al., 2002; Furgal and Prowse, 2008; Laidler and Gough, 2003).

Aboriginal hunters and local residents today have reported changes in animal behaviour and health, migration routes, abundance of species, and vegetation growth (Furgal and Prowse, 2008; Laidler and Gough, 2003; McDonald et al., 1997). Cree and Inuit elders consider that a combination of a number of factors have led to these significant changes of vegetation and wildlife over the past two decades (McDonald et al., 1997). McDonald et al. (1997) point out that natural fluctuations of wildlife populations in the Hudson Bay region may occur in response to a number of environmental conditions such as habitat loss, food availability, reproduction rates, and disturbances caused by weather and humans.

Projecting Future Climate Trends

Developing a climate scenario is the most common approach to assess the impacts of climate change. A climate scenario is defined by the IPCC (2001b) as “a plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change” (p. 741). It must be noted that a scenario is neither a prediction nor forecast of future climate; rather, it represents possible descriptions of the future climatic conditions based on our consideration of increased atmospheric concentrations of substance such as greenhouse gases and aerosols (Carter et al., 1994,1996;

CCCSN, 2007; IPCC, 2001b; Natural Resources Canada, 2007). In addition, constructing a climate scenario requires information from a climate projection and also additional information from the observed current climate because climate projections alone do not provide adequate knowledge for projecting future impacts of climate change (IPCC, 2001b). The benefits of constructing a climate scenario are as follows (CCCSN, 2007; Natural Resources Canada, 2007):

- to provide data for vulnerability, impacts, and adaptation studies;
- to raise awareness regarding climate change and environmental issues;
- to scope the range of plausible futures; and
- to aid public policy and decision-making processes.

The IPCC (2001b) articulates that there is a clear distinction between a *climate scenario* and a *climate change scenario*, although a number of scientific papers use the latter term to indicate a plausible future climate. A *climate change scenario* is considered as an interim step toward establishing a climate scenario (CCCSN, 2007; IPCC, 2001b). A *climate scenario*, on the other hand, needs to combine the climate change scenario with a description of the present climate regime provided by climate observations (CCCSN, 2007; IPCC, 2001b). These distinctions are summarized by the CCCSN (2007) in the following formula:

- Climate scenario = Current climate + Climate change scenario.

The recent IPCC Special Report on Emissions Scenarios (SRES) has been constructed as a basis for climate projections, and they are used in the assessments of future climate change (CCCSN, 2007; IPCC, 2007). Factors such as population, economic growth, and energy use are considered as driving forces for the future emissions of greenhouse gases and aerosols (Barrow et al., 2004; CCCSN, 2007). The SRES project approximately 40 different emission scenarios grouped into four families; A1, A2, B1, and B2 (CCCSN, 2007; IPCC, 2007). The A1 and A2 families focus on economics, while the B1 and B2 families focus on environmental forces; the A1 and B1 families focus on global, while the A2 and B2 families focus on regional development (CCCSN, 2007; IPCC, 2007). Of these 40 emission scenarios, six are called marker scenarios; A1FI, A1B, A1T, A2, B1, and B2, because they are best reflect the four family scenarios (CCCSN, 2007; IPCC, 2007). These six scenarios are described as follows (CCCSN, 2007; IPCC, 2007):

- A1 – a world of very rapid economic growth and a global population that peaks in mid-century and then gradually declines: A1FI is a fossil fuel intensive, A1B achieves a balance across all sources, and A1T uses non-fossil fuel energy resources;
- A2 – a world of moderate economic growth and a higher population growth rate; business-as-usual;
- B1 – a world of rapid economic growth like A1, but with changes in economic structures toward being more ecologically friendly, and the lowest rate of population growth; and

- B2 – a world in which emphasis is on local rather than global solutions to economic, social, and environmental stability, and a lower population growth rate than A2.

Most of the global climate modelling groups in the IPCC Third Assessment Report (TAR) have completed the A2 and B2 emission scenario simulations, and then these groups, in the IPCC Fourth Assessment Report (AR4) have finished the A2, A1B, and B1simulations (Barrow et al., 2004; CCCSN, 2007).

General Circulation Models

There are a number of types of climate scenarios that are widely accepted as methods of constructing future climate. However, none of these approaches are perfect and advantages and disadvantages are associated with each method. The most common approaches to scenario construction use General Circulation Models (GCMs). Most climate scenarios derived from GCMs are generally consistent with the assumptions proposed by the IPCC Task Group on Data and Scenario Support for Impact and Climate Assessment (Barrow et al., 2004; CCCSN, 2007; IPCC-TGICA, 2007).

GCMs, also known as Global Climate Models, are "sophisticated, mathematically based simulations of the world's climate, including atmospheric, oceanic, cryospheric, and land-surface components" (Gough and Leung, 2002, p. 178). Carter et al. (1996) deemed GCMs to be the most reliable tools available at present time for simulating the physical processes of global climate, including the effects of increasing atmospheric concentrations such as greenhouse gases and aerosols.

In recent GCM experiments, the transient response models like coupled atmosphere-ocean models provide a number of advantages over the equilibrium response models, which evaluate an instantaneous doubling or quadrupling of atmospheric concentrations of CO_2 (Barrow et al., 2004; Carter et al., 1996; CCCSN, 2007). For example, the representation of the ocean circulation and heat transfer from the oceanic surface is more realistic so that the transient models are able to simulate time dependent responses to changing atmospheric composition (Barrow et al., 2004).

Despite improvements in the representation of certain climate processes over the last few years, there are still limitations in the spatial resolution of GCMs (Barrow et al., 2004; Carter et al., 1996; CCCSN, 2007). First, the resolution of GCMs is quite coarse because GCMs employ a large computational grid cell, so simulation of some of the smaller scale climate processes, such as cloud formation and precipitation, is often imprecise (Barrow et al., 2004; Carter et al., 1996; CCCSN, 2007). In addition, Gagnon and Gough (2005a) and Gough and Wolfe (2001) suggest that a finer resolution would allow a more precise representation of sea-ice distributions and processes in the Hudson Bay region. Second, constructing the scenarios of climate variability and extremes requires daily or hourly climate information to analyze the changes of climate regimes; however, most climate scenarios derived from GCM outputs are based on monthly or seasonal mean values (Barrow et al., 2004; CCCSN, 2007). Third, GCM's spatial and temporal scales are too coarse to provide a comprehensive scenario of future climate, particularly for changes in climate variability and extreme events (Barrow et al., 2004; CCCSN, 2007). Thus, climate model results derived from GCM outputs are generally not considered to be sufficient for most impact and adaptation studies, in particular, on a local scale. Subsequently, downscaling methods have been developed to obtain a finer resolution and a better representation of regional physiographic features of some climate processes (Barrow et al., 2004; CCCSN, 2007). Regional Climate Models (RCMs), also known as dynamical downscaling, are now widely used for regional climate simulations (Barrow et al., 2004; CCCSN, 2007).

Regional Climate Models

Over the last decade, RCMs have been greatly improved to provide a higher spatial resolution (Barrow et al., 2004; CCCSN, 2007; Natural Resources Canada, 2007). In general, the grid-size meshes of GCMs are at 200 – 300 km, whereas the meshes of RCMs are typically at 45 – 50 km, in order to enhance regional climate and climate-change projections at finer scales (Barrow et al., 2004; CCCSN, 2007). For instance, RCMs are better able to simulate regional precipitation systems than GCMs (Barrow et al., 2004; Christensen, 2007). Moreover, RCMs can be effective tools to identify anthropogenic forcing of the climate system on a regional scale (Laprise et al., 2003). Thus, RCMs are able to simulate more spatially detailed features and processes of local climate than are represented in the coarse scale GCMs (Barrow et al., 2004; CCCSN, 2007; Natural Resources Canada, 2007).

The Canadian Regional Climate Model (CRCM), developed by the Université du Québec à Montréal and the Canadian Centre for Climate Modelling and Analysis (CCCma), has been used to perform various climate change simulations for certain regions in Canada (Barrow et al., 2004; CCCSN, 2007; Laprise et al., 1998, 2003; Music and Caya, 2007; Plummer et al., 2006). The latest version, CRCM4.2, simulates water and energy exchange on more sophisticated land-surface and atmosphere schemes (CCCma, 2008). The latest and previous versions of CRCMs are available for use through the Canadian Climate Change Scenarios Network (CCCSN) website (CCCSN, 2007).

Although there has been a remarkable progress in the spatial detail produced by RCMs, a number of important aspects need to be considered. First, RCMs are computationally expensive so that fewer scenarios are currently available compared to GCMs (CCCSN, 2007). Second, RCMs use a one-way nesting method (CCCSN, 2007; Christensen, 2007). Third, RCMs require data from GCMs, so they are susceptible to systematic errors created by GCMs (Barrow et al., 2004; CCCSN, 2007). For these reasons, IPCC (2001a) and Barrow et al. (2004) recommend the use of both climate scenarios.

Scenario Uncertainties

A number of scientific sources have addressed uncertainties about future climate change (IPCC, 2001b). For example, future emissions of greenhouse gases and aerosols into the atmosphere may be caused by anthropogenic driving factors such as population, economic growth, and energy use (Barrow et al., 2004; IPCC, 2001b). In addition, natural factors such as volcanic eruptions and solar irradiance changes may contribute to global climate change on annual and decadal time scales (Barrow et al., 2004). Consequently, the climate system itself, in response to such human and natural forces, has inherent uncertainties (Barrow et al., 2004; IPCC, 2001b; McMichael, 2006; Woodward and Scheraga, 2003).

Likewise, uncertainties in climate scenarios have been a major subject for impact and adaptation studies. Scenario construction methods such as GCMs and RCMs can represent some uncertainties, but not all (Barrow et al., 2004; IPCC, 2001b). For example, climate scenarios may be able to show uncertainties associated with the climate response modelling for a given radiative forcing; however, they may not be able to represent other uncertainties that relate to the modelling of atmospheric concentrations for a given emissions scenario (IPCC, 2001b). Climate modelling researchers use different assumptions with respect to the cascade of uncertainties, when constructing climate scenarios; however, because the assumptions used vary, climate models do not provide consistent results (Barrow et al., 2004; IPCC, 2001b; Lobell et al., 2008).

A case study by Gough (2001) reports that the model simulations of the sea ice thickness in Hudson Bay are highly dependent on the choice of model parameters, as well as the seasonal distribution and magnitude of warming. The two different sets of parameters, a realistic and tuned value, are examined by the simple proxy model (Gough, 2001). They produce the same peak ice thickness, but they show a different response to warming (Gough, 2001). For these reasons, it must be noted that climate scenarios derived from climate parameters may present reasonable current climate conditions; however, they may be misleading about future climate conditions (Gough, 2001). The sensitivities of climate models to climate parameters and atmospheric forces such as the vertical diffusivity of sea water, in this case study, are important issues for future research (Gough and Allakhverdova, 1999).

Food Security for Aboriginals in Northern Canada

In November 1996, the Food and Agriculture Organization (FAO) adopted the definition of food security at the World Food Summit (WFS): “Food security exists when all people at all times have physical or economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO, 2008, p. 3, as cited in FAO, 1996). Food security is reduced when food systems are stressed from climate and other environmental changes (Gregory et al., 2005). Food systems are defined by Gregory et al. (2005) as “a set of dynamic interactions between and within the biogeophysical and human environments which result in the production, processing, distribution, preparation and consumption of food” (p. 2141). There are three main elements of food systems which underpin food security (GECAFS, 2008):

1. Food availability (with components related to production, distribution and exchange);
2. Food access (with components related to affordability, allocation and preference); and
3. Food utilization (with components related to nutritional value, social value, and food safety).

Historically, Aboriginal people have a unique food system of harvesting/gathering, sharing, and consuming of traditional foods (Gregory et al., 2005; Power, 2008). This food system affects the three components of food security: availability, access, and utilization. Food availability refers to availability of sufficient, safe, and nutritious food (Ford, 2008; Gregory et al., 2005). In terms of food access, households and individuals have adequate resources to access traditional and market foods for their nutritious diets (Ford, 2008; Power, 2008). Food utilization concerns the overall ability to acquire foods that remain safe, as well as foods that have sufficient nutritional and social values (Ford, 2008; Power, 2008).

Canada has developed many international commitments which are related to food security, and also such obligations have been built on domestic programs for enhancing health and well-being for all Canadians (Agriculture and Agri-Food Canada, 1998; Power, 2008). *Canada’s Action Plan for Food Security* is the response to the WFS, and the plan recognizes the important role of traditional foods to Aboriginal communities as one of its priorities

(Agriculture and Agri-Food Canada, 1998). The plan also acknowledges that harvesting of traditional foods and sharing and processing of food – and the transferring of TEK between generations – is vital to sustain Aboriginal livelihoods (Agriculture and Agri-Food Canada, 1998). Despite a wide range of present international and national commitments which affect food security, Power (2008) points out that there is little analysis in the literature about Aboriginal conceptualizations of food security. Power (2008) argues that current conceptual models of food security have been and still generally are developed in non-Aboriginal contexts; thus, these models do not give appropriate consideration to traditional food practices. Conceptualization of food security for Aboriginals must consider both traditional and market food systems alongside social and cultural aspects, as well as the diversity of Aboriginal people, including geographic location, community, gender, and age (Power, 2008).

Climate Change and Food Security in Northern Aboriginal Communities

The focus of research on food security in the Canadian arctic has increased since the 1990s (Ford, 2008). For example, the exposure to environmental contaminants such as organochlorines and toxic metals through the consumption of traditional food has resulted in a high level of food insecurity among the northern Aboriginal communities (Chan, 2006; Ford, 2008; Myers et al., 2004).

Most of the recent studies on the potential impacts of climate change on food security and on systems focus on Aboriginal communities in the Canadian arctic. Inuit communities, for example, have a strong relationship to the land and sea through hunting, gathering, harvesting, and fishing (ACIA, 2004; Furgal et al., 2002; Furgal and Prowse, 2008; Kuhnlein et al., 2004; Laidler et al., 2008; Myers et al., 2004; Paci et al., 2004). Such land and sea-based activities are sensitive to climatic conditions, so there is a significant concern that traditional food systems are particularly vulnerable to climate change (Chan, 2006; Ford, 2008; Furgal et al., 2002; Furgal and Prowse, 2008; Furgal and Seguin, 2006; Guyot et al., 2006; Newton et al., 2005; Nickels et al., 2006; Paci et al., 2004).

Changes in animal and plant distributions due to climate-related impacts have been reported by local hunters and residents, and these changes have led to a decrease in both availability of and access to important traditional food sources (Ford, 2008; Furgal et al., 2002; Furgal and Seguin, 2006). Changes in ice conditions such as later freeze-up and earlier break-up dates due to increasing temperatures and shifting precipitation regimes result in increased hunting costs and travel time (Ford, 2008; Ford et al., 2008a; Furgal et al., 2002; Furgal and Prowse, 2008; Furgal and Seguin, 2006; Laidler et al., 2008). As well, the changes cause increased risks to hunters who travel across the ice to access hunting areas (Ford, 2008; Ford et al., 2008a; Furgal et al., 2002; Furgal and Prowse, 2008; Furgal and Seguin, 2006; Laidler et al., 2008). The number of accidents and drowning incidents associated with ice conditions has increased throughout smaller coastal communities in the north (Furgal and Prowse, 2008; Nelson, 2003; Nickels et al., 2006). All these changes have negatively affected traditional food systems, human health, and well-being in the northern Aboriginal communities. Therefore, further investigation is required to understand the potential implications of climate change on the northern environment in the context of food security.

Socio-economic, cultural, generational, political, and other environmental factors have also influenced food security and systems in Inuit communities (Ford, 2008; Furgal et al., 2002; Myers et al., 2004). For example, socio-economic factors that include low-paying jobs and unreliable access to cash income create less availability of and access to nutrient-dense and high-quality foods, and then increase barriers to food security (Chan, 2006; Chan et al., 2006; Ford, 2008; Lawn and Harvey, 2003). According to the Canadian Community Health Survey (CCHS) in 2000/01, 49 % of Nunavut households reported food insecurity because of a lack of money, compared to the national average of 7 % (Ledrou and Gervais, 2005). Food security at the household level is an essential aspect of human development (Hamelin et al., 1999). Ethical considerations of the right to food, underscores the need to prevent food insecurity (Hamelin et al., 1999).

As for many families in Nunavut, healthy market foods, such as fresh fruits and vegetables, remain unaffordable options because of high prices, poor quality, and limited variety (Chan et al., 2006; Lambden et al., 2006; Lawn and Harvey, 2003; Myers et al., 2004). Such market foods in the north are 2 – 3 times more expensive than in southern Canada due to high transportation and shipping costs (Chan, 2006; Chan et al., 2006; Furgal and Prowse, 2008; Lambden et al., 2007; Lawn and Harvey, 2003; Myers et al., 2004). On the other hand, lowcost but high-energy market foods such as “junk” food and “fast” food are regularly consumed by younger generations in northern communities (Chan et al., 2006; Ford, 2008; Furgal and Prowse, 2008; Myers et al., 2004). Concomitantly, there has been a rapid shift in food preferences away from traditional foods (Chan, 2006; Chan et al., 2006; Ford, 2008; Myers et al., 2004).

A decrease in traditional food consumption and physical activities along with an increase in consumption of poor nutrient foods contribute to obesity and diabetes among Aboriginal people (Ford, 2008; Kuhnlein et al., 2002; Kuhnlein et al., 2004; Myers et al., 2004; Van Oostdam et al., 2005; Young, 1996; Young et al., 2000). In fact, type 2 diabetes mellitus has become a serious health issue among many of Canada’s Aboriginal communities (Young et al., 2000). Furthermore, the prevalence of diabetes in western James Bay Cree is higher than in other Cree populations (Maberley et al, 2000).

Therefore, food security in the northern Aboriginal communities is susceptible to the combination of changing climatic conditions and traditional subsistence lifestyle of Aboriginal peoples. Furgal and Seguin (2006) conclude that engaging Aboriginal communities and establishing a local baseline for understanding the vulnerability of northern food systems is critical, and such approaches would be useful to identify and characterize food insecurity in other regions.

Aboriginal Perspectives on Traditional Foods

Traditional foods have been defined as a variety of locally harvested plants and locally obtained wildlife species (Chan, 2006; Ford, 2008; Kuhnlein et al., 2004; Van Oostdam et al., 2005). In the Hudson and James Bay Lowland, there are 138 types of animals and 36 plant species that are identified by residents of the region (McDonald et al., 1997). The most common wildlife species are waterfowl, fish, furbearers, and big game and small game species (Berkes et al., 1994).

The importance of traditional foods on the physical health, social and cultural well-being, and traditional economy of the northern Aboriginal communities is widely acknowledged in the literature (ACIA, 2004; Berkes et al., 1994; Chan, 2006; Chan et al., 2006; Egeland et al., 2001; Ford, 2008; Ford et al., 2006a, 2006b, 2008a, 2008b; Furgal and Seguin, 2006; Kuhnlein et al., 2004; Kuhnlein and Receveur, 2007; Myers et al., 2004; Power, 2008; Van Oostdam et al., 2005; White et al., 2007). As for the Inuit perspective on food and health, traditional foods synthesize two elements: the body and the soul (Myers et al., 2004; Van Oostdam et al., 2005). The word body refers to “physical actuality and functionality of the human body”, whereas the word soul refers to “spirit, mind, immediate emotional state or even the expression of consciousness” (Myers et al., 2004, p. 427). Indeed, dietary surveys in Inuit communities show that more than 80 % of Canadian Inuit agree that harvesting and using traditional foods provides a wide range of benefits in their everyday lives (Van Oostdam et al., 2005).

Benefits of Traditional Foods

The nutritional benefits of traditional foods and their contribution to health are integral components of the well-being of Aboriginal people. Traditional foods are significantly low in fat, carbohydrates and sucrose, and they are the main contributors of lipids, vitamins, minerals, and proteins (Kuhnlein et al., 2004; Kuhnlein and Receveur, 2007; Van Oostdam et al., 2005). Most of the research on nutrition has focused on nutrients in traditional foods for the communities of arctic Aboriginal peoples because they are experiencing rapid dietary pattern and lifestyle changes so that their traditional ways of nutrient acquisition are in transition (Ford, 2008; Kuhnlein et al., 2002, 2004, 2006; Kuhnlein and Receveur, 2007; Van Oostdam et al., 2005). Kuhnlein and Receveur (2007) conduct nutrition research that shows that Aboriginal adults in arctic communities derive 6–40 % of their daily energy from traditional foods; however, this average depends on the degree of geographic remoteness to commercial centres or urban areas. In fact, the dependence of traditional foods is greater in remote communities which are not accessible by road (Van Oostdam et al., 2005).

The procurement, preparation, and consumption of traditional foods are strongly attached to the local environment, such that activities in the environment are vital for holding the social, cultural, and economic values in many Aboriginal communities (Chapin, 2005; Ford et al., 2008b; Myers et al., 2004; Power, 2008; Van Oostdam et al., 2005). Hunting, gathering, and sharing of wildlife resources are a part of social activities for Aboriginal people, and these activities create or maintain an important social fabric among individuals, families, and communities (Van Oostdam et al., 2005). Moreover, through traditional land and sea-based activities, traditional foods not only form symbolic and spiritual values, but also define and maintain aspects of ethics and identity of Aboriginals (Chapin, 2005; Power, 2008; Van Oostdam et al., 2005). In addition, the transfer of traditional knowledge between generations is important during traditional activities (Tsuji and Nieboer, 1999).

Despite the numerous benefits associated with traditional foods, a decrease in consumption of traditional foods has reduced these benefits; as a result, it is likely to bring negative health consequences to Aboriginal communities (Chan et al., 2006; Ford, 2008; Kuhnlein et al., 2004; Kuhnlein and Receveur, 2007; Myers et al., 2004; Van Oostdam et al., 2005; Young, 1996). As mentioned previously, increasing risks of obesity, diabetes, and cardiovascular disease have been reported throughout Aboriginal communities in northern Canada (Chan et al., 2006; Ford, 2008; Kuhnlein et al., 2004; Kuhnlein and Receveur, 2007; Myers et al., 2004; Van Oostdam et al., 2005; Young, 1996). Therefore, the nutritional, social, cultural, and economic significances of traditional foods must be considered as a whole in northern Aboriginal communities.

Chapter 2

The use of traditional environmental knowledge to assess the impact of climate change on subsistence fishing in the James Bay region, Ontario, Canada

Introduction

There is increasing evidence that northern Canada is undergoing major climatic change (ACIA, 2004; Anisimov et al., 2007; Cohen et al., 1994). Although the global-average surface temperatures have risen by 0.6 ± 0.2 °C over the past century – the arctic and sub-arctic regions have experienced a general warming of up to 5 °C (Anisimov et al., 2007; IPCC, 2001c) – the most rapid rates of increasing average surface temperatures among the world's regions during the last century (ACIA, 2004; Anisimov et al., 2007). Thus, the Hudson and James Bay regions of northern Ontario, Canada, have been affected disproportionately by such rising temperatures (Gagnon and Gough, 2002, 2005a). For example, the duration of sea-ice cover in Hudson and James Bay – a key indicator of climatic changes and trends in the north (ACIA, 2004; Gough and Houser, 2005) – has been decreasing as a consequence of earlier break-up and later freeze-up dates over the past few decades (Gagnon and Gough, 2005b; Gough et al., 2004). Indeed, Gough et al. (2004) report a statistically significant increase in the length of the ice-free season for the southwestern region of Hudson Bay and the northwestern region of James Bay for the period 1971 to 2003. The trends in river-ice break-up dates in the western James Bay region are not as consistent, as there are many confounding variables, although the average temperatures in spring and winter have increased in the region (Ho et al., 2005). In addition, a significant trend in the summer and fall seasons of increasing precipitation has been reported for the western James Bay region (Gagnon and Gough, 2002).

In the Hudson Bay region, the climate change projections indicate an increase in temperature ranging from 3.9 to 4.5 °C for the 2040 – 2069 period (2 × CO_2 concentration), and from 4.8 to 8.0 °C for the 2070 – 2099 period (3 × CO_2 concentration) (Gagnon and Gough, 2005a). Similarly, annual precipitation in the region is projected to increase 3.2 to 7.1 mm per month for the 2040 – 2069 period and 5.2 to 11.3 mm per month for the 2070 – 2099 period (Gagnon and Gough, 2005a). However, relatively little research has been done specifically addressing the western James Bay region of northern Ontario with respect to climate change projections.

Climate change is of particular importance to people of the western James Bay region because the potential impacts of climate change would have on subsistence activities. The procurement of wild game, fish, and other material from subsistence pursuits (e.g., hunting, fishing, and gathering) are worth $9.4 million (in 1990, Canadian dollars) to the western James Bay Cree (also referred to as Omushkego Cree), being approximately one-third as large as the cash economy (Berkes et al., 1994). The subsistence lifestyle has been called the cornerstone of the regional mixed (i.e., subsistence lifestyle, government transfer payments, and wage work) economy (Berkes et al., 1994). The importance of fish as a staple food cannot be over-emphasized (Honigmann, 1948). Subsistence fishing in spring, summer, and fall occurs in all the major rivers of the western James Bay region; while, fishing in the winter is more widely dispersed (Berkes et al., 1995). In 1947–1948, the type of fish eaten were identified as whitefish (*Coregonus* spp.; most commonly caught and consumed), northern pike (*Esox lucius*), brook trout (*Salvelinus fontinalis*), sucker (*Catostomus* spp.), walleye (*Sander vitreus*), sturgeon (*Acipenser fulvescens*), and burbot/ling (*Lota lota*) (Honigmann, 1948). Similarly, in a 1990 harvest study of the Omushkego Cree, whitefish were the most commonly harvested fish (44,707 harvested fish were reported), followed by northern pike (19,758), walleye (17,678), sucker (9,710), brook trout (6,384), burbot/ling (4,451), and sturgeon (3,850) (Berkes et al., 1994). Clearly, subsistence fishing is still an important activity for the Omushkego Cree.

Although subsistence fishing is important in northern Canada, the geographic distribution of fish species is not well known in the arctic (Reist et al., 2002) and sub-arctic regions of Canada such as the western James Bay region of northern Ontario (Browne, 2007; Seyler, 1997). As fish are ectothermic, their body temperature is dependent on water temperature (which is primarily dependent on air temperature); however, fish can use behavior to control body temperature by choosing areas where optimal physiological temperature is attainable (i.e., fish species have specific thermal preferenda; Coutant, 1987; Reist et al., 2006a). Thermal preferenda or temperature preferenda can be defined as the water temperature a fish gravitates too irrespective of previous acclimation (Schlesinger and Regier, 1983). Nevertheless, the thermal range a fish species can tolerate is often narrow, and differs depending on the life stage of the fish (Coutant, 1987; Reist et al., 2006a). Thus, water temperature is a key factor influencing the distribution of freshwater fish species, but presence of competitors is also important (Parkinson and Haas, 1996).

There are three thermal guilds, as characterized by summer temperatures, identified for fish species (note: fish do not necessarily, exclusively belong to one guild): coldwater (11 – 15 °C; whitefish and brook trout); coolwater (21 – 25 °C; northern pike, walleye, and yellow perch); and warm water (27 – 31 °C; sturgeon and suckers) (Schlesinger and Regier, 1983; Reist et al., 2006a). An increase in air temperature (and increase in water temperature) due to climate change will alter the thermal aquatic habitat and may impact the range of several fish species (Sharma et al., 2007). Indeed, Reist et al. (2002) report an observed range extension of 500 km north in the Canadian arctic of the bull trout, *S. confluentus*; while, Babaluk et al. (2000) report the northern extension of the distribution of several salmonid species (sockeye, *Oncorhynchus nerka*; pink, *O. gorbuscha*; coho, *O. kisutch*). Taking into account that shifts in temperature and precipitation will result in direct and indirect effects on ecosystems and the fish species present – there is a paucity of information on basic fish biology and habitat requirements with respect to fish of northern Canada to accurately predict northern range changes – but scenarios that have been presented indicate that climate change will result in an increase in fish diversity, as well as competition, as a result of the changing distribution of fish species (Reist et al., 2006a).

There are several factors, other than increasing temperature, potentially aiding the northward shift of some fish species distributional range with respect to the western James Bay region: watersheds drain northward allowing northward movement of fish (Reist et al., 2006b; Sharma et al. ,2007); and the low gradient change from southern Ontario to the north is ideal for expansion along the sub-arctic river system (Jackson and Mandrak, 2002). Specifically, it has been suggested by researchers (Jackson and Mandrak, 2002; Shuter and Post, 1990) that climate change (i.e., increasing air temperature) has the potential to lengthen the growing season of smallmouth bass (*Micropterus dolomieu*) with a concomitant increase in body condition; thereby, increasing overwinter survival of young-of-the-year which typical determines population viability and northern distribution of this species. In addition, it has been reported that in areas of Ontario where the July temperature approached 16 °C, the viability of smallmouth bass was zero – a mean July temperature of 18 °C was required for the presence of smallmouth bass – and the southern James Bay region mean July temperature is at the 18 °C threshold (Jackson and Mandrak, 2002; Shuter and Post, 1990). If the smallmouth bass extend their distributional range northward, as has been predicted by Jackson and Mandrak (2002), there will be negative impacts on many fish species (Chiotti and Lavender, 2008; Jackson and Mandrak, 2002). Adding further, Chu et al. (2005) examined the potential impact of climate change on the distribution of selected freshwater fish in Canada, using the Canadian Global Coupled Model 2 (CGCM2) with the IS92a ("business as usual") emission scenario and report that coldwater species (e.g., brook trout) may be extirpated from their present western James Bay region range by 2020 (except for an isolated population on Akimiski Island).

In a recent report on climate change impacts, vulnerabilities, and adaptation in Ontario, it was recognized that the northern part of Ontario is the least studied region of Ontario even though remote and resource communities in northern Ontario are highly susceptible to climate change (Chiotti and Lavender, 2008). At a recent climate change impact workshop sponsored by Indian and Northern Affairs Canada, one area of potential concern was climate change impact on traditional food supplies (Chiotti and Lavender, 2008). It has been suggested that traditional environmental knowledge (TEK) – a body of knowledge and beliefs orally transmitted, being both cumulative, dynamic, and building upon the experience of earlier generations, but adapting to the present (Dene Cultural Institute, as cited in Stevenson, 1996) – could act as an important source of knowledge (Tsuji and Ho, 2002) for the western James region with respect to fish distribution (Seyler, 1997) and climatic change (Chiotti and Lavender, 2008).

In this paper, we will use TEK to examine whether there has been any change in fish species distribution, as predicted in climate change-fish distribution models, for the western James Bay region; while, also documenting any other pertinent TEK as related to climate change and fish biology. In addition, we will investigate plausible climate change scenarios specifically for the western James Bay region, using General Circulation Models (GCMs or General Climate Models) and Regional Climate Models (RCMs).

Methods

The study area

According to the Köppen climate classification, the western James Bay region is characterized as having a sub-arctic climate (i.e., microthermal climate, year-round precipitation, and 1 – 4 months above 10 °C), with short and fairly warm summers, and long and cold dry winters (Christopherson, 2003). There are approximately 10,000 First Nations people inhabiting the communities of this region (Fig. 1): Moose Factory (Moose Cree First Nation); the town of Moosonee; Fort Albany First Nation; Kashechewan First Nation; and Attawapiskat First Nation (Tsuji and Nieboer, 1999). Fort Albany, Kashechewan, and Attawapiskat First Nations are remote, coastal, and fly-in communities; accessible only by plane year round, boat and barge during the ice-free season, and snow/ice road during the winter season (Ho et al., 2005; Tsuji and Nieboer, 1999; Tsuji et al., 2006). The residents of these communities speak mainly the Cree language and follow a subsistence lifestyle (Tsuji, 1996a, 1996b; Tsuji and Nieboer, 1999). Moose Factory is also a remote community; while, Moosonee is accessible by rail transportation. As described previously, the Cree communities of the western James Bay region are still dependent on wildlife harvesting, predominantly fish and game meat (Berkes et al., 1994, 1995; George et al., 1996; Tsuji et al., 2006).

There are three major river systems in the region (Fig. 1): the Moose River basin is a highly fragmented river system containing natural (e.g., waterfalls) and human-made (e.g., dams and hydro-electric generating stations) barriers (Seyler, 1997); there is some hydro-development on the Albany River upriver (slightly regulated with 17% of its flow diverted from its origin); and the Attawapiskat River basin which remains essentially unaltered (Browne, 2007). Taking into account that the Moose River is highly fragmented and there are many impediments to the northward migration of regionally novel fish species – and that TEK with respect to the Attawapiskat River basin has already been collected (Victor Project TEK Working Group, 2004) – we focus the present study on the Albany River.

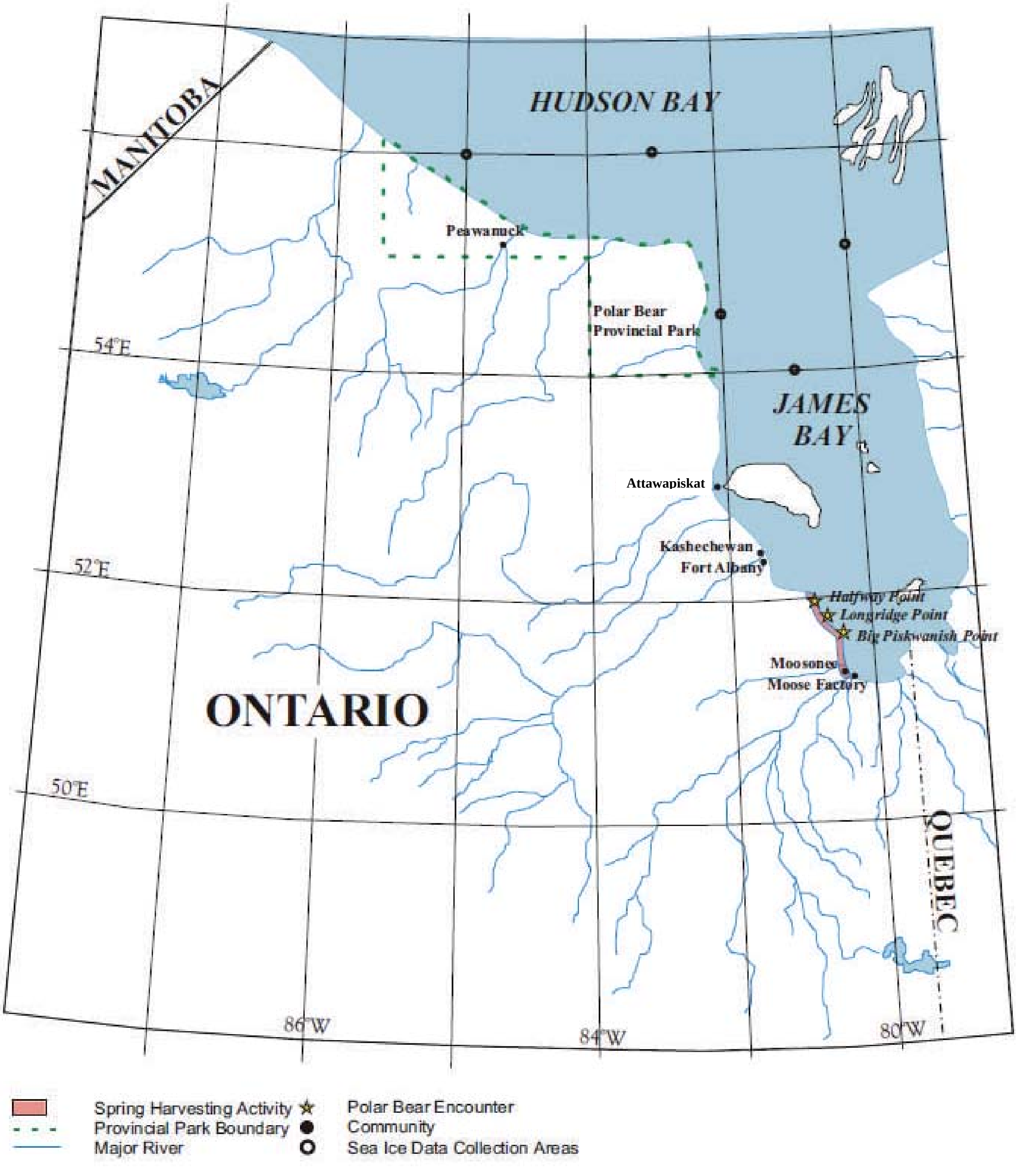

Figure 1. Study area of the western James Bay region.

Traditional environmental knowledge

Published TEK

An extensive literature review was performed to gather any written/electronic material related to TEK for the western James Bay region, as related to climatic change and fish distribution (or other aspects related to fish biology). We report only on positives results.

Unpublished TEK

Relevant unpublished TEK data were collected and collated from previous western James Bay research projects. The different sources are described below.

In June of 1999, 146 people (≥ 18 years old; females = 71; males = 75) residing in Fort Albany First Nation participated in a study documenting land use on Anderson Island (the site of an abandoned mid-Canada radar line base and source of terrestrial organochlorine contamination), which is located in the Albany River (Tsuji et al., 2005). The study consisted of a questionnaire and the marking on a map of land use information, as well as two open-ended questions at the end of the questionnaire to allow for discussion of concerns not directly addressed in the questionnaire. We have previously reported on the mapping and questionnaire data (Tsuji et al., 2005), but have not reported on the results of the open-ended questions, which are relevant to the present study, as these questions had been added to the study at the request of Fort Albany First Nation Band Council (local government), as they had concerns about organochlorine contamination of the Albany River system (McCreanor et al., 2008; Tsuji and Martin, 2008), and the health and distribution of the fish inhabiting the Albany River. We report on whether any unusual fish (or fish species) was observed by people fishing in the Albany River around Anderson Island (Tsuji unpublished data).

In 2002, ten semi-directive interviews (three in Fort Albany and seven in Moose Factory) were conducted with local elders in their preferred language (Cree or English) who were identified as knowledgeable people by members of the community who regularly worked with elders (Ho, 2003). The semi-directive interviews were conducted in person and consisted of a short list of questions related to indicators of climatic change (e.g., Have you noticed any changes in the fish [distribution, novel species, etc]?) but allowed for open-dialogue, as is a culturally appropriate form of discussion (Ho et al. unpublished data).

In 2005, TEK was provided, unsolicited, to one of the authors of the present study, during an unusually hot and dry period of time during the summer. We present this information in this section, as it informs the type of climatic data analyzed.

> I found one dead whitefish around Old Post [old Fort Albany fur trading post]. It was small (Experienced Kashechewan bushman, July 17, 2005).

I found three, small, dead whitefish around Old Post (Experienced Kashechewan bushman, July 18, 2005).

Last week [July 11 – 15], [I] saw 4–5 suckers [6–8”] and 2 whitefish [6–8”] [dead] by Old Post (Fort Albany First Nation elder, July 17, 2005).

I saw fresh fish carcasses, and two dead, older carcasses. One was a sucker and the rest were whitefish [fish 4–8”]. They were down by the youth camp, approximately one mile downstream by Old Post (Member of Fort Albany Band Council, July 18, 2005).

In 2009, seven semi-directive interviews were conducted with four experienced bushman and three elders (six members of Fort Albany First Nation and one from Kashechewan First Nation), in English, who were known as being knowledgeable people with respect to fish of the Albany River. The semi-directive interviews were conducted in person and focused on the topic of subsistence fishing (and contaminants) and novel fish species in the Albany River.

In the winter of 2010, four semi-directive interviews were conducted with two experienced bushman and two elders (three members of Fort Albany First Nation and one from Kashechewan First Nation) who are known to fish for brook trout. The semi-directive interviews were conducted in English, in person, and focused on the abundance of brook trout at traditional fishing areas. A follow-up interview was conducted in April 2010, by phone with one elder.

Gillnets were set daily and checked once a day, as part of the regular routine of subsistence fishing, in the Albany River near the community of Fort Albany First Nation, for a four-week period in June and July, 1999. Likewise, gillnets were set daily and checked once a day, in the Albany River near the community of Fort Albany, for a 10-day period in August 2009. The catch for both these time periods were checked for unusual fish and regionally novel fish species. The use of subsistence fisheries to document the distribution of novel fish species, in northern Canada, has been successfully used, previously (Babaluk et al., 2000).

Climate data

To investigate whether a temporal relationship exists between the fish die-offs of July 2005 (as identified by TEK) and an extreme climatic event, temperature (the daily maximum, minimum, and mean temperatures, ^{o}C) as well as daily precipitation data (mm) for July 2005 were examined. Climate data were obtained from climate datasets maintained by the National Climate Data and Information (NCDI) Archive of Environment Canada. The Moosonee weather station (51^{o}16’200” N, 80^{o}39’000” W; Environment Canada, 2008) is situated in the south of the James Bay area, and this is the only station located in this northern region, with an extended, intact climate record; the other weather station at Fort Albany was only operational for a short period of time and data are incomplete (Environment Canada, 2002). The Moosonee weather station climatic records were used to examine daily maximum temperatures in relationship to the number of days exceeding a specific thermal threshold. In Canada, a “heat wave” is defined as “three or more consecutive days in which the maximum temperature is greater than or equal to 32 °C” (Environment Canada, 2009, p. 1).

To determine if there is an increasing trend in mean maximum summer temperatures with year, in the western James Bay region, past summer (June, July, and August) temperature data were examined, using regression analysis. To this end, the historical homogenized temperature datasets (i.e., adjustment for non-climatic inhomogeneities such as station relocations and changes to observational procedures; Vincent and Mekis, 2006; Vincent et al., 2002) were obtained from Environment Canada (the Adjusted and Homogenized Canadian Climate Data; AHCCD, 2008). The homogenized climate datasets available for the Canadian north prior to the mid-1940s are limited (AHCCD, 2008); thus, we concentrate our study to the monthly maximum mean temperatures (^{o} C), 1960 to 2006 (Moosonee UA weather station; 51^{o}27’ N, 80^{o}65’ W).

Climate scenarios

To investigate plausible climate scenarios for the western James Bay region, GCMs and RCMs were used, as studies in the Hudson Bay region have suggested that finer spatial resolution is required to allow for a more accurate representation of climate change in the north (Gagnon and Gough, 2005a; Gough and Wolfe, 2001). NCDI temperature (the average of daily maximum, minimum, and mean temperatures, ^{o} C) and precipitation (daily total precipitations, mm) data for the Moosonee UA weather station were used as the baseline (1961 – 1990), for the climate scenarios (IPCC-TGICA, 2007). The Canadian Climate Change Scenarios Network (CCCSN) offers GCMs from a number of international modeling centres and a limited number of RCMs (CCCSN, 2007). An ensemble approach (CCCSN, 2009a) was utilized in the present study. Twenty-four GCMs (BCM2.0, Bjerknes Centre for Climate, Norway; CGCM3T47, CGCM3T63, Canadian Centre for Climate Modelling and Analysis, Canada; CNRMCM3, Centre National de Recherches Meteorologiques, France; CSIROMk3.0, CSIROMk3.5, Australia's Commonwealth Scientific and Industrial Research Organisation, Australia; ECHAM5OM, Max Planck Institute für Meteorologie, Germany; ECHO-G, Meteorological Institute, University of Bonn Meteorological Research Institute, Germany; FGOALS-g1.0, Institute of Atmospheric Physics, Chinese Academy of Sciences, China; GFDLCM2.0, GFDLCM2.1, Geophysical Fluid Dynamics Laboratory, USA; GISSAOM, GISSE-H, GISSE-R, Goddard Institute for Space Studies, USA; HADCM3, HADGEM1, UK Meteorological Office, UK; INGV-SXG, National Institute of Geophysics and Volcanology, Italy; INMCM3.0, Institute for Numerical Mathematics, Russia; IPSLCM4, Institute Pierre Simon Laplace, France; MIROC3.2 hires, MIROC3.2 medres, National Institute for Environmental Studies, Japan; MRI-CGCM2.3.2, Meteorological Research Institute, Japan; NCARPCM, NCARCCSM3, National Center for Atmospheric Research, USA) with two or three emission scenarios (A2/A1B/B1) and four RCMs

(CRCM3.7.1, CRCM4.1.1, CRCM4.2.0, CRCM4.2.3, OURANOS Consortium, Canada) with one emission scenario (A2) were obtained from the CCCSN (2009a) website.

The recent IPCC Special Report on Emissions Scenarios (SRES) has been constructed as a basis for climate projections, and these scenarios are used in the assessments of future climatic change (CCCSN, 2007; IPCC, 2007). Factors such as population, economic growth, and energy use are considered as driving forces for the future emissions of greenhouse gases and aerosols (Barrow et al., 2004; CCCSN, 2007). The SRES project approximates 40 different emission scenarios grouped into four families: A1, A2, B1, and B2 (CCCSN, 2007; IPCC, 2007). The A1 and A2 families focus on economics, while the B1 and B2 families focus on environmental forces; the A1 and B1 families focus on the global, while the A2 and B2 families focus on regional development (CCCSN, 2007; IPCC, 2007). Of these 40 emission scenarios, six are called marker scenarios (A1FI, A1B, A1T, A2, B1, and B2), because these marker scenarios best reflect the four family scenarios (CCCSN, 2007; IPCC, 2007). In the present study, we used A2, A1B, and B1 scenarios for our projections.

Before considering projections of future climate scenarios, the GCMs and RCMs were assessed with respect to how well the climate models reproduced the past observed climate (baseline summer [June, July, and August] temperature and precipitation) in the study region (CCCSN, 2009b). A scatterplot was selected for this purpose because this tool can be used for initial selection of plausible climate scenarios (CCCSN, 2009b). Models that best agreed with the observed climatology (mean summer air temperature and mean total precipitation) of the study region were identified (CCCSN, 2007; Downing, 1993), and subjected to a validation test. A one sample t-test was performed on summer mean temperatures (and summer mean total precipitation) of the identified models (four GCMs and two RCMs) versus NCDI observed data (1961 – 1990), to test for validity. For the validated GCMs and RCMs, future projections were generated for three time periods: 2011 – 2040, 2041 – 2070, and 2071 – 2100. It should be noted that there were insufficient data (<90%) for RCMs to produce projections for the time periods of 2011 – 2040 and 2071 – 2100. Thus, results for RCMs only include one projection time period, 2041 – 2070. Similar methodology was employed for the other seasonal data: mean autumn/fall (September, October, and November) air temperature and mean total precipitation; mean winter (December, January, and February) air temperature and mean total precipitation; and mean spring (March, April, and May) air temperature and mean total precipitation.

Results

Traditional environmental knowledge

Published TEK

TEK collected during the time period 1992 to 1995 for 28 communities of the Hudson Bay bioregion (which includes the First Nations communities of the western James Bay region) was collated and presented in the publication *Voices from the Bay* (McDonald et al., 1997). Although the publication included a section describing environmental change and impact on the western James Bay Cree traditional lifestyle there was no mention of sightings/harvesting of novel fish species or any other climatic effects with respect to known fish species (McDonald et al., 1997). Similarly, in a TEK study (2002 – 2004) initiated to meet requirements of an environmental assessment for the Victor Diamond mine, located near Attawapiskat First Nation – although there were reported rare sightings, defined as organisms not commonly seen in the Attawapiskat River Basin and associated coastline – there were no reported sightings/harvesting of novel fish species (Victor Project TEK Working Group, 2004). In addition, there were no observable climatic-related effects on known fish species in the region; however, this finding may be attributable to the limited focus of the study (Victor Project TEK Working Group, 2004).

Unpublished TEK

There were no reported sightings/harvesting of regionally-novel fish species (Tsuji unpublished data; Ho et al. unpublished data) nor climatic-related effects on known fish species (Ho et al. unpublished data). None of the people who participated in semi directive interviews in 2009, reported observing regionally-novel fish species. Likewise, no climatic effects on fish were reported in 2009, other than the 2005 summer die-offs. Although there were two reports that brook trout were not being caught in the winter of 2010, in traditional subsistence fishing locations, by April 2010, brook trout were again being harvested from these same locations.

In 1999, a yellow perch was caught in a gill net. No regionally-novel fish were observed in the subsistence harvest in 1999 and 2009.

Climate data

The daily maximum temperature, daily minimum temperature, and daily mean temperature (^{o} C) for the July 11 – 18, 2005, period and the corresponding temperatures for the summer of 2005 are summarized in Table 1. The daily maximum temperatures for the summer of 2005 are illustrated in Figure 2, where it is apparent that there was a heat wave during the period of reported fish die-off, as well as a period of reduced precipitation. In addition, during the time period of July 11 – 18, 2005, when the fish die-offs occurred in the Albany River, this time period corresponds to the period where the highest daily temperature for this region was recorded (37 °C; Table 1). What is also of interest is the relatively elevated daily minimum temperatures recorded during the period of fish die-offs (Fig. 2).

The relationship between the homogenized-monthly, mean-maximum temperatures (in the summer season) versus the years 1960 to 2006, is presented in Figure 3. A highly significant

($p<0.0009$) positive relationship was evident (Fig. 3), where approximately 22% of the variation in homogenized-monthly, mean-maximum temperature was explained by year.

Table 1. Summary of the daily maximum temperature, daily minimum temperature, and daily mean temperature for July 11-18, 2005, and the summer of 2005 (June, July, and August).

		Mean ± SD (°C)	Range (°C)
July 11-18, 2005	Daily maximum temperature	31.6 ± 5.29	22.0 – 37.0
	Daily minimum temperature	16.5 ± 4.23	10.5 – 21.5
	Daily mean temperature	24.1 ± 4.52	17.5 – 28.5
Summer 2005	Daily maximum temperature	23.1 ± 6.19	7.0 – 37.0
	Daily minimum temperature	10.2 ± 4.97	-1.0 – 21.5
	Daily mean temperature	16.7 ± 4.94	4.0 – 28.5

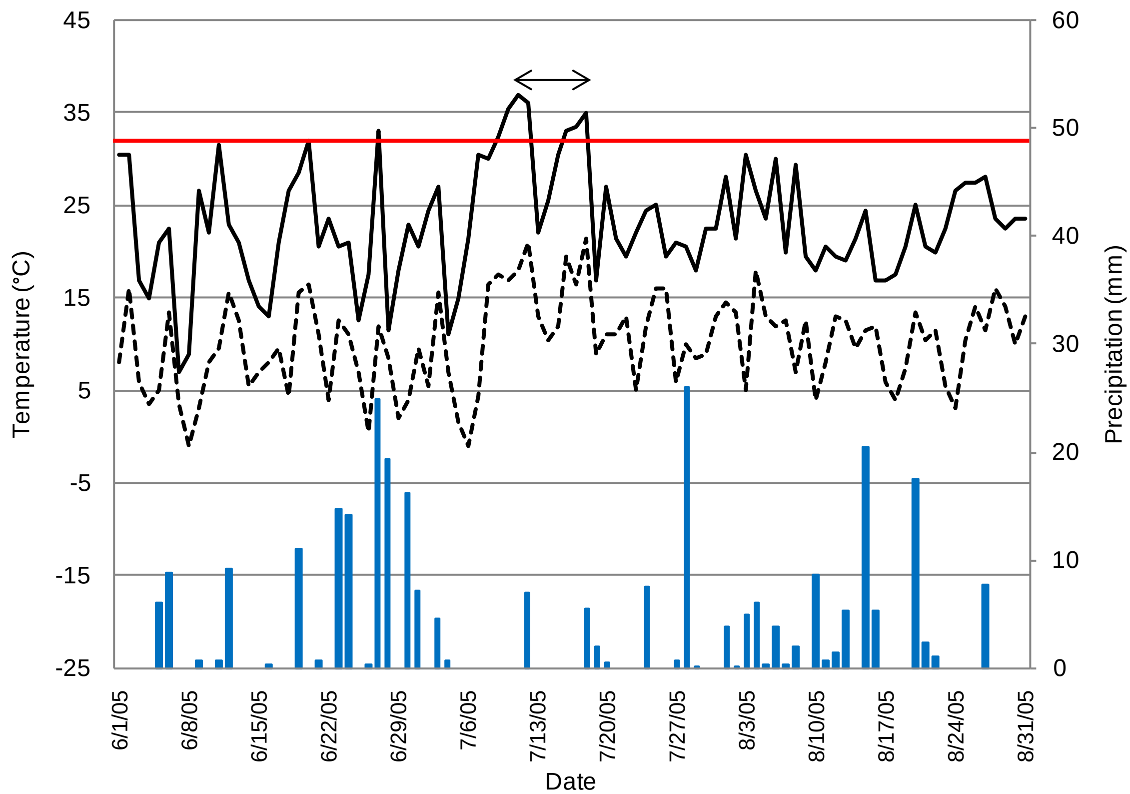

Figure 2. The daily maximum temperature (solid line), daily minimum temperature (dashed line), and daily total precipitation (bars) for June, July, and August 2005. The solid horizontal line indicates 32 °C. Three or more consecutive days of at least 32 °C is considered a "heat wave" in Canada. The occurrence of fish die-offs is indicated by the double arrow.

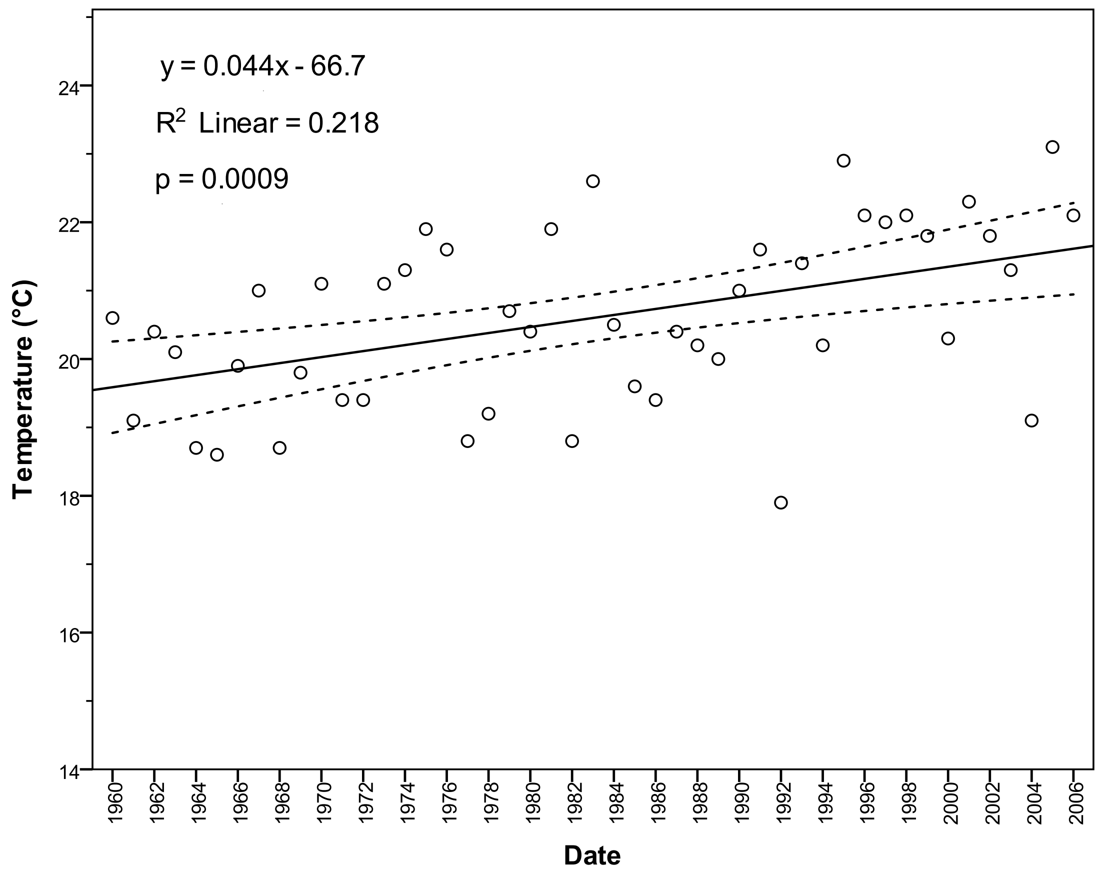

Figure 3. The relationship between homogenized-monthly, mean-maximum temperature (°C) and year in summer (June, July, and August) for the period 1960-2006.

Climate scenarios

The scatterplot for the summer season revealed six potential climate models (CGCM3T47, GISSE-R, ECHAM5OM, ECHO-G, CRCM4.2.0, CRCM4.2.3; Fig. 4), five potential models (ECHAM5OM, CGCM3T47, HADGEM1, HADCM3, ECHO-G; Fig. 5) for the autumn/fall season, five potential models (CGCM3T63, CGCM3T47, HADCM3, CRCM4.2.0, CRCM4.2.3; Fig. 6) for the winter season, and four models (CGCM3T63, MRI-CGCM2.3.2, CRCM4.2.0, CRCM4.2.3; Fig. 7) for the spring season. The potential climate models were found to be valid for the summer (temperature, $p = 0.34$; precipitation, $p = 0.74$), autumn/fall (temperature, $p = 0.13$; precipitation, $p = 0.54$), winter (temperature, $p = 0.13$; precipitation, $p = 0.52$), and spring (temperature, $p = 0.40$; precipitation, $p = 0.83$) seasons.

All climate models predict an increase in mean air temperature for all seasons, all time periods (2011– 2040, 2041– 2070, and 2071– 2100), and all emission scenarios (Table 2, 4, 6, 8). The results for seasonal total precipitation were variable (some models predicting an increase in precipitation, while others predicted a decrease) and dependent on the season, time period, and emission scenario (Table 3, 5, 7, 9).

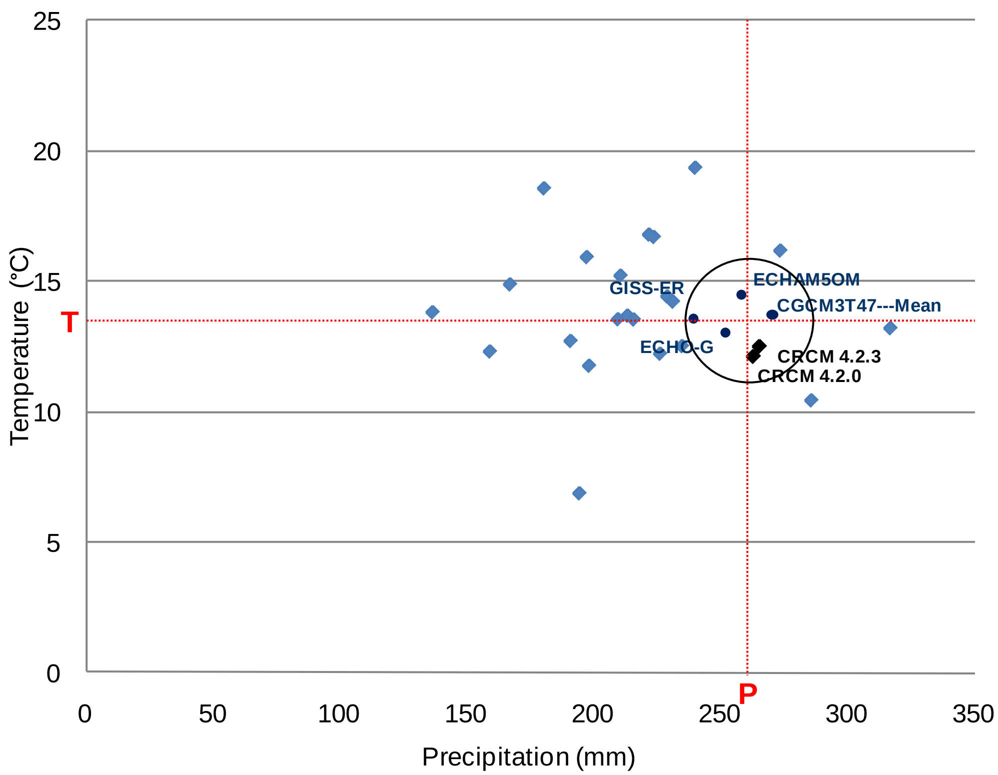

Figure 4. The baseline projections (1961-1990) of the summer mean temperature and total precipitation for 24 General Circulation Models and four Regional Climate Models. Note that the solid horizontal line (T) represents the observed summer mean temperature of 13.5 ^{o}C, for the Moosonee weather station (1961-1990); while, the solid vertical line (P) corresponds to the summer mean total precipitation of 259.7 mm. Potential climate models are encircled.

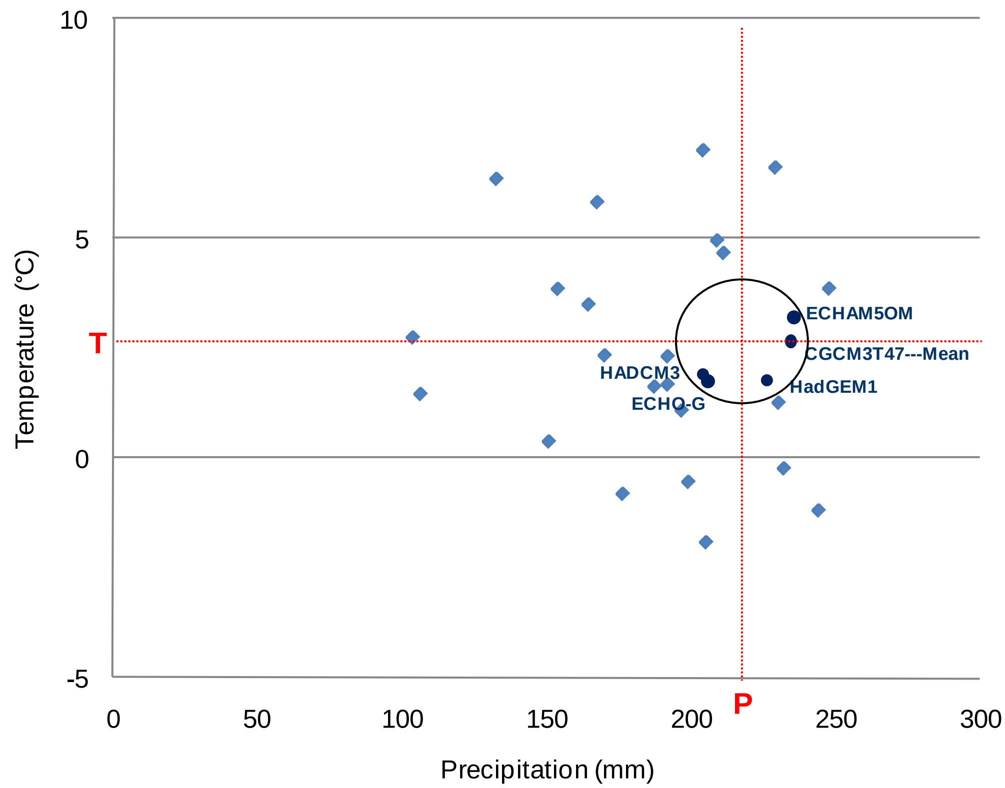

Figure 5. The baseline projections (1961-1990) of the autumn/fall mean temperature and total precipitation for 24 General Circulation Models and four Regional Climate Models. Note that the solid horizontal line (T) represents the observed autumn/fall mean temperature of 2.8 ^{o}C, for the Moosonee weather station (1961-1990); while, the solid vertical line (P) corresponds to the autumn mean total precipitation of 216.5 mm. Potential climate models are encircled.

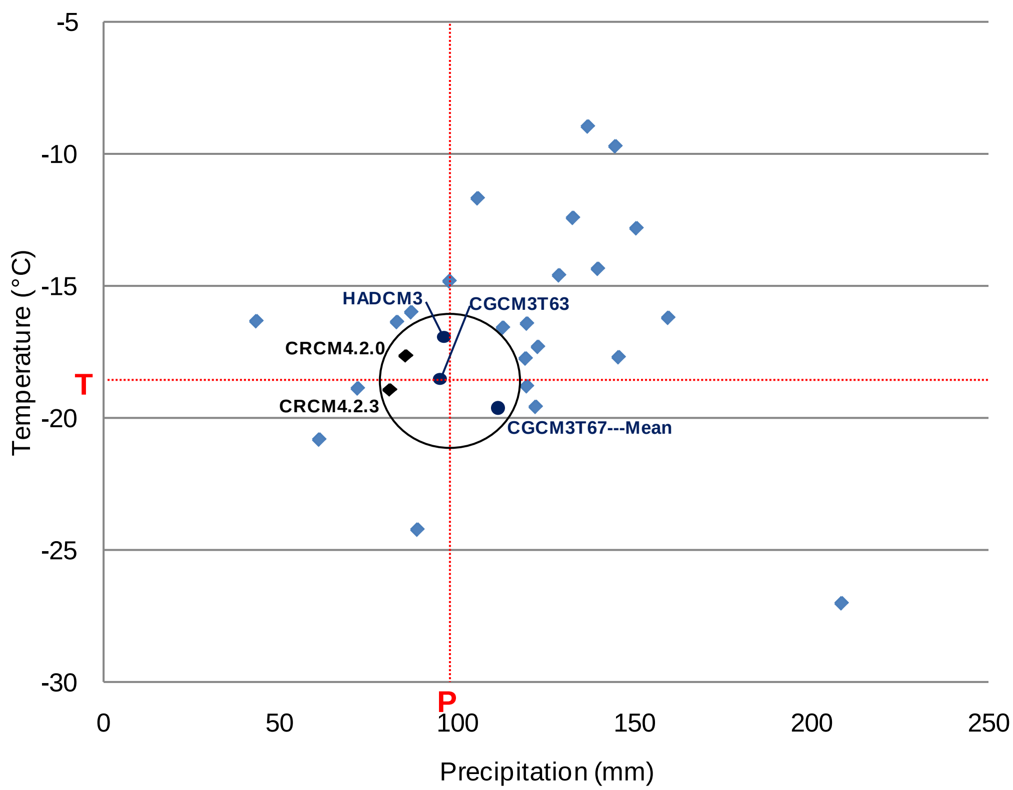

Figure 6. The baseline projections (1961-1990) of the winter mean temperature and total precipitation for 24 General Circulation Models and four Regional Climate Models. Note that the solid horizontal line (T) represents the observed winter mean temperature of -18.6 ^{o}C, for the Moosonee weather station (1961-1990); while, the solid vertical line (P) corresponds to the winter mean total precipitation of 97.9 mm. Potential climate models are encircled.

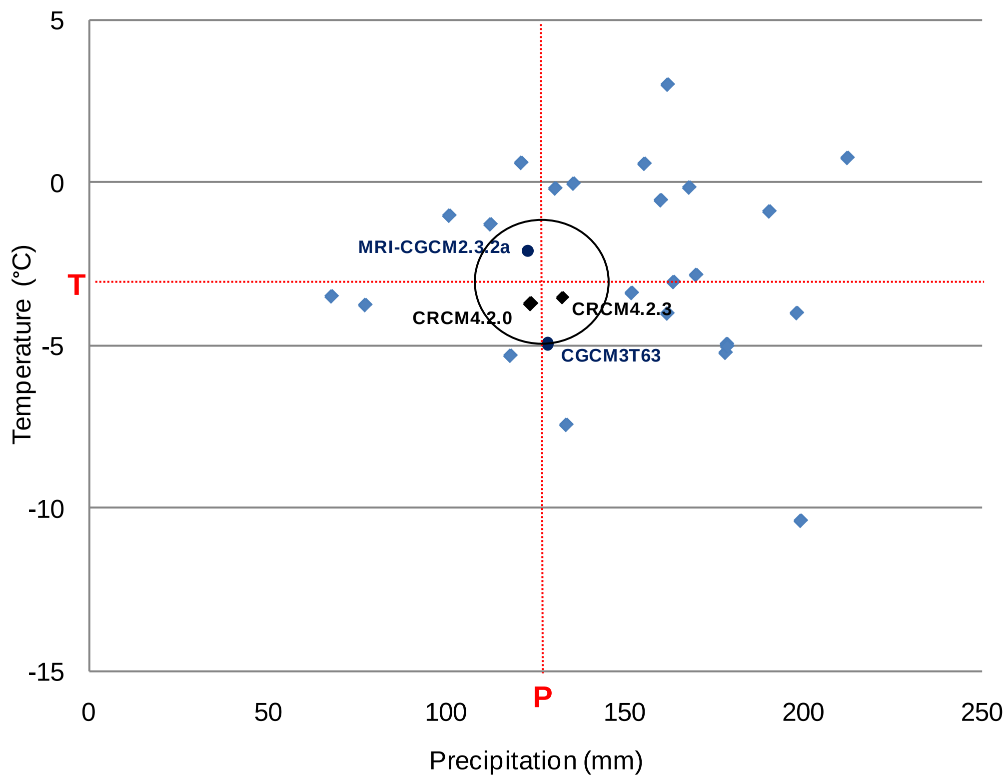

Figure 7. The baseline projections (1961-1990) of the spring mean temperature and total precipitation for 24 General Circulation Models and four Regional Climate Models. Note that the solid horizontal line (T) represents the observed spring mean temperature of -3.0 ^{o}C, for the Moosonee weather station (1961-1990); while, the solid vertical line (P) corresponds to the spring mean total precipitation of 126.1 mm. Potential climate models are encircled.

Table 2. Projected summer mean air temperatures (°C). The observed summer mean air temperature was 13.5 °C for the Moosonee weather station (1961-1990).

Models		Summer avg. baseline (1961–1990)	2011–2040	2041–2070	2071–2100
GCMs	CGCM3T47---Mean.SR-A2	13.70	15.27	16.69	18.49
	ECHAM5OM.SR-A2	14.49	15.67	16.97	18.37
	ECHO-G.SR-A2	13.02	15.13	16.25	18.22
	GISS-ER.SR-A2	13.55	15.14	15.78	16.91
	Average (A2 models)	13.69	15.31	16.42	18.00
	Range (A2 models)	13.02 – 14.49	15.13 – 15.67	15.78 – 16.97	16.91 – 18.49
	CGCM3T47---Mean.SR-A1B	13.70	15.31	16.44	17.40
	ECHAM5OM.SR-A1B	14.49	16.09	17.67	18.89
	ECHO-G.SR-A1B	13.02	14.99	16.13	17.65
	GISS-ER.SR-A1B	13.55	14.75	15.53	16.38
	Average (A1B models)	13.69	15.29	16.44	17.58
	Range (A1B models)	13.02 – 14.49	14.75 – 16.09	15.53 – 17.67	16.38 – 18.89
	CGCM3T47---Mean.SR-B1	13.70	15.05	15.93	16.20
	ECHAM5OM.SR-B1	14.49	15.55	16.82	17.79
	ECHO-G.SR-B1	13.02	14.83	15.68	16.40
	GISS-ER.SR-B1	13.55	15.00	15.30	15.55
	Average (B1 models)	13.69	15.11	15.93	16.49
	Range (B1 models)	13.02 – 14.49	14.83 – 15.55	15.30 – 16.82	15.55 – 17.79
RCMs	CRCM4.2.0.SR-A2	12.12	–	15.33	–
	CRCM4.2.3.SR-A2	12.46	–	15.55	–
	Average (A2 models)	12.29	–	15.44	–

Table 3. Projected summer mean total precipitation (mm). The observed summer mean total precipitation was 259.7 mm for the Moosonee weather station (1961-1990).

Models		Summer avg. baseline (1961–1990)	2011–2040	2041–2070	2071–2100
GCMs	CGCM3T47---Mean.SR-A2	270.37	276.98	276.67	269.11
	ECHAM5OM.SR-A2	258.42	294.35	297.90	311.60
	ECHO-G.SR-A2	251.76	249.95	293.96	268.08
	GISS-ER.SR-A2	239.17	218.39	250.29	260.95
	Average (A2 models)	254.93	259.92	279.70	277.44
	Range (A2 models)	239.17 – 270.37	218.39 – 294.35	250.29 – 297.90	260.95 – 311.60
	CGCM3T47---Mean.SR-A1B	270.37	274.20	286.68	274.24
	ECHAM5OM.SR-A1B	258.42	277.58	276.63	309.82
	ECHO-G.SR-A1B	251.76	257.44	285.51	293.05
	GISS-ER.SR-A1B	239.17	237.26	257.65	250.43
	Average (A1B models)	254.93	261.62	276.62	281.88
	Range (A1B models)	239.17 – 270.37	237.26 – 277.58	257.65 – 286.68	250.43 – 309.82
	CGCM3T47---Mean.SR-B1	270.37	277.22	272.82	279.41
	ECHAM5OM.SR-B1	258.42	279.87	263.54	293.26
	ECHO-G.SR-B1	251.76	254.97	274.25	277.80
	GISS-ER.SR-B1	239.17	242.84	234.48	258.75
	Average (B1 models)	254.93	263.72	261.27	277.30
	Range (B1 models)	239.17 – 270.37	242.84 – 279.87	234.48 – 274.25	258.75 – 293.26
RCMs	CRCM4.2.0.SR-A2	263.17	–	268.01	–
	CRCM4.2.3.SR-A2	265.72	–	289.05	–
	Average (A2 models)	264.44	–	278.53	–

Table 4. Projected autumn/fall mean air temperatures (°C). The observed autumn/fall mean air temperature was 2.8°C for the Moosonee weather station (1961-1990).

Models		Autumn avg. baseline (1961–1990)	2011–2040	2041–2070	2071–2100
GCMs	CGCM3T47---Mean.SR-A2	2.65	4.34	5.70	7.50
	ECHAM5OM.SR-A2	3.20	4.47	5.78	7.45
	ECHO-G.SR-A2	1.76	4.24	5.79	8.47
	HADCM3.SR-A2	1.92	3.49	4.89	7.04
	HadGEM1.SR-A2	1.77	3.38	5.42	8.18
	Average (A2 models)	2.26	3.99	5.51	7.73
	Range (A2 models)	1.76 – 3.20	3.38 – 4.47	4.89 – 5.79	7.04 – 8.47
	CGCM3T47---Mean.SR-A1B	2.65	4.25	5.55	6.31
	ECHAM5OM.SR-A1B	3.20	4.13	6.30	7.29
	ECHO-G.SR-A1B	1.76	4.36	6.15	7.85
	HADCM3.SR-A1B	1.92	3.29	5.32	6.43
	HadGEM1.SR-A1B	1.77	3.65	5.91	7.62
	Average (A1B models)	2.26	3.93	5.84	7.10
	Range (A1B models)	1.76 – 3.20	3.29 – 4.36	5.32 – 6.30	6.31 – 7.85
	CGCM3T47---Mean.SR-B1	2.65	4.30	5.02	5.38
	ECHAM5OM.SR-B1	3.20	3.85	5.17	6.10
	ECHO-G.SR-B1	1.76	3.95	5.04	6.39
	HADCM3.SR-B1	1.92	2.90	4.55	5.18
	Average (B1 models)	2.38	3.75	4.95	5.76
	Range (B1 models)	1.76 – 3.20	2.90 – 4.30	4.55 – 5.17	5.18 – 6.39

Table 5. Projected autumn/fall mean total precipitation (mm). The observed autumn/fall mean total precipitation was 216.5 mm for the Moosonee weather station (1961-1990).

Models		Autumn avg. baseline (1961–1990)	2011–2040	2041–2070	2071–2100
GCMs	CGCM3T47---Mean.SR-A2	234.42	243.09	256.99	278.58
	ECHAM5OM.SR-A2	235.33	271.13	277.69	299.64
	ECHO-G.SR-A2	205.77	221.58	240.07	227.00
	HADCM3.SR-A2	203.85	203.31	217.43	219.51
	HadGEM1.SR-A2	226.12	248.02	233.98	249.56
	Average (A2 models)	221.10	237.43	245.23	254.86
	Range (A2 models)	203.85 – 235.33	203.31 – 271.13	217.43 – 277.69	219.51 – 299.64
	CGCM3T47---Mean.SR-A1B	234.42	248.23	258.66	271.47
	ECHAM5OM.SR-A1B	235.33	274.06	283.15	295.02
	ECHO-G.SR-A1B	205.77	215.22	231.63	234.01
	HADCM3.SR-A1B	203.85	198.04	217.70	234.73
	HadGEM1.SR-A1B	226.12	234.40	263.40	245.57
	Average (A1B models)	221.10	233.99	250.91	256.16
	Range (A1B models)	203.85 – 235.33	198.04 – 274.06	217.70 – 283.15	234.01 – 295.02
	CGCM3T47---Mean.SR-B1	234.42	239.63	250.08	266.11
	ECHAM5OM.SR-B1	235.33	273.39	286.44	292.12
	ECHO-G.SR-B1	205.77	216.71	209.99	224.85
	HADCM3.SR-B1	203.85	214.14	204.91	221.36
	Average (B1 models)	219.84	235.97	237.85	251.11
	Range (B1 models)	203.85 – 235.33	214.14 – 273.39	204.91 – 286.44	221.36 – 292.12

Table 6. Projected winter mean air temperatures (°C). The observed winter mean air temperature was -18.6 ^{o}C for the Moosonee weather station (1961-1990).

Models		Winter avg. baseline (1961–1990)	2011–2040	2041–2070	2071–2100
GCMs	CGCM3T47---Mean.SR-A2	-16.64	-14.08	-11.58	-9.58
	CGCM3T63.SR-A2	-18.56	-15.16	-11.85	-8.75
	HADCM3.SR-A2	-16.95	-16.31	-14.28	-11.71
	Average (A2 models)	-17.38	-15.18	-12.57	-10.01
	Range (A2 models)	-16.64 – -18.56	-14.08 – -16.31	-11.58 – -14.28	-8.75 – -11.71
	CGCM3T47---Mean.SR-A1B	-16.64	-13.98	-12.11	-10.47
	CGCM3T63.SR-A1B	-18.56	-15.32	-12.21	-10.78
	HADCM3.SR-A1B	-16.95	-15.13	-13.51	-12.26
	Average (A1B models)	-17.38	-14.81	-12.61	-11.17
	Range (A1B models)	-16.64 – -18.56	-13.98 – -15.32	-12.11 – -13.51	-10.47 – -12.26
	CGCM3T47---Mean.SR-B1	-16.64	-14.32	-13.16	-12.43
	CGCM3T63.SR-B1	-18.56	-15.72	-13.51	-12.79
	HADCM3.SR-B1	-16.95	-16.10	-15.89	-13.32
	Average (B1 models)	-17.38	-15.38	-14.18	-12.85
	Range (B1 models)	-16.64 – -18.56	-14.32 – -16.10	-13.16 – -15.89	-12.43 – -13.32
RCMs	CRCM4.2.0.SR-A2	-17.65	–	-17.65	–
	CRCM4.2.3.SR-A2	-18.93	–	-18.93	–
	Average (A2 models)	-18.29	–	-18.29	–

Table 7. Projected winter mean total precipitation (mm). The observed winter mean total precipitation was 97.9 mm for the Moosonee weather station (1961-1990).

Models		Winter avg. baseline (1961–1990)	2011–2040	2041–2070	2071–2100
GCMs	CGCM3T47---Mean.SR-A2	112.88	130.74	143.73	162.58
	CGCM3T63.SR-A2	94.81	98.00	116.41	129.59
	HADCM3.SR-A2	96.03	97.67	111.40	126.33
	Average (A2 models)	101.24	108.80	123.85	139.50
	Range (A2 models)	94.81 – 112.88	97.67 – 130.74	111.40 – 143.73	126.33 – 162.58
	CGCM3T47---Mean.SR-A1B	112.88	136.03	145.33	148.62
	CGCM3T63.SR-A1B	94.81	114.62	111.66	121.10
	HADCM3.SR-A1B	96.03	112.23	122.21	132.17
	Average (A1B models)	101.24	120.96	126.40	133.96
	Range (A1B models)	94.81 – 112.88	112.23 – 136.03	111.66 – 145.33	121.10 – 148.62
	CGCM3T47---Mean.SR-B1	112.88	127.62	139.08	141.20
	CGCM3T63.SR-B1	94.81	104.42	111.07	116.06
	HADCM3.SR-B1	96.03	105.10	107.11	113.04
	Average (B1 models)	101.24	112.38	119.09	123.43
	Range (B1 models)	94.81 – 112.88	104.42 – 127.62	107.11 – 139.08	113.04 – 141.20
RCMs	CRCM4.2.0.SR-A2	85.41	–	112.59	–
	CRCM4.2.3.SR-A2	80.85	–	109.17	–
	Average (A2 models)	83.13	–	110.88	–

Table 8. Projected spring mean air temperatures (°C). The observed spring mean air temperature was -3.0 °C for the Moosonee weather station (1961-1990).

Models		Spring avg. baseline (1961–1990)	2011–2040	2041–2070	2071–2100
GCMs	CGCM3T63.SR-A2	-4.95	-3.01	-1.30	0.75
	MRI-CGCM2.3.2a.SR-A2	-2.10	-0.88	0.19	1.55
	Average (A2 models)	-3.53	-1.95	-0.55	1.15
	CGCM3T63.SR-A1B	-4.95	-3.49	-1.32	-0.13
	MRI-CGCM2.3.2a.SR-A1B	-2.10	-0.62	0.48	1.63
	Average (A1B models)	-3.53	-2.06	-0.42	0.75
	CGCM3T63.SR-B1	-4.95	-3.08	-2.23	-1.85
	MRI-CGCM2.3.2a.SR-B1	-2.10	-1.01	-0.39	0.69
	Average (B1 models)	-3.53	-2.04	-1.31	-0.58
RCMs	CRCM4.2.0.SR-A2	-3.73	–	-0.81	–
	CRCM4.2.3.SR-A2	-3.53	–	-0.86	–
	Average (A2 models)	-3.63	–	-0.83	–

Table 9. Projected spring mean total precipitation (mm). The observed spring mean total precipitation was 126.1 mm for the Moosonee weather station (1961-1990).

Models		Spring avg. baseline (1961–1990)	2011–2040	2041–2070	2071–2100
GCMs	CGCM3T63.SR-A2	128.12	159.65	159.74	179.30
	MRI-CGCM2.3.2a.SR-A2	122.64	129.58	133.76	149.16
	Average (A2 models)	125.38	144.62	146.75	164.23
	CGCM3T63.SR-A1B	128.12	141.83	160.61	173.28
	MRI-CGCM2.3.2a.SR-A1B	122.64	124.87	126.12	131.58
	Average (A1B models)	125.38	133.35	143.37	152.43
	CGCM3T63.SR-B1	128.12	156.95	147.08	156.20
	MRI-CGCM2.3.2a.SR-B1	122.64	127.35	120.17	134.79
	Average (B1 models)	125.38	142.15	133.63	145.50
RCMs	CRCM4.2.0.SR-A2	123.55	–	157.61	–
	CRCM4.2.3.SR-A2	132.22	–	164.86	–
	Average (A2 models)	127.89	–	161.23	–

Discussion

Reist et al. (2006b) suggested three potential outcomes for fish (and fish species), as related to temperature increases: the extirpation of a fish species due to thermal stress, the rapid evolution of a fish species due to natural selection; and the northward shift of a fish species' distributional boundary. In the present study, we are the first to report on fish die-offs as an observed climatic change impact on specific fish species (i.e., suckers and whitefish) and a specific age class, in the western James Bay region. Although we report specifically on the fish die-offs of July 2005, in the Albany River, as we have direct confirmation through TEK, it should be mentioned that fish die-offs appear to have been regional phenomena during this time period, as fish die-offs were reported in the other river basins of the western James Bay region via the regional broadcasting organization, Wawatay News (note: written transcripts were sought of the specific audio broadcast heard by one of the authors of the present study, but the specific transcript was not available from the Wawatay News' website).

Although direct effects on individual fish may differ because of life stage, temperature-related mortality may have populational effects (Reist et al., 2006a). As reported earlier with respect to the die-offs, the dead suckers and whitefish were described as being small or estimated to be in the 4–8" range; however, we do not know what life stage these fish correspond to, as very little is known about fish biology in the sub-arctic region. Nevertheless, we can assume that these dead fish were sub-adults by the morphological descriptions given by the Cree individuals, and this assumption is supported by other studies where yearling suckers have been found to inhabit the edge of main water channels (i.e., near-shore region and young-of-the-year can be found in the shallow water over sand/gravel bars; Seyler, 1997). Although water at the periphery of water courses can have elevated temperatures and marginal oxygen supplies, juvenile fish (e.g., striped bass, *Morone saxatilis*) often reside in the warm shallows, where there is abundant small food and protection from predators (Coutant, 1987). The Albany River is home to two main piscivorous fish, northern pike (*Esox lucius*) (a lie-and-wait predator) and walleye (*Sander vitreus*) (a roving predator), that most often inhabit the interface between open water and the near-shore region (Bertolo and Magnan, 2005). Predatory pressure may have kept the small suckers and whitefish in the shallow water of the Albany River – even though warming in-stream/river temperatures reduced oxygen (Cingi et al., 2010; Mote et al., 2003) and the ability of fish to maintain or re-establish homeostasis (Iwama et al., 1999) – ultimately, leading to the death of a fish.

Climate data specific for the period of the fish die-offs in the Albany River and the western James Bay region revealed not only a temporal relationship between a heat wave and the fish die-offs, but also a concurrent period of reduced precipitation (Fig. 2). The climate data show that the mean daily maximum and minimum air temperatures for the July 11 – 18, 2005, period were elevated compared to the rest of the summer of 2005 (Table 1). Two heat waves were recorded during the July 11 – 18 period: July 9 – 12, daily maximum air temperatures were in the range, 32.5 °C – 37 °C; and July 16 – 18, daily maximum air temperatures were in the range 33 °C – 35 °C. Thus, during the fish die-offs, it was not just the daily maximum air temperatures, but the elevated daily minimum air temperatures coupled with a period of time of decreased precipitation (Table 1, Fig. 2) that led to an inhospitable aquatic environment. One cannot ignore the importance of rainfall to the freshwater budget (Prowse et al., 2006). In addition, a significant positive relationship between historical homogenized-monthly, mean maximum temperature data from the Moosonee UA station and year (Fig. 3) was found. However, it should be emphasized that it appears that there were a number of factors accounting for the observed 2005 fish die-offs, not just monthly, mean maximum temperature. An interesting note, is that in Finland, during “the exceptionally warm autumn of 2005, an unusually high mortality of *C. lavaretus* [whitefish] eggs was reported within 2 weeks of fertilization in a hatchery by the River Kemijoki [Finland]…During the…spawning run that year, the water temperature in the River Kemijoki reached 9.6 °C” (J. Rytilahti, pers. comm., as cited in Cingi et al., 2010, p. 503). Perhaps, the year of 2005 provided a glimpse of the future with respect to the impact of climatic change on fish and fish populations.

The Food and Agriculture Organization of the United Nations (2005) maintains that “food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. The four pillars of food security are availability, stability of supply, access, and utilization” (p. 5). Thus, food insecurity would exist if food were unavailable, the food supply unstable, the food supply inaccessible, or not utilizable. Although the fish die-offs of 2005 may have an impact on the population dynamics of suckers and whitefish in the future, and then indirectly impact the yield of Cree fish harvests in the future, food insecurity would be an indirect effect of the 2005 fish die-offs. However, there was a direct effect of the July 2005 heat wave on food security related to the Cree fish harvesters, as detailed by TEK:

> This is the only time I have seen this. [It was] really hot, never seen this before. Fish got all mushy [and not edible] because they were left in the net too long [the afternoon]. Had to go early in the morning after the tide went out, and check after every tide [so the fish did not rot]. Fish net [set] by old post (Experienced Kashechewan bushman, July 18, 2005; reaffirmed March 26, 2010)

> [I had to check] the net early in the morning, not late in [the] day. Fish already mushy, quickly. [When] it is cooler, it is okay [to leave the fish]. First time in [his] life [that he has seen this] (Fort Albany First Nation elder, July 18, 2005).

Thus, fish nets could not be checked once a day during the 2005 summer season in the western James Bay region, as typically done in the past (Honigmann, 1948); the Cree fish harvesters had to adapt their traditional practice or else risk losing their harvest to spoilage. Similarly, in the arctic region, it has been reported that individuals are changing their behavior such as shifting timing and/or location of particular subsistence activities to adapt to local environmental change (Anisimov et al., 2007; Ford, 2008).

Another food security issue relates to the potential changes in fish species distribution impacting food supply, that is, the introduction of new food species and/or the diminishing of traditional food sources (Anisimov et al., 2007). In the present study, only one yellow perch (*Perca flavescens*) was caught with the regular subsistence harvest of fish in the Albany River and this occurred in 1999. Although the northern range of yellow perch in Ontario has been reported to approximate the region south of James Bay, in the upper reaches of the Albany River (Ontario Ministry of Natural Resources, 2010), the Omushkego Cree have a Cree name for the yellow perch (Victor Project TEK Working Group, 2004), which the Cree would not, if this fish species was truly novel to the region. Indeed, Omushkego Cree names for 38 species of fish from 26 genera, and many are not subsistence species, have been recorded (Victor Project TEK Working Group, 2004).

In a review of Cree fish names for the eastern James Bay Cree, there was good agreement with the western James Bay Cree names for subsistence species; and like the western James Bay Cree, eastern James Bay Cree have names for prey species, even though these “forage” fish species are too small to be caught by gillnets used for subsistence (Berkes and MacKenzie, 1978). It is important to note that eastern James Bay Cree names for fish species closely parallel the actual distribution of these fish as reported in the scientific literature (Berkes and MacKenzie, 1978). In other words, certain First Nations communities on the east coast of James Bay have never encountered a fish species due to subsistence activities occurring beyond the said fish species distribution – thus, there is no Cree name, as the fish species has not been encountered, previously (Berkes and MacKenzie, 1978) – we have assumed the same for the western James Bay region, novel fish species should not have a traditional Cree name. The relatively regular capture of yellow perch at the same location over time is probably indicative of an established population not a rare extralimital occurrence (Reist et al., 2002). Perhaps, northern pike and walleye which are a common part of the subsistence harvest in the Albany River keep the abundance of yellow perch in check through predation-induced mortality, as has been documented in the headwater regions of the northern Ontarian rivers (Bertolo and Magnan, 2005). However, one cannot discount that the number of yellow perch in subsistence harvests will increase in northern Ontario, as air temperature increases, as has been suggested by several researchers (Shuter and Post, 1990; Reist et al., 2006a).

It is important for fish young-of-the-year to attain a minimal amount of growth to sustain them over the winter season; this constraint has been used to explain the northern distribution of yellow perch and smallmouth bass (*Micropterus dolomieu*; Shuter and Post, 1990). We have found no evidence that the smallmouth bass is present in the Albany River close to the mouth of James Bay. Smallmouth bass were introduced to the headwater lakes in the Canadian Shield of Ontario in the 1920s, and the smallmouth bass has spread to several river systems including the Missinaibi River (part of the Moose River Basin), as far north as Thunder House Falls, but the distribution has been spotty (Seyler, 1997). Very little is known about the riverine smallmouth bass population in the Moose River tributaries (Seyler, 1997); however, the smallmouth bass may be spreading northward as one smallmouth bass has been reported to have been caught in the Moose River (Browne, 2007).

The results of the climate scenarios indicate an increase in mean air temperatures for all time periods considered, but precipitation predictions were variable (some models predicted an increase in precipitation for specific time periods, while others predicted a decrease in precipitation for specific time periods; e.g., Table 3). Similarly, Chiotti and Lavender (2008) used seven GCMs and seven different emission scenarios (with baseline average temperature and precipitation data for 1961 to 1990) for all of Ontario, and reported warming in the northern region of Ontario by the 2050s, and large variation in the precipitation projections.

As summer mean air temperature is predicted to be in the 18 °C range by 2100 for the western James Bay region (Table 2), suitable thermal habitat should be available for smallmouth bass (Jackson and Mandrak, 2002). Adding further, a significant positive trend in warm days (number of days with daily maximum > 90th percentile), summer days (number of days with daily maximum > 25 °C), diurnal temperature range (mean of the difference between daily maximum and minimum) for the period 1950 – 2003, has been reported for the Moosonee region by Vincent and Mekis (2006), as part of a larger national study that used 210 weather stations situated across Canada. However, it is difficult to relate air temperature directly to water temperature in lakes and especially rivers because of ground water inputs, as well as surface runoff (Schlesinger and Regier, 1983). Nevertheless, there may be a restriction in the range of northern pike in the sub-arctic North America, as northern pike are known to avoid surface temperatures > 25 °C (Reist et al., 2006b). In addition, Chu et al. (2005) have reported that coldwater species such as brook trout may be extirpated from their present western James Bay region range by 2020, but TEK collected in the present study do not indicate a range contraction for brook trout, at this time.

Increasing mean air temperatures in the other seasons can also have negative effects on fish. Lake whitefish in southern Ontario usually start spawning in November; while further north, spawning would occur earlier in the autumn/fall season (Fisheries and Oceans Canada, 2010). As autumn/fall mean air temperatures are projected to increase by as much as 6 °C, by 2100 (Table 4) in the western James Bay region, there is the potential for negative effects on whitefish egg fertility. Cingi et al. (2010) have shown experimentally that poor fertilization of whitefish (*C. lavaretus*) eggs occurs at 9.6 °C. They conclude that global warming has increased risks for stenothermic species, such as whitefish, with early life stages being particularly susceptible to small fluctuation in river water temperatures (Cingi et al., 2010).

In a study by Sharma and Jackson (2008), 4181 geo-referenced records of smallmouth bass occurrence were matched with climate data to test which predictive model of smallmouth bass distribution in North America was the most sensitive – mean winter and summer air temperatures were the best predictors of smallmouth bass occurrence – where smallmouth bass could persist where winter air temperatures were as cold as -21 °C and summer temperatures were as warm as 29 °C (Sharma and Jackson, 2008). Thus, winter mean air temperatures projected to increase by as much as 9 °C from a baseline range of -16.64 to -18.56 (Table 6) in northern Ontario, would not hinder the northward expansion of the smallmouth bass.

In addition, projected spring mean air temperatures close to 0 °C for the 2041–2070 and 2071–2100 for most of the climate models (Table 8), suggest a decreasing period of ice cover. This decreased period of ice cover would decrease the probability of overwinter fish kill in lakes due to depletion of dissolved oxygen; thus, aiding the potential northward migration of smallmouth bass (Jackson and Mandrak, 2002). By contrast, elevated temperatures during the development of salmonid (*Coregonus, Salvelinus*) eggs and larvae during the spring hatch period (Fisheries and Oceans Canada, 2010) would be detrimental and may result in teratogenic effects, sex ratio disruption, and effects on muscle cellularity (Finn, 2007).

Clearly, climate change has had a negative impact on specific fish species (i.e., suckers and whitefish) native to the western James Bay region, as illustrated by the observed fish die-offs in 2005. In addition, it was seen that the Omushkego Cree can quickly adapt their fish harvesting activities to account for extreme temperatures. As rising temperatures have been predicted for all seasons, observed climate change impacts will become more frequently documented in the coming years. Although TEK did not reveal northward expansion of novel fish species into the western James Bay region or distribution contraction (i.e., brook trout disappearance), it should be emphasized that our gillnetting was restricted to the area on the Albany River near the mouth of James Bay, which is the northernmost area of the Albany River. There may already be movement of novel fish species northward in the Albany River, but at the more southern end of the river. Thus, there is a need to continue monitoring for changes in fish species distribution in the western James Bay region, as changes in fish species abundance will negatively impact Cree subsistence fishing. However, it should be emphasized that we examined environmental change only in the context of temperature and precipitation; we did not consider post-glacial isostatic adjustment (and its influence on hydrology) which is an important driver of environmental change (but beyond the scope of the present study) in the arctic and sub-arctic regions of the world, especially the western James Bay region (Tsuji et al., 2009).

Lastly, climatic change in the form of rising temperature has not only the potential for direct effects on fish, but also indirect effects on fish. For example, in a food security study investigating the timing of the first appearance of furunculosis (identified using TEK) in fish of the eastern James Bay region, Quebec, Canada – regression analysis revealed a significant, positive relationship between mean air temperature and year – whereby the temperature range conducive for *Aeromonas salmonicida* (the bacteria causing furunculosis in fish) corresponded to the time period furunculosis was first observed (Tam et al., 2010). Climatic change and food security issues in the sub-arctic regions are areas that require further research.

Chapter 3

Conclusions and Recommendations for Future Studies

The main objective of this thesis was to use TEK to assess the impacts of climate change on food security for First Nations communities located in the western James Bay region of northern Ontario.

A literature review was conducted to better understand climate change in northern Canada, climate scenarios, and food security for First Nations communities in the sub-arctic region. In this thesis, TEK was used to examine fish species distribution with respect to present and future impacts of climatic change in the western James Bay region. In addition, climate models such as General Circulation Models (GCMs) and Regional Climate Models (RCMs) were used to project plausible climate change scenarios for the region.

Climate change appears to have a negative impact on specific fish species such as suckers and whitefish in the western James Bay region. TEK in the region recorded uncharacteristic climate extremes, which the Cree fish harvesters have never experienced before, in the summer of 2005. Climate data in the western James Bay region revealed that there was a heat wave, as well as a reduced precipitation during the period of the fish die-offs in the Albany River. Climate scenarios indicated an increase in mean air temperatures for all seasons with all time periods. As summer and winter mean air temperatures continue to increase, warm water fish species such as smallmouth bass may expand northward. On the other hand, coldwater species such as brook trout may be extirpated from their present distribution in the western James Bay region.

Changes in the distributions and populations of fish species in the region will have a significant impact on traditional diet for the Cree communities. Although a number of studies have addressed the implications of climate change on food security in the Canadian arctic, relatively little research has been done to examine the potential impacts of climate change on subsistence foods, game fish in particular, among the Cree communities in the western James Bay region.

It is suggested that continuous monitoring of the distribution of fish species should be undertaken with spatial and geographical analyses on the present western James Bay range. Such analyses could provide more rigorous assessment on the distribution, population, and biodiversity of fish species in the region. In addition, continuous collection of TEK would allow for further insight into the effects of climate change on aquatic ecosystem, as well as on subsistence fishing for the communities.

Further research should therefore concentrate on the investigation of climate change and food security issues for the communities. Moreover, more integrated research may provide the communities with information that could provide adaptive planning for their food and health in sub-arctic regions.

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